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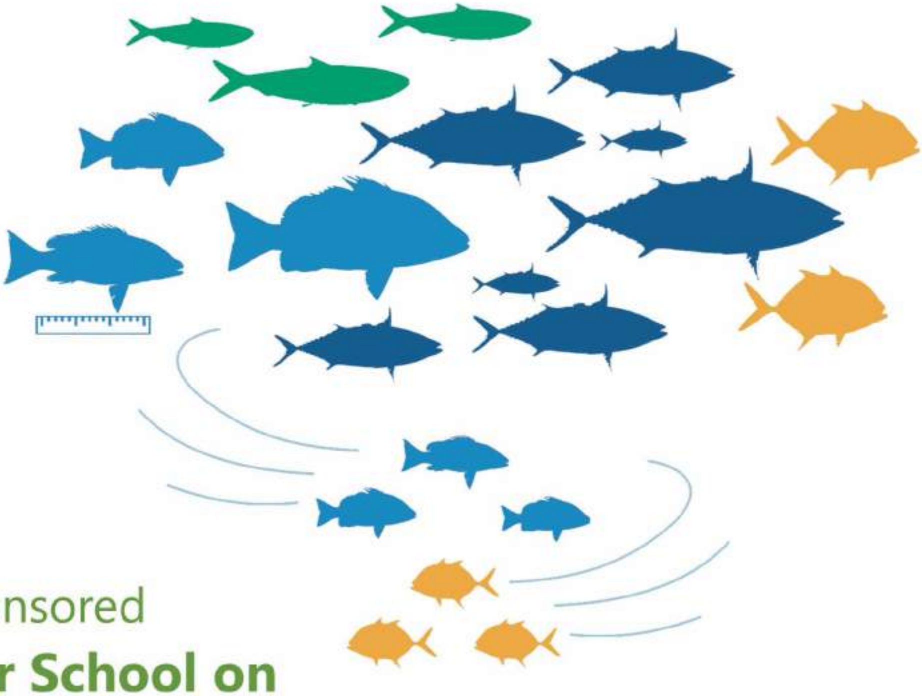

ICAR Sponsored

Summer School on

Advanced Methods for Fish Stock Assessment and Fisheries Management

12th July - 01st August 2017

Fishery Resources Assessment Division
ICAR-Central Marine Fisheries Research Institute
Post Box No. 1603, Ernakulam North P.O., Kochi-682 018
Kerala, India

Course Manual

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FISHERY RESOURCES ASSESSMENT DIVISION
ICAR-Central Marine Fisheries Research Institute
(Department of Agricultural Research and Education, Government of India)
P.B. No. 1603, Ernakulam North P. O., Kochi – 682018, Kerala, India

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Advanced Methods for Fish Stock Assessment and Fisheries Management

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FOREWORD

The fish production from marine sector is contributed by the wild capture that is happening from the sea. There are nearly 1 million active fishermen and nearly 4 million people directly or indirectly involved in this fishing activity. They harvest nearly 3.5 million tonnes of fish every year. Scientific studies have estimated Indian marine fisheries potential as 4.41 million tonnes. This indicates that our resources are exploited almost to its potential level and we have very few untapped resources. The fish production in the sector is contributed by more than 800 species of fish that constitute our commercial fishery. Most these species are not exploited in a sustainable manner. In India, the capacity of fishing fleets is more than our harvestable potential. Therefore it is imperative to know the stock size of various commercially harvested species. It is difficult to really estimate the fish biomass in the sea. It is like lifting the entire fish biomass form the seas and estimating the mass of individual species also and arriving at a potentially harvestable value. With various concentrated efforts in fisheries science, CMFRI was able to deduce few mechanisms to estimate the fish stock available in our coastal waters. Since long officials from CMFRI have been involved in gathering the species-wise and gear-wise information on fish landings from around 1300 landing centres based on a scientifically designed estimation procedure known as stratified multi stage random sampling method. The estimates of landings along with the fishing effort expended and the data on the biology of various species collected enable us to identify whether a stock is over exploited. Few years back CMFRI developed a rapid stock assessment method too. Based on such assessment methods, the information on stock status of various species was ascertained and the knowledge is passed on to policy planners at international, national and state/UT level for management of fishery.

The proposed national level summer school is for teaching the theory, practical, analysis and interpretation techniques in marine fish stock assessment, including the most modern methods. This is organized with the full funding support from ICAR New Delhi and the 25 participants who are attending this programme has been selected after scrutiny of their applications based on their bio-data. We have participants form north, south, east west and Islands of India. They are serving as academicians such as Professors/ scientists and in similar posts. This training will enable them to do their academic programmes in a better manner. Selected participants will be scrutinized initially to understand their knowledge level and classes will be oriented based on this. In addition all of them will be provided with a study manual. All selected participants are provided with their travel and accommodation grants. The faculty include the scientists who developed this technology, those who are practicing it and few user groups who do their research in related areas. The programme is coordinated by the fishery resources assessment division of CMFRI. This programme will generate a team of elite academicians who can contribute to marine fish stock assessment studies of the country in a big way and they will further contribute to capacity building in the sector by training many more in the years to come. The unique selling point of this programme is that CMFRI is the only organization with such vast experience in fish stock assessment with indigenously developed methods and analytical soft wares.

A. Gopalakrishnan

P R E F A C E

Fisheries Monitoring has a role to play in all aspects of management, including those related to the sustainability of the resource, the economic performance of the fishery, the distribution of benefits from the exploitation of the resource and use of the environment.Monitoring fisheries operations to assist fisheries management faces formidable technical challenges. The large number of species involved, the multiplicity of fishing gears, the dynamic marine environment and the widely dispersed landing sites make monitoring, enforcement and compliance measures extremely difficult. As the demands on fisheries resources become greater, the problems of fisheries management become more complex, and we will be facing escalating needs for good fisheries monitoring data. Without the ability to estimate how many fish exist in the ocean there's no way to determine how many of them we can catch while allowing the remaining fish populations to stay viable. But fish live in a mostly invisible world beneath the ocean surface, they move around constantly, and they eat each other. This creates a dynamic population structure that's incredibly difficult to track, making fish virtually impossible to count. We collect the samples, raise it for the entire population and plug them into scientific models which, in turn, create estimates of population health. Because the entire population of a given species is frequently divided into subpopulations known as "stocks," these estimates are called "stock assessments," and they form the backbone of modern fishery management. These assessments provide an estimate of the current state of a fish population and in some cases, forecast future trends.

The present summer school on Advance Methods for Fish Stock Assessment and Fisheries Management is design to acquaint the participants with the advances in stock assessment of fisheries with emphasis of ecosystem and multispecies approach. The course is planned in such a way that it covers both theoretical and practical aspect of all stock assessment methods. Participants will analyse several data sets of marine fisheries by using MS-Excel/ R-Computing Environment/FiSAT, etc. This programme will strengthen the knowledge of participants in regards of fisheries management aspects.

I wish to thank the Education Division of Indian Council of Agricultural Research for giving us an opportunity to organize this summer school. We are also grateful to Dr. A. Gopalakrishnan, Director, ICAR-CMFRI, for his guidance, continuous interest in the course and providing all necessary facilities. I am highly obliged to Dr. T. V. Sathianandan, Head, Fishery Resources Assessment Division for his guidance and support forthe programme. All the scientists of Fishery Resources Assessment Division, technical staff, supporting staff and research scholars also supported us in organizing the Summer School. I recall with gratitude the marvelous effort and help in preparing this manual by Dr. Mini, K.G., Principal Scientist, Fishery Resources Assessment Division. I take this opportunity to thank all the faculty members who have devoted their valuable time and contributed material for the preparation of the manual. I am confident that the Course Manual would aid the participants to enhance their knowledge and competence in the area of Fish Stock Assessment and Management.

Somy Kuriakose
Course Director

July, 2017

CONTENTS

PRESENT STATUS OF ICHTHYOFAUNAL DIVERSITY OF INDIAN SEAS

K. K. Joshi, Thobias P. A. and Varsha M. S.

Marine Biodiversity Division

ICAR-Central Marine Fisheries Research Institute

1

Introduction

Indian fish taxonomy has a long history, which started with Kautilya's *Arthasastra* describing fish as a source for consumption as early as 300 B.C and the epic on the second pillar of Emperor Ashoka describing the prohibition of consumption of fish during a certain lunar period which can be interpreted as a conservation point of view. Modern scientific studies on Indian fishes could be traced to the initial works done by Linnaeus in 1758. M. E. Bloch is one of the pioneers in the field of fish taxonomy along with the naturalists, zoologists and botanists who laid the foundation for fisheries research in India such as Bloch and Schneider (1795-1801) and Lacepède (1798-1803). Russell who worked on 200 fishes off Vizagapatanam during 1803. Hamilton (1822) described 71 estuarine fishes of India in his work *An Account of Fishes Found in the River Ganges and Its Branches.* The mid 1800s contributed much in the history of Indian fish taxonomy since the time of the expeditions was going through. Cuvier and Valenciennes described 70 nominal species off Puducherry, Skyes, Gunther and *The Fishes of India* by Francis Day and another book *Fauna of British India* Series in two volumes describing 1,418 species are the two most indispensable works on Indian fish taxonomy to date.

In the 20th century, the basis of intensive studies on the different families and groups of freshwater fishes was done by Chaudhuri along with Hora and his co-workers. Misra published *An Aid to Identification of the Commercial Fishes of India and Pakistan* and *The Fauna of India and Adjacent Countries (Pisces)* in 1976. Jones and Kumaran (1980) described about 600 species of fishes in the work *Fishes of Laccadive Archipelago* in 1980. Talwar and Kacker (1984) gave a detailed description of 548 species under 89 families in his work Commercial *Sea Fishes of India. The FAO Species Identification Sheets for Fishery Purposes- Western Indian Ocean* (Fischer and Bianchi, 1984) is still a valuable guide for researchers. Recently, Talwar and Jhingran (1991a, 1991b) published description on 930 inland species of India known till date.

Basics of sample collection, preservation and species identification of finfish

Fish resources are considered as an important renewable resources. With increasing fishing pressure, the only option left for the sustainability of fisheries is their rational management. Proper management is possible with a thorough knowledge of the dynamics of the fish stocks. For a meaningful study of the dynamics, knowledge of natural history of the species is necessary and this in turn can be acquired by the correct identification of fish species. This assumes greater importance in tropical seas where, a multitude of closely related and morphologically similar species occur. The role of taxonomy and proper identification cannot be overstressed in studies of population dynamics. Acquaintance with the main species should be such that there should no errors in identification of them in any special form such as racial differentiation, abnormalities, malformation due to decay or disease. Species identification study is also a step towards understanding the bewildering biodiversity that characterizes in the marine ecosystem. Measuring linear dimensions of whole or parts of fish is probably the most widely used technique in taxonomic studies. Such observations are made with taps and calipers. Measurements are usually but not always taken along straight lines.

A. Fish Collection Methods. The major objective of the bioinventory is to identify all the available species in the habitat using all the gear combinations. Two types of gears are employed *viz*., active and passive categories. Passive gear is usually set and left stationary for a period and commonly used gear are gillnet and traps. Active gears used in the inventory are seine nets, trawl nets, dip nets, hooks and line and electric fishing. Different factors affect fish sampling such as water depth, conductivity, water clarity, water temperature, fish size and fish behavior.

B. Identification of fish: Characters of importance for the identification of fishes should be studied correctly to identify the species. Line drawings, colour plates and photographs provide basis for the learning the salient characters which can be for their classification. Identification keys can be used as distinguishing characters of each family and order according to the phylogeny.

1. Determine the family based on “Key”.
2. Identify to the lowest taxonomic unit listed in key to the family of which the fish is a member
3. Verify the final determination by ascertaining or by comparing the similarities of the specimen with illustration.
4. Match the collected specimen with previously identified specimen by taxonomist.
5. Confirm the geographical range as given in the standard texts includes the locality from which the specimen was taken.

6. Compare the descriptions given in the FAO identification sheets, Catalog of Fishes and Fish base.

C. Measurements

Smoothly working dividers or digital calipers can be used for measurements. A steel scale of good quality is recommended for precise reading. Measuring board commonly used in fishery biology investigations is not suitable for taxonomic studies. All measurements are taken in a straight line. Definition of Body Measurements (All measurements along the antero-posterior axis).

1. **Total Length (TOL):** The greatest dimension between the most anteriorly projecting part of the head and the farthest tip of the caudal fin when the caudal rays are spread out together.
2. **Standard Length (STL)**: The distance from the anterior most part of the head backward to the end of the vertebral column (structural base of caudal rays).
3. **Fork Length (FOL):** Distance from the tip of snout to the end of the middle ray of the caudal fork when the fish is being flattened out.
4. **Head Length (HEL):** Taken from the tip of the snout to the posterior most point reached by the bony margin of the operculum.
5. **Pre-orbital length (PRO):** Distance from the tip of the snout to the forward point of eye.
6. **Eye diameter (EYD):** Horizontal diameter of the visible part of the eye, i.e., the distance between the front edge and the back edge of the orbit.
7. **Postorbital length (PSO):** Distance from the backward point of eye to middle of the backward bony edge of the operculum.
8. **Upper jaw length (UPJ):** Length of maxillary is taken from the anterior most point of the premaxillary to the posterior point of the maxilla.
9. **Lower jaw length (LOJ):** Length of lower jaw from anterior tip to angle of mouth.
10. **Body depth (BDD):** Distance between the middle point of dorsal finbase to straight downward central margin of the body, excluding fins.
11. **Pre-dorsal length 1 (PD1):** Distance from the tip of the snout to the forward origin of the dorsal (intersection point of the forward edge of the first ray of the dorsal, D1, with the outline of the back, the fish being flattened out)
12. **Pre-dorsal length (PD2):** Distance from the tip of snout to the forward origin of the dorsal (intersection point of the forward edge of the first ray of the dorsal, D2, with the outline of the back, the fish being flattened out).

13. **Pectoral fin length (PEL):** Distance from the extreme base of the uppermost ray to the farthest tip of the fin, filament if any.

14. **Pelvic fin length (PVL):** Distance from the extreme base of the uppermost ray to the farthest tip of the fin, filament if any.

15. **Dorsal fin length 1 (DF1):** Distance from the origin of the tip of the fin to the anterior lobe.

16. **Dorsal fin length 2 (DF2):** Distance from the origin of the tip of the fin to the anterior lobe.

17. **Inter dorsal length (IDL):** Distance from the base of the last spine (ray) of first dorsal to the intersection point of second dorsal fin.

18. **Pectoral fin base length (PEB)**: Distance from the base of the anterior fin ray of the pectoral (P) to the backward end of the last ray, the pectoral being extended on the side of the fish in its normal position.

19. **Pelvic fin base length (PVB):** Distance from the base of the anterior fin ray of the pelvic fin (P) to the backward end of the last ray, the ray being extended on the side of the fish in its normal position.

20. **Dorsal fin base length (DB1**): Distance from the forward origin of the dorsal (D1) to the backward edge (Intersection point of the backward edge of the last spine, D′, with the outline of the back, the fin being extended).

21. **Dorsal fin base length (DB2)**: Distance from the forward origin of the dorsal (D2) to the backward edge (Intersection point of the backward edge of the last ray, D2, with the outline of the back, the fin being extended.

22. **Anal fin length (AFL):** Distance from the origin of the anal between the and fin tip of the fin to the anterior most outer tip of the anal fin.

23. **Anal fin base length (ABL):** Distance from the forward origin of the anal (A) to its backward edge (intersection point of the backward edge of the last ray, A′ with outline of the abdomen, the fin being extended).

24. **Caudal peduncle length (CPL):** Distance from the base of the second dorsal end to origin of the caudal fin.

25. **Caudal peduncle depth (CPD):** Depth of the caudal peduncle.

26. **Pre-pelvic length (PRP):** Distance from the tip of the snout to the anterior origin of the pelvic (intersection point of the forward edge of the first ray of the pelvic, with the contour of the abdomen, the fin being extended).

27. **Pre-pectoral length (PRV)**: Distance from the tip of the snout to the margin of the insertion of pectoral fin.
28. **Pre-anal distance (PRA):** Distance from the tip of the snout to the forward origin of the anal (interior point of the forward edge of the first ray of the anal, A, with the outline of the abdomen, the fin being extended).

Taxonomists also play an important role in supporting the study of the richness of diversity as well as protecting and making vigilant of the diverse system. The assessed diversity of the oceans is just a drop, and the unrevealed sources are yet to be explored making the world more biodiversity rich. Hence the need to conserve the ichthyofaunal diversity is to be looked into as they pose major threats that need to be tackled and sorted out. The role of Marine Protected Areas (MPAs) and fish sanctuaries have been designated in many places worldwide, which can help to protect and restore threatened species. Human activities are the major causes for the loss of biodiversity and degradation of marine and coastal habitats, which needs immediate attention and comprehensive action plan to conserve the biodiversity for living harmony with nature. Some of the measures such as control of excess fleet size, control of some of the destructive gears, regulation of mesh size, avoid habitat degradation of nursery areas of the some of the species, reduce the discards of the low value fish, protection of spawners, implementation of reference points and notification of marine reserves for protection and conservation of marine and coastal biodiversity. The Wild Life (Protection) Act, 1972 amended by the Government make sure of the species protected under this Act and any capture, killing and trade of these species is punishable.

Species richness

Of the 33,059 total fish species from the world, India contributes of about 2492 marine fishes owing to 7.4% of the total marine fish resources. Of the total fish diversity known from India, the marine fishes constitute 76 percent, comprising of 2492 species belonging to 941 orders 240 families (Table 1). Among the fish diversity-rich areas in the marine waters of India, the Andaman and Nicobar archipelago shows the highest number of species, 1431, followed by the east coast of India with 1121 species and the west coast with 1071. As many as 91 species of endemic marine fishes are known to occur in the coastal waters of India. As of today, about 50 marine fishes known from India fall into the Threatened category as per the IUCN Red List, and about 45 species are Near-Threatened and already on the path to vulnerability. However, only some species (10 elasmobranchs, 10 seahorses and one grouper) are listed in Schedule I of the Wildlife (Protection) Act, 1972 of the Government of India.

Table 1. Species diversify of marine fishes of India

No	Order	Family	No. of Genera	No. of species
Class: Elasmobranchii				
1	Hexanchiformes			
	1	Hexanchidae	2	2
2	Heterodontiformes			
	2	Heterodontidae	1	1
3	Echinorhiniformes			
	3	Echinorhinidae	1	1
4	Orectolobiformes			
	4	Rhincodontidae	1	1
	5	Hemiscylliidae	1	5
	6	Stegostomatidae	1	1
	7	Ginglymostomatidae	1	1
5	Lamniformes			
	8	Odontaspididae	2	3
	9	Pseudocarchariidae	1	2
	10	Lamnidae	2	3
	11	Alopiidae	1	3
6	Carcharhiniformes			
	12	Pseudotriakidae	1	1
	13	Scyliorhinidae	6	9
	14	Proscylliidae	1	1
	15	Triakidae	2	4
	16	Hemigaleidae	4	4
	17	Carcharhinidae	10	26
	18	Sphyrnidae	2	5
7	Squaliformes			
	19	Etmopteridae	2	7
	20	Somniosidae	2	2
	21	Centrophoridae	2	8
	22	Squalidae	1	5
8	Pristiformes			
	23	Pristidae	2	5

9	Torpediniformes			
	24	Narkidae	2	4
	25	Narcinidae	2	7
	26	Torpedinidae	1	5
10	Rajiformes			
	27	Rhinobatidae	4	10
	28	Rhyncobatidae	1	4
	29	Zonobatidae	1	1
	30	Acanthobatidae	1	1
	31	Rajidae	7	8
11	Myliobatiformes			
	32	Hexatrygonidae	1	1
	33	Dasyatidae	7	28
	34	Gymnuridae	2	4
	35	Myliobatidae	2	8
	36	Mobulidae	2	9
	37	Placiobatidae	1	1
Sub class: Holocephali				
12	Chimaeriformes			
	38	Rhinochimaeridae	1	1
	39	Chimaeridae	1	1
Class Actinopterygii				
13	Elopiformes			
	40	Elopidae	1	2
	41	Megalopidae	1	1
14	Albuliformes			
	42	Albulidae	1	2
15	Notacanthiformes			
	43	Halosauridae	2	5
	44	Notacanthidae	1	1

16	Anguilliformes			
	45	Anguillidae	1	5
	46	Moringuidae	1	6
	47	Muraenidae	10	38
	48	Synaphobranchidae	2	3
	49	Ophichthidae	17	24
	50	Colocongridae	1	1
	51	Congridae	12	17
	52	Muraenesocidae	4	6
	53	Nemichthyidae	2	2
	54	Serrivomeridae	1	1
	55	Nettastomatidae	2	2
17	Clupeiformes			
	56	Clupeidae	12	26
	57	Dussumieriidae	1	2
	58	Engraulidae	5	34
	59	Chirocentridae	1	2
	60	Pristigasteridae	4	12
18	Gonorynchiformes			
	61	Chanidae	1	1
19	Siluriformes			
	62	Ariidae	10	25
	63	Plotosidae	1	3
	64	Bagaridae	2	4
20	Stomiiformes			
	65	Gonostomatidae	4	6
	66	Sternoptychidae	4	8
	67	Phosichthyidae	2	3
	68	Stomiidae	6	9

21	Aulopiformes			
	69	Chlorophthalmidae	1	3
	70	Ipnopidae	2	4
	71	Synodontidae	4	23
	72	Paralepididae	2	3
	73	Evermannellidae	2	2
	74	Alepisauridae	1	2
22	Myctophiformes			
	75	Neoscopelidae	2	3
	76	Myctophidae	11	41
23	Lampriformes			
	77	Veliferidae	1	1
	78	Lophotidae	1	1
	79	Regalecidae	1	1
	80	Ateleopodidae	2	3
24	Polymixiiformes			
	81	Polymixiidae	1	4
25	Gadiformes			
	82	Bregmacerotidae	1	1
	83	Macrouridae	9	18
	84	Moridae	1	2
26	Ophidiiformes			
	85	Ophidiidae	16	28
	86	Carapidae	3	5
	87	Bythitidae	6	7
	88	Aphyonidae	1	1
27	Batrachoidiformes			
	89	Batrachoididae	4	6

28	Lophiiformes			
	90	Lophiidae	2	4
	91	Antennariidae	2	9
	92	Chaunacidae	1	1
	93	Ogcocephalidae	5	11
	94	Diceratiidae	1	1
	95	Oneirodidae	1	1
	96	Ceratiidae	1	1
29	Mugiliformes			
	97	Mugilidae	7	18
30	Atheriniformes			
	98	Atherinidae	4	9
	99	Notocheiridae	1	1
31	Beloniformes			
	100	Belonidae	4	8
	101	Hemiramphidae	5	16
	102	Zenarchopteridae	2	8
	103	Exocoetidae	6	18
32	Stephanoberyciformes			
	104	Melamphaidae	1	1
33	Cypridontiformes			
	105	Aplocheilidae	1	1
34	Beryciformes			
	106	Monocentridae	1	1
	107	Trachichthyidae	2	3
	108	Berycidae	2	4
	109	Holocentridae	4	25
35	Argentiniformes			
	110	Platytroctidae	3	4
	111	Alepocephalidae	9	14

36	Zeiformes			
	112	Parazenidae	1	1
	113	Grammicolepididae	2	2
	114	Zeidae	1	2
37	Gasterosteiformes			
	115	Pegasidae	2	4
38	Syngnathiformes			
	116	Aulostomidae	1	1
	117	Fistulariidae	1	3
	118	Centriscidae	2	4
	119	Macrorhamphosidae	1	1
	120	Solenostomidae	1	2
	121	Syngnathidae	14	42
39	Scorpaeniformes			
	122	Apistidae	1	1
	123	Aploactinidae	4	6
	124	Bembridae	1	1
	125	Dactylopteridae	1	5
	126	Peristediidae	5	7
	127	Platycephalidae	11	16
	128	Scorpaenidae	15	35
	129	Setarchidae	2	3
	130	Synanceiidae	5	13
	131	Tetrarogidae	9	12
	132	Triglidae	2	7
40	Polynemiformes			
	133	Polynemidae	5	11

41	Perciformes			
	134	Acropomatidae	2	5
	135	Ambassidae	2	11
	136	Apogonidae	19	63
	137	Bathyclupeidae	1	1
	138	Bramidae	3	3
	139	Caesionidae	4	16
	140	Caproidae	1	2
	141	Carangidae	20	66
	142	Centrogenyidae	1	1
	143	Chaetodontidae	8	48
	144	Coryphaenidae	1	2
	145	Datnioididae	1	1
	146	Drepaneidae	1	2
	147	Echeneidae	3	6
	148	Emmelichthyidae	1	1
	149	Gerreidae	2	11
	150	Haemulidae	3	28
	151	Hapalogenyidae	1	1
	152	Kyphosidae	1	3
	153	Lactariidae	1	1
	154	Latidae	2	2
	155	Leiognathidae	9	22
	156	Lethrinidae	5	24
	157	Lobotidae	1	1
	158	Lutjanidae	10	45
	159	Malacanthidae	2	3
	160	Menidae	1	1
	161	Monodactylidae	1	3
	162	Mullidae	3	27
	163	Nemipteridae	4	33

164	Opistognathidae	1	7
165	Ostracoberycidae	1	1
166	Pempheridae	2	7
167	Plesiopidae	3	5
168	Pomatomidae	1	1
169	Priacanthidae	3	9
170	Pseudochromidae	4	9
171	Rachycentridae	1	1
172	Sciaenidae	19	43
173	Serranidae	19	85
174	Sillaginidae	2	11
175	Sparidae	7	12
176	Symphysanodontidae	1	3
177	Toxotidae	1	2
178	Acanthuridae	5	39
179	Ammodytidae	1	3
180	Blenniidae	26	65
181	Callionymidae	4	21
182	Cepolidae	2	4
183	Champsodontidae	1	2
184	Chiasmodontidae	3	3
185	Cirrhitidae	4	8
186	Clinidae	1	1
187	Creediidae	1	1
188	Eleotridae	11	18
189	Ephippidae	3	4
190	Gobiidae	71	190
191	Kuhliidae	1	3
192	Kurtidae	1	1
193	Labridae	28	85
194	Cichlidae	2	3

195	Samaridae	2	2
196	Microdesmidae	3	9
197	Pentacerotidae	1	1
198	Percophidae	2	3
199	Pholidichthyidae	1	1
200	Pinguipedidae	1	12
201	Pomacanthidae	6	21
202	Pomacentridae	19	92
203	Scaridae	7	29
204	Scatophagidae	1	1
205	Schindleriidae	1	2
206	Siganidae	1	17
207	Terapontidae	2	4
208	Trichonotidae	1	2
209	Tripterygiidae	3	8
210	Uranoscopidae	2	6
211	Xenisthmidae	1	1
212	Zanclidae	1	1
213	Ariommatidae	1	1
214	Centrolophidae	1	2
215	Istiophoridae	3	5
216	Nomeidae	2	3
217	Scombridae	11	22
218	Scombrolabracidae	1	1
219	Stromateidae	1	2
220	Trichiuridae	6	12
221	Kraemeriidae	1	1
222	Sphyraenidae	1	10
223	Gempylidae	9	10
224	Xiphiidae	1	1

42	Pleuronectiformes			
	225	Psettodidae	1	1
	226	Citharidae	1	1
	227	Paralichthyidae	2	9
	228	Bothidae	9	21
	229	Pleuronectidae	3	4
	230	Soleidae	11	27
	231	Cynoglossidae	3	21
43	Tetradotnifromes			
	232	Triacanthodidae	6	6
	233	Triacanthidae	3	5
	234	Balistidae	11	22
	235	Monacanthidae	14	22
	236	Ostraciidae	4	7
	237	Triodontidae	1	1
	238	Tetradontidae	8	32
	239	Diodontidae	3	6
	240	Molidae	3	4
			941	2492

Reference: Table prepared based on the list of species published in Eschmeyer, W. N., 1998. **Eschmeyer, W. N. and R. Fricke (eds). 2015.** Gopi, K.C. and Mishra, S. S., 2014. Akhilesh et al., 2014; Joshi et al., 2016.

Marine and coastal diversity

Gujarat Coast

Gujarat has the longest coastline of more than 1,600 km and the most extensive continental shelf of nearly 164,000 km^2, which represents nearly 20% and 32 % of India's coastline and continental shelf. The EEZ of Gujarat covers 214,000 km^2. The coast has been broadly divided into four sections: the Gulf of Kachchh, the Saurashtra coast, the Gulf of Khambhat and the South Gujarat coast. The ecological India's first Marine National Park was notified in the Gulf of Kachchh. The habitats exhibit considerable diversity and they include mangroves, salt marshes, coral reefs, beaches, dunes, estuaries, intertidal mudflats, gulfs, bays and wetlands. Gujarat has India's second largest extent of area under the mangroves. The major rivers are Narmada, Tapti, Sabarmati and Mahi. Gulf of Khambhat (Gulf of Cambay) is 190 km wide at its mouth between Diu and Daman, rapidly narrows to 24 km. The gulf receives many rivers, including the Sabarmati, Mahi, Narmada, and Tapti. The Gulf of Kachchh is rather shallow with a depth of nearly 60 m at the mouth to less than 20 m near the head. The total gulf area is about 7350 km^2. In the Gulf of Kachchh, there are 42 islands & some islets, covering a total area of about 410.6 km^2. About 306 fish species are listed from the sea and coastal waters of Gujarat. The fishery at present is dominated by fishes like ribbonfishes (*Trchiurus lepturus*), Bombay duck (*Harpodon nehereus*), croakers, carangids, threadfin breams, lizardfishes, tuna (*Euthynnus affinis, Thunnus tonggol, Katsuwonus pelamis, Thunnus albacores* and *Sarda orientalis*), seerfish, pomfrets, catfish, flatfishes and non-penaeid prawns. The Bombay duck (*Harpodon nehereus*) fishery was dominant at Nawabunder, Rajpara and Jaffrabad along the Saurashtra coast. Out of total 306 reported species, 23 fish species were found in the IUCN's Red Data list. Importantly, 9 of these species belong to shark families, including the whale shark, are also listed in Schedule I of Wildlife Protection Act, 1972.

Mumbai Coast

The Maharashtra coast that stretches between Bordi/Dahanu in the North and Redi/Terekhol in the South is about 720 km long and 30-50 km wide. The shoreline is indented by numerous west flowing river mouths, creeks, bays, headlands, promontories and cliffs. There are about 18 prominent creeks/estuaries along the coast many of which harbor mangrove habitats. Bombay duck fisheries form the mainstay of the commercially important fisheries of the coast from Ratnagiri to Broach. The coastline between Bombay and Kathiawar is found to be productive for Sciaenids, *Leptomelanosoma indicus* (=*Polynemus indicus*), *Polynemus* spp., perches and eels. The Gulf of Cambay and North Bombay coast are also rich in Bombay duck fisheries. About 285 species have been reported from the coast. Major finfishes along this coast was Bombay duck, ribbonfish, sharks, pomfrets, lizardfish, catfishes, oil sardine, anchovy, barracudas, full beaks, sailfish, cobia, wolf herring, groupers, whitefish and mackerel.

Konkan Coast

The Konkan coast stretches like a beautiful chain of 720 km formed from the coastal districts of states of Maharashtra, Goa and Karnataka. Many river mouths, creeks, small bays, cliffs and beaches, interspersed with historic forts, lend an alluring charm to this landscape. Konkan is also rich in coastal and marine biodiversity. Mangrove forests, coral reefs, charismatic marine species like dolphins, porpoises, whales, sea turtles, etc., many species of coastal birds and other fauna make the Konkan coast a veritable treasure trove biological diversity. The Malvan Marine Sanctuary has spread over 29 km^2; the sanctuary is rich in coral and marine life. The Karwar group of islands with its unique rocky with sandy shore supports a wide range of fauna. There are more than 170 different species of food fishes landing in the coast and is famous for its large shoals of mackerel, *Rastrelliger kanagurta* dominating the coasts of Karnataka. Oil sardine along with *Sardinella fimbriata,* anchovies, clupeids, ribbonfishes, seerfishes, *Lactarius* sp., carangids, pomfrets, croakers, catfish, whitefish, flatfishes, silver bellies also contribute much to the fisheries of both the coasts.

Malabar Coast

Malabar Coast which stretches from Goa to Kanyakumari supports vast habitats such as Mangroves, Swamps, coral reefs, Sea grass meadows, beaches and deltaic regions. About 308 fish species has been reported off Malabar Coast of which most of them are clupeids followed by, groupers, anchovies, scombirds, snappers and butterfly fishes. Oil sardine along with Indian mackerel, threadfin beams, lizardfish's, eels, several carangids, sharks, rays, the Malabar sole, *Cynoglossus semifasciatus,* catfishes, small croakers, pomfrets, tuna, groupers, snappers, pigfacebreams, priacanthids, silverbellies, contribute to the commercial fishery along the Malabar coast. *Acanthurus matoides, A. xanthopteres, Apogon aureus, Chaetodon collare, Diodon hystrix, Gymnothorax flavimarginatus, Pseudobalistes flavimarginatus, Ostracion tuberculatum, Lactaia cornuta, Plataxteira, Pteroise volitans, Siganus javus, Tetradon immaculatus* are important ornamental species for their abundance and economic value.

Lakshadweep

The Union territory of Lakshadweep consists of 36 islands covering an area of 32 km^2 of which 10 islands are inhabited, 20,000 km^2 of lagoons and 4000 km^2 oceanic zones. Among the fishes of Lakshadweep, those of ornamental value are abundant. Of 603 species of marine fishes belonging to 126 families that are reported from the islands, at least 300 species belong to the ornamental fish category. Oceanic species of tuna such as Skipjack and Yellowfin tuna constitute the major tuna resources from Lakshadweep Islands. The main economy of the islanders is dependent on the tuna catch and fishing is done for nearly six months of the year from October to April. The most common species of sharks that occur in Lakshadweep are the Spade-nose shark/Yellow dog shark, and the Milk shark. The Blacktip Shark and Hammerhead shark are also commonly found in the waters around Lakshadweep.

Gulf of Mannar

The Gulf of Mannar located in the Southern part of the Bay of Bengal with a string of 21 islands which has been declared as a marine national park under the Wild Life (Protection) Act 1972 by the Government of India. The reserve covers 10,500 km^2, which comprises of a variety of sensitive marine habitats like coral reefs, mangroves and sea grasses, and could be considered as one of the most productive ecosystems. The core area of the reserve is comprised of a 560 km^2 of coral islands and shallow marine habitat. The Gulf of Mannar alone produces about 20% of the marine fish catch in Tamil Nadu. Of 2200 fish species distributed in Indian waters, 650 species have so far been recorded from the Gulf of Mannar. The finfish resources, mainly comprises of small pelagics, barracudas, silver bellies, rays, skates, eels, carangids, flying fish, full beaks and half beaks. The demersal finfish resources, mainly associated coral reefs are threadfin breams, grouper, snappers, emperor and reef associated fishes. Further, large pelagic species like skipjack tuna, yellow fin tuna, bigeye tuna, kawakawa, frigate tuna and seer fish, bill fishes, eagle rays are most abundant in offshore and oceanic areas, but also occur in coastal waters are found in certain areas of the Gulf of Mannar.

Palk bay

Palk Bay is situated on the southeast coast of India encompassing the sea between Point Calimere near Vedaranyam in the north and the northern shores of Mandapam to Dhanushkodi in the south. The Palk Bay itself is about 110 km long and is surrounded on the northern and western sides by the coastline of the State of Tamil Nadu in the mainland of India. The coastline of Palk Bay has coral reefs, mangroves, lagoons and sea grass ecosystems. Elasmobranchs are the largest group of fishes and are well represented in the fishery wealth of the Rameswaram Island on the Palk Bay side. This is one of the best fishing grounds for smaller sardines, silver bellies, common white fish and half beaks, mullets and sciaenids. The common fishes found in this area also include Sharks, Rays, Skates, Tiger-sharks rays, and Hammer-headed sharks.

Coromandel Coast

Seer fishes are most abundant in the coromandel coast of Tamil Nadu along with miscellaneous fisheries formed of trichiurids and percoids. The flying fish fishery is an important seasonal fishery on the east coast of India extending from Madras to Point Calimere along the Coromandel coast. Three species of flying-fish, viz., *Hirundichthys coromandelensis, Cheliopogon spilopterus* and *C. bahiensis*, are generally found in these waters, but more than 90% of the catch consists of *H. coromandelensis.*

Andaman and Nicobar islands

The Andaman and Nicobar islands situated in the Bay of Bengal constitutes of about 524 islands with a coastline of 1962 km. The major habitats of the coastal region include the bio-diverse coral reefs with both fringing reefs off the east coast and barrier reefs off the west coast, mangroves, estuaries and wetlands. Coral reefs are the most complex ecosystems in the seas. Fish communities reach their highest degree of diversity in these ecosystems, and differ enormously within and between reefs in the same area and between geographic regions since the confluence of Andaman fishes with the waters of pacific as well as Indian Ocean. A total of 1431species under 586 genera with 175 families has been reported from Andaman waters. The number of reef fishes is the highest among the Indian reefs with a contribution of 72.5% of the recorded fishes of the region. Major species belong to the family pomacentridae and gobiidae.

West Bengal

The Sundarbans mangrove forests form a geographical landmark at the Ganges delta. The Sundarbans biosphere reserve is a majestic natural region in the world which covers 102 swampy island, mangroves, estuaries, backwaters and waterways. The Sundarbans represent the largest remaining tract of coastal mangrove wetlands in tropical Asia formed at the estuarine phase of the Ganges- Brahmaputra river system. The Indian Sundarbans in the north east coast of India occupies 9630 Km^2 and are bounded by River Hooghly in the West, River Raimangal in the East, Bay of Bengal in the South and Dampier Hodges line in the North. There are 56 islands of various sizes and shapes in Sundarbans and these are separated from each other by a network of tidal channels. Sundarban boast around 172 species of fishes. Along the coast the fisheries comprise of sardines, sharks, anchovies and other miscellaneous clupeoids. Sundarbans is the nursery for nearly 90% of the aquatic species of the eastern coast, the coastal fishery of eastern India is dependent upon Sundarban. Most commercially important marine and estuarine fishes are; *Lates calcarifer, Tenualosa ilisha, Liza parsia, Liza tade, Harpadon nehereus, Plotosus canius, Pampus argenteus, Rhinobatos annandalei, Pangasius pangasius, Polydactylus indicus, Chanos chanos, Eleutheronema tetradactylum, Leptomelanosoma indicum, Polynemous paradiseus* and *Pama pama.*

Estuarine and brackish water diversity

India has rich estuarine and other brackish water resources along the east and west coasts formed by the Ganges, Mahanadi, Brahmaputra, Godavari, Krishna, Cauvery, Narmada and Tapti rivers, and smaller coastal rivers along the west coast, mainly in Kerala, Karnataka and Goa. The total brackish water resources of India as estimated by the Government of India were 1.44 million ha. The states of Odisha, Gujarat, Kerala and West Bengal have rich brackish water resources. West Bengal is endowed with rich brackish water area, estimated to be 405,000 ha with Hooghly-Matlah estuary accounting for 8,029 km^2 and marshy area of Sunderbans to be 2,340 km^2. The estuary serve as a nursery ground for migrant species proving spawning grounds for the migratory fishes such as *Hilsa ilisha*, *Polynemus paradiseus*, *Sillaginopsis domina, Pangasius pangasius, Pama pama, Polynemus tetradactylus* and *Leptomelanosoma indicum*. About 172 species of fishes has been reported from the estuary of which 99 occupy higher salinity zones. Odisha has a total brackish water resource of 417,537 ha. Estuaries, lakes and backwater account for 247,850 ha, 79,000 ha and 8,100 ha respectively. The Mahanadi estuary lies in the Cuttack and Puri districts of Odisha and drains into Bay of Bengal. The major fauna includes *Tenualosa ilisha, Nematalosa nasus, Sardinella* sp., *Ilisha* sp., *Mugil cephalus, Planiliza parsia* and other perches.

The Chilka lagoon is the biggest brackish water lagoon of the east coast of India and is designated as a Ramsar site since 1981. The area during summer and rainy season has been estimated to be 906 and 1,105 km^2, respectively. The brackish water of Andhra Pradesh is about 2.0 lakh ha and mangrove swamp of 27,500 ha. It supports almost 268 species of fishes which includes *Nematalosa nasus, Mystus gulio, Planiliza macrolepis, Tenualosa ilisha* and *Gerres setifer.* Pulicat Lake is a very important brackish water lake of Nellore district of Andhra Pradesh and the rest in Tamil Nadu region with a total area 77,000 ha. The fishery includes *Nematalosa nasus, Planiliza macrolepis, Sillago sihama, Chanos chanos,* etc. The Godavari estuarine system has an area of 330 km^2, drains to Bay of Bengal on the east coast in the state of Andhra Pradesh. The major fisheries are formed by *Gerres filamentosus, Caranx* sp., *Sillago sihama, Platycephalus* sp., *Lates calcarifer* and *Mugil cephalus.*

Threats and conservation of ichthyofaunal diversity

The major threats to ichthyofaunal diversity are:

- **Pollution**: Untreated sewage, garbage, fertilizers, pesticides, industrial chemicals, plastics. Most of the pollutants on land eventually make their way into the ocean, either deliberately dumped there or entering from water run-off and the atmosphere. Not surprisingly, this pollution is harming the entire marine food chain - all the way up to humans.
- **Unsustainable fishing**: 90% of the world's fisheries are already fully exploited or overfished, the catch of juveniles also pose threat to the diversity of fishes. Unsustainable fishing is the largest threat to ocean life and habitats. Untargeted fish catching methods brings about large quantities of fishes and other fauna that leads to loss of the species.
- **Inadequate protection**: Oceans cover over 70% of our planet's surface, but only a tiny fraction of the oceans has been protected: just 3.4%. Even worse, the vast majority of the world's few marine parks and reserves are protected in name only.
- **Tourism and development**: Around the world, coastlines have been steadily turned into new housing and tourist developments, and many beaches all but disappear under flocks of holiday-makers each year.
- **Shipping**: Heavy traffic is leaving its marks of oil spills; ship groundings, anchor damage, and the dumping of rubbish, ballast water, and oily waste are endangering marine habitats around the world.

- **Oil and gas**: Important reserves of oil, gas, and minerals lie deep beneath the seafloor. However, prospecting and drilling for these poses a major threat to sensitive marine habitats and species.
- **Aquaculture**: Fish farming is often regarded as the answer to declining wild fish stocks. But the farming of fish is actually harming wild fish, through the pollution from the farms discharge, escaped farmed fish, increased parasite loads, and the need to catch wild fish as feed.
- **Climate change**: Global warming and climate change are already having a marked effect on the oceans through coral bleaching, rising sea level and changing species distribution. Strategies are needed to deal with these phenomena, and to reduce other pressures on marine habitats already stressed by rising water temperatures and levels.
- **Invasion of alien species**: The introduction of harmful aquatic organisms to new marine environments is believed to be one of the four greatest threats to the world's oceans. Those species are described as 'invasive' if they are ecologically and/or economically harmful.

Fishes are of immense value for ecosystems, hence they are to be valued, nourished and conserved. Fish as well as fisheries forms the economic as well as social backbone of Indian society. Unfortunately, over dependence and over exploitation of these naturally bestowed resources has led to a heavy fall in the number and in turn affect the biodiversity of the system. These provide recreational, physiologic and aesthetic values to the people of interest. This has been a resource of exchange in capital, investment and livelihood for majority. Fish culture, processing, trade and marketing have been providing with sufficient job opportunities for the common man. Various fishery agreements have been established internationally as well as domestically, which have immense importance in conservation of fish biodviersity. Institutes and researchers are greatly indebted to nature for the scientific information collected from various research activities.

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MARINE FISH PRODUCTION IN INDIA – PRESENT STATUS

2

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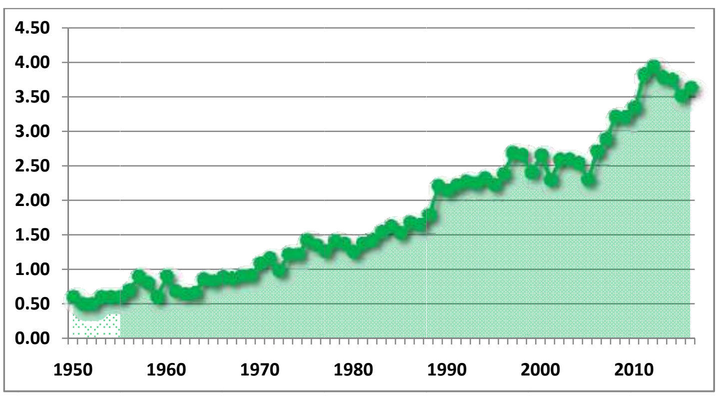
Introduction

India being a tropical country is blessed with highly diverse nature of marine fishery resources in its 2.02 million square kilometer Exclusive Economic Zone with an estimated annual harvestable potential of 4.414 million metric tonnes. The marine fisheries sector provide livelihood to nearly 4.0 million people of India and meets the food and nutritional requirements of a significant proportion of the population. Also, it contributes to export earnings of the country. Sustainable harvest of the marine fishery resources are necessary as over exploitation of the resources is likely to harm the diversity and cause reduction in the availability of some of the resources. Monitoring of the harvest of the diverse marine fishery resources of the country is being carried out regularly by CMFRI since its inception through a scientific data collection and estimation system from all along the Indian coast leading to fish stock assessment for deriving management measures to keep the harvest of the resources at sustainable levels.

Marine fisheries is an important source of food, nutrition, employment and income generation. In India, four million people depend for their livelihood on marine fisheries sector which provides employment to nearly one million fishermen and contributes significantly to the export earnings of the country and balance of trade. The sector contributes to an economic wealth valued at nearly Rs. 65,000 crores annually.The marine fisheries of the country consist of small-scale and artisanal fishers belonging mechanized, motorized and non-mechanized sectors and a range of other stakeholders, including governmental and non-governmental agencies. The marine fisheries resources are not in-exhaustive and over-exploitation would lead to loss of biodiversity and reduced availability of resources for our future generations. Uncontrolled harvest will result in depletion of the resources. Management and regulations are necessary for sustainable harvest of marine fishery resources India is one among the top marine fish producing countries of the world and at present the country is at 7th position in global marine capture fish production after China, Indonesia, USA, Russia, Japan and Peru. The global marine fish catch remains almost stagnant after 1990 whereas the marine fish production in India showed a steady increase from 2.3 million tonnes in 1990 to 3.94 million tonnes in 2012.

Many of the world's fisheries have experienced series of environmental shifts in recent decades involving collapse or fluctuations in the dominant fish assemblages and as a result, many fisheries-dependant human communities have lost majority of their population, while the respective countries in general were growing (Hamilton and Otterstand 1998). In a tropical country like India, wherein the marine fisheries is supported by multispecies assemblages, severe collapses in fishery are unlikely and the marine fish production of the country has been increasing from a meager of 0.05 million t to 3.94 million t over the last 62 years. This is imperative, as the marine fisheries sector in India is characterised by the dominance of small scale subsistence based fishery. In many of the societies, small-scale fishermen suffer the greatest deprivations as they have low social status, low incomes, poor living conditions and little political influence (Pomeroy and Williams 1994). Implementation of regulations in the fishery for the sustained production from the sector have to take into account its impact on the livelihood of the considerably poor fisher population. The information necessary for such inference are generated through census.

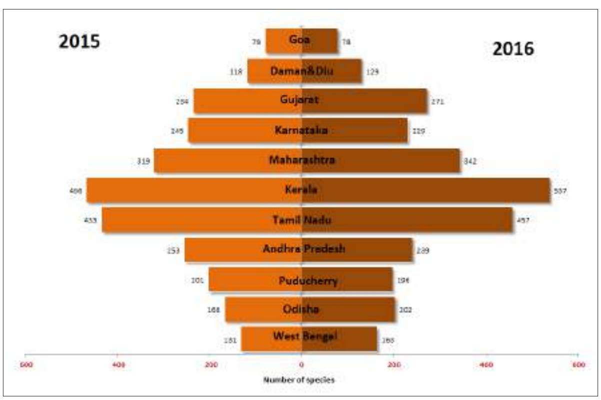


Time series plot of marine fish landings in India from 1950 to 2016 (in million tonnes)

The estimate of landings of marine fishery resources along the coast in the main land of India for the year 2016 is 3.63 million metric tonnes. The contribution by the maritime states West Begal, Odisha, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Goa, Maharashtra, Gujarat, union territories of Puducherry and Damen & Diu towards the total landings (in lakh tonnes) are 2.72 (7.5%), 1.17 (3.2%), 1.92 (5.3%), 7.07(19.5%), 5.23 (14.4%), 5.30 (14.6%), 0.61 (1.7%), 2.92 (8.1%), 7.74 (21.3%), 0.45 (1.2%), 1.17 (3.2%) respectively. The increase in landings in 2016 is mainly due to increase in marine fish landings along the coasts of West Bengal by 1.53 lakh tonnes, Karnataka by 86,000 tonnes, Gujarat by 53,000 tonnes, Kerala by 40,000 tonnes, Damen & Diu by 35,000 tonnes and Maharashtra by 27,000 tonnes. There is reduction in landings in Andhra Pradesh by 1.03 lakh tonnes, Puducherry by 34,000 tonnes, Odisha by 24,000 tonnes, Goa by 7,000 tonnes and Tamil Nadu by 2,000 tonnes.

When examined at the resource level contribution, Indian mackerel had the maximum with 2.49 lakh tonnes (6.8% of total landings) followed by oil sardine 2.45 lakh tonnes (6.7%), ribbonfishes 2.20 lakh tonnes (6.0%), penaeid prawns 2.01 lakh tonnes (5.5%) and lesser sardines 1.95 lakh tonnes (5.4%). The resources showed increased landings in 2016 are Perches by about 77,000 tonnes (81%), Hilsa shad 73,000 tonnes (354%), Ribbon fishes 43,000 tonnes (24%), Bombayduck 35,000 tonnes (31%), Squids 22,000 tonnes (24%) and Non-penaeid prawns 21,000 tonnes (14%). The resources with significant reduction in landings are Lesser sardines 61,000 tonnes (24%) and oil sardine 21,000 tonnes (8%).

Among the three sectors there was 81% contribution from mechanized sector towards the total landings, motorized sector contributed 17% and the contribution from the traditional non-mechanized sector was only 2%. Mechanized trawlnets accounted for 58% of the total marine fish landings whereas mechanized gillnets and outboard ringseines contributed 8% each. The total number of species found in the landings along the Indian coast during 2016 is 817 where as it was 730 in 2015. Numbers of species landed in different maritime states in 2016 and 2015 are shown in the following diagram. Though Gujarat had maximum landings among all the maritime states species diversity is less compared to Kerala and Tamil Nadu.



India is one among few countries where a system based on sampling theory is used to collect marine fish catch statistics. The sampling design was developed by CMFRI in association with the Indian Agricultural Statistics Research Institute by conducting preliminary surveys. The sampling design adopted is stratified multistage random sampling, stratification being done over space and time

Fish landings takes place at numerous locations all along the coastline in all seasons during day and night.Sampling and estimation are performed for geographical area referred as fishing zone.There are 75 fishing zones covering 9 maritime states and two coastal Union territories. All the 1511 landing centres are covered under the sample design and data collection is by qualified and trained field staff stationed at 25 locations across all maritime states. The overall operation is coordinated by the Fishery Resources Assessment Division of CMFRI.

Fish is a natural resource with capacity to rebuild. If not monitored and managed over exploitation will lead to stock depletion and some may become extinct. Harvest of this resource needs to be maintained at sustainable level through monitoring and control.

The primary objective of fish stock assessment is to provide advice on the optimum exploitation of aquatic living resources. Fish stock assessment can be described as the search for the exploitation level that in the long run gives maximum yield from the fishery. The aim of fish stock assessment is for a fishing strategy that gives the highest steady yield year after year.

The basic goal of fishery management is to estimate the amount of fish that can be removed safely while keeping the fish population healthy. These estimates may be modified by political, economic, and social considerations to arrive at an optimum yield.

Overly conservative management can result in wasted fisheries production due to under-harvesting, while too liberal or no management may result in over-harvesting and severely reduced populations.Fisheries Management draws on fisheries science inorder to find ways to protect fishery resources so that sustainable exploitation is possible. Fisheries Management is the integrated process of information gathering, data analysis, planning, consultation, decision making, allocation of the resources and implementation of regulations or rules to govern fishing activities with enforcement as and when necessary to ensure steady and sustainable harvest of the resources. Fisheries Management is not about managing fish but about managing people and related businesses. Fish populations are managed by regulating the actions of people. These management regulations should also consider its implications on the stakeholders.

PELAGIC FIN FISHERY RESOURCES OF INDIA

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3

Introduction

India is endowed with a long coastline of 8129 km. Being tropical country, the marine ecosystem bordering Indian sub-continent contain large number of species adapted to wide range of habitats, from mangrove swamps, estuaries, saline lagoons, sea grass meadows, sandy/ muddy/rocky coasts, coral reefs, oceanic islands to deep oceanic realms. Theses resources are supporting the marine fishery of the country. The water spread of continental shelf is 0.5 million sq. km and of EEZ is 2.02 million sq. km. The annual catchable marine fishery potential of the EEZ is 4.42 million tonnes. India is one of the leading nation of the world in marine fish production and export.

Growth in Marine Fisheries

Coastal marine fishery made remarkable growth since mechanisation started in early sixties. The marine fish production increased steadily from 0.68 million t in 1961 to 3.94 million t in 2012. This increase may be attributed mainly to the increase in fishing intensity coupled with introduction of mechanised fishing vessels, motorisation of the country crafts, modernisation of harvesting techniques coupled and extension of fishing to deeper waters. Mechanisation and diversification of fishing have slowly extended fishing activity beyond the continental shelf. Adoption of advanced techniques to detect resources and to identify productive ground and use of fish aggregating devices added to the efficiency of fishing operation. Yield of pelagic resources also registered similar growth as of total marine production from 0.44 to 2.1 million t by 2011. Fishery registered marginal decline thereafter.

Marine Finfish Resources

Fishery resources are classified broadly as pelagic and demersal based on their distribution in the water column. Pelagics are diverse group of small to large fishes which occupy mainly the surface and column layers of the water mass. Most of them are characterised by their shoaling behaviour. Large numbers of species which are either bottom dwelling or inhabiting mainly along the lower layers of water column are termed as demersal resources. Assessment of the stocks of major exploited resources from the coastal waters have revealed the present level of fishing pressure, which each resource is experiencing.

Oil sardine

The resource is represented by a single species, *Sardinella longiceps and* distributed widely along the Indo-Pacific region. They form the mainstay of pelagic fishery of India. They occur all along the Indian coast. Till recently their abundance was largely restricted to the coastal waters between Quilon and Ratnagiri with 90% of the reported fishery from this area alone. However, in recent years, they emerged as the major resource along the entire east coast up to Orissa waters towards north.

Lesser sardines

Nearly 13 species constituted the resource and fishery. They occur along the entire Indian coast but their abundance and fishery confined largely to the inshore waters of Kerala, Tamilnadu and Andhrapradesh. It include 10 species under the genus *Sardinella,* two species under *Dussumieria* and *Esculosa thoracat.* Dominant species are *Sardinella gibbosa, S.albell,a S.fimbriata S.dayii* and *S.sirm.* Species show discontinuous distribution.

Dorabs

They are non-shoaling fishes, abundant along both east and west coast with large abundance along the southeast coast. Two species namely, *Chirocentrus dorab and C.nudus* supported the resource and fishery. Large abundance in shallow waters between 10 –30 m depth. They migrate to deeper waters for spawning. They usually form fishery along with other resources. Their average annual landing is 18,403 t during the last decade, forming 0.6% of the total marine production. 50% of the total landing is from the Tamilnadu coast between Palkbay and Gulf of Mannar.

Anchovies

Resources and fishery are supported by species belonging to the genera *Stolephores, Thryssa, Thryssina, Coilia* and *Setipinna.* White bait belonging to the genus *Stolephores* constitite nearly 70% of the catch. They are abundant in coastal waters of 5-20 m depth. 90% of the resource was concentrated in area between Ratnagiri and Gulf of Mannar. Abundance of other anchovies are relatively large along the coastal waters of Andhra, Tamilnadu, Kerala, Karnataka and Maharashtra.

Other Clupeids

Several species belonging to different genera, *Pellona, Hilsa, Ilisha, Elops, Megalops, Anadontosoma etc.* support the fishery. They are widely distributed along the east and west coast, with large abundance along the east coast.

Mackerel

Resource is represented by three species in Indian waters. However more than 98% of the stock and fishery was supported by Indian mackerel, *Rastrelliger kanagurta* alone. *R.brachisoma* and *R.faugni* form sporadic fishery respectively in Andaman Madras waters. Mackerel is abundant in coastal waters within 25 m depth. Nearly 80-90% of the total mackerel catch is from west coast. However in recent years, their abundance and fishery is on the increase along east coast. The present average production was 176,103 t during the last decade and constitute nearly 5.7% of the marine fish production during this period.

Tunas

These are typical oceanic fast swimming and highly migratory pelagic fishes and most of them have cosmopolitan distribution. Resource is represented by nine species belonging to the genus *Auxis, Euthynnus, Thunnus Katsuonus Sarda* and *Gymnosarda*. These are typical shoaling fishes and aggregate in large numbers around any floating objects in open sea.

Billfishes

Bill fishes form by-catch in oceanic tuna and shark fishery. They are represented by *Istiophores, Makyra* and *Xiphia* Spp. Their average production was 6,372 t during last decade. They constitute only 0.3% of the marine fish production during this period.

Seerfishes

They are the most relished fishes with very high market demand. Five species namely *Scomberomores commerson, S.guttatus, S.lineolatus, S.koreanus* and *Acanthocybium solandri* supported the resource and fishery. They are abundant in the neretic and oceanic waters of both coasts. But undertake long term inshore migration and form fishery in shallow waters. *S.guttatus* is available in less saline turbid waters of coastal belt. Average production was 50,450 t during the last decade and constitute nearly 1.6 % of the marine fish production.

Carangids

Carangids are a diverse group of fishes having different body shapes. They are widely distributed along the entire coastal waters of India, Their major abundance confined to shallow waters up to 60 m depth. More than 35 species constituted the resource, with many species showing discontinuous distribution. However, commercial fishery was supported by few species. Horse mackerel and scads dominated the fishery. Average production was 200,324 t during the last decade constitute nearly 6.5% of the marine fish production.

Ribbonfishes

They are abundant along east and west coast with large abundance along the peninsular region. Resource was supported by six species dominated by *Trichiurus lepturus*. Their maximum abundance was reported in deeper waters between 25-75 m depth. They being carnivores, used to follow shoals of small pelagics and Acetes and were fished in large quantities by shrimp trawls. Average production was 168,853 t during last decade and constitute nearly 5.5% of the marine fish production.

Bombay duck

Fishery was supported by three coastal water species dominated by *Harpodon neherius*. Resource distribution was discontinuous confined to northern sector of east and west coast. Major share of the resource and fishery is confined to north west coast ie. Gujarat and Maharashtra coast and the rest from coast of Orissa, Andhrapradesh and Tamilnadu. They are fished mainly by fixed Dolnetat 15-50m depth zone. Sizeable quantities were also landed by trawls. Average production was 114,576 t during last decade and constitute nearly 3.7% of the marine fish production.

Flying Fishes

They inhabit off shore waters of 30-40 km away from the shore. Several species belonging to *Parexocoetus, Cypselurus* and *Exocoetus* supported the fishery. Good fishery occur along the Coramandal and Gulf of Mannar coast of Tamilnadu and small quantities from Andhra coast. Average production was 1,825 t during last decade.

Belonids and Hemirhamphids

Good resource of garfishes and half- beaks were available in the Gulf of Mannar and Palk Bay and support a potential local fishery. Average production was 4,140 t during last decade.

Other pelagic

Other resources which contribute considerably to pelagic fishery are barracudas, king fishes (cobias),barramundi, mullets, milkfish, tarpons, lady fishes, glossy perclets, fusiliers etc. They form commercial fishery at varying levels at certain areas.

DIVERSITY AND EXPLOITATION STATUS OF DEMERSAL FISHERY RESOURCES OF INDIA

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4

Introduction

Fisheries are an important source of income and means of livelihood in developing countries, particularly in rural areas. Estimates by the Food and Agricultural Organisation indicates that capture fisheries employ over 27 million people worldwide, of which 85% live in Asia. Marine fisheries play an important role in food security and nutrition in developing countries. There is serious concern about the state of marine fisheries worldwide. While over-fishing is likely to have been the major cause of the serious setbacks, these have probably been exacerbated by habitat degradation. Fisheries sector plays an important role in the overall socio-economic development of India. The fisheries sector contributed 76,913 crores to the GDP during 2009-10 which is 0.96 per cent of the total GDP at factor cost and 5.4 per cent of the GDP at factor cost from agriculture forestry and fishing (Zacharia and Najmudeen, 2013). During 2015-16, the export of marine products from India reached over 9.45 lakh tonnes valued at Rs.30,421 crores and US$ 4.688 billion (MPEDA, 2017). India is one of major fish producing countries in the world contributing over 3 per cent of both marine and freshwater fishes to the world production (Srinath and Pillai, 2006) with third position in capture fisheries and second in aquaculture. India has an Exclusive Economic Zone (EEZ) covering a total area of 2.02 million sq. km, i.e., 0.86 million sq. km on the west coast including the Lakshadweep Islands and 1.16 million sq. km on the east coast, including the Andaman and Nicobar Islands and a continental shelf of half a million sq. km (Vivekananadan *et al.,* 2003).

The marine fishes, based on their depth-wise distribution may be grouped mainly as pelagic and demersal, the former occupying surface and subsurface waters and the latter the neretic areas in the continental shelf. Demersal fishes can be divided into two main types: Strictly benthic fish which can rest on the sea floor, and bentho pelagic fish which can float in the water column just above the sea floor. Benthic fish, sometimes called groundfish, are denser than water, so they can rest on the sea floor. Benthic fish which can bury themselves include dragonets, flatfish and stingrays. Demersal finfishes are one of the major components in the marine fish landings along the Indian coast. The major gear which exploit the demersal finfish resources in India are bottom trawlnets. Demersal fish though generally occupy the seafloor; feeding on the benthic organisms and detritus, perform vertical and horizontal migration in search of their feeding and breeding grounds. Hence, the day and night catches in bottom trawl show differences, eg. catfish, rays, eels etc. In the in shore fishing activities below 50 m depth, occurrence of pelagics in bottom trawl and catfish, perches and penaeid prawns in pelagic net is common. Trawl catch consists of 76% demersal (finfish 38% and inveretebares-38%) remaining pelagic or column water fishes.

When compared to the pelagic resources, proper exploitation of the demersal finfishes in India has been a initiated only three decades ago (Bensam, 1992). With the introduction of mechanized bottom trawling from the late fifties, the exploitation of demersal finfishes attained a 2.7- fold increase during late eighties. With the large-scale introduction of mechanized trawling, several environmental problems and stock-recruitment hazards to inshore fisheries have come up. Demersal fish groups such as the sharks, groupers, snappers, threadfins, pomfrets and Indian halibut are commercially valuable and contribute substantially to the economy of Indian marine fisheries. Some of these groups, especially of large-size, are targeted by the fishermen by using different craft and gear combinations. However, several other demersal finfishes are not targeted, but are landed as by catch by shrimp trawlers (Vivekanandan, 2011).

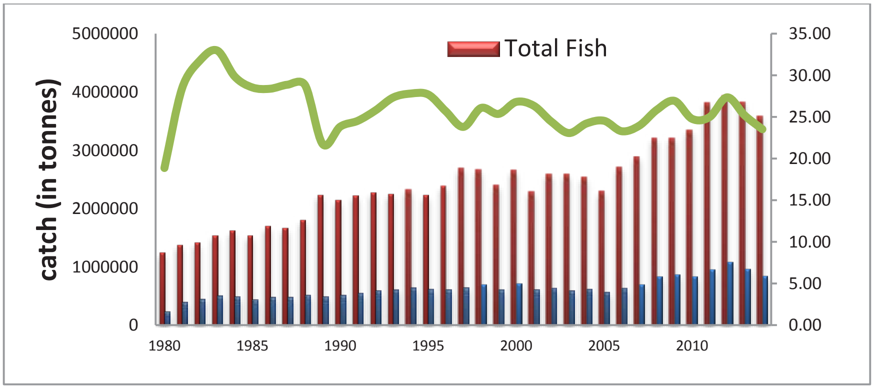

Fig.1. Trends in the landings of demersal finfishes in India during 1980-2014

The landings of demersal finfishes India during 1980-2014 period shows that the catch is increasing steadily over the years from a meagre of 2,34,408 tonnes to nearly 10,76,789 tonnes in 2012, and thereafter declined to 8,42,199 tonnes in 2014. However, the catch share of demersal finfishes during the last 35 years indicate that the contribution of demersal finfishes to the total Indian marine landings are decreasing over the years. The maximum share was reported in 1983 with 33% contribution and the lowest share (21.7%) was in 1989. The region-wise average share of demersal finfishes along the Indian coast shows that the northwest region comprising of Gujarat and Maharashtra contributes the highest share, followed by southwest coast comprising Kerala and Karnataka and southeast coast comprising Tamil Nadu and Andhra Pradesh. The share of demersal finfishes to all India marine landings of India in 2016 was 29%.

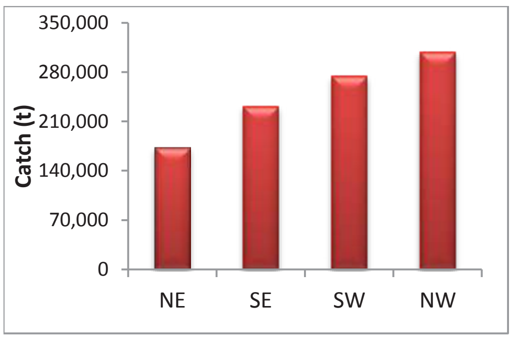

Fig. 2. Region-wise landings of demersal finfishes for the period 2007– 2012

The group wise composition of demersal finfish assemblages in Indian marine fish landings during 2016 indicate that the major contributors are the perches (37%), followed by the croakers (18%), silverbellies (11%), lizardifishes and catfishes each contributed 9%, elasmobranchs (6%) and flatfishes and promfrets (5% each). The exploitation status of the important groups of demersal finfishes along the coast of India are briefly mentioned below.

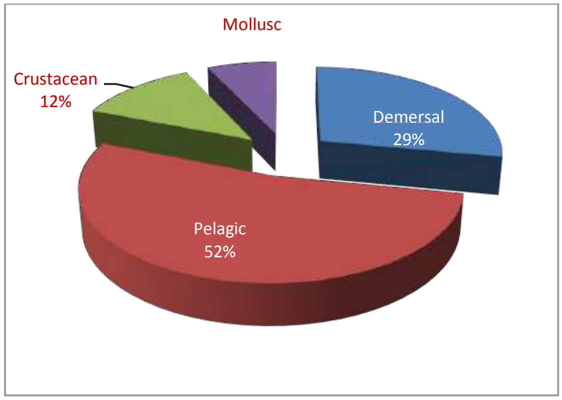

Fig. 3. Share of demersal finfishes to the all India Marine Capture fisheries during 2016

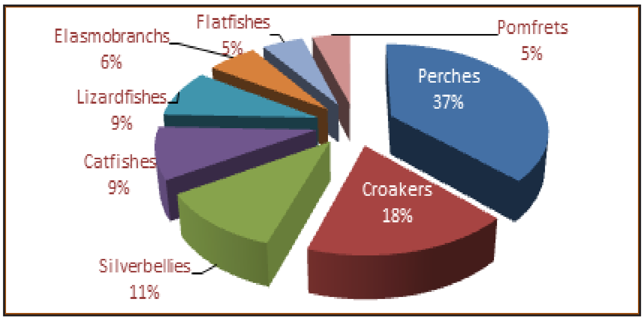

Fig. 4. Share of demersal finfishes to the all India Marine Capture fisheries during 2016

ELASMOBRANCHS

In India, there are about110 species of elasmobranchs, of which 66 species of sharks, 4 sawfishes, 8 guitarfishes and 32 species of rays are landed in the commercial catches. Among these, 34 species are commercially important. Some species of elasmobranchs are protected under the Wildlife Protection Act (10 species), which include, *Pristis microdon, Rhynchobatus djiddensis, Pristis zijsron Carcharhinus hemiodon* (Pondicherry shark), *Glyphis glyphis, Rhincodon typus* (whale shark), *Urogymnus asperrimus* (Porcupine

Fig. 5. Heavy landings of sharks at Cochin Fisheries Harbour, Kerala

ray). Majority of the species of elasmobranchs in the Indian seas are viviparous, some are oviparous and few are ovo-viviparous with very low fecundity. All India landings of elasmobranchs during 2016 was 52,424 tonnes, forms 5.6% of demersal catch. Trawl nets accounting for 48.8%, gillnets 35.6% and hook & line units 6% of the total elasmobranch landings of the country.

Sharks : Shark landings in India during 2016 was 23,002 tonnes, which formed 45% of the total elasmobranch landings of the country. The major families appeared in the landings were Carcharhinidae, Triakidae, Sphyrnidae, Echinorhinidae, Hemiscylliidae, Alopiidae, Lamnidae, Centrophoridae, Squalidae and Stegostomatidae. The dominant species in the landings were *Carcharhinus falciformis*(37.25%), *Alopias superciliosus (11.85%), Sphyrna lewini(11.53%), Alopias pelagicus*(8.53%).

Rays: The landing of rays in India during 2016 was 26,211 tonnes, which formed 51% of the total elasmobranch landings of the country. The major families in the landings were Dasyatidae, Mobulidae, Myliobatidae, Gymnuridae and Rhinopteridae

Fig. 6. Landings of rays at Cochin Fisheries Harbour along Kerala coast

Skates/guitar fishes: All India landings of guitarfishes were estimated at 3627 tonnes, which constituted 4% of the total elasmobranch landings of the country.

Fig. 7. Landings of guitarfishes along the Kerala coast

The major families of guitarfishes landed along the coast are Rhinidae and Rhinobatidae.

There are significant changes in the share of sharks and rays to total elasmobranch landings recent years. The all India Production Elasmobranchs during 1999-2010, shows that sharks were dominant in the catch with 49.7% share and that of the rays was 44.5%. However, the landings during 2006 indicate that the rays has emerged as the dominant group with 51% followed by sharks with 45% share.

PERCHES

This group was abundant in the rocky grounds off Kerala and Tamil Nadu and was exploited by drift nets, hooks and lines and traps. All India landings of Perches is 4.07 lakh tonnes and forms 40% of total demersal finfish landings. Among the different groups of perches landed along the Indian coast, threadfin breams were the dominant group with 42% of the total perch landings, followed by bullseyes belonging to the family priacanthidae with 32% share, rock codes/groupers 10%, snappers and pigface breams 3% each and other minor perch groups contributed 10%.

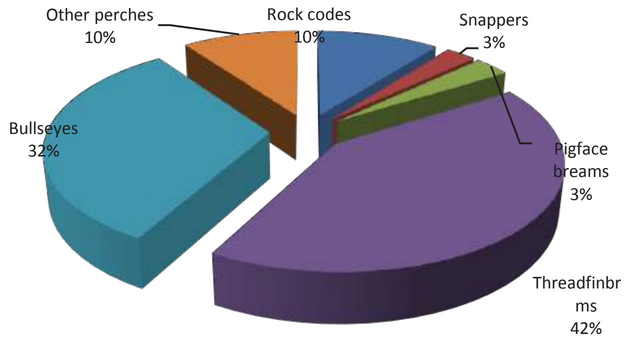

Fig. 8. Composition of different groups to the total perch landings in India

THREADFIN BREAMS

Six species of thredfin breams are known from the seas around India. *Nemipterus japonicus, N. randalli, N. bipunctatus, N. metopias, N. zysron, N. nematophorus, N. tolu.* Among these, *Nemipterus japonicus,*

Fig. 9. Landings of threadfin breams along southwest of India

*N. randalli*are commercially important. Their abundance is influenced by upwelling and are known to move to inshore waters during monsoon period along the west coast. They are Fractional spawners with protracted spawning periods. Spawning in *N. japonicas takes* place during October-April with a peak during October - December along Gujarat. In Kerala, *N. japonicus* and *N. randalli* spawn during monsoon and post monsoon periods with peaks during monsoon in the former and during post monsoon in the latter species. All India landings of threadfin breams in 2016is 1.63 lakh tonnes, forms 17.3% of the total demersal finfish catch in India.

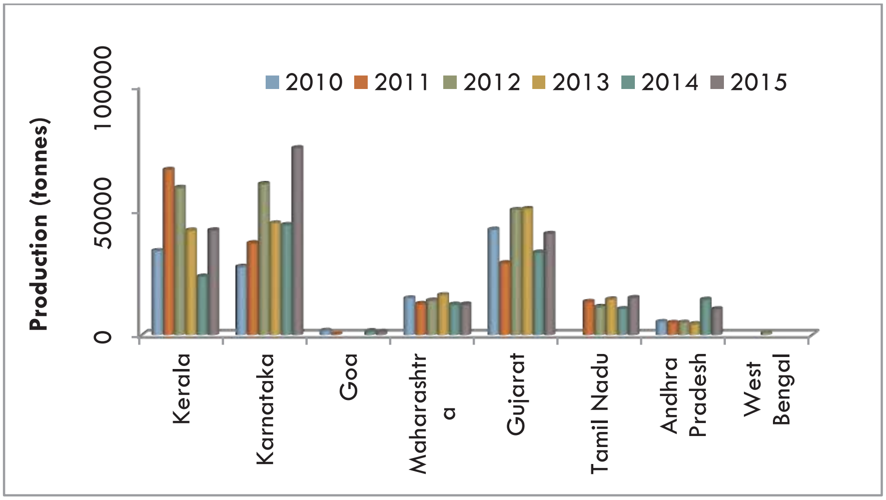

Fig. 10. State-wise trend of threadfin breams during 2012-2016

GROUPERS

Rock cods or groupers are protogynous hermaphrodites, initially maturing as females then reverting to males as they grow in age and size. The major species observed in the landings are *Epinephelus chlorostigma, E. diacanthus, E. areolatus, E. tauvina, E. morrhua, E. bleekeri,*

Fig. 11. Landings of groupers along southwest coast of India

E. longispinnis, Cephalopholis argus, Aetheloperca rogaa, Variola louti. The total landings of groupers during 2016 in India was 42781 tonnes, which formed 10% of the perch landings of India.

SNAPPERS

The major species observed in the all India landings of snappers were *Pristipomoides typus, L. argentimaculatus, Lutjanus gibbus, L. rivulatus, L. bohar*, and *L. lutjanus*. The catch of snappers during 2016 in India was 10,533 tonnes. Southeast coast of India contributed the majority of landings of snappers in India followed by southwest coast of India.

Fig. 12. Landings of Snappers at Cochin Fisheries Harbour, Kerala

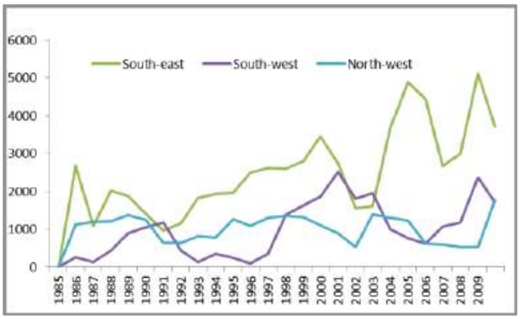

Fig. 13. Region wise distribution of snappers along the Indian coast

BULLSEYES

The landings of Bullseyes during 2016 in India was 130740 tonnes, which formed 32% of the total perch landings of the country. They belongs to a single family Priacanthidae. The major species observed in the landings are *Priacanthus hamrur*, *Oookeolus japonicas* and *Priacanthus sagittarius*. From a mere 43,576 tonnes in 2015 its landings of bullseye has been escalated to a three- times-high of 1.3 lakh tonnes during 2016.

Fig. 14. Catch of Bullseye, *Priacanthus* sp

PIGFACE BREAMS

The major species observed in the landings of pigface breams/ emperor breams in India are *Lethrinus mahsena, L. lentjan, L. conchyliatus, L. nebulosus, L. ramak, L. elongatus* and *Lethrinus miniatus*. The landings of Pigface breams in India during 2016 was 12519 t, which formed about 3% of the total perch landings of the country. Southeast coast of India contributed the major share of landings of pigface breams in India.

Fig. 15. Emperor bream/ pigface bream landings along the Kerala

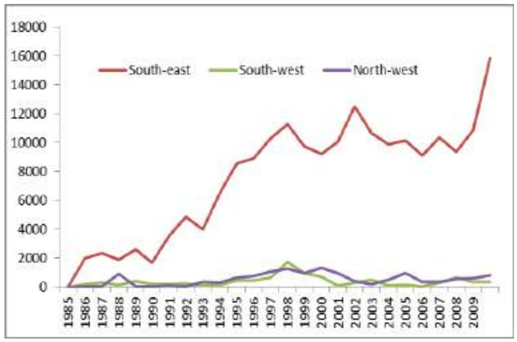

Fig. 16. Region wise distribution of pigface breams in India

LIZARDFISHES

All India landings of lizardfishes is 94, 817 tonnes, forms 8.3% of demersal catch20 - 40 m depth up to 150-200 m depth. The species of lizardfishes landed along the west coast of India are *Saurida tumbil, S. undosquamis, Trachinocephalus myops, Synodus englemani* and that of East coast are *Saurida undosquamis, S. longimanus* and *S. micropectoralis, Saurida tumbil, Trachinocephalus myops, Synodus englemani*. Spawning in *S. tumbil* occurs during September to March off Veraval and Bombay along North west coast; August to November off Cochin.

Fig. 17. Lizardfish landings along the west coast of India

CATFISHES

Catfishes are important demersal resources which have wide distributional range in the Indo-Pacific region. They are distributed all along the Indian coastal waters up to the middle shelf with preferential concentration on muddy grounds of 30-70 m depths. Catfishes migrate both vertically (diurnal migration) and horizontally (seasonal) in small schools to large shoals in response to seasonal climatic / hydrographic variations. Marine catfishes belong to the family Ariidae, of which 11 species appear in the commercial fisheries.

Fig. 18. Catfish landings along the west coast of India

West coast of India landed 70% of the total catfish catch and the east coast 30%, northwest coast landed 90% of the west coast catch. All species of catfishes exhibit parental care - the male carrying the brood (25-120 eggs) in the oro-buccal cavity for 1 to 2 months' time until the juveniles (4-7 cm) are released. After spawning the brooding males segregate into shoals and move along the surface and prefer shallow water. The newly released juveniles of all species of tachysurids live in the shallow muddy grounds feeding on the bottom epi-and in-fauna – become easy target in fishing. The all India landings of catfishes is during 2016 was estimated at 80559 tonnes, which formed 8.9% of demersal finfish catch of India.

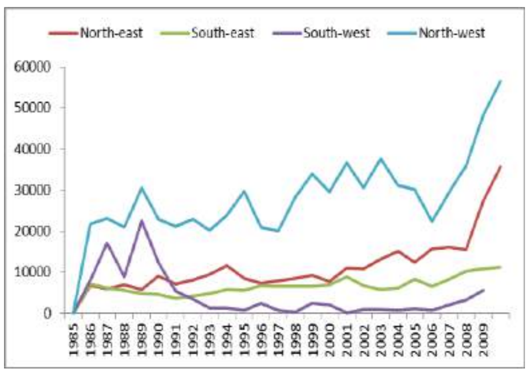

Fig. 18. Catfish landings along the west coast of India

FLATFISHES

These were abundant in muddy and/or sandy bottom up to about 80 m depth belonging to genera such as *Cynoglossus, Psettodes, Pseudorhombus, Bothus, Paraplagusia,* etc. and exploited by trawl nets, gill nets and other artisanal gears. The Commercial exploitation of flatfishes along the Indian coast varies widely with *Cynoglossus macrostomus* dominating in the West Coast and *Cynoglossus macrolepidotus* along the East coast. The Fishery of *Psettodes erumei* showed a decline in recent years. The all India landings of flatfishes during 216 was 43,828 tonnes, which formed 4.7% of demersal finfish catch of India.

Fig. 20. Landings of flatfishes along the southwest coast of India

SCIAENIDS

Sciaenids include high value demersal resources like croakers, which are landed mainly from Gujarat and Maharashtra. The important gears used are trawls and gill nets. These fishes are caught mainly during October - December and January - March. They mainly consist of the species like *Pseudosciaena diacanthus, Otolithes* spp. and *Johneiops* spp. *Protonibea diacanthus, Johniops macrorhynus, Otolithe scuvieri, J. dussumieri, J. glaucus,* and *O. ruber.* All India landings of Sciaenids during 2016 is 1, 57, 793 tonnes, which forms 16.5% of demersal finfish catch of the country.

Fig. 21. Sciaenid landings along the southwest coast of India

POMFRETS

Pomfrets belong to two families, the black pomfret *Parastromateus niger* is coming under the family Carangidae and the silver pomfret *Pampus argenteus* belongs to the family Stromateidae. They are landed abundantly in Gujarat and Maharashtra. The blackpomfret landings in India during 2016 was 13,924 tonnes, and that of silver pomfret was 26,012 tonnes, which formed 3.3% of demersal finfish catch of the country

Fig. 22. Black pomfret (*Parastromateus niger)*

Fig. 23. Silver pomfret *(Pampus argenteus)*

SILVERBELLIES

Silverbellies belonging to the family Leiognathidae. Exploited by trawl nets and artisanal gears, this group formed about 12% of demersal finfishes production.The major species landed along the coast of India are *Leiognathus splendens, L. equlus, Gazzaminuta, L. bindus, L. dussumieri, L. jonesi, Secutor insidiator.*

Table.1. Changes in the scientific names of the silverbellies exploited in India

Previous name	Present name
Leiognathus bindus	*Photopectoralis bindus*
L. blochi	*Nuchequula blochii*
L. edwardsi	*Equulites elongatus*
L. insidiator	*Secutor insidiator*
L. jonesi	*Eubleekeria jonesi*
L. splendens	*Eubleekeria splendens*
L. ruconius	*Secutor ruconius*
L. daura	*L. daura*
L. dussumieri	*L. dussumieri*
L. longispinis	*L. longispinis*

All India landings of silverbellies is 92764 tonnes, which forms 10.4% of demersal finfish catch of India.

WHITEFISH

This resource is also called butterfish and known to be depleted/overexploited by the mechanised trawl operations along the near-shore waters of west coast of India. Although distributed all along the coastline, it has been supporting notable fisheries along the southwest and southeast regions. All India landings of whitefish is 6,312 tonnes, forms 0.8% of demersal catch *Lactarius lactarius*is the only species available in this family. Whitefish production in India shows wide fluctuation. Shows steady fall except spurt in 1983 and 1985. In Karnataka it fluctuated between a lowest of 37t in 1964 and highest of 2,930 t in 1988. East coast shows a steady decline from 4,738 t in 1960-69 to 888 t in 1990-99. West coast showed an increase from 2,901 t in 1960-69 to 12,354 t in 1980-89 then steep decline to 6,109 in 1990-99.

Fig. 24. Whitefish *Lactarius lactarius* landed along the Kerala coast

GOATFISHES

This group has three important genera in India, *Upeneus, Parupeneus* and *Mulloidichthys*. These were exploited by trawls and traditional gears mostly in Tamil Nadu, Andhra Pradesh, Kerala, Karnataka and Maharashtra. Dominant species along the east coast of India include *Upneus taenipterus, Upeneus bensasi, Upenues sulphureus, Upeneus sundaicus,*

Fig. 25. Goatfish landings along southeast coast of India

Parupenus indicus and *U. molluccensis.* All India landings of goatfishes during 2016 was 30,276 tonnes, which formed 3.2% of demersal finfish catch of the country.

EELS

Eels are long-bodied, snake like fishes, having a crevice dwelling or sediment-burrowing mode of life, though some live in the pelagic realm of the open oceans.

Fig. 26. Eels belonging to the family Muraenesocidae landed along the Kerala coast

Traditionally marketable species of eels are caught from conventional fishing grounds of northwest and northeast coasts of India and are largely a by-catch. Pike congers belonging to the family Muraenesocidae occur in tropical waters in the soft bottoms upto 100 m depth and in estuaries. Four species are recorded in Indian waters and they grow to a maximum length of 80 cm (*Congresox talabon*) (Cuvier, 1829), 250 cm (*C. talabonoidies*) (Sleeker, 1853), 180 cm (*Muraenesox bagio*) (Hamilton-Buchanan) and of 80 cm (*M. cinereus*) (Forsskal, 1775).

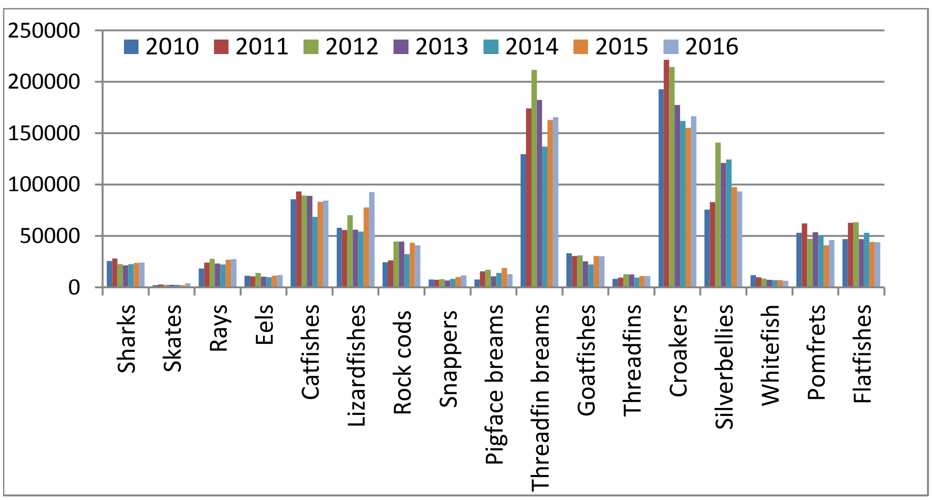

Fig. 27. Trends in the landings of major demersal finfish species during 2010-2016

Regionwise Distribution of Species

Finfishes exploited by trawls belong to 21 major fish groups, which are mostly demersal groups. Each maritime region of India is characterized by dominance of specific demersal finfish groups. Along the northeast (NE) coast, sciaenids, catfishes and pomfrets (74.0% to the demersal landings) are dominant. The southeast coast is characterised by the abundant landings of silverbellies and pigface breams. Along the southwest coast of India, threadfin breams and other perches are the major demersal resources and the northwest coast is characterised by the dominance of sciaenids, catfish, pomfrets and threadfin breams.

DIVERSITY AND EXPLOITATION STATUS OF CRUSTACEAN FISHERY RESOURCES IN INDIA

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Introduction

India is blessed with long coastline of about 8118 km along the West Bengal, Odisha, Andhra Pradesh, Tamil Nadu and Pondicherry along the east coast; along Gujarat, Maharashtra, Goa, Karnataka, Kerala along the west coast. India has 2.02 million sq.km exclusive economic zone area and 0.53 million sq.km continental shelf area, a potential source for marine fisheries.The rich continental shelf area, a good habitat for demmersal fishes as well as crustaceans such has penaeid prawns , non-penaeid prawns, crabs, lobsters and stomatopods. Mechanised trawler is the main gear operated in the continental area targeting crustacean resources, Though trawl net is operated for penaeid prawn, non penaeid prawns, crabs and stomatopods will be formed as by catch because all these resources habituate in the same fishing ground.

Crustacean resources

Crustacean resources comprises with penaeid prawns, non-penaeid prawns, crabs, lobsters and stomatopods. Total annual marine fish landings of India ranged from 2.29 to 3.93 million t with mean at 2.92 million t. Annual total crustacean resources ranged from 3.52 lakh t to 5.32 lakh t with mean at 4.45 lakh t, and its contribution to total marine fish landings ranged from 12.6 % to 18.9 % with mean at 15.2 %. The landings of penaeid prawns ranged from 1.71 lakh t to 2.67 lakh t with mean at 2.07 lakh t. Landings of non-penaeids ranged from 1.04 lakh t to 2.13 lakh t with mean at 1.54 lakh t. The catches for lobsters ranged from 1,201 t to 2,787 t with mean at 1,860 t. Crab landings ranged from 27,538 t to 55,695 t with mean at 42,675 t. Stomatopod catches varied from 21,187 t to 92,611t with mean at 39,433 t.

On an average penaeid prawns contributed 7.1%, non-penaeidprawns 5.3 %, crabs 1.5%, stomatopods 1.3 % and lobsters 0.1 % (Fig.1).

Trends in crustacean resource landings, group wise, are shown in fig.2. Increasing trend was observed in total crustacean resources during the 19 years period. Both penaeids and non –penaeids have shown increasing trends. A marginal increasing trend was observed in crab landings. Though lobster catches have shown decreasing trend, its contribution to total crustacean resources was very less (0.1%). Despite increasing trends exhibited by penaeids, non penaeids, crabs, stomatopods have shown decreasing trend because of competing in the same fishing ground with penaeids.

East Coast

Mean state-wise contribution (%) of crustacean resources to total crustacean landings of India for the period 1996-2014 along the east coast and state-wise contribution (%) to the total crustacean resources of the east coast are shown in Fig. 3 & 4. The contribution of crustacean resources from the east coast is 27.0 % to total crustacean landings. Tamil Nadu contributed highest (8.3 %) followed by Andhra Pradesh (6.8 %), West Bengal (6.1%), Odisha (5.5%) and Pondicherry (0.3 %). Tamil Nadu contributed 30.9 % to the total crustacean resources of the east coast, followed by Andhra Pradesh (25.0%), West Bengal (22.7%), Odisha (20.4%) and Pondicherry (1.1%).

West Coast

State-wise contribution (%) to the total crustacean resources of the west coast and mean state-wise contribution (%) of crustacean resources to total crustacean landings of India for the period 1996-2014 along the west coast are shown in Fig. 5 and 6. West coast contributed 72.9 % of total crustacean resources of India. Gujarat contributed high (28.3 %) followed by Maharastra (23.9 %), Kerala (13.2 %), Karnataka (6.3 %) and Goa (1.3 %). Along the west coast Gujarat contributed high (38.9%), followed by Maharastra (33.7%), Kerala (18.1%), Karnataka (8.6%) and Goa (1.7%)

Commercially important species

Commercially important of penaeids, non penaeids, crabs, lobsters, state-wise, are shown in table 1.

Fig. 1. Mean contribution of crustacean resources, group wise, to total marine fish landings for the nineteen years period (1996-2014)

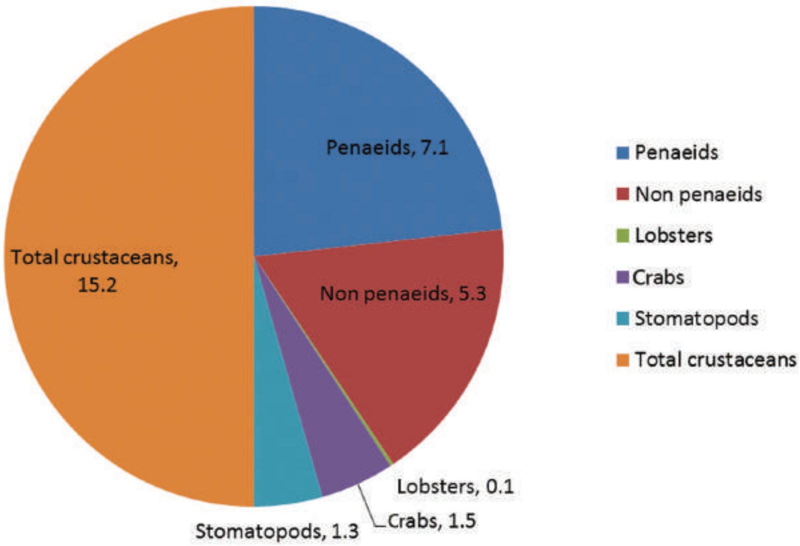

Fig.2. Group-wise, trends in crustacean resource landings during 1996-2014

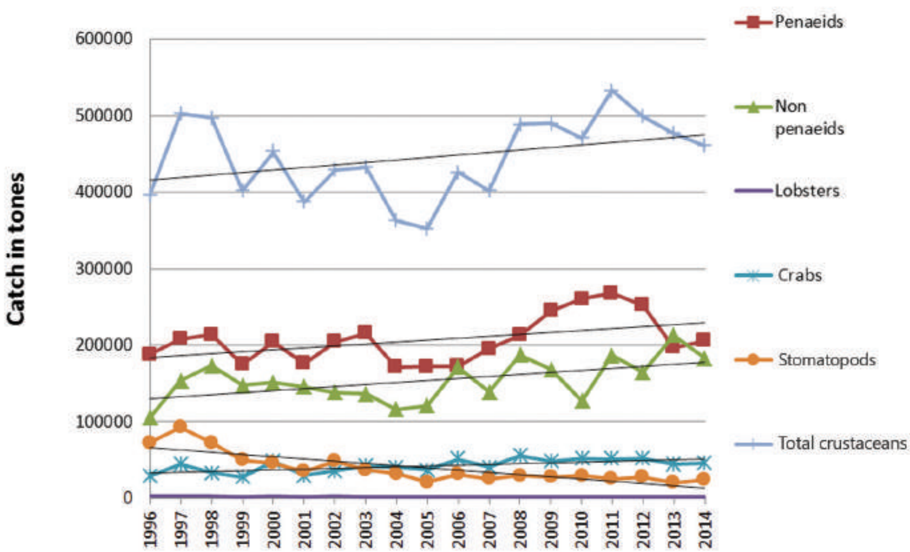

Fig. 3. Mean state-wise contribution (%) of crustacean resources to total crustacean landings of India for the period 1996-2014 along the east coast

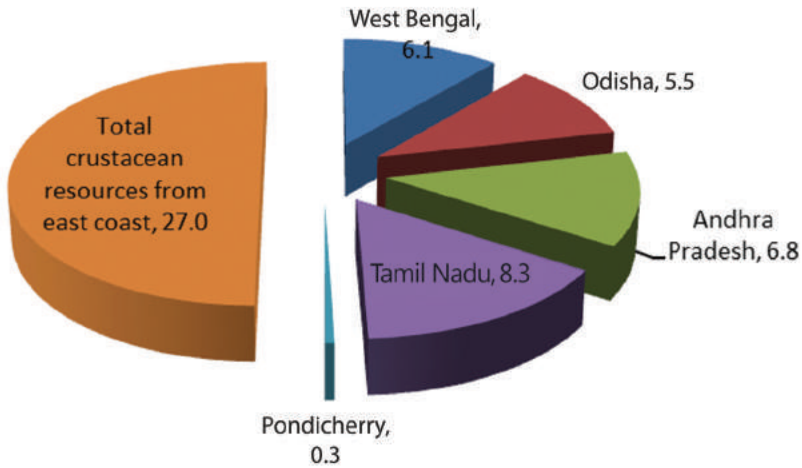

Fig.4. State-wise contribution (%) to the total crustacean resources of the east coast

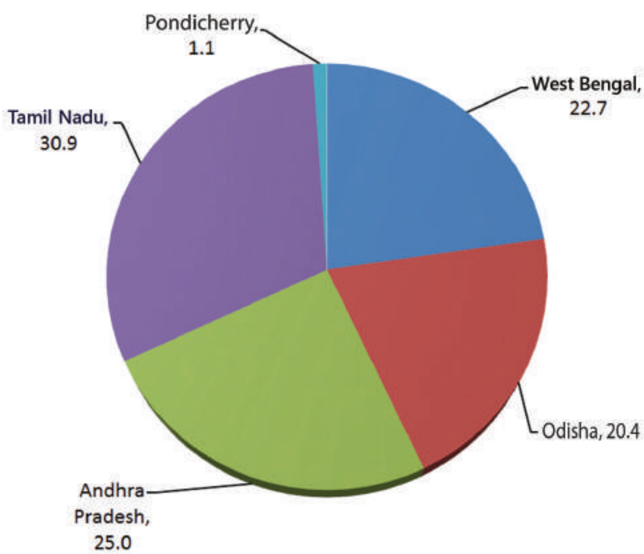

Fig.5. State-wise contribution (%) to the total crustacean resources of the west coast

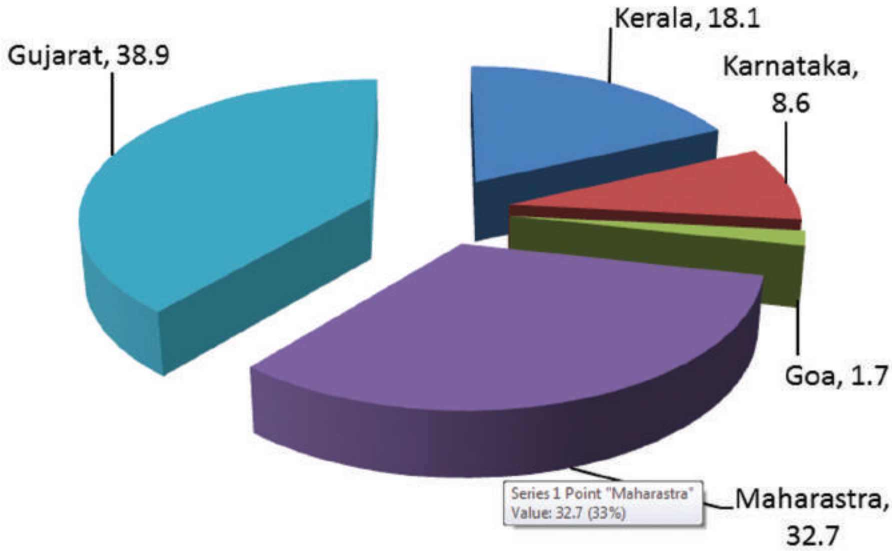

Fig.6. Mean state-wise contribution (%) of crustacean resources to total crustacean landings of India for the period 1996-2014 along the west coast

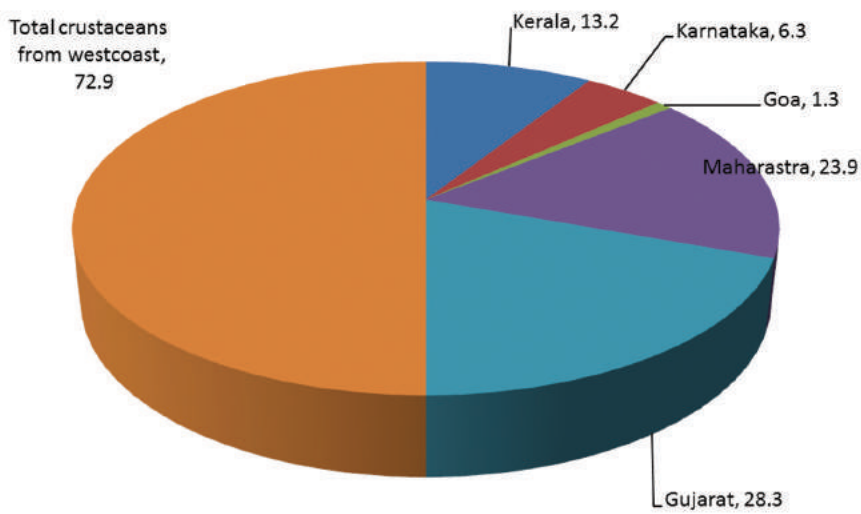

Table 1. Commercially important species of penaeids, non-penaeids, crabs, lobsters and stomatopods

State	Penaeids	Non-penaeids	Crabs	Lobsters
Gujarat	1. *Penaeus semisulcatus*	1. *Acetes* spp.	1. *Portunus sanguinolentus*	1. *P. polyphagus*
	2. *Fenneropenaeus merguiensis*	2. *N. tenuipes*	2. *C. feriatus*	
	3. *Metapenaeus affinis*	3. *E. ensirostris*		
	4. *M. monoceros*			
	5. *M. kutchensis*			
	6. *Parapenaeopsis stylifera*			
	7. *P. hardwickii*			
	8. *P. sculptilis*			
	9. *Metapenaeopsis stridulans*			
	10. *Solenocera crassicornis*			
Maharashtra	1. *Fenneropenaeus indicus*	1. *Acetes* spp.	1. *C. feriatus*	1. *P. polyphagus*
	2. *Metapenaeus affinis*	2. *N. tenuipes*	2. *P. sanguinolentus*	
	3. *M.monoceros*	3. *Exhippolysmata ensirostris*	3. *P. pelagicus*	
	4. *M. dobsoni*			
	5. *Parapenaeopsis stylifera*			
	7. *Solenocera crassicornis*			
	8. *S. choprai*			
Karnataka	1. *Fenneropenaeus indicus*		1. *C. feriatus*	
	2. *Penaeus monodon*		2. *P. sanguinolentus*	
	3. *P. canaliculatus*		3. *P. pelagicus*	
	1. *M. dobsoni*			
	2. *M. monoceros*			
	3. *M. affinis*			
	4. *P. stylifera*			
	5. *S. choprai*			

State	Penaeids	Non-penaeids	Crabs	Lobsters
Kerala	1. *M. monoceros*	1. *Plesionika spinipes*	1. *P. pelagicus*	1. *Thenus unimaculatus*
	2. *M. affinis*	2. *Heterocarpus gibbossus*	2. *P. sanguino-lentus*	2. *P. homarus*
	3. *M. dobsoni*	3. *H. woodmasoni*	3. *C. feriatus*	
	4. *F. indicus*		4. *C. lucifera*	
	5. *P. stylifera*		5. *Podophthalmus vigil*	
	6. *S. choprai*		6. *Scylla serrata*	
	7. *Metapenaeopsis andamanensis*			
	8. *Aristeus alcocki*			
Tamil Nadu	1.*Penaeus semisulcatus*	1. *Plesionika spinipes*	1. *P. pelagicus*	1. *P. homarus*
	2.*Fenneropenaeus indicus*	2. *Heterocarpus gibbossus*	2. *P. sanguinolentus*	2. *P. ornatus*
	3. *P. latisulcatus*	3. *H. woodmasoni*	3. *C. feriatus*	3. *P. polyphagus*
	4. *Metapenaeus dobsoni*		4. *C. natator*	4. *P. versicolor*
	5. *M. moyebi*		5. *C. smithii*	5. *P. ornatus*
	6.*Parapenaeopsis maxillipedo*		6. *C. annulata*	6. *P. penicillatus*
	7. *P. uncta*		7. *C.lucifera*	7. *Thenus unimaculatus*
	8. *Metapenaeopsis stridulans*		8. *C. hellerii*	
	9. *Solenocera hextii*		9. *Podophthalmus vigil*	
	10. *Aristeus alcocki*		10. *P. gladiator*	
	11. *Parapenaeus fissuroides*		11. *P. haanii*	
	12. *Parapenaeus investigatoris*			
	13. *Penaeopsis jerry*			
	14. *M. andamanensis*			
	15. *Solenocera alphonso*			

State	Penaeids	Non-penaeids	Crabs	Lobsters
Andhra Pradesh	1. *Metapenaeus monoceros*	1. *Acetes* spp.	1. *P. pelagicus*	1. *Thenus unimaculatus*
	2. *M. dobsoni*	2. *N. tenuipes*	2. *P. sanguinolentus*	
	3. *M. brevicornis*	3. *E. ensirostris*	3. *C. feriatus*	
	4. *M. affinis*		4. *Scylla serrata*	
	5. *M. lysianassa*		5. *S. olivacea*	
	6. *F. indicus*			
	7. *P. monodon*			
	8. *F. merguiensis*			
	9. *P. japonicus*			
	10. *P. semisulcatus*			
	11. *Metapeaeopsis stridulans*			
	12. *M. barbata*			
	13. *M. mogiensis*			
	14. *Solenocera crassicornis*			
	15. *S. melantho*			
	16. *Parapenaeopsis stylifera*			
	17. *P. hardwickii*			
	18. *P. uncta*			
	19. *P. maxillipedo*			
	20. *P. coromondelica*			
	21. *Trachypenaeus curvirostris*			
	22. *T.granulosus*			
	23. *T.sedili*			
	24. *Parapenaeus longipes*			

State	Penaeids	Non-penaeids	Crabs	Lobsters
Odisha	1. *Metapenaeus dobsoni* 2. *M. monoceros* 3. *M. affinis* 4. *F. merguiensis* 5. *P. monodon* 6. *F.indicus* 7. *P. stylifera* 8. *P. hardwicki* 9. *M. lysianasa* 10. *Solenocera* spp. 11. *M. burkenroadi*		1. *P. pelagicus* 2. *P. sanguinolentus* 3. *C. feriatus* 4. *Scylla serrata* 5. *S. olivacea*	
West Bengal	1. *Metapenaeus dobsoni* 2. *M. monoceros* 3. *M. affinis* 4. *M. lysianasa* 5. *F. penicillatus* 6. *F. merguiensis* 7. *P. monodon* 8. *P. stylifera* 9. *P. hardwicki* 10. *Solenocera* spp. 11. *M. burkenroadi*			

MARINE MOLLUSCAN DIVERSITY IN INDIA - EXPLOITATION, CONSERVATION

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Introduction

The molluscs (soft bodied animals) belong to the large and diverse phylum Mollusca, which includes a variety of familiar animals well-known as decorative shells or as seafood. These range from tiny snails, clams, and abalone to larger organisms such as squid, cuttlefish and the octopus. These molluscs occupy a variety of habitats ranging from mountain forests, freshwater to more than 10 km depth in the sea. They range in size from less than 1 mm to more than 15 m (for example the giant squid) and their population density may exceed 40,000/m^2 in some areas. In the tropical marine environment, molluscs occupy every trophic level, from primary producers to top carnivores. India has extensive molluscan resources along her coasts. In the numerous bays, brackish waters and estuaries and in the seas around the subcontinent; molluscs belonging to different taxonomic groups, such as, mussels, oysters, clams, pearl-oysters, window-pane oysters, ark-shells, whelks, chanks, cowries, squids and cuttlefish have been exploited since time immemorial for food, pearls and shells.

About 3270 species have been reported from India belonging to 220 families and 591 genera. Among these the bivalves are the most diverse (1100 species), followed by cephalopods (210 species), gastropods (190 species), polyplacophores (41 species) and scaphopods (20 species). The first three orders are exploited by Indian fishermen from time immemorial. Presently over 150,000 tonnes of cephalopods, over 100,000 t of bivalves and nearly 20,000 t of gastropods are exploited from Indian waters. The importance of molluscs in the coastal economy of India is often overlooked. For example, the cephalopod fishery is now a US$ 250 million industry and is one of the mainstays of the Indian trawl fleet in terms of revenue. The bivalve exports amount to US$ 1.2 million and gastropod exports amount to US$ 1.8 million per annum.

The importance of gastropods, clams, oysters and mussels in maintaining both the economic base and the ambiance of our coastal communities is also frequently overlooked. Details on specific aspects of bivalve and gastropod management, biology, aquaculture and their relations to economic, public and ecosystem health are of paramount importance, but are at present lacking. An endangered species is an animal or plant that is in danger of becoming extinct. In most cases species that are listed as endangered will become extinct in the very near future unless some positive action is taken. The fact that a large number of gastropods have been placed in the endangered list is a cause for major concern. The importance of maintaining healthy molluscan populations and the type of information needed to sustain these structural and functional resources cannot be over emphasized.

General Characteristics of Molluscs

Three classes of the phylum Mollusca namely, Gastropoda, Bivalvia and Cephalopoda are of fisheries interest and their general characters as given by (Narasimham, 2005) are briefly given below.

Gastropoda: Gastropoda is the largest molluscan class with about 35,000 extant species. The gastropods are torted asymmetrical molluscs and usually possess a coiled shell. The soft body normally consists of head, foot, visceral mass and the mantle. Among the marine gastropods, the members belonging to the subclass Prosobranchia, are of major fishery importance (Poutiers, 1998). The shell in this subclass is typically coiled with an opening at the ventral end known as aperture. The aperture is covered by operculum which closes the opening of the shell. The head normally protrudes anteriorly from the shell and bears mouth, eyes and tentacles. The foot is muscular, ventrally located with a flattened base and is used for creeping or burrowing. The visceral mass fills dorsally the spire of the shell and contains most of the organs. The mantle forms mantle cavity which lines and secrets the shell. Asymmetry of the internal anatomy of the gastropods is due to twisting through 180^{o} called the 'torsion' which takes place during the first few hours of larval development.

Bivalvia: There are about 10,000 living bivalve species. The bivalve as the name implies, possesses two valves (shells) lying on the right and left sides of the body. Bilateral symmetry is a characteristic feature. The shell is mostly composed of calcium carbonate. Umbo is the first formed part of the valve and is above the hinge. The soft body of the bivalve is covered by the mantle comprising two lobes. The foot is muscular and is ventral. Byssus is a clump of horny thread spun in the foot and helps the sedentary bivalve to attach to hard substrates. In bivalves head is absent. Many bivalves possess a pair of gills, which are respiratory in function and produce water currents from which food is collected (Poutiers, 1998).

Cephalopoda: Cephalopods are purely marine in habit, and there are about 600 living species. They are considered as the fastest marine invertebrates. Head is highly developed.

The cuttlefishes come under the order Sepioidea and are characterised by the presence of a shell (chitinous or calcareous), 10 circum oral appendages and the tentacles are retractile into pockets. Suckers have chitinous rings. Posterior fin lobes are free and not connected at midline. The cuttlebone is internal and located dorsally underneath the skin.

The squids come under the order Teuthoidea. The shell is internal and is known as gladius or pen. It is chitinous and feather or rod shaped. There are 8 sessile arms and 2 tentacular arms which are contractile but not retractile. Suckers are stalked, and with or without hooks. Fin lobes are fused posteriorly. Eyes are without lids and either (1) covered with a transparent membrane, with a minute pore (Myopsida) or (2) completely open to the sea, without a pore (Oegopsida).

Octopuses are members of the order Octopoda. There are 8 circumoral arms and tentacles are absent. Fins are sub-terminal (on sides of mantle), widely separated or absent. Shell is reduced, vestigial, “cartilaginous”, or absent. Suckers are without chitinous rings and are set directly on the arms without stalks.

Magnitude of Molluscan Fisheries in India

Cephalopods are by far the most important group with decadal average annual production of about 1, 70,000 tonnes and in 2016, the production has touched an all-time high of 2, 31,276 t. They are landed as by-catch and as a targeted fishery mostly in mechanized trawlers operating up to 200 m depth, and beyond in some areas. Next in importance are the bivalves and fishing is pursued as a small-scale activity, mostly at subsistence level in various estuaries and inshore seas. The annual average clam production is about 57,000 t, oysters about 18,800 t, and marine mussels about 14,900 t. There was no fishery for marine pearl oysters since 1962 in the Gulf of Mannar area, which earlier supported major fisheries.

Scallops occur in stray numbers and do not form a fishery, while the windowpane oyster was of considerable fishery value till a few years back. Among gastropods, the chank is most important with annual production of over 1,000 t till a few years back. The fishing for top shell (*Trochus* sp) has been banned as they have been declared as endangered. Abalones occur in stray numbers and are not fished. Mining for subsoil shell deposits for industrial purposes is a major activity in the Ashtamudi and Pulicat Lakes.

A brief description of gastropod, bivalve and cephalopod fisheries of India is given below. Material from recent reviews by Mohamed (2006), Narasimham (2005) on molluscan fisheries; Ramadoss (2003) on gastropod fisheries; Kripa and Appukuttan (2003) on bivalve fisheries and Meiyappan and Mohamed (2003) on cephalopod fisheries have been principally used in this paper.

Bivalve Fishery

A variety of clams, oysters, mussels and the windowpane oysters are distributed along the Indian coastline where they are fished by the local people (Table 1). Clams and cockles form 73.8%, followed by oysters (12.5%), mussels (7.5%) and windowpane oysters (6.2%). The major bivalve resources and their total landing are given in Table 2. The production levels in other states are meagre. Information on the bivalve production from the NE and NW states are scanty.

Table 1. Commercially important bivalves of India

Resource	***Common English name***	***Local name***
Clams and Cockles		
Villorita cyprinoides	Black clam	Karutha kakka,(Ma)
Paphia malabarica, Paphia sp.	Short neck clam, textile clam	Manja kakka (Ma), Chippi kallu (Ka), Tisre (Ko)
Meretrix casta, Meretrix meretrix	Yellow clam	Matti (Ta)
Mercia opima	Baby clam	Njavala kakka (Ma), Vazhukku matti (Ta)
Mesodesma glabaratum		Kakkamatti (Ta)

Resource	Common English name	Local name
Clams and Cockles		
Sunetta scripta	Marine clam	Kadal kakka (Ma)
Donax sp.	Surf clam	Mural,Vazhi matti (Ta)
Geloina bengalensis	Big black clam	Kandan kakka (Ma)
Anadara granosa	Cockle	Aarippan kakka (Ma)
Placenta placenta	Window pane oyster	
Tridacna sp., *Hippopus hippopus*	Giant clam	Kakka (Ma)
Mussel		
Perna viridis	Green mussel	Kallumakkai, Kadukka (Ma) Alichippalu (Te)
Perna indica	Brown mussel	Kallumakkai, Chippi (Ma)
Pearl oyster		
Pinctada fucata	Indian pearl oyster	Muthu chippi, (Ma, Ta)
Pinctada margaritifera	Blacklip pearl oyster	Muthu chippi (Ma, Ta)
Edible oysters		
Crassostrea madrasensis	Indian backwater oyster	Kadal muringa (Ma); Ali, Kalungu (Te) Patti (Ta)
Saccostrea cucullata	Rock oyster	Kadal muringa (Ma); Ali,Kalungu, Patti (Ta)

Ka – Kannada, Ko – Konkani, Ma- Malayalam, Mr – Marati, Ta- Tamil, Te- Telugu

Table 2. Bivalve fishery details in different maritime states

State	Commercially important bivalve resources	Average Total landing (t)	Prospects
Kerala	Vc, Pm, Mc, Mo, Cm, Sc, Pv, Pi	58763	Clams and mussels are optimally exploited. Fishing effort for oysters can be increased. As management measures for Vc and Pm which are intensely fished semiculture is recommended
Karnataka	Mc, Vc, Pm, Cm, Sc, Pv	12750	Clams are optimally fished. Effort can be increased for oysters and mussels. Establishment of Clam fishermen Cooperative societies for marketing is suggested.
Goa	Mc, Vc, Pm, Cm, Sc, Pv	1637	Effort can be increased for all resources.
Maharashtra	Pm, Mc, Gb, Cg, Cr, Sc	2035	Effort can be increased for all resources.
Gujarat	Cg, Cr, Sc, Pp, Pf	4202	Utilization of pearls from windowpane oysters, Repopulating of pearl oyster beds in Gulf of Kutch will be beneficial
Tamil Nadu & Pondicherry	Mc, Mm, Pm, Cm, Sc, Pv, Pi, Pf	2098	Resources are fished only for shell; meat can be used instead of being discarded. Establishment of Clam fishermen Cooperative societies for marketing is suggested. Repopulating of pearl oyster beds of Gulf of Mannar and PalkBay will help to revive the pearl industry
Andhra Pradesh	Ag, Gb, Mc, Mm, Pm, Cm, Pv, Pp,	1278	Resources are fished only for shell; meat can be used instead of being discarded. Establishment of Clam fishermen Cooperative societies for marketing is suggested.
Andaman & Nicobar Islands	Tc, Tm, Pmar, Pv, Pm	NA	Intense effort to be made to replenish and conserve the existing stock
Lakshadweep	Tc, Tm	NA	Estimation of standing stock of these endangered resources, Effort to repopulate the coral reef with giant clams and pearl oysters

Ag- Anadaragranosa, Cg- Crassostreagryphoides, Cm - C.madrasensis, Cr- C. rivularis,
Mc – Meretrixcasta, Mo – Mercia opima, Mm – Meretrix meretrix, Pf – Pinctadafucata, Pi – Pernaindica, Pv – Pernaviridis, Pm – Paphiamalabarica, Pp – Placentaplacenta, Pmar- Pinctadamargaritifera, Sc- Saccostrea cucullata, Tc – Tridacnacrocea, Tm – T .maxima, Vc – Villorita cyprinoids, Gb – Geloinabengalensis

Stock Assessment of Bivalves

Only few studies have been made to assess the stock of bivalves. However, short term surveys have been conducted in the estuaries and coastal regions of maritime states to study the standing stock bivalve resource. Using the standing stock estimates by CMFRI the potential yield of bivalves has been estimated (Table 3).

The present status shows that the clam and oyster resources are underutilized in Gujarat and Maharashtra and effort to utilize these resources should be enhanced. However bivalves have varied reproductive potential hence these resource estimates have to be revalidated frequently. In other states like Kerala and Karnataka the resources are utilized and in some regions they require conservation.

Management Strategies

Bivalves offer one of the important examples of marine resource management along the Indian coast. However, apart from the restriction on the pearl oyster

Table 3. Standing stock and potential yield estimates of bivalves

Resource/ State	Estimated standing stock	Potential Yield Estimate
CLAMS AND COCKLES		
Maharashtra	4000	5000
Goa	1200	2000
Karnataka	8027	6823
Kerala	65000	55250
TN & PON	5770	4905
Andhra Pradesh	58000	49300
TOTAL	**141997**	**123278**
OYSTERS		
Gujarat	1500	1050
Maharashtra	335	235
Karnataka	450	315
Kerala	4200	2940
Tamil Nadu	19032	13322
Andhra Pradesh	23000	16100
TOTAL	**48517**	**33962**
MUSSEL		
Maharashtra	1800	1260
Goa	1120	784
Karnataka	9800	6860
Kerala	17473	12231
Tamil Nadu	350	245
Andhra Pradesh	1000	700
TOTAL	**31543**	**22080**
WINDOWPANE OYSTERS		
Gujarat	5000	3500
Goa	120	84
Andhra Pradesh	12420	8694
TOTAL	**17540**	**12278**
GRAND TOTAL	**239597**	**191598**

fishery by the Government of Tamil Nadu, and the management measures on the short-neck clam fishery of Ashtamudi Lake, Kerala, there are no regulations for effective utilization and conservation of these sedentary marine resources. One of the major bivalve resources, the short-neck clam (*P. malabarica*) is well protected by the following regulations formulated by the Government of Kerala based on recommendations made by CMFRI. a) Ban on fishing activity during breeding season (September to February), b) use of gears with 30 mm mesh size to avoid exploitation of smaller clam, c) Restrict the grade of export of frozen clams meat to 1400 nos/kg and above and d) Initiate semi-culture or relaying of small clams. The minimum legal size (MLS) for exploitation of *P. malabarica* and *Villorita cyprinoides* from Vembanad Lake has been set at 20 mm APM. After the creation of the fishery management plan (FMP) for Ashtamudi Lake short-neck clams and the Ashtamudi Lake Clam Fisheries Governance Council (ACFGC), the fishery became the first Marine Stewardship Council (MSC) certified fishery in the country in November 2014. This will help to boost sustainable fisheries and also protect the ecosystem. Benefits of certification include potential for premium prices, access to new markets, preferred supplier status, potential to attract ethical investment in the fishery, improvements in management of fisheries and public recognition of fishery conservation effort.

Ashtamudi Lake
A managed Clam Fishery

The short-neckclam fishers (numbering about 500 fulltime and part time fishers) of AshtamudiLake are perhaps one of the best examples of a well managed local fishery benefiting the fishers and maintaining sustainable harvests. The management practices are implemented by the cooperative societies with the active scientific support of CMFRI.

One of the major drawbacks in bivalve fishery management is that there is no proper data collection system on the fishery landings. A proper database on the resource availability and their utilization pattern is essential.

Cephalopod Fishery

Cephalopods are a marine fishery resource of increasing importance and many species are exploited as by-catch by trawlers from throughout the Indian coast. Although they form only 4-5% of the total marine fish landings, cephalopod stocks are under heavy fishing pressure because of their high value as an exportable commodity. So much so, of late, they are even targeted by the trawl fleet in certain seasons of the year along parts of the west coast of India. The CMFRI has initiated studies on cephalopod stock from Indian waters during the seventies. The initial results of this programme on the taxonomy, biology, fishery and stock assessment of cephalopod stocks pertaining to the seventies were published as a bulletin (Silas, 1985). Subsequently a major exercise on the stock assessment of Indian cephalopod stocks with data of 1979-89 was made by CMFRI. These studies indicated that squids were exploited at optimum level on both coasts (Meiyappan et al, 1993) and cuttlefishes were optimally exploited along east coast and under exploited along west coast (Nair et al., 1993 and Rao et al., 1993). Besides, a number of authors (Kasim, 1985; Rao, 1988; Mohamed, 1996; Mohamed and Rao, 1997) have published information on specific aspects of cephalopod stocks. Other contributions from India on cephalopod resources, biology and population dynamics include that of Kore and Joshi (1975) on the food of squids, Oommen (1977) on the food, feeding and fishery of squids, Silas et al (1982) on the resources, Philip and Ali (1989) on cuttlefish population dynamics, Nair et al (1992a and b) on squids caught by jigging along SW coast and the monsoon fishery for cephalopods along west coast and Kripa and Mathew (1994) on the octopus resources of Cochin.

Exploited Cephalopods

Cephalopods exploited from Indian seas can be broadly divided into three, viz., squids (order Teuthoidea), cuttlefishes (order Sepiiodea) and octopuses (order Octopodidea). A list of neretic species commercially exploited is given in Table 4.

Table 4. List of commercially exploited cephalopods from Indian Seas

Species	Common Name	Distribution
Squids		
Uroteuthis(P.) duvaucelii	Indian squid	All along Indian coast
Loliolus (N) uyii	Little squid	Madras & Visakhapatnam
U (P) edulis	Swordtip squid	SW coast
U (P) singhalensis	Long barrel squid	SW and SE coast
Loliolus (L) hardwickei	Little Indian squid	All along Indian coast
Sepioteuthis lessoniana	Palkbay squid	Palk bay & Gulf of Mannar
Sthenoteuthis oualaniensis	Oceanic squid	Oceanic Indian EEZ
Thysanoteuthis rhombus	Diamond squid	Oceanic Indian EEZ

Species	Common Name	Distribution
Cuttlefishes		
Sepia pharaonis	Pharaoh cuttlefish	All along Indian coast
S. aculeata	Needle cuttlefish	All along Indian coast
S. elliptica	Golden cuttlefish	Veraval & Cochin
S. prashadi	Hooded cuttlefish	SW & SE coast
S. brevimana	Shortclub cuttlefish	Madras & Visakhapatnam
Sepiella inermis	Spineless cuttlefish	All along Indian coast
Octopuses		
Amphioctopus neglectus	Webfoot octopus	SW & SE coast and islands
A. marginatus	Veined Octopus	SW & SE coast and islands
A.aegina	Marbled octopus	SW & SE coast and islands
O. lobensis	Lobed octopus	SW & SE coast and islands
O. vulgaris	Common octopus	SW & SE coast and islands
Cistopus indicus	Old woman octopus	SW & SE coast and islands

The dominant species occurring in commercial catches are *Uroteuthis (Photololigo) duvaucelii*, *Sepia pharaonis, S. aculeata* and *Amphioctopus neglectus*.

Methods of Exploitation

Although about 40% of the world's cephalopod catches are taken by squid jigging and 25% by trawling (Rathjen, 1991), in India, cephalopods are principally caught by bottom trawlers operating upto 200m depth zones. While most of the catch is brought in as by-catch from the shrimp and fish trawls employed by the trawlers, of late, there is a targeted fishery for cuttlefishes during the post monsoon period (Sep-Dec) using off bottom high opening trawls along the SW and NW coast. Prior to the seventies traditional gears like shore seines, boat seines, hooks and lines and spearing were the principal gear employed to capture cephalopods. These traditional gears continue to be used especially for cuttlefishes at Vizhinjam, where there is no trawl fishery. Experimental squid jigging has been tried with Japanese expertise along the west coast by GOI vessels with considerable success (Nair et al., 1992a). However, commercial squid jigging is not practised in India.

Cephalopod Production

Cephalopod production, which remained at very low level upto the early seventies, has shown a remarkable increase crossing the 150,000 tonne mark in 2006. From 1973 onwards the commencement of export of frozen cephalopod products to several countries saw the transition of the resource from a discard to a quality resource fetching high foreign exchange (Silas, 1985). Thereafter its production showed a steep increase. The west coast maritime states, Gujarat (GUJ), Maharashtra (MAH), Goa (GOA), Karnataka (KAR) and Kerala (KER) contribute to the bulk (86%) of the production. While the production from the east coast amounts to only 14%, of which, Tamil Nadu (TN) contributes the maximum followed by Andhra Pradesh (AP). The states of West Bengal (WB), Orissa (OR) and Pondicherry (PON) contribute only a small percentage. Overall, KER ranks first contributing a third of the all India production followed by MAH, GUJ and KAR. The cephalopod production ($t.km^{-2}$) in different maritime states indirectly this indicates the relative abundance in the continental shelf and level of exploitation of cephalopods in the different maritime states. Maximum productivity (0.699 t/km^2) was observed in Kerala, followed by Tamil Nadu, Karnataka, Maharashtra and Goa.

At the national level, Jan-Mar and Oct-Dec were the most productive period. Along the upper east and west coast, the above months were the most productive, while in KAR, KER, TN and AP Jul-Sep was also equally productive.

Species-wise Production

The neretic squid *U. (P) duvaucelii* followed by the pharaoh cuttlefish *S. pharaonis* and the needle cuttlefish *S. aculeata* together contribute to 84% of the total cephalopod production from India. Along the west coast, *U. (P) duvaucelii* contributes to more than 50% of the landings, followed closely by *S. pharaonis* and *S. aculeata* (47%). Among squids, *Doryteuthis* sp. and among cuttlefishes, *S. elliptica* form significant part of the catch from Kerala and Gujarat respectively. A number of octopus species, chiefly, *O. membranaceous* forms 1% of the catch mainly from Kerala.

The dominant species in landings from the east coast is *S. pharaonis*, followed by *U. (P) duvaucelii* and *S. aculeata*. The diversity of squid and cuttlefish species exploited in commercial quantities is more along east coast as compared to west coast. *Doryteuthis* sp. and *S. lessoniana* are also caught in considerable quantities from TN and AP. Octopus species, which were formerly discarded, has gained importance in recent years. The major production is from Kerala State (Kripa and Mathew, 1994). Their proportions in the landings from both the coasts are increasing considering the export value of the same.

Stock Assessment and Management of Cephalopods

Ever since the CMFRI initiated a major research project on the biology and stock assessment of cephalopod resources of India, a number of research papers have been published on the subject (see Table 7 for complete list). Mostly F based models have applied to study cephalopod stocks. In the first study on Indian cephalopod stocks, Silas et al (1985) used length cohort analysis to estimate stock sizes. Later studies (Meiyappan et al., 1993; Nair et al., 1993 and Rao et al., 1993) also used cohort analysis to estimate mortality and stock and the yield and biomass estimates were obtained with length based Thomson and Bell analysis. Mohamed (1996) used the yield per recruit model to estimate MSY for Mangalore populations of *U.(P) duvaucelii*. Later Mohamed and Rao (1997) assessed the squid yield along Karnataka coast using the TB model to derive MSY and MSE. They also studied the relationship between spawning stock and recruitment of squids to assess the productivity of the population in terms of recruitment. They found that Ricker's stock recruitment curve could adequately explain the variation in recruitment with respect to spawning stock biomass (SSB).

Most of these studies indicated that cephalopods were either under exploited (e.g. *S. pharaonis* and *S. aculeata* along east coast) or optimally exploited (Table 7). While Mohamed (1996) and Mohamed and Rao (1997) found squid stock along Karnataka coast to be marginally over exploited.

Since trawl is the principal gear used for exploitation, and since the cod-end mesh used by these trawls are much below the notified mesh sizes, a large number of juveniles or young ones are caught. Thus there is need for curtailing this exploitation. It is quite clear that regulation of cod-end meshes by the state fisheries departments has not been effective. An alternate measure would be to regulate the trade in such a manner that young or juvenile cephalopods are not traded or exported. Prescription of a minimum legal size (MLS) as a trade barrier is an accepted practice in such instances. The MLS and corresponding weights for 3 species of commercial cephalopods was determined as shown in Table 5 and recommended to the MPEDA (Mohamed et al. 2009) and the same is also prescribed by the Government of Kerala notification G.O.(P) No. 40/15/F&PD dated 24th July 2015.

Table 5. Recommended minimum legal sizes and weights for the 3 major commercial cephalopods exploited in India

Species	MLS(Mantle Length)	Corresponding Total Live Weight
U. (P) duvaucelii	80 mm	25 g
Sepia pharaonis	115 mm	150g
A. neglectus	45 mm	15 g

At present, the proportion of juveniles commercially exploited for *U.(P) duvaucelii* is 5.3%; *S. pharaonis*, 8.7% and *A. neglectus*, 5.9%. If the juveniles are permitted to grow to L_{mean} by implementing the MLS, the estimated economic gain is to the tune of Rs. 426 crores per annum. Mohamed et al. (2009) showed that harvest weights can be improved by up to 34 times and would result in higher incomes to trawl fishers.

Cephalopods are not a targeted fishery along the Indian coast (excepting seasonally along the SW coast) and therefore, it is difficult to set management targets and many of the models applied would have little relevance. Yet, Rosenberg et al (1990) suggests that the most effective means of managing cephalopod fisheries is by regulating fishing effort, which will reduce the risk of recruitment overfishing. The present ban on trawl fishing during the monsoon as variously practised by different maritime states is in effect a means of regulation of fishing effort and should be continued.

A policy guidance document on Fish Aggregating Devices (FAD) based cuttlefish fishery is prepared highlighting the negative impacts on the spawning stocks leading to recruitment overfishing in Karnataka (Sasikumar et al. 2015). They found that the average annual loss in cuttlefish eggs is very high (estimated as 927 million /Rs. 1130 crores). The annual Spawning stock Biomass (SSB) is reduced to one fifth of the mean value.

Utilization and Marketing

There is very little internal market demand for cephalopods and consequently almost all the catch is exported. While the export quantity peaked in 1995 the annual average is about 24%. However, the value of cephalopods in total marine exports has remained at 15% from 1992 onwards without much variation. In 2003 the value of cephalopods exported amounted to more than Rs 800 crores. Category-wise, squid products are the maximum in all years followed by cuttlefish products. The products include dried, frozen whole, filleted, tentacles, rings, roe, wings, IQF and bones and ink. Octopus products exported are meagre, but from 1994 onwards there is rising trend in its exports. The main markets for export of Indian cephalopods are Europe, Japan and China.

The emergence of cephalopods as an important marine fishery resource of the country with almost cent percent export potential warrants careful monitoring and appropriate management particularly because we are exploiting above the revalidated potential yield of 101,000 tonnes. Several gaps exist in our knowledge of these valuable resources, especially on the life histories of our species. For example, we still have not resolved the question of semelparity of most of our species. At present we know that most of the species lay their eggs in the shallow inshore waters. These grounds are subjected to sedimentation due to man-made causes such as dumping of sludge. This might degrade the benthic conditions with a negative impact on cephalopod egg laying and consequently on the recruitment.

Oceanic Squids

The purpleback flying squid *Sthenoteuthis oualaniensis* (Lesson, 1830) is distributed in the tropical and sub-tropical areas of the Pacific and Indian Oceans. The Arabian Sea is considered as one of the richest regions for these oceanic squids in the Indian Ocean. These squids are pelagic animals living in the open ocean, usually absent over the continental shelves (<200 m), and first appear over continental slopes at depths above 250-300 m. The species has been called as the *master of the Arabian Sea* due to its high abundance, large size, short life-span, fast growth and near monopoly of the higher trophic niche. The estimated squid stock in the Arabian Sea varies in the range 0.9-1.6 million t. In recent years, the species has been found to occur in hook and line and gillnet catches in Cochin (Mohamed et al., 2006) and Veraval (Moorthy et al., 2009) and Mohamed et al. (2006) has worked out its population characteristics as $L\infty = 49.1$ cm; $K = 0.83\ yr^{-1}$ and $t_0 = -0.06$ yr. Total biomass and the annual fishable biomass (MSY) of this species is estimated (Mohamed et al. 2014). It is established that purse seining and gillnetting with light attraction from converted commercial fishing boats are the most efficient gears for exploiting oceanic squids in the Arabian Sea (Mohamed et al. 2014). A major programme is currently underway to exploit this resource using squid jigging.

Gastropod Fishery

The exploitation of gastropods in India is age-old for both as food and as curios. The famous money cowries used as currency and the religious sentiments attached to the sacred chank are well known. The gastropod biodiversity in Indian waters is very large (see Table 6) and no systematic effort has been made to document this qualitatively and quantitatively, apart from few works. Considering the intense exploitation of these shelled animals in certain areas of the country as a raw material for the shell-craft industry, a number (24) of these ornamental molluscs have been declared as endangered and are protected under the Indian Wildlife Protection Act.

Table 6. List of commercially exploited gastropods from Indian waters

Species	Common name	Utility		Availability
		Edible	Ornamental	
Turbinella pyrum	Sacred chank		O	SW, AN &Gulf of Mannar
Turritella attenuata	Screw shells		O	WC
Polystirasp	Screw shells		O	WC
Crassispirasp	Screw shells		O	WC
Architectonica perspectiva	Staircase shells		O	WC
Epitonium scalaris	Ladder shells		O	WC
Xenophorasp	Carrier shells		O	WC
Tibia curta	Wing shells		O	WC &EC
Naticaalbula	Moon snail		O	WC &EC
Naticalineata	Moon snail		O	WC & EC
Phalium glaucum	Ton shells		O	WC & EC
Ficus ficus	Fig shells		O	WC & EC
Rapana bulbosa	Purples		O	WC
Murex pecten	Venus comb		O	EC
Murex trapa	Rock shells		O	WC

Species	Common name	Utility		Availability
		Edible	Ornamental	
Murex virgineus	Rock shells		O	WC
Murex badius	Rock shells		O	WC & EC
Murex sp.	Rock shells		O	WC &EC
Babylonia spirata	Whelk	E	O	WC
Babylonia zeylanica	Whelk	E	O	WC
Hemifuses pugilinus	Spindle shells		O	WC
Fusinus toreuma	Spindle shells		O	WC
Oliva gibbossa	Olive shells		O	WC &EC
Oliva sp.	Olive shells		O	WC & EC
Harpa conoidalis	Harp shells		O	WC &EC
Conus glans	Cone shells		O	WC & EC
Conus sp.	Cone shells		O	WC & EC
Umbonium vestiarium	Button shells		O	EC
Cellana radiata	Limpet shell	E	O	EC
Turbo intercostalis	Turban shell	E	O	EC
Turbo sp.	Turban shell		O	Lakshadweep
Strombus sp.	Conch	E	O	EC & Lakshadweep
Thias sp.	Dog whelk	E	O	EC
Chicoreus ramosus	Ramose murex	E	O	EC
Plueroploca trapezium	Elephant shell	E	O	EC
Lambis lambis	Spider conch		O	EC
Melo indica	Begger's bowl		O	EC
Dentalium sp.	Tusk shell		O	WC & EC
Nassa sp.	Button shells		O	EC
Nerita sp.	Nerite shells		O	EC
Trochus niloticus	Top shell	E	O	AN
Turbo marmoratus	Turban shell	E	O	AN
Cypraea moneta	Money cowry		O	EC & Lakshadweep
Cypraea arabica	Cowry		O	EC & Lakshadweep
Cyprea tigris	Cowry		O	EC & Lakshadweep
Lambis truncata	Spider shell		O	Lakshadweep
Charonia tritonis	Trumpet triton		O	Lakshadweep

Chank Fishery

Chanks (*Turbinella pyrum*) are fished mainly for the shell and an organised fishery of considerable magnitude exists along the southeast coast of India. They are also collected at a few other places along the Indian coast.

Major chank resources occur in the Gulf of Mannar, particularly along the Ramanathapuram – Tirunelveli coast. Other areas are Tanjavur, South Arcot and Chingelpet in Tamil Nadu, Trivandrum coast in Kerala, the Gulf of Kutch in Gujarat and the Andamans. Nayar and Mahadevan (1973, 1974) dealt in detail the chank fisheries while Alagarswami and Meiyappan (1989) gave a general review. Appukuttan et al. (1980) described the long line fishing for chanks in Kerala and Pota and Patel (1988) reported on the Gulf of Kutch chank fisheries. Unlike pearl oysters, the chanks are regularly fished with few exceptions.

Whelk Fishery

The whelks come under the order Neogastropoda and family Buccinidae. They are mostly carnivorous and scavengers. The meat is edible and the shell is used in the shell craft industries. In India, two species namely, *Babylonia spirata*, and *B. zeylanica* are landed as by-catch, mostly in the bottom trawls. The former species is more abundant and most of the production is exported. Except for some fishery data in the by-catch of shrimp trawls, no information seems to be available on *B. zeylanica*.

Till early 1990s, *Babylonia* spp. were incidentally caught, mainly in shrimp trawls, and were not considered as of much fishery value. In July 1993, their meat was exported to Japan for the first time (Philip and Appukuttan, 1995). Since then the by-catch landed by shrimp trawlers, particularly off Kollam, is being sorted and the whelks collected. Total whelk meat export amounted to an average 247 tonnes valued at Rs. 528 lakhs during 1999-2003 period. The meat of *B. spirata* fetches US $ 6.9/kg and the operculum US $ 17/kg (Shanmugaraj and Ayyakkannu, 1997).

Philip and Appukuttan (1997) described on the heavy landings of *Babylonia* spp. off Kollam. During January-May 1996 as the whelk price shot up to Rs.35-70/kg from an earlier price of Rs.20-30/kg coupled with relatively poor shrimp landings, the shrimp trawl owners modified the net by adding 20-28 kg of lead rings to the trawl nets and increased the cod end filament thickness to 1.5 mm. As a result, the trawl net operated much closer to the bottom and the thick cod end filament helped to withstand the weight of shells. This was reflected in higher by-catch and the whelk catch was estimated at 390 t in May 1996, compared to an average monthly catch of <50 t during the preceding four months. *B. spirata* formed 60% of whelk catch and the length ranged from 19-51 mm (average length 33.7 mm and average weight 12.7 g). *B. zeylanica* accounted for 40% of the production and the length ranged from 21-67 mm (average length 48.1 mm and average weight 17.87 g). The value of the whelks fished in May 1996 was estimated at Rs.1.75 crores. It was observed that 390 t of whelk would yield 3.9 t of operculum valued at Rs.15.5 lakhs (Philip and Appukuttan, 1997).

The population characteristics of *B. spirata* and *B. zeylanica* have been studied by Anjana (2007). The estimates (Table 7) indicate that both *B. spirata* and *B. zeylanica* are overfished at Kollam following the $E_{0.1}$ management strategy.

Table 7. Population parameters of whelk fishery at Kollam, Kerala (from Anjana, 2008)

Parameters	***B. spirata***	***B. zeylanica***
L_∞ (mm)	*68.7*	*76.0*
K (y^{-1})	*1.08*	*1.15*
Z (y^{-1})	6.05	5.02
M (y^{-1})	1.61	1.65
F (y^{-1})	4.4	3.6
E	0.73	0.71
Emax	0.73	0.77
$E_{0.1}$	0.66	0.72
Spawning stock biomass (t)	92.9	267.7
Standing stock biomass (t)	216.2	404.1
Recruitment numbers	84,565	92,782

Since 1995, the fishermen began to exploit *Babylonia* spp. off Pondicherry in 5-25 m depth with slightly modified ring net, normally used for crab fishing. The average daily catch for ring net/catamaran unit varied from 14 kg in March 1996 to 42 kg in February 1996

(Chidambaram, 1997). Ayyakkanuu (1994) reported that at Annappanpettai landing centre along the Porto Novo coast, fishing for *B. spirata* was carried by special traps with dried octopus or eel as bait and operated from catamarans in 5-20 m depth. Fishing is throughout the year except during October-December. There are 7 mechanised and 6 non-mechanised catamaran trap units and the former unit carries 60-70 traps and the latter 25-40 traps. During March-August 1993, the production of *B. spirata* was estimated at 211 t. Boiled meat from 211 t of the whelk was estimated at 54 t (Rs.40/kg) and operculum 11 t (Rs.400/kg).

At Tuticorin, both the whelk species occur in 100-150 m depth at a distance of 50-60 km from the coast. During January-February the whelk catch was 1.5 t/trawler/month and in July it was 1.7 t/trawler/month. In other months the whelk catches were poor (Selvarani, 2001).

Along southern Karnataka whelk (*B. spirata*) fishing is practiced using traps normally used for crabs and ladyfish (Sasikumar et al. 2006). Annual yields are around 175 t and maximum abundance is seen in January-February and November. The major market for Indian whelk (as chilled whelk, shell-on) is Hong Kong (90%) followed by Thailand, UAE and Maldives.

Fishery for ornamental gastropods

There are several economically important species of gastropods which are regularly collected for meat / and or shell. They come under many families, extensively used in shell craft industry and are popularly called as ornamental gastropods. Many of them live in coral reef habitat in regions such as the Gulf of Kutch, Gulf of Mannar, Palk Bay, Andaman and Nicobar Islands and the Lakshadweep group of Islands.

Philip and Appukuttan (1995) reported on the occurrence of 29 species of gastropods in the by-catch of shrimp trawls, operated off Kollam. In addition to *Babylonia* spp. and chank, important ornamental gastropods landed are *Tibia curta* (wing shell), *Bursa spinosa* (purse shell), *Turritella attenuata* (screw shell), *Rapana bulbosa* (purple shell) and *Conus glans* (cone shell). They accounted for 80% of total gastropod landings.

The Ramanathapuram coast in Tamil Nadu is famous for the production of several ornamental gastropods and 12 small scale shell-craft industries exist at Rameswaram and Keelakarai. Natarajan et al. (1988) reported that species of the following genera are collected and used by the industry: *Oliva, Cypraea, Natica, Cerithidea, Cymatium, Lambis, Xancus, Pyrena, Umbonium, Littorina, Tibia, Strombus, Conus, Murex, Babylonia, Fusinus, Cymbium, Faciolaria, Cassis, Bursa, Phalium, Tonna* and *Thais*. Among these, 1,75,000 *Lambis* spp. are fished annually and each shell fetches Rs.1-3 for the fishermen. The methods of collection include hand-picking, skin diving, hand dredging and as by-catch from different fishing gears. On an average 4,00,000 shells, which also include those brought from the Andamans are used by the shell-craft industry. The shells are placed in bleaching powder solution for 24 h in cement tanks, followed by immersion in caustic soda solution for one hour. They are polished by keeping them in 5% Hydrochloric acid for 10 seconds to 4 minutes, depending on size, thickness and colour. The ornamental products made out of these shells include table lamps, lamp shades, necklaces, ear-drops, beads, hair pins, sculptures of Gods and Goddesses, agarbathi stands, bangles, flower vases, and shell screens for doors and window curtains. There are about 70 shell craft selling shops at Rameswaram and the annual turn over is about Rs.10 lakhs (Natarajan *et al*., 1988).

In the Andaman and Nicobar Islands, in addition to the use of topshell, green snail and chank, species of *Cypraea, Strombus, Lambis, Conus* and *Thais* are regularly used in shell craft industry (Appukuttan and Ramadoss, 2000). Appukuttan *et al.* (1989a) reported on the ornamental gastropods of the Lakshadweep. The cowries *Cypraea caputserpentis*, *C. moneta* and *C. tigris* are important and are exploited at a sustenance level by hand-picking during low tides. Other methods adopted are by diving and by collecting from the coconut leaves, placed in the lagoon water for a few days on which *C. moneta* congregate. The estimated production in numbers of *C. moneta* was 5-7 lakhs per year priced at Rs.25-30/kg and *C. caputserpentis* 2-3 lakhs/year valued at Rs.30-35/100 cowries. Other ornamental gastropods collected include *Cypraea rufa, C. arabica, Conus leopardus, C. litteratus, Cassis cornuata* and the spider conchs, *Lambis truncata* and *L. chiragra.*

From the Kakinada Bay, Rao and Somayajulu (1996) estimated the average annual production of *Cerithidia* sp. at 990 t, *Telescopium* sp. 221 t, *Umbonium* sp. 292 t, *Thais* sp. 79 t and *Hemifusus* sp. 35 t. Some of these gastropods are also used in lime preparation.

Alagarswami and Meiyappan (1989) estimated the production of ornamental gastropods from the country at 600 t/year. Since then substantial increase in production is discernible. During 1991-2003, on an average 271 t/year of sea shells (average value Rs.7.20 crores) were exported from the country (MPEDA).

In a notification dated July 21, 2001 the Ministry of Environment and Forests, Government of India has included 44 gastropod species in Schedule I of the Wild Life Protection Act,

1972. The species include 11 under the genus *Cypraea*, 6 each under the genera *Conus* and *Lambis*, 3 under *Murex*, 2 each under *Harpulina, Strombus* and *Mitra* and one species each under 12 different genera. A vast majority of them are ornamental gastropods and are protected by the Act.

An estimated production of ornamental gastropods at Kollam during 2016 was 1676 tonnes forming 99% of entire Kerala's catch. *Babylonia spirata* and *B. zeylanica* are the dominant species in the catch forming 97.8%. Exports take place from mainly Rameswaram, Tuticorin and Chennai and a large number of species such as *Busycon, Haliotis, Cypraea* and *Mitrella* are imported for processing and re-export. The major regularly landed ornamental gastropods at Tuticorin by bottom set gill nets are *Turbinella pyrum* and *Chicoreus ramosus.* Apart from the stray number of other ornamental gastropods such as *Murex spp, Lambis lambis, Babilona spp, Cypraea sp* etc are also landed by the bottom set gill nets primarily set for lobster and crabs. Fossilised *Turbinella pyrum* is also exploited regularly from Kalavasal at Tuticorin. These fossilised *T. pyrum* is mostly exported to Kolkata (CMFRI, 2017-unpublished).

Future of Molluscan Exploitation

The following are areas of concern with regard to exploitation of molluscs in India:

- Exploitation of cephalopods above the potential yield estimate and localized over-exploitation of stocks
- Oceanic cephalopod potential to the tune of 20-50,000 t which are yet to be exploited
- Grossly under-reported catches of bivalves and gastropods
- No major studies in the country on bivalve and gastropod biology and no information on the magnitude and economics of the shell-craft industry
- Conservation and stock rebuilding strategies with respect to endangered molluscs are not in place

In the light of this, it is important to determine the science, management and institutional requirements needed to obtain the tremendous potential value from molluscan resources to the country and to make a path for sustaining molluscan fisheries and rebuilding protected species stocks to realize their long-term potential.

Suggested Reading

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STATISTICAL METHODS

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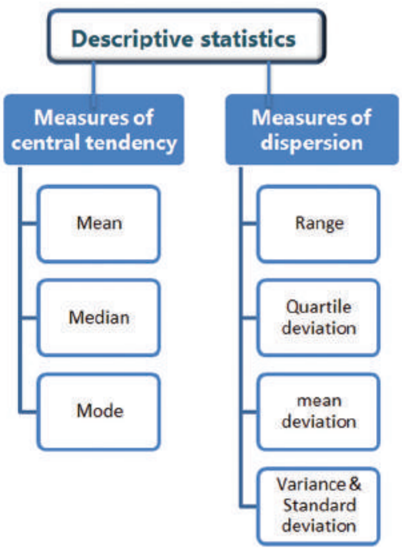
7

Statistics plays a central role in research, planning and decision-making in almost all natural and social sciences. It is the Science of collecting, organizing, analyzing, interpreting and presenting data. It deals with all aspects of this, including not only the collection, analysis and interpretation of such data, but also the planning of the collection of data, in terms of the design of surveys and experiments. Two types of statistical methods are used in analysing data: descriptive statistics and inferential statistics. **Inferential statistics** makes inferences and predictions about a population based on a sample of data taken from the population in question. **Descriptive statistics** uses the data to provide descriptions of the population, either through numerical calculations or graphs or tables. Descriptive statistics therefore enables us to present the data in a more meaningful way, which allows simpler interpretation of the data.



Measures of central tendency

Description of a variable usually begins with the specification of its single most representative value, often called the measure of central tendency. The best way to reduce a set of data and still retain part of the information is to summarize the set with a single value.

A measure of central tendency is a single value that attempts to describe a set of data by identifying the central position within that set of data. Measures of central tendency are sometimes called measures of central location or summary statistics. Measures of central tendency are measures of the location of the middle or the center of a distribution. There are several measures for this statistic.

Measures of central tendency

Arithmetic mean

The arithmetic mean of a set of values is the quantity commonly called the mean or the average. For a data set, the mean is the sum of the values divided by the number of values. The mean of a set of numbers $x_1, x_2, \ldots, x_n$ is typically denoted by $\bar{x}$ pronounced "*x* bar".

$$Arithmetic\ Mean = \bar{x} = \frac{x_1 + x_2 + \cdots + x_n}{n} \qquad Or \quad \bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

Arithmetic Mean from a grouped data

i) Discrete frequency distribution

Data arising from organising n observed values into a smaller number of disjoint groups of values, and counting the frequency of each group; often presented as a frequency table. In this case the values of the variable are multiplied by their respective frequencies and this total is then divided by the total number of frequencies.

$$Arithmetic\ Mean = \bar{x} = \frac{f_1x_1 + f_2x_2 + \cdots + f_nx_n}{f_1 + f_2 \ldots + f_n} \qquad Or \quad \bar{x} = \frac{\sum_{i=1}^{n} f_ix_i}{\sum_{i=1}^{n} f_i}$$

where $x_1, x_2, \ldots x_n$ are values of the variable x and $f_1, f_2, \ldots f_n$ are their corresponding frequencies.

ii) Continuous frequency distribution

We take mid values of each class as representative of that class, multiply this mid values by their corresponding frequencies, total these products and divide by the total number of items. If $x_1, x_2 \ldots x_n$ represent the mid values of classes and $f_1, f_2, \ldots f_n$ the frequencies, then

$$Arithmetic\ Mean = \bar{x} = \frac{f_1x_1 + f_2x_2 + \cdots + f_nx_n}{f_1 + f_2 \ldots + f_n} = \frac{\sum_{i=1}^{n} f_ix_i}{N}, \quad N = \sum_{i=1}^{n} f_i$$

The mean is valid only for interval data or ratio data. Since it uses the values of all of the data points in the population or sample, the mean is influenced by outliers that may be at the extremes of the data set. The mean uses all the observations and each observation affects the mean. Even though the mean is sensitive to extreme values (i.e., extremely large or small data can cause the mean to be pulled toward the extreme data) it is still the most widely used measure of location. This is due to the fact that the mean has valuable mathematical properties that make it convenient for use with inferential statistics analysis. For example, the sum of the deviations of the numbers in a set of data from the mean is zero, and the sum of the squared deviations of the numbers in a set of data from the mean is minimum value. The merits and demerits of arithmetic mean is given in the infographic.

Merits

- It is rigidly defined.
- It is easy to calculate and simple to follow.
- It is based on all the observations.
- It is determined for almost every kind of data.
- It is finite and not indefinite.
- It is readily put to algebraic treatment.
- It is least affected by fluctuations of sampling.
- It is easy to calculate

Demerits

- The arithmetic mean is highly affected by extreme values.
- It is not an approprite average for highly skewed distributions.
- It cannot be computed accurately if any item is missing.

Merits and Demerits of Arithmetic Mean

Median

Median is the value in the middle of the data set, when the data points are arranged from smallest to largest. If there are an odd number of data points, then just arrange them in ascending or descending order and take the middle value. If there is an even number of data points, you will need to take the average of the two middle values. Hence median is determined by sorting the data set from lowest to highest values and taking the data point in the middle of the sequence. There is an equal number of points above and below the median.

Calculation of median in a grouped data

i) Discrete series

In this case also, data should be arranged in ascending or descending order of magnitude and find out the cumulative frequencies. Now find out the value of $(n+1/2)^{th}$ item. It can be found by first locating the cumulative frequency which is equal to (n+1/2) and then determine the value corresponding to it. This will be the value of median.

ii) Continuous series

For computing the value of the median in a continuous series, first determine the particular class in which the value of the median lies. Use N/2 as the rank of Median where N= total frequency. Hence it is N/2 which will divide the area of the curve into two parts.

The following formula is used for determining the exact value of the median.

$$Median = l + \frac{\left(\frac{N}{2} - m\right) * c}{f}$$

where N= $\sum fi$ = Total frequency, l- the lower limit of the median class, m -cumulative frequency up to the median class, f- frequency of the median class and c- class width.

The median can be determined for ordinal data as well as interval and ratio data. Unlike the mean, the median is not influenced by outliers at the extremes of the data set. Generally, the median provides a better measure of location than the mean when there are some extremely large or small observations (i.e., when the data are skewed to the right or to the left). For this reason, the median often is used when there are a few extreme values that could greatly influence the mean and distort what might be considered typical. Note that if the median is less than the mean, the data set is skewed to the right. If the median is greater than the mean, the data set is skewed to the left. Median does not have important mathematical properties for use in future calculations.

Merits

- Median is rigidly defined.
- It is simple to understand and easy to calculate.
- Median is not affected by extreme observations.
- Median can be computed even for open-end classes.
- Median can sometimes be located by inspection.
- Median value is real value and is a better representative value of the series compared to arithmetic mean.
- Median can be obtained graphically.
- Median is only the average to be used while dealing with qualitative characteristics such as intelligence, beauty etc.

Demerits

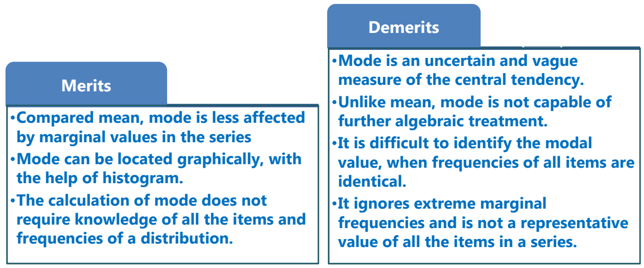
- Arrangement of data according to magnitude is necessary.
- Median is not based on all observations:
- For an ungrouped data, if the number of observation is even, median cannot be determined exactly.
- Median is not suitable for further mathematical treatment.
- For a small size sample, median is affected by fluctuation of sampling.

Merits and Demerits of Median

Mode

Mode is the most common value or most frequently occurring value in the data set. For finding the mode, just look at the data, count how many of each value you have, and select the data point that shows up the most frequently. If no value occurs more than once, then there is no mode. If two values occur as frequently as each other and more frequently than any other, then there are two modes. In the same way, there could also be more than two modes.

Mode is very simple measure of central tendency. Because of its simplicity, it is a very popular measure of the central tendency. The mode can be very useful for dealing with categorical data. The mode also can be used with ordinal, interval, and ratio data. However, in interval and ratio scales, the data may be spread thinly with no data points having the same value. In such cases, the mode may not exist or may not be very meaningful. The merits and demerits of mode is given in the infographic.



Merits and Demerits of Mode

Weighted Mean

When two or more means are combined to develop an aggregate mean, the influence of each mean must be weighted by the number of cases in its subgroup.

$$\bar{X}_w = \frac{n_1\bar{X}_1 + n_2\bar{X}_2 + n_3\bar{X}_3}{n_1 + n_2 + n_3}$$

Geometric Mean (GM)

The geometric mean is an average that is useful for sets of positive numbers that are interpreted according to their product and not their sum (as is the case with the arithmetic mean) e.g. rates of growth.

$$\bar{x} = \left(\prod_{i=1}^{n} x_i\right)^{1/n}$$

Harmonic Mean (HM)

The harmonic mean is an average which is useful for sets of numbers which are defined in relation to some unit, for example speed (distance per unit of time).

$$\bar{x} = n\left(\sum_{i=1}^{n} \frac{1}{x_i}\right)$$

Relationship between AM, GM, and HM

AM, GM, and HM satisfy these inequalities:

$AM \geq GM \geq HM$

Equality holds only when all the elements of the given sample are equal.

The mean (often called the average) is most common measure of central tendency, but there are others, such as, the median and the mode. The mean, median and mode are all valid measures of central tendency but, under different conditions, some measures of central tendency become more appropriate to use than others.

Measures of Dispersion

Measure of variation describes how spread out or scattered a set of data. It is also known as measures of dispersion or measures of spread. Measures of variation determine the range of the distribution, relative to the measures of central tendency. Measures of average such as the mean and median represent the typical value for a dataset. Within the dataset the actual values usually differ from one another and from the average value itself. The extent to which the mean and median are good representatives of the values in the original dataset depends upon the variability or dispersion in the original data. Where the measures of central tendency are specific data points, measures of variation are lengths between various points within the distribution. It provide us with a summary of how much the points in our data set vary, e.g. how spread out they are or how volatile they are. Measures of variation together with measures of central tendency are important for identifying key features of a sample to better understand the population from which the sample comes from. Datasets are said to have high dispersion when they contain values considerably higher and lower than the mean value. The most common measures of variation are Range, Quartile déviation or semi Interquartile Range, Mean deviation, Variance, Standard deviation and Coefficient of Variation

Range

The range is the distance between the lowest data point and the highest data point. In other words, it is difference between the highest value and the lowest value.

Range = Highest value–lowest value

The range is the simplest measure of variation to find. Since the range only uses the largest and smallest values, it is greatly affected by extreme values, that is - it is not resistant to change.

The range is simple to compute and is useful when you wish to evaluate the whole of a dataset. It is useful for showing the spread within a dataset and for comparing the spread between similar datasets.

Since the range is based solely on the two most extreme values within the dataset, if one of these is either exceptionally high or low (sometimes referred to as outlier) it will result in a range that is not typical of the variability within the dataset. The range does not really indicate how the scores are concentrated along the distribution. The range only involves the smallest and largest numbers, and is affected by extreme data values or outliers. In order to reduce the problems caused by outliers in a dataset, the inter-quartile range is often calculated instead of the range.

Quartile Deviation or Semi Inter-quartile Range

The inter-quartile range is a measure that indicates the extent to which the central 50% of values within the dataset are dispersed. If the sample is ranked in ascending order of magnitude two values of *x* may be found, the first of which is exceeded by 75% of the sample, the second by 25%; their difference is the interquartile range. It is based upon, and related to, the median. In the same way that the median divides a dataset into two halves, it can be further divided into quarters by identifying the upper and lower quartiles. The lower quartile, Q1 is found one quarter of the way along a dataset when the values have been arranged in order of magnitude; the upper quartile Q3 is found three quarters along the dataset. Therefore, the upper quartile lies half way between the median and the highest value in the dataset whilst the lower quartile lies halfway between the median and the lowest value in the dataset. Between Q1 and Q3 there is half the total number of items. Q3-Q1 affords a convenient and often a good indicator of the absolute variability. Usually one half of the Q3-Q1 is used and given the name semi-interquartile range or quartile deviation.

$$Quartile\ deviation = \frac{Q3 - Q1}{2}$$

The relative measure of quartile deviation is known as the coefficient of Q.D.

$$Coefficient\ of\ Q.D. = \frac{\frac{Q3 - Q1}{2}}{\frac{Q3 + Q1}{2}} = \frac{Q3 - Q1}{Q3 + Q1}$$

The larger the semi – interquartile range, the larger the spread of the central half of the data. Thus the semi –interquartile rang provides a measure of spread. Thus it indicate how closely the data are clustered around the median.

Mean Deviation

Mean deviation is the average of the absolute values of the deviation scores; that is, mean deviation is the average distance between the mean and the data points. It is calculated as

$$\sum \frac{|\bar{X} - X_i|}{n}$$

Closely related to the measure of mean deviation is the measure of *variance*.

Variance

The variance is the most commonly accepted measure of variation. It represents the average of the squared deviations about the mean. Variance also indicates a relationship between the mean of a distribution and the data points; it is determined by averaging the sum of the squared deviations. Squaring the differences instead of taking the absolute values allows for greater flexibility in calculating further algebraic manipulations of the data. It is the average of the squared deviations between the individual scores and the mean. The larger the variance the more variability there is among the scores. When comparing two samples with the same unit of measurement (age), the variances are comparable even though the sample sizes may be different. Generally, however, smaller samples have greater variability among the scores than larger samples.

The average deviation from the mean is:

$$Ave.\ Dev = \frac{\sum (x - \mu)}{N}$$

The problem is that this summation is always zero. So, the average deviation will always be zero. That is why the average deviation is never used. So, to keep it from being zero, the deviation from the mean is squared and called the “squared deviation from the mean”. This “average squared deviation from the mean” is called the variance. The formula for variance depends on whether you are working with a population or sample:

The formula for the variance in a population is where $\sigma^2 = \frac{\sum (X - \mu)^2}{N}$ where μ is the mean and N is the number of scores.

When the variance is computed in a sample, the statistic $\sigma^2 = \frac{\sum (X - M)^2}{N-1}$

where M is the mean of the sample and gives an unbiased estimate of σ^2.

Standard Deviation

Standard deviation is the most familiar, important and widely used measure of variation. It is a significant measure for making comparison of variability between two or more sets of data in terms of their distance from the mean.

The standard deviation is the square root of the variance. It is denoted by σ and is computed as

$$\sigma = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n}}$$

The standard deviation has proven to be an extremely useful measure of spread in part because it is mathematically tractable. Many formulas in inferential statistics use the standard deviation. It possess the majority of the properties which are desirable in a measure of dispersion and is based on all observations. Because of these merits SD should always be used as the measure of dispersion unless there is some definite reason for selecting any other measure of dispersion.

Coefficient of Variation

The coefficient of variation is the ratio of the sample standard deviation to the sample mean. It is calculated as

Coefficient of variation (C.V.) = $\frac{\sigma}{x} * 100$

It expresses the standard deviation as a percentage of the mean, so it can be used to compare the variability of two or more distributions even when the observations are expressed in different units of measurement. The coefficient of variation is a dimensionless number. So when comparing between data sets with different units or widely different means, one should use the coefficient of variation for comparison instead of the standard deviation.A standard application of the Coefficient of Variation is to characterize the variability of geographic variables over space or time. Coefficient of Variation is particularly applied to characterize the interannual variability of climate variables or biophysical variables. When coefficient of variable is lesser in the data, it is said to be more consistent or have less variability. On the other hand, the series having higher coefficient of variable has higher degree of variability or lesser consistency. When the mean value is close to zero, the coefficient of variation will approach infinity and is hence sensitive to small changes in the mean. Unlike the standard deviation, it cannot be used to construct confidence intervals for the mean.

Correlation

Correlation is a statistical technique that can show whether and how strongly pairs of variables are related. The correlation analysis enables us to have an idea about the degree & direction of the relationship between the two variables under study. It is used to assess the possible linear association between two variables. If there is any relation between two variables i.e. when one variable changes the other also changes in the same or in the opposite direction, we say that the two variables are correlated. Thus correlation is the study of existence, magnitude and direction of the relation between two or more variables. The measure of correlation called the correlation coefficient. If the ratio of change between two variables is uniform, then the correlation is said to be linear. If the amount of change in one variable does not bear a constant ratio to the amount of change in the other variable, then the correlation is said to be non-linear or curvilinear. The nature of the graph gives us the idea of the linear type of correlation between two variables. If the graph is in a straight line, the correlation is called a "linear correlation" and if the graph is not in a straight line, the correlation is non-linear or curvi-linear.

Positive and Negative Correlation

If two variables change in the same direction i.e., if one increases the other also increases, or if one decreases, the other also decreases), then this is called a positive correlation. If two variables change in the opposite direction i.e., if one increases, the other decreases and vice versa), then the correlation is called a negative correlation. Through the coefficient of correlation, we can measure the degree or extent of the correlation between two variables. On the basis of the coefficient of correlation we can also determine whether the correlation is positive or negative and also its degree or extent.

If two variables changes in the same direction and in the same proportion, the correlation between the two is **perfect positive**. According to Karl Pearson the coefficient of correlation in this case is +1. On the other hand if the variables change in the opposite direction and in the same proportion, the correlation is **perfect negative** and its coefficient of correlation is -1. In practice we rarely come across these types of correlations.

If two variables exhibit no relations between them or change in variable does not lead to a change in the other variable, then we can say that there is **no correlation** between the two variables. In such a case the coefficient of correlation is 0.

Methods of Determining Correlation

The following are the most commonly used methods of determining correlation.

(1) Scatter Plot

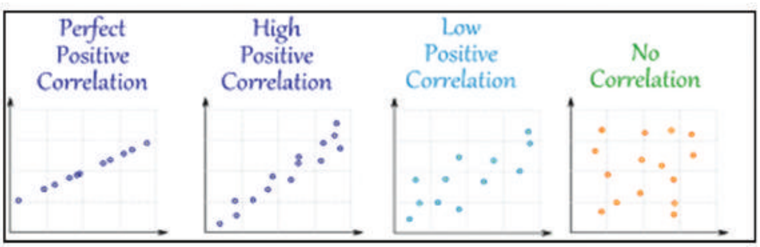
(2) Karl Pearson's coefficient of correlation

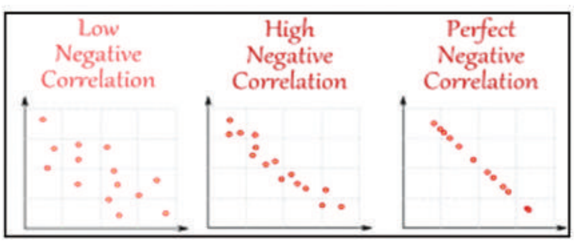
Scatter Plot (Scatter diagram or dot diagram)

The scatter diagram may be described as the diagram which helps us to visualize the relationship between two phenomena. This is the simplest method for finding out whether there is any relationship present between two variables. In this method the values of the two variables are plotted on a graph paper. One is taken along the x-axis and the other along the y-axis. By plotting the data, we get points on the graph which are generally scattered and hence the name 'Scatter Plot'. The manner in which these points are scattered, suggest the degree and the direction of correlation. The grater the scatter of the points on the chart, the lesser is the relationship between the two variables. The more closely the points come to a straight line, the higher the degree of relationship. The degree of correlation is denoted by ' r ' and its direction is given by the signs positive and negative. Scatter diagrams will generally show one of five possible correlations between the variables:

- *Strong Positive Correlation* :The value of Y clearly increases as the value of X increases.
- *Strong Negative Correlation:* The value of Y clearly decreases as the value of X increases.
- *Weak Positive Correlation :* The value of Y increases slightly as the value of X increases.
- *Weak Negative Correlation:* The value of Y decreases slightly as the value of X increases.
- *No Correlation:* There is no demonstrated connection between the two variables.

Though this method is simple and provide a rough idea about the existence and the degree of correlation, it is not reliable. As it is not a mathematical method, it cannot measure the degree of correlation.





Karl Pearson's coefficient of correlation

The most widely-used type of correlation coefficient is *Pearson r*, also called *linear* or *product-moment* correlation. It gives the numerical expression for the measure of correlation. The value of ' r ' gives the magnitude of correlation and sign denotes its direction. It is defined as

$$r = \frac{\Sigma XY}{n\sigma_x\sigma_y}$$

Where $X = (X_i - X)$, $Y = (Y_i - Y)$, σ_x = s.d.of X, σ_y= s.d.of Y, and n is the number of pairs of observations

Properties of Correlation coefficient

- The value of correlation does not depend on the specific measurement units used; for example, the correlation between height and weight will be identical regardless of whether *inches* and *pounds*, or *centimeters* and *kilograms* are used as measurement units.
- The value of correlation coefficient lies between -1 and +1, -1 means perfect negative linear correlation and +1 means perfect positive linear correlation.
- The correlation coefficient r only measures the strength of a linear relationship. There are other kinds of relationships besides linear.
- If the two variables are independent, then the value of the correlation coefficient is zero. If the value of the correlation coefficient is zero, it does not mean that there is no correlation, but there may be non-linear correlation.
- The value of r does not change if the independent (x) and dependent (y) variables are interchanged.
- The correlation coefficient r does not change if the scale on either variable is changed. You may multiply, divide, add, or subtract a value to/from all the x-values or y-values without changing the value of r.
- The correlation coefficient r has a Student's t distribution.

Assumptions to use the Pearson product-moment correlation

- The measures are approximately normally distributed
- The variance of the two measures is similar (homoscedasticity)
- The relationship is linear
- The sample represents the population
- The variables are measured on a interval or ratio scale

Testing the Significance of the Correlation Coefficient

The correlation coefficient, *r*, tells us about the strength and direction of the linear relationship between *x* and *y*. However, the reliability of the linear model also depends on how many observed data points are in the sample. We need to look at both the value of the correlation coefficient *r* and the sample size *n*, together.

We perform a hypothesis test of the "significance of the correlation coefficient" to decide whether the linear relationship in the sample data is strong enough to use to model the relationship in the population.

The sample data are used to compute *r*, the correlation coefficient for the sample. If we had data for the entire population, we could find the population correlation coefficient. But because we have only have sample data, we cannot calculate the population correlation coefficient. The sample correlation coefficient, *r*, is our estimate of the unknown population correlation coefficient.

The hypothesis test lets us decide whether the value of the population correlation coefficient σ is "close to zero" or "significantly different from zero". We decide this based on the sample correlation coefficient *r* and the sample size *n*.

The correlation coefficient r has a t distribution with n-2 degrees of freedom. The test statistic used is

$$t = r\sqrt{\frac{n-2}{1-r^2}}$$

If the test concludes that the correlation coefficient is significantly different from zero, we say that the correlation coefficient is significant and there exists a linear relationship between the two variables. If the test concludes that the correlation coefficient is not significantly different from zero (it is close to zero), we say that correlation coefficient is not significant and there is insufficient evidence to conclude that there is a significant linear relationship between the two variables.

Regression Analysis

Regression analysis is a statistical tool used for the investigation of relationships between variables. It is the study of *linear*, *additive* relationships between variables Correlation gives us a measure of the magnitude and direction between variables. It is a technique used for predicting the unknown value of a variable from the known value of another variable. When there is only one independent variable then the relationship is expressed by a straight line. This procedure is called simple linear regression or bivariate regression. More precisely, if X and Y are two related variables, then linear regression analysis helps us to predict the value of Y for a given value of X. Multiple regression is an extension of bivariate regression in which several independent variables are combined to predict the dependent variable. In multiple regression analysis, the value of Y is predicted for given values of $X_1, X_2, \ldots, X_k$. This technique is used for forecasting, time series modelling and finding the causal effect relationship between the variables.

Dependent and Independent Variables

By simple linear regression, we mean models with just one independent and one dependent variable. The variable whose value is to be predicted is known as the dependent variable and the one whose known value is used for prediction is known as the independent variable. Similarly for Multiple Regression the variable whose value is to be predicted is known as the dependent variable and the ones whose known values are used for prediction are known independent variables.

The Regression Model

The line of regression of Y on X is given by Y = a + bX where a and b are unknown constants known as intercept and slope of the equation. This is used to predict the unknown value of variable Y when value of variable X is known.

The Simple Linear Regression model is

$$Y = a + bX$$

The **Regression Coefficient** is the constant 'b' in the regression equation that tells about the change in the value of dependent variable X corresponding to the unit change in the independent variable Y and can be represented as:

$$b = r\,\frac{\sigma_x}{\sigma_y}$$

Where r is the correlation coefficient σ_x, is the standard deviation of x, σ_y is the standard deviation of y

In general, the multiple regression equation of Y on X1, X2, ..., Xk is given by:

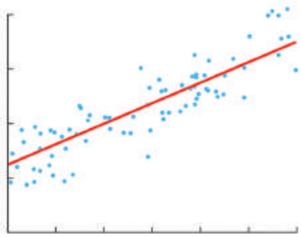
$$Y = b_0 + b_1 X_1 + b_2 X_2 + \ldots\ldots\ldots\ldots\ldots\ldots + b_k X_k$$

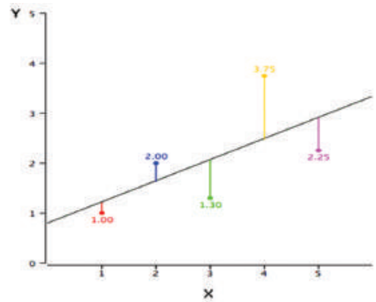
Here b_0 is the intercept and $b_1, b_2, b_3, \ldots, b_k$ are analogous to the slope in linear regression equation and are also called regression coefficients. They can be interpreted as the change in the value of dependent variable (Y) corresponding to unit change in the value of independent variable X_i.

Fitting of regression line

In scatter plot, we have seen that if the variables are highly correlated then the points (dots) lie in a narrow strip. If the strip is nearly straight, we can draw a straight line, such that all points are close to it from both sides. Such a line can be taken as an ideal representation of variation. This line is called the line of best fit if it minimizes the distances of all data points from it and also called as the line of regression. Now prediction is easy because all we need to do is to extend the line and read the value. Thus to obtain a line of regression, we need to have a line of best fit.

The problem of choosing the best straight line then comes down to finding the best values of a and b. By 'best' we mean the values of a and b that produce a line closest to all n observations. This means that we find the line that minimizes the distances of each observation to the line. Choose the values of a and b that give the line such that the sum of squared deviations from the line is minimized. This method of estimation of parameters is called least square method. The best line is called the regression line, and the equation describing it is called the regression equation. The deviations from the line are also called residuals.





R^2 - coefficient of determination

Once a line of regression has been constructed, one can check how good it is (in terms of predictive ability) by examining the coefficient of determination (R^2), which is defined as the proportion of variance of the dependent variable that can be explained by the independent variables. The coefficient of determination is a measure of how well the regression equation $y = a + bX$ performs as a predictor of y. Its value represents the percentage of variation that can be explained by the regression equation. R^2 always lies between 0 and 1. Higher values of this are generally taken to indicate a better model. A value of 1 means every point on the regression line fits the data; a value of 0.5 means only half of the variation is explained by the regression. The coefficient of determination is also commonly used to show how accurately a regression model can predict future outcomes.

SAMPLING TECHNIQUES FOR FISHERIES DATA COLLECTION

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8

Introduction

Intuitive application of the principles of sampling in science has been taking place for a long time. However, it was not called sampling but inductive reasoning. Many scientific results are based on observations in just a few experiments. Apparently, it was possible to generalize these experimental results. Although inductive reasoning has been commonly applied both in everyday life and in science for a long time, sampling as a well-defined statistical method is fairly young. Its history started just more than a century ago, in the year 1895.

Anders Kiaer, the founder and first director of Statistics Norway, was the founder and advocate of the survey method that is now widely applied in official statistics and social research. With the first publication of his ideas in 1895 he started the process that ended in the development of modern survey sampling theory and methods.

The classical theory of survey sampling was more or less completed in 1952. Horvitz and Thompson (1952) developed a general theory for constructing unbiased estimates. Whatever the selection probabilities are, as long as they are known and positive, it is always possible to construct a useful estimate. Horvitz and Thompson completed the classical theory, and the random sampling approach was almost unanimously accepted. Most of the classical books about sampling were also published by then (Cochran, 1953; Deming, 1950, Hansen, Hurwitz and Madow 1953, Yates 1949).

The primary objective of a sample survey is to estimate the characteristic(s) under study using a representative sample, which is a subset drawn from population that accurately reflects the members of the entire population. A representative sample should be an unbiased indication of what the population is like. The representative sample is drawn using a sampling method which is a scientific and objective procedure of selecting units from a population and provides a sample that is expected to be representative of the population as a whole.Even though the sample is representative of the population, and data is reliable, the sample can never reproduce the result a population will give. Therefore, an error gets introduced due to sampling. The discrepancy between the sample estimate and the population value that would be obtained by enumerating all the units in the population in the same manner in which the sample is enumerated are termed as sampling error.

Some situations arise where a probability sampling is not possible. For example, in case of a survey where the respondents are to face unpleasant questions, to ensure sufficient number of responses, volunteers are selected. Also in cases where convenience is the priority units are selected accordingly. Such a sample is called purposive sample.

Sampling Design

Let a finite population U consists of N units labelled {1,2,....N}. A sample s* from U is an ordered sequence of n units from U which may be represented as s*={i_1, i_2,.....i_n}. Here i_1, i_2,.....i_n represent the labels of 'n' units drawn from U and 'n' is the sample size. There may be many such sets of samples of size 'n' which can be drawn from the population. Also, while drawing the units from the population, we can perform the selection with or without replacement. For example while drawing five cards from a pack of 52 playing cards, we can select the first card, again place it in pack, and draw the second card and so on. Here there is a chance that same card gets selected again. This type of sampling is called with replacement sampling.

Sampling in which the units are selected without replacing them back or where the units once got selected doesnot have a chance of getting selected in the subsequent selections is called sampling without replacement.

Let S* ={s*} i.e. the set of all possible samples from population U. Let p(s*) denote the probability of drawing the sample s* from S* and let p(s*)≥ 0 so that $\sum_{s^*\in S^*} p(s^*) = 1$. Let π_i denote the probability that ith unit is included in a sample. Then using the addition law of probability, π_i= P(one of the samples containing the ith unit is selected)=$\sum_{i\in s^*} p(s^*)$ where the summation is taken over all the samples containing the i^{th} unit. Assume that $\pi_i > 0, i = 1,2, \dots . N$. An ordered sampling design is defined as the collection S^*={s^*} together with the probability measure P^*={p(s^*)} defined on S^* such that p(s^*)≥ 0 and $\sum_{s^*\in S^*} p(s^*) = 1$ and is denoted by $D(S^*), P^*)$

Probability Sampling

Any procedure of selecting a sample s* with probability p(s*) for all s*∈ S* is called a probability sampling procedure and a sample selected through such a procedure is called a probability sample.When the probability of selecting a unit from a population is equal for all units in the population then p(s*)= (1/total number of possible samples). When all the units in the population have the equal chance of getting selected in a sample we call the procedure as equal probability sampling.

Suppose there are 5 aqua farms in a village and the annual fish production is to be studied on the basis of a sample of size 2. Let aqua farm units be numbered as {1,2,3,4,5}. Then the possible samples of size 2 without replacement is as follows :

s_1^* ={1,2}, s_2^*={1,3}, s_3^*= {1,4}, s_4^*={1,5}, s_5^*={2,3},s_6^*={2,4}, s_7^*= {2,5}, s_8^* = {3,4}, s_9^* ={3,5}, s_{10}^*={4,5}

Also we have p(s_i^*)=1/10, i=1,2,...5 which is equal for all the samples listed.

Equal probability sampling procedure is called simple random sampling. Simple random sampling or srs in short form, can be performed with or without replacement.A method of sampling such that every one of the ${}^N C_n$ possible samples of size n from N has the same probability namely $\frac{1}{{}^N C_n}$of being selected is called simple random sampling without replacement.In the above mentioned example, probability of selecting a sample s_i^*, from the above set of samples is same, in case of simple random samplingwithout replacement i.e. p(s_i^*)=1/10, i=1,2,...10

Let Y denote the characteristic under study. In the above example it is the fish production. Denote Y_i the value of the characteristic associated with unit U_i,i=1,2,....N.Further let $\bar{Y} = \frac{1}{N}\sum_{i=1}^{N} Y_i$ be the mean per unit of the population. This term is generally referred to as the population mean. Using a sample we have to estimate this term and the estimator is commonly known as the estimator of the population mean and denoted as $\bar{y}$. Similarly $S^2 = \frac{1}{N-1}\sum_{i=1}^{N}(Y_i - \bar{Y})^2$ is called the population variance which always associated with the population mean which also has to be estimated along with the population mean. It gives a measure of precision of our estimate. The estimator of the population variance is called as the sampling variance is generally represented as s^2.

Let y_i, i=1,2,3,....n be the values of the characteristic under study Y from the sample of size n selected from the population. Then the sample mean and variance is given by $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$ and $s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(y_i - \bar{y})^2$ are unbiased estimators of the population mean and variance respectively.

Probability Proportional to Size Sampling

In the previous section, we discussed the selection of sample from a population by assigning equal probability to the units to be included in the sample. In certain practical situations, some units have to given more weightage because of their contribution to the characteristic under study. For example, we want to estimate the total fish production based on a day's landing. There will be fishing boats which have gone for single day fishing, some of them for 2-5 days and a few boats might have landed fish after fishing for a week. The quantity of catch may also vary based on the number of fishing days. Therefore, more weightage should be given for the fishing vessels whose fishing duration is more compared to boats which go for single day fishing. Likewise, suppose the aquafarms discussed in the previous example are of varying sizes and because of this variation their fish production also varies. Probability proportional to size sampling or pps sampling as it is called is a sampling procedure where the sampling units are assigned probabilities for selection based on size criteria.

Suppose there are 5 aqua farms in a village and the annual fish production is to be studied on the basis of a sample of size 2. Let aqua farm units be numbered as {1,2,3,4,5}.Let us assume that depending on their size the following probabilities can be assigned to the individual units of the 5 aquafarms : p_1=0.2,p_2=0.1,p_3=0.2,p_4=0.4,p_5=0.1. Note that $\sum p_i$=1.Here, if the scheme is without replacement for the following set of possible samples,
s_1^* ={1,2}, s_2^*={1,3}, s_3^*= {1,4}, s_4^*={1,5}, s_5^*={2,3},s_6^*={2,4},s_7^* {2,5}, s_8^* = {3,4}, s_9^* ={3,5}, s_{10}^* ={4,5}, the probability is calculated as follows :
p(s_1^*) = p_1p_2=0.02; p(s_2^*) = p_1p_3=0.04; p(s_3^*) = p_1p_4=0.08; p(s_4^*) = p_1p_5=0.05; p(s_5^*) = p_2p_3=0.02; p(s_6^*) = p_2p_4=0.04;p(s_7^*) = p_2p_5=0.01 p(s_8^*) = p_3p_4=0.08;p(s_9^*) = p_3p_5=0.02; p(s_{10}^*) = p_4p_5=0.04.

Given a sampling procedure D(S^*,P^*) a straightforward procedure for selecting a probability sample is given below :

(i) Identify all possible samples s^*, say, M in number and denote the serial number from 1 to M.So here we have s_1^* ={1,2}, s_2^*={1,3}, s_3^*= {1,4}, s_4^*={1,5}, s_5^*={2,3},s_6^*={2,4},s_7^* {2,5}, s_8^* = {3,4}, s_9^* ={3,5}, s_{10}^* ={4,5}, if the scheme is without replacement and M=10.

(ii) Form successive cumulative totalsT_i=$\sum_{j=1}^{i} p(s_j^*), i = 1,2, \dots, M$.Choose a random number R such that 0≤ $R \leq 1$ and select the sample s_i^* with serial number i if $T_{i-1} \leq R \leq T_i$. Now T_1=0.02, T_2=0.06; T_3=0.14; T_4=0.19; T_5=0.21; T_6=0.30; T_7 =0.31; T_8=0.39; T_9=0.41; T_{10}=0.45.

Suppose R=0.43. Then sample number 10 will be selected which is {4,5}. When the number of all possible samples are manageable and can be written down easily as in the above example of aquafarms, then it is possible to select a sample from the population using probability proportional to size sampling using the above procedure. In general, the procedure for selecting a sample with varying probability is given below.

Let X_i denote an integer which is proportional to size of the ith unit i=1,2,....,N. Form the successive cumulative totals X_1, X_1+X_2,.... $\sum_i^n X_i$ and draw a random number R not exceeding $\sum_i^N X_i$ using either the table of random numbers or the random number generator function in excel. If $\sum_i X_i \leq R \leq \sum_i X_i$, the ith unit is selected. The procedure is repeated till 'n' units get selected.

Let Y_i, i=1,2,...,N denote the value of the characteristic under study Y for the ith unit of the population. Let P_i be the probability of selecting the i^{th}unit in the population. Obviously, $\sum_{i=1}^N P_i = 1$. We shall now consider the problem of estimating the population mean $\bar{Y}$ based on the sample of n units with replacement. If the sample of size n is selected using a probability proportional to size sampling method, then denote$Z_i = \frac{Y_i}{NP_i}$, i=1,2,...N. An estimator of population mean is$\bar{z} = \frac{1}{n}\sum_{i=1}^n z_i$. The variance of $\bar{z}$ is given by $\hat{V}(\bar{z})=\frac{s_z^2}{n}$ where$s_z^2 = \frac{1}{n-1}\sum_i^n (z_i - \bar{z})^2$. It is proven that both $\bar{z}$ and $\frac{s_z^2}{n}$ are unbiased estimators of the population mean and variance.

Stratified Sampling

This type of sampling mechanism is frequently used in sample surveys where we need estimate the population parameter for a population which can be divided as groups or strata. For example a market researcher has to conduct a consumer preference study for a convenience product from fish which is planned to capture the super markets. Then his population will consist of households from an urban area and from varying levels of income groups. In order to have an reasonable representation from all sections of the population, the households should be divided into low, middle, high income groups or strata. Then a suitable sample from each group can be drawn using either simple random sampling or any procedure and the parameter(consumer preference) studied.

Another example is in agriculture where total yield of a crop is to be estimated from a state. Stratification of the farms will be done districtwise and the total crop production from each district can be estimated.The groups into which the population is divided is called strata and whole procedure of drawing samples from each stratum is known as stratified random sampling.When simple random sampling is used to select samples from each stratum, then the procedure is called a stratified random sample. We shall assume that the population of size N is divided into L strata and that sampling within each stratum is simple random sampling without replacement. Further for the h^{th} stratum h=1,2,...L the following notations apply :

N_h the number of units

n_h the sample size

$f_h = \frac{n_h}{N_h}$, sampling fraction

Y_{hi} is value of the characteristic under study Y for the ith unit, I =1,2,….,N_h

$W_h = \frac{N_h}{N}$

Let Y_h denote the total of Y-values for units belonging to stratum h. Then the mean of stratum h is given by $\bar{Y}_h = \frac{1}{N_h}\sum_{i=1}^{N_h} Y_{hi}$.

Let y_{hi} denote the value of the characteristic under study Y pertaining to the i^{th} unit in the sample from h^{th} stratum. The mean of sample from h^{th} stratum is given by $\bar{y}_h = \frac{1}{n_h}\sum_{i=1}^{n_h} y_{hi}$.

$S_h^2 = \frac{1}{(N_h-1)}\sum_{j=1}^{N_h}(Y_{hj} - \bar{Y}_h)^2$, the mean square based on N_h units

$s_h^2 = \frac{1}{(n_h-1)}\sum_{j=1}^{n_h}(y_{hj} - \bar{y}_h)^2$, the sample mean square based on n_h units

Unbiased estimator of the population mean $\bar{Y}$ is given as

$$\bar{y}_{st} = \sum_{h=1}^{L} W_h \bar{y}_h$$

Here it is assumed that the sampling is carried out independently in each stratum. The variance of the stratified sampling estimator $\bar{y}_{st}$ is given by

$$V(\bar{y}_{st}) = \sum_{h=1}^{L} W_h^2 \frac{(N_h - n_h)}{N_h}\frac{S_h^2}{n_h}$$

An unbiased estimator of the variance of $\bar{y}_{st}$ is given by $\widehat{V}(\bar{y}_{st}) = \sum_{h=1}^{L} W_h^2 \frac{(N_h-n_h)}{N_h}\frac{s_h^2}{n_h}$. The expression for variance of the stratified sampling estimator shows that the precision of the estimator is based on the n_h i.e. the stratum sample sizes. Once we decide to conduct any survey for estimating characteristic under study pertaining to a population we will be given a cost within which the survey should be conducted. Therefore we have the liberty only to decide the sample size within cost limit. But the precision will be more if the variance is less or in other words, when the sample size is more. Practically, when we desire that the sample size should be increased, cost of coverage will also increase. Since the sample size *n* is fixed in advance, the problem at hand usually is the allocation of sample sizes n_h within each stratum.

Optimum allocation : The guiding principle is that decide n_h in such a manner to estimate population mean $\bar{Y}$ with desired precision for a minimum cost or with a maximum precision for a given cost. The allocation of the sample in accordance with this principle is called the optimum allocation.Suppose c_h denotes the cost of the survey in stratum h. Then total cost of survey can be represented as

$$C = \sum_{h=1}^{L} c_h \, n_h$$

Then the variance of the estimator $\bar{y}_{st}$is minimum for given cost C_0 or the cost of the survey is minimum for a given variance V_0 when n_h is proportional to $\frac{W_h S_h}{\sqrt{c_h}}$. Therefore in optimum allocation the sample sizes are allotted to stratum according to the formula $n_h = \frac{W_h S_h}{\sqrt{\mu_0 c_h}}$.

Neyman allocation: When c_h is sample for all the strata, then the sample sizes are allotted to stratum according to the following formula $n_h = \frac{W_h S_h}{\sqrt{\mu_N}}$ and this type of allocation is called the Neyman allocation. $1/\sqrt{\mu_N}$is called the constant of proportionality.

Proportional allocation: When n_h is proportional to W_h then the sample size can be allocated according to the formula $n_h = \frac{W_h}{\sqrt{\mu_P}}$ where $1/\sqrt{\mu_P}$ is called the constant of proportionality.

Cluster Sampling

Before applying any sampling procedure, the population is divided into finite number of distinct identifiable units called the sampling units or elements. Groups of elements can be called clusters. In some practical situations it is more convenient to sample clusters from a population than selecting the individual sampling units. In crop estimation surveys, when the total yield of a crop is to be determined, the sampling frame or list of farms may not be readily available from all the villages. But the list of villages will be available. Here, cluster sampling can be employed by considering the villages as cluster of farms.

When the sampling unit is a cluster then the sampling is called cluster sampling. In cluster sampling all the elements in the selected cluster will be enumerated. A necessary condition for employing a cluster sampling procedure is that every element or smallest unit in the population will correspond to one and only one unit of the cluster so that the total number of sampling units in the frame will cover all the units of population under study with no omission or duplication.

When the entire area containing the population under study is subdivided into area segments, and each element of a population is associated with one and only one area segment then the procedure is called area sampling.It is not necessary that all the elements associated with an area segment be located physically within its boundaries. For example in case of aquaculture, different ponds belonging to the same farm household or farmer will not necessary be in the same location or adjacent. Such a segment is called a open segment.

Let the population consist of N clusters of M elements each. Using simple random sampling without replacement n clusters are selected from the N clusters. We use the following notations : Y_{ij} denotes the value of the characteristic under study for the j^{th} element of the i^{th} cluster; j=1,2,....M; i=1,2,.....N.

$\bar{Y}_{i.} = \frac{1}{M}\sum_{j=1}^{M} Y_{ij}$, denote the mean per element of i^{th} cluster

$\bar{\bar{Y}} = \frac{1}{N}\sum_{i=1}^{N} \bar{Y}_{i.}$, the mean of cluster means

$\bar{Y} = \frac{1}{NM}\sum_{i=1}^{N}\sum_{j=1}^{M} Y_{ij}$, the population mean.

Then an unbiased estimator of the population mean is given by $\bar{\bar{y}} = \frac{1}{n}\sum_{i=1}^{n} \bar{y}_{i.}$, which is actually mean of cluster means based on the sample observations from the selected n clusters.
The mean square between elements in the i^{th} cluster is $S_i^2 = \frac{1}{M-1}\sum_{j=1}^{M}(Y_{ij} - \bar{Y}_{i.})^2$.

The mean square between cluster means is given as $S_b^2 = \frac{1}{N-1}\sum_{i=1}^{N}(\bar{Y}_{i.} - \bar{Y})^2$.

The variance of the estimator $\bar{\bar{y}}$ is V($\bar{\bar{y}}$)=$\left(\frac{1}{n} - \frac{1}{N}\right) S_b^2$.
An unbiased estimator of V($\bar{\bar{y}}$) is given by $\hat{V}(\bar{\bar{y}}) = \left(\frac{1}{n} - \frac{1}{N}\right) s_b^2$ where is the sample mean square between the cluster means.For example, in order to estimate the fish production from aqua farms of a particular district, clusters of aquafarms can be formed and a sample of few clusters selected and completely enumerated.

Systematic Sampling

A method of sampling in which only the first unit is selected at random and the rest being selected automatically according to a pre-determined pattern is called systematic sampling.Examples where this kind of sampling is often employed is forest survey. To estimate the number of trees or timber in a forest where the units are innumerable systematic sampling is used. Another example is application in mangrove forestation where the parameter of interest to find out the density.

Assume that the population consists of N units serially numbered from 1,2,...N. Assume further that N is expressible as a product of two integers k and n, so that N=kn. Draw a random number less than or equal to k, say i, and select the unit with the corresponding serial number and every k-th unit in the population thereafter.The sample will contains the units with serial numbers, i, i+k, i+2k,....i+(n-1)k.

Selection of every kth time interval to observe fishing crafts for estimation of fish production is an example where systematic sampling can be used. The advantages of systematic sampling is it involves low cost and is simple to follow.

Systematic sampling resembles stratified sample in the sense that one unit is selected from each stratum containing k consecutive units. However this resemblance is only casual. In stratified sampling the unit to be drawn from each stratum is randomly selected and in systematic sampling the position of the unit is predetermined relative to the first units selected.Unless the units in each stratum are arranged at random, systematic sampling can never be equivalent to stratified random sampling.Systematic sampling strictly resembles cluster sampling. A systematic sample is equivalent to one cluster of elements selected from k clusters of n units each, . Since the first number less than or equal to k is chosen at random, each one of the k clusters get an equal chance of getting drawn as a sample.
Let Y_{ij} denote the value of the characteristic under study for the j^{th} unit of the i^{th} cluster bearing

the serial number i+(j-1)k, i=1,2...,k, j=1,2,....,n. Further let

$\bar{Y}_{i.} = \frac{1}{n}\sum_{j=1}^{n} Y_{ij}$, $\bar{Y}_{.j} = \frac{1}{k}\sum_{i=1}^{k} Y_{ij}$, $\bar{Y} = \frac{1}{N}\sum_{i=1}^{k}\sum_{j=1}^{n} Y_{ij} = \frac{1}{n}\sum_{j=1}^{n} \bar{Y}_{.j} = \frac{1}{k}\sum_{i=1}^{k} \bar{Y}_{i.}$

The sample mean $\bar{y}_{sys} = \bar{y}_{i.} = \frac{1}{n}\sum_{j=1}^{n} y_{ij}$is an unbiased estimator of $\bar{Y}$ with variance given by
$V(\bar{y}_{sys}) = \frac{1}{k}\sum_{i=1}^{k}(\bar{Y}_{i.} - \bar{Y})^2$

Sub-sampling or Two-stage Sampling

In the cluster sampling, all the units of the selected clusters are measured completely. If the units within the same cluster give more or less the same value, then it is less costlier to observe a sample of units from it. A common practice is to select first the clusters which are called the first stage or primary units. Units which are chosen from the cluster are called second stage units. This is known as two-stage sampling or sub-sampling. An application of two-stage sampling in fisheries is for estimation of marine fish landings from the country. Here selected landing centres are the first stage units and the second stage units are the selected boats landing at these centres for recording the data on fish catch. When the number of stages is more than two from which a sample is selected, then it is called multi-stage sampling.

Consider two-stage sampling when the first-stage units are of equal size and simple random sampling without replacement is employed at each stage. Let the population consist of N first stage units with M second stage units in each of the first stage unit. Let $\bar{Y}_{i.} = \frac{1}{M}\sum_{i=1}^{M} Y_{ij}$ be the mean of observations in the i^th^ first stage unit.

The population mean is given by $\bar{Y} = \bar{Y}_{..} = \frac{1}{NM}\sum_{i=1}^{N}\sum_{j=1}^{M} Y_{ij}$, and the estimate of the population mean is given by $\hat{y}_2 = \frac{1}{n}\sum_{i=1}^{n} \bar{y}_i$ where $\bar{y}_i$ is the mean of the 'm' secondary units selected from the i^{th} first stage unit.

The estimate of the variance of the sample mean $\hat{y}_2$ is given by

Var($\hat{y}_2$) = $\left(\frac{1}{n} - \frac{1}{N}\right).s_b^2 + \frac{1}{N}\left(\frac{1}{m} - \frac{1}{M}\right)\bar{s}_w^2$, where $s_b^2 = \frac{\sum_{i=1}^{n}(\bar{y}_i - \bar{y}_2)}{n-1}$, $\bar{s}_w^2 = \frac{1}{n}\sum_{i=1}^{n} s_i^2$, where

$$s_i^2 = \frac{\sum_{i=1}^{m}(y_{ij} - \bar{y}_i)}{m-1}$$

Sukhatme et. al. (1997) gives the estimation procedure for estimating population mean when the first stage units are unequal.

Estimation of Marine Fish Landings

India has a coastline of about 8129 km and there are about 3000 marine fishing villages and about 1400 landing centres along the coastline. Fishing boats arrive at numerous locations all along the coastline during day and at times during night also for landing the fish catch. Central Marine Fisheries Research Institute, Cochin has standardized the methodology for estimation fish landings from marine sources for the entire nation.The sampling design adopted by CMFRI to estimate resource-wise/region-wise landings is based on stratified multi-stage random sampling technique and the details are given in chapter 9.

Estimation of inland fish production in India and practical issues

Inland fisheries enjoys prime of place in Indian economy. It provides employment and livelihood for fishers who solely depend on it. In inland fishery sector, the data collection on various important parameters such as the catch, size of fleet, level of employment, per capita yield etc. is an enormous task owing to the sporadic spatial and temporal distribution of the resources. Attempts are being made by Central Inland Fisheries Research Institute to collect data using communication devices like mobile from the fishermen operating in remote centres. Unlike marine sector, inland fisheries cannot claim a satisfactory status with regard to data collection.

India has vast potential inland resource scattered through out the country. However, their concepts and definitions vary from one region to another region. So the data collected from these resources are sometimes neither comparable nor compliable at central Level. There is a strong need for uniform concepts, definition, collection and compilation of methodology for this sector.

The Central Inland Fisheries Research Institute, Barrackpore, made an attempt to estimate the area and catch from ponds in the district of Hoogly, West Bengal during 1962-63 but it did not lead to accomplishment of the task at hand. In 1973-75, the NSSO conducted a survey covering three districts, one each in West Bengal, Tamil Nadu and Andhra Pradeshwith the aim of obtaining estimate of catch both from impounded water and riverine resources by enquiry. The estimates worked out were not satisfactory, particularly from riverine resources.

In another pilot survey conducted by IASRI, New Delhi and CIFRI, Barrackpore in one district of West Bengal during 1978-81, the data were collected both by enquiry and by physical observation. The main objectives of the survey were (1) to evolve suitable sampling methodology for estimation of (a) inland water resources, (b) total catch for inland fisheries and (2) to study the prevailing practices of pisciculture. The study covered only ponds in the district of 24-Parganas in West Bengal. The catch estimate of other important resources like estuaries, rivers, brackish water impoundments, beels could not be attempted due to limited manpower. In spite of all these attempts, there is no scientifically designed and accepted method for collection and estimation of all types of inland fishery resources.

However, the Department of Animal Husbandry and Dairying, Ministry of Agriculture, Govt. of India, Plan, entrusted the development of uniform concepts, definitions and terminologies for various inland fishery resources and a suitable and standardized methodology for collection and estimation of inland fishery resources and catch to Central Inland Fisheries Research Institute, Barrackpore in collaboration with the states. The methodologies have been developed and tested in various states during 8th and 9th Plans. The states have been provided training and guidance for estimation of catch from various inland resources during 10th Plan and since then the estimation of inland fish catch is continuing.

Sampling and Non-sampling Errors

The errors involved in the collection, processing and analysis of data can be broadly classified as Sampling and Non-sampling errors.

(i) Sampling errors : Sampling errors have their origin in sampling and arise due to the fact that only a part of the population (i.e. sample) has been used to estimate the population parameters and draw inferences about the population, As such the sampling errors are absent in a complete enumeration survey. The reasons of such errors may be due to faulty selection of sample, substitution of observation for the sampling unit which could not be covered during the survey, faulty demarcation of the sampling unit and constant error due to improper choice of the statistics for estimating the population parameters.

(ii) **Non-sampling errors**: These errors mainly arise at the stages of observation, ascertainment and processing of the data and are thus present in both complete enumeration survey and the sample survey. Thus the data obtained from the complete census though free from the sampling errors, would still be subject to non-sampling errors whereas data obtained in a sample survey would be subject to both sampling and non-sampling errors. Non-sampling errors may occur due to

- **Faulty planning or definitions**: After stating the objectives of the survey, definitions about the characteristics for which data to be collected should be specified. Here the non-sampling errors may occur due to data specification being inadequate and inconsistent with the objectives of the survey. At times error may be due to the location of the units and actual measurement of the characteristic, errors in recording or may be due to a ill-designed questionnaire.
- **Response error :** When the respondent misunderstood a particular question and furnish improper information. At times, the respondent deliberately gives wrong information when the questions are sensitive. Questions based on 'recall' memory of the respondent will sometimes lead to improper or incomplete information.
- **Non-response bias:**Non-response bias occurs when the full information is not got from all the sampling units. In the event of respondent not at home or even after repeated calls the respondent is not able to furnish the information fully such a bias occurs.
- **Errors in coverage:**If the objectives of the survey is not precisely stated then some units which are not to be covered will be enumerated under the survey and certain units will be excluded from the survey which are relevant and are to be covered under the survey.
- **Compiling errors:**Various operations such as data processing such as editing and coding of the responses, tabulation and summarizing the orginal observations made in the survey are a potential source of error. Compilation errors are subject to control though verification, consistency check, etc.
- **Publication errors:** The errors committed during presentation and printing of tabulated results are basically due to two sources. The first refers to the mechanics of publication – the proofing error and the like. The other, which is of more serious nature lies in the failure of the survey organization to point out the limitations of the statistics.

SAMPLING METHODOLOGY EMPLOYED BY CMFRI FOR MONITORING THE FISHERY AND ESTIMATION OF MARINE FISH LANDINGS IN INDIA

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9

Fisheries sector plays a key role in Indian economy. The sector supports livelihood, nutritional security, and subsistence to large number of people as well as foreign exchange earnings. India's coast line stretches about 8129 km. There are 1355 landing centres scattered along the coastline of the main land as per the records from National Marine Fisheries Data Centre at Central Marine Fisheries Research Institute (CMFRI). Marine fish landings take place almost all along the coast line throughout the day and sometimes during night. Under these circumstances, collection of statistics by complete enumeration would involve a very large number of enumerators and a huge amount of money apart from the time involved in collection of data. Therefore, a possible solution for quantifying marine fish landings is adoption of a suitable sampling technique. As, monitoring and assessment of the exploited marine fishery resources of India is one of the important mandates of the CMFRI, institute made attempts to evolve the scientific methods for collection of data on catch and effort, since its inception in 1947. Pilot surveys were conducted along the coastline of India and different sampling designs were tested.

Fig. 1. Stratification over Space

CMFRI introduced collection of marine fish statistics through a stratified sampling design along the west coast of India in the year 1959 and extended to other states over the years. Keeping in pace with the changing marine fisheries scenario, the sampling design has been modified over the periods. Presently, CMFRI estimate marine fish landings based on a multi-stage stratified random sampling technique, stratification is done over space and time. Each maritime state is divided into suitable, non-overlapping zones on the basis of fishing intensity and geographical considerations (Fig. 1). The number of landing centres varies from zone to zone.

Reprinted from the CMFRI, FRAD. 2014. Training Manual on Fish Stock Assessment and Management, p.150.

Over space, each zone is regarded as a stratum and over time, a calendar month is considered as a stratum. Consequently, a zone and a calendar month constitute a space-time stratum. Suppose, in a zone, if there are 5 landing centres and 30 fishing days in the month; then 5 x 30 = 150 landing centre days, combination of centre and day constitute the primary stage units (PSU). The fishing craft that land on a landing centre day forms the second stage units (SSU). Furthermore, the fish landings vary considerably among the landing centres in a multi-centre zone, mainly in different seasons and hence a zone is further stratified into substrata viz., major, minor and very minor. The centres in which either mechanised crafts or 100 or more non-mechanised/motorised crafts are operating are considered as major centres. Likewise, other strata are defined based on the number and type of fishing crafts operating.

Further, a month is divided into three groups each with ten days. A day is selected at random from the first five days of a month and 5 successive days are selected automatically. Three clusters of two successive days are made from the above selected days. To illustrate the selection of landing centres and days, let us consider a fishing zone in a month. Initially, select a date at random from the first five days, let it be 3. Then from the first 10 day group, three clusters of 2 days (3,4) (5,6) and (7,8) can be formed. From the second group of 10 days, the clusters are systematically selected with an interval of 10 days. The clusters of days formed are (13,14) (15,16) and (17,18). Similar selection can be done for the next group of ten days. Accordingly, 9 clusters of two days can be formed in a month. Afterwards, 9 centres are selected with replacement from the total number of landing centres in a zone and allotted to the 9 cluster days as explained before. Thus, a combination of a landing centre and a day (landing centre day) forms the Primary Stage Units. A landing centre day has been divided into 3 periods as given in the infographic. That means a landing centre day is 24 hour duration which starts at noon of the first day and ends at noon of the following day.

The marine fish landings data collection is done by the technical staff of CMFRI. Usually, one staff is identified to collect data from each zone. Data collection starts from period 1 on each selected landing centre day. The staff will be present throughout the periods 1 and 2 at the centres. The data on landings during period 3 (night landings) is usually collected from the landing centre by enquiry on the following day morning. The observations on the 3 periods contribute the data for one landing centre day (24hrs). So, in a 10 day period, data from 3 centre-days are sampled and thus in a month 9 landing centre days are sampled.

Period 1	• 1200-1800 hours on 1^{st} day
Period 2	• 0600-1200 hours on 2^{nd} day
Period 3	• 1800 hours to next morning 0600 hours

After reaching the landing centre, if the landed number of crafts is large, it may not be practical to record the catches of all crafts landed during an observation period. In that situation, sampling of crafts become essential. When the total number of crafts landed is 15 or less, the total landings from all the crafts are enumerated for catch composition and other particulars. When the total number of crafts exceeds 15, the following procedure is followed to sample the number of crafts.

The catches are normally removed in baskets of standard volume from the crafts. The weight of fish contained in these baskets being known, the total weight of the fish in each boat under observation has been obtained. The procedures of selection of the landing centre days and the crafts landed on the selected day for single centre zones are the same as in the case of a stratum in a multi-centre zone. From the landings of the observed fishing units, the landings for all the units landed during the observation period are estimated. By adding the quantities landed during the two 6- hour's periods and during the night (12-hours) the quantity landed for a day (24-hours) at a centre that is the landings for each centre day included in the sample is estimated. From these, the monthly zonal landings are obtained. From the zonal estimates, district-wise, state-wise and all India landings are arrived. The corresponding sampling errors are also estimated. The estimation procedure is detailed in Srinath *et.al.* (2005).

Administration of the Survey

The survey staff is given 10-12 weeks training course immediately after recruitment and is posted to the survey centres. Each survey centre each centre is provided with literature connected with the identification of fish, a reference collection of local fish species, crustaceans and molluscs, field notebooks and registers. The programme of work for the following month is carefully designed by the staff of Fishery Resources Assessment Division at the CMFRI headquarters. Generally one field staff is allotted to each zone to collect the fish landings data. At the end of every month, the survey staff receives the programme of work for the next month by post, that includes the names of landing centres to be observed and details such as dates and time for observations at each landing centre. The field staff are instructed to send the data collected during every month to reach the Institute's headquarters at least by the end of first week of the subsequent month.

Surprise inspections are carried out by the supervisory staff of the Institute and the enumerators are inspected while at work in the field and their field notebooks and diaries are scrutinised. The estimated zonal landings are always compared with the previous year's survey figures, and if any variation which cannot be explained is observed, the technique of interpenetrating sub-samples is adopted to detect observational errors. Zonal workshops are held periodically to review the progress of work and update the sampling frame and to impart refresher courses to the field staff. Non-response occurs when the regular field staff is not available to observe the centre-day included in the sample. Usually, arrangements are made at the Headquarters/Research/Regional Centre to minimise the non-response.

In the existing sampling methodology, the interest is to estimate gear-wise, species-wise landings for the state in a month, fishing effort according to different types of fishing crafts and also in terms of man hours. The analysis is carried out at CMFRI headquarters. Before the data is processed for analysis it will be ensured that the data collection is made as per the approved schedule, by checking the appropriate proforma. The responsibilities and functions of staff at the headquarters are data coding, estimation and database management. The data analysis is computerised and estimates are made using the software developed by the Fishery Resources Assessment Division of the Institute. The processed data are again counter- checked for errors. When discrepancies are detected, the estimation procedure is scrutinised in detail.

Suggested Reading

M. Srinath, Somy Kuriakose and K.G. Mini, 2005. Methodology for the Estimation of Marine Fish Landings in India, CMFRI Special Publication No. 86, p.57

CONCEPT AND OBJECTIVES OF STOCK ASSESSMENT

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10

Introduction

Among all the exploited natural animal resources, fisheries resources are the largest. The magnitude, dynamics and resilience of fish stock pose great challenge to their assessment as well as management. The fishery resources are unique at least on three factors (Vivekanandan, 2005). (i) Many species have wide spatial distribution. (ii) Several species show wide temporal variations in abundance. (iii) Since the resources cannot be seen visually, gaining an insight into the structure and function of the resources is a challenge. It is reported that 667 marine species are fished (Sathianandan et al., 2013) by 194,490 boats (DAHDF and CMFRI, 2012) along the Indian coast, showing the dynamism of fisheries. To exploit these resources, to manage and develop the fisheries, and to conserve the fish stocks, it is essential to have accurate information on these stocks such as how much or how many are present in the sea, what is their reproductive capacity, their growth potential, etc.

The success of fisheries depends critically on the state of the fish stocks. The fish stocks are controlled by several natural factors such as weather, physical, chemical and biological oceanographic conditions and predator-prey relationships. They are also affected by man's activities, and primarily, to an increasing extent, by fishing. The assessment of a fish stock must consider all the relevant factors, especially the direct impact of a fishery on a single species. Those concerned with making policy decisions about fisheries must take into account, the state of fish stocks and the effect of the proposed decisions on these stocks. The science of stock assessment provides scope for extending advice on these aspects.

Stock assessment is the process of collecting, analyzing and reporting fish population information to determine changes in the abundance of fishery stocks in response to

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fishing and, to the extent possible, predict future trends of stock abundance (Sparre and Venema, 1992). For instance, if the stock assessment studies indicate decline in fish stocks, fishing regulatory measures such as closed fishing seasons, no fishing zones, restrictions on the expansion of fishing fleet or total amount of catch that could be taken, may be contemplated. The stock assessment work would also calculate the amount of increase in the catch, the time required to increase the catch, and the possibility of sustaining the catch if any of the measures mentioned above is implemented. Likewise, if the stock suffers from growth overfishing (exploitation of large quantities of juveniles), mesh size regulation can be suggested. The study can determine that if the juveniles are not caught (by increasing the mesh size), and allowed to grow in the sea, the juveniles would grow to a better size, which may result in, say, 20% increase in total catch.

Objectives of Stock Assessment

Maximum Sustainable Yield (MSY) and Maximum Economic Yield (MEY)

Fisheries resources, although renewable, are exhaustible. The objective of fish stock assessment is to predict changes in the size of stock and the size of yields as functions of both fishery dependant (fishing effort etc) as well as fishery independent factors, so that optimum levels of effort and yield could be determined. Figure 1 illustrates the increase in yield with increase in fishing effort up to a certain level, after which, the renewal of stock (reproduction + growth) does not compensate the loss of biomass due to fishing, and hence, further increase in fishing effort leads to decline in yield.

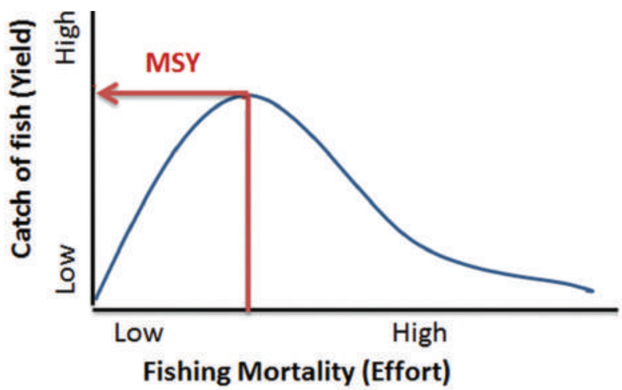

Fig. 1. Concept of Maximum Sustainable Yield

Stock assessment pursues short-term as well as long-term objectives. Assessments for the short-term objectives depend to a large extent on the current state of the stock and suggest what is likely to happen to it in the near future, say, next year or the year after. Those pursuing long–term objectives (such as estimating the Maximum Sustainable Yield, the MSY), on the other hand, depend little on the present state of the stock, but much on recruitment and growth. While long-term objectives seek to formulate strategies for long-term management of fisheries, the short–term objectives relate to the tactics required for the implementation of the strategies of which they are concerned, for example, with the effort required in the immediate future.

The MSY is a useful tool for describing the fish stocks in relation to exploitation. It explains the fact that more fishing does not necessarily mean more fish and that fishing beyond a certain point, overfishing can mean less fish. The fishing effort, which in the long term gives the highest yield, is indicated as F_{MSY}.

The *MSY is defined as the largest average catch, which can continuously be taken from a stock*. The MSY estimate has the important objectives of (i) maximizing the catch, (ii) ensuring that the maximized catch can be sustained, and (iii) interpreting the catch as an approximate measure of the well being of a fishery. The role of MSY for advocating management measures is as follows: In simple cases, if the abundance of a stock is above the MSY, the stock is considered as underexploited and fishing can be increased; if below, the stock is overexploited and fishing should be restricted; and if the stock abundance is equal to the MSY, the fishing is considered as well maintained.

One criticism of the MSY concept is that the actual yield in a particular year can be subject to considerable variations due to non-fishery causes such as environmental factors. It is often felt that in the complex modern fisheries situation, MSY is not an adequate tool either to understand the resource or as an index of management success. In recent years, economic and social considerations are receiving increasing attention. The economic considerations can be seen by converting the curve of Fig. 1 in to relationship between the cost of fishing and the value of the catch (Fig. 2). If economic return is considered as the measure of success, fishing at the point of Maximum Economic Yield (MEY) would be the appropriate objective. However, the MEY also ignores several factors such as the environmental parameters, fishermen empowerment etc. A consensus is now emerging that a single objective of management (MSY or MEY) should not be applied in all situations regardless of changes in the status of the natural resources and in the society's needs.

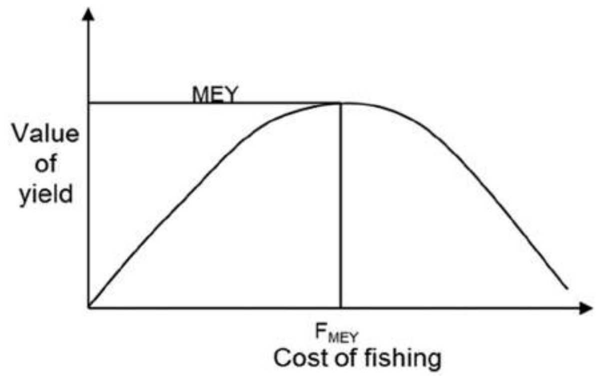

Fig. 2. Concept of Maximum Sustainable Yield

The Unit Stock

For gaining proper understanding of the dynamics of the exploited fisheries resources, information on the fundamental units of such resources, called the unit stocks, is essential. The stock is a term applied in a special way in fisheries management. It is a subset of a species characterized by the same growth and mortality parameters, and inhabiting a particular geographical area. The members of a stock share a common gene pool, and hence, belong to a particular race within a species. A biological fish stock is a group of fish of the same species that live in the same geographic area and mix enough to breed with each other when mature. A management stock may refer to a biological stock, or a multispecies complex that is managed as a single unit.

There are distinctions between the fisheries concept of a stock and the biological concepts of a population (Table 1). Capture fisheries research is usually concerned with the stock of fish exploited by a particular fishery, rather than with an individual fish or with the total population of a species. For instance, the Indian mackerel, *Rastrelliger kanagurta* is exploited along the east and west coasts of India; but the biological characteristics like growth, reproduction, mortalities etc of the different stocks of these species differ greatly from one area to another. The stocks, therefore, should be treated and investigated separately for fisheries management purposes.

Table 1. Differences in the concept between a population and a stock (FAO, 1978)

Population	Stock
i. Basically a biological concept	i. Basically a fisheries concept for management purpose
ii. Breeding unit of a species	ii. Basic fish sampling unit
iii. Each member shares a common spawning ground	iii. Basic fish sampling unit (stock) has production characteristics (like K,Z,F,M etc) as any other individual of the stock
iv. In a species' geographic range, these individuals have rapid gene flow among all members of the group	iv. If geographic clusters of a species differ in the above characteristics, more than one stock is set up for management purpose
v. Larvae develop in the same geographic area	v. Stock may be a portion of a population or include more than one population
vi. Mixing between populations very rare	

Ideally, a unit stock is a self-contained and self-perpetuating group, with no mixing from outside. There are well-defined geographical limits of spawning and gene exchange within stocks of the non-migratory or short distance migratory species unlike the highly migratory species. Therefore, it is much easier to identify the stocks of such non-migratory species than those of the species undertaking long distance feeding and spawning migrations like the tunas.

Russell was one of the first to express the factors in the year 1931, which affect the size of a fish stock by the following formula:

$S_2 = S_1 + (R + G) - (C + M)$

where S_1 = size of the stock at the beginning of the year; S_2 = size of the stock at the end of the year; R = recruitment; G = growth; C = catch; and M = death due to natural causes. If the stock is to be in equilibrium ($S_2 = S_1$), then R + G = C + M or C = R + G – M. This is a very simple way of considering the factors that govern stock size. During the last 70 years, fishery biologists have devised methods to estimate the parameters in the equation.

Data Requirements for Stock Assessment

Stock assessments require three primary categories of information: catch, abundance, and biology. To ensure the highest quality stock assessments, the data used must be accurate and timely.

(i) Catch Data (*The amount of fish removed from a stock by fishing)*:

A national network of fishery monitoring programs should continuously collect catch data for stock assessment. Sources of catch data include:

- Commercial catch monitoring: Often conducted in partnership with state agencies and research institutions, monitoring catch gives an accurate measure of commercial landings and provides biological samples for determining length, sex, maturity and age of fish.
- Logbooks: Records from commercial fishermen of their location, gear, and catch.
- Observers: Biologists observe fishing operations on a certain proportion of fishing vessels and collect data on the amount of catch and discards

(ii) Abundance Data (*A measure, or relative index of the number or weight of fish in the stock):*

Data ideally come from a statistically-designed, fishery-independent survey (systematic sampling carried out by research or contracted commercial fishing vessels separately from commercial fishing operations) that samples fish at hundreds of locations throughout the stock's range. Most surveys are conducted annually and collect data on all ecosystem components.

(iii) Biology Data (*Provides information on fish growth rates and natural mortality):*

Biological data includes information on fish size, age, reproductive rates, and movement. Annual growth rings in fish ear bones (otoliths) are read by biologists in laboratories. The samples may be collected during fishery-independent surveys or be obtained from observers and other fishery sampling programs. Academic programs and cooperative research with the fishing industry are other important sources of biological data.

Complexities in Stock Assessment of Tropical Fishes

The dynamics of the tropical fish stocks are more complex than those of the temperate stocks (Pauly, 1983). Nevertheless, the methods of fish stock assessment available today are basically those designed for the temperate stocks. Perhaps the most conspicuous difference in stock assessment between the tropical and temperate fishes is in the nature of the basic input data, rather than in the models, as explained here: (i) As age determination is difficult in tropical fishes, length frequencies have to be converted into age frequencies. There are several techniques now available for the conversion of length groups into age groups. (ii) Unlike in the temperate fishes, prolonged spawning makes it extremely difficult to assign seasonality to spawning patterns in tropical fishes. Hence, identification of different cohorts and tracing the length frequency progression of each cohort of tropical fishes has to be carried out under conditions of high subjectivity. The recruitment patterns are also not properly understood at present. (iii) Tropical fishes are characterized by faster growth and shorter life span unlike the temperate fishes. It is more realistic and appropriate to estimate the population parameters of tropical fishes for shorter time units of age, say, one month, and then raise the values to annual basis. (iv) Another complexity of the tropics is that they support multispecies fisheries where a large number of species are caught in the same ground in some important gears like the bottom trawl in almost every haul. Hence, the interspecies relationship and natural mortality under tropical conditions must be very different from those under temperate conditions. As the stock assessment models are tailored to suit the biological characteristics of temperate fisheries, it becomes very difficult to apply them to tropical fisheries. These models are very sensitive to seasonal patterns of recruitment, catchability and mortality. Therefore, appropriate adjustments or modifications in the existing models to suit tropical fisheries are necessary.

Limitations

All the stock assessment and prediction models contain uncertainties in the estimates of specific parameters. This is particularly true for length-based assessment methods, which are mostly applied on tropical species. The length-based assessments depend critically on the estimation of the highly sensitive and variable growth parameters. In a length-based VPA, overestimating the K will mean that the time required to grow through a length interval will be underestimated. This implies that the fishing mortality for that interval will be overestimated. In turn, the exploitation rate, which is an input for later analysis, will be overestimated.

Most of the studies on stock assessment suffer from one or other deficiency relating to the estimation of population parameters. A few typical cases are: (i) Estimation of growth and mortality parameters based on samples of larger pelagics collected from selective gears like the large mesh gillnets, which exploit mostly larger fishes. (ii) Growth and mortality estimates of shoaling smaller pelagic such as the oil sardine and the Indian mackerel sampled from the purseseines. The smaller pelagics tend to form schools of fish of same size. (iii) Estimating the stocks of migratory fishes like the tunas without considering the characteristics of the cohorts and the stocks in the fishing areas from where the samples were collected. It is possible that the samples represented different cohorts and also different stocks. Systematic aerial surveys are conducted regularly in some countries for assessing the stocks of migratory pelagic fishes. (iv) Often, there is bias in the selection of the length frequency modes. (v) Collection of data from an array of gears without properly standardizing the effort. (vi) Selecting inappropriate methods especially for the estimation of the total mortality coefficient. Results obtained from discrepant analyses would lead to distorted conclusions on the status of the stocks. When working with mathematical models, it is essential that the fisheries scientists check whether the basic assumptions of the models are fulfilled.

Fisheries assessments are highly sophisticated scientific exercises calling for a variety of skills, a sound knowledge on the biology of the system and a good understanding of the fishing operations and the industry. Fisheries scientists often face the problem of lack of information, or even if information is available, it is either inadequate or could not be processed in time. This is because the stock assessment studies have to rely on the quantity and quality of the data and knowledge, which depend to a large extent on the cooperation provided by the fishing industry. In India, the cooperation from the fishing industry in providing the basic data on catch and effort is zero or minimum.

Further, the resource system itself varies with time in such a way that the basic scientific conclusions of today may have to be modified, often radically, within a short time in the future. For data analysis one has to wait. By the time the catch and biological data become available and put to analysis, the assessments get outdated by several years. The importance of such delays cannot be underestimated, considering the need for timely assessments to understand the status and resilience of the tropical multispecies fish stocks in withstanding overfishing over a good deal of time because of their characteristic multiple spawning frequency and fast growth. Most of the fast growing and short lived tropical fishes, penaeid prawns and cephalopods have high potential increase rates, *vis-a-vis* rapid decline rates within a short duration. Furthermore, the interactions between the trophic levels are too great that one could not expect consistence in the stocks and in the stock estimates over the time-scale. The existing single species stock assessment models are often found inadequate to accommodate the resilience of tropical stocks.

Moreover, any change in the exploitation pattern of commercial fisheries like the introduction of a new gear or a change in the mesh size may considerably alter the assessment estimates. Change of fishing areas from time to time is another major causative factor for the tentativeness and inaccuracy of the estimates. With the induction of more large vessels and the consequent extension of fishing to deeper grounds all over the coastline, this factor has assumed greater importance in stock assessment.

Stock assessment models provide estimates of the optimum yield, usually taking into consideration only the biological factors. These models consider that the environment is invariable, which is not true. In addition to the environmental factors, the economic factors, such as the escalation of operational cost and fluctuations in the value of the catch, also play an important role in arriving at appropriate management decisions. It is necessary that each of these considerations and their alternatives are investigated and addressed thoroughly.

Discards and Their Effects on Stock Assessment

An important factor that could not be ignored in stock estimates based on fish landings is the discard. Discards are fish thrown back into the sea because they are too small, of little market value or unmarketable. The problem of discards arises mainly because of mobile gears like the trawl, which catch everything accessible to it on the bottom in front of its sweep, and there is no space in the fish hold of the vessel to accommodate the entire catch. In general, discards are not recorded. The discard factor has assumed alarming proportions in recent years with every fishing cruise lasting for 7 days and more. These trawlers discard almost the entire tiny fishes caught, especially during the early part of the cruise. Ignoring the discard leads to the underestimation of the catch as well as the number recruited to the fishery. The exact quantity and nature of discards could be observed only onboard the fishing vessels. The discards comprise of large number of species, ranging from the gastropods and the echinoderms to the juveniles of economically important fishes, the crustaceans and cephalopods. Considerable effort has been made in many countries to account for the effects of discards on stock assessment by adjusting the data on the reported landings and their age composition. It is apprehended that the exploitation of small fishes may affect the food balance in the ecosystem.

Other Indicators of Stock Status

If fish stock assessments and predictions fail, the ways by which the stocks respond to exploitation provide an opportunity to gain an understanding of the status of the fishery. Changes in catch per unit effort, mean length in the catch, length at first maturity and other biological characteristics are the responses of fish stocks to exploitation. For instance, as the intensity of fishing increases, there is a progressive decrease in the abundance of the stock, the mean length of the fish in the catch and the length at first maturity. By continuously monitoring these changes, a clue, though of limited value, could be gained on the effects of fishing pressure on the stock. There are many responses, such as drastic fluctuations in the catch, which do not provide specific answers. The factors mentioned in Table 2, though not exhaustive, reflect the response of stocks to fishing pressure or to environmental changes. Reasons for responses for drastic fluctuations in catches, for example, do not provide specific answers.

Table 2. Indicators of decline in fishery resources and the causes

Nature of decline	Indicators	Causes
Decrease in catch	Decrease in catch rate	Environment, fishing competition
	Change in species composition	Environment, changes in gear & area of fishing,market preference etc.
Decrease in recruitment	Sudden increase in mean age/length	High vulnerability to fishing
	Spawners exploitation	Target fishing
F = M or F>M	Reduction in mean age/length	Environment, fishing pressure exploitation of juveniles
Deviations from normal pattern	Changes in spawning pattern	Environment, biological
	Changes in length at first maturity	Environment, biological
	Changes in fecundity	Environment, biological
	Changes in size composition	Fishing, market preference

Summary

- Due to their incredible collective abundance in the ocean, fishes are typically managed by species; species are further divided into stocks and populations.
- A fish species is divided into stocks for management purposes.
- A fish species is divided into populations to reflect actual differences in geographic range or biological characteristics.
- An evaluation of the stock-recruitment relationship (the relationship between the number of adult fish in a stock and the number of new fish entering the stock) allows scientists to estimate the carrying capacity and surplus production of a stock. This information forms the basis of management decisions designed to maximize the output and sustainability of a fishery.

The most common use of the results of stock assessment is to provide advice to the fisheries administrators about the development and management of the fisheries. In spite of the limitations and uncertainties in stock estimates, it is highly desirable that advice is suggested on the basis of stock estimates, even if the advice tends to be approximate. This would in no way diminish the value of the advice. A reasonable professional estimate of future trends appears acceptable than lack of any information.

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IMPORTANCE OF FISH STOCK ASSESSMENT TO FISHERIES MANAGEMENT

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11

Introduction

Fisheries tend to collapse because of fleet over-capacity, leading to harvesting the stocks of fish beyond their ability to recover. Fishery collapses have been very common, creating economic, social and ecological problems of great complexity. One of the major aims of fisheries management is to avoid fleet overcapacity by directly controlling the fishing effort (input control) or by setting limits to the total catch per season/year and its biological characteristics (output control).

On the other hand, fish stocks may also be under-utilized because of fleet under-capacity. This is particularly the case when fleets are artisanal, in initial stages of development, or with poor infrastructure facilities. When fish stocks are under-utilized because of fleet under-capacity there is loss of economic diversification, revenue, employment and food security. In this situation, the prices of sea food are usually higher because domestic supply may not meet the demand.

Due to the reasons mentioned above, fisheries management must strike a balance between over-exploitation and under-exploitation (Restrepo et al., 1992). The risk of over-exploitation is the risk of management inaction, letting fishermen take too many fish from the sea thereby negatively impacting the sustainability of the stock and the fishing industry. The risk of under-exploitation is the risk of excessive management interference, setting too many obstacles to the fishermen to take fish. The fishery manager has to strike a balance by directly controlling the fishing capacity (input control) and/or by setting restrictions on the catch (output control).

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From the point of view of managers, fisheries are successful if they provide the maximum quantities of sea food in an ecologically and economically sustainable manner for indefinite periods of time. This definition of fisheries management success embodies the notion that it is necessary to avoid both kinds of risks, the risks of over- and under-utilization of fish stocks.

The key factor in the success of striking this balance is the application of fisheries management based on scientific advice coming from results of stock assessment models (Hilborn and Ovando, 2014; Melnychuk et al., 2017). This insight is widely acknowledged around the world and has crystallized as legislation in fisheries. All these legislations explicitly state that fisheries management must be based on science. The Magnusson-Stevens Act of the United States of America is even more definite, stating that all stocks exploited by commercial fisheries must be subject to stock assessment.

In the words of Gulland (1983), one of the most experienced stock assessment in the world, "*All those concerned with making policy decisions about fisheries must take into account, to a greater or lesser extent, the condition of fish stocks and the effect on these stocks of the actions being contemplated*".

Definition of Fisheries Management

Fisheries management has been defined as "The integrated process of information gathering, analysis, planning, consultation, decision-making, allocation of resources and formulation and implementation, with enforcement as necessary, of regulations or rules which govern fisheries activities in order to ensure the continued productivity of the resources and the accomplishment of other fisheries objectives" (Cochrane, 2002).

The Technical Guidelines on Fisheries Management (FAO, 1997) describe a management plan as "a formal or informal arrangement between a fisheries management authority and interested parties which identifies the partners in the fishery and their respective roles, details the agreed objectives for the fishery and specifies the management rules and regulations which apply to it and provides other details about the fishery which are relevant to the task of the management authority." It is a process *of considering the following components to make* decisions and implement actions to achieve goals:

- Biological considerations
- Ecological and Environmental considerations
- Technological considerations
- Social and Cultural considerations
- Economic considerations
- Considerations imposed by other parties.

Other parties would include, for example, tourism, conservation, oil and gas exploration and exploitation, offshore mining and shipping, aquaculture and mariculture, and coastal zone development for business or industry. All these can impose significant constraints on fishing activities and may be impacted by fishing activities. The fisheries manager therefore needs to be aware of such activities and of real or potential impacts in both directions.

A modern fisheries manager is required to be familiar not only with the national legislation governing fisheries, but also with international legislations and voluntary instruments dealing directly with or impinging on fisheries. There has been a proliferation of such instruments in recent decades. This process shows the highly complex nature of management, and the need for considering the above-mentioned six different but interconnected and perhaps equally important elements for developing a management framework.

Principles of Fisheries Management

Arising from the considerations discussed above, a number of key principles can be identified which may serve to focus attention on effective fisheries management:

1. Fish resources are a common property resource
2. Sustainability is paramount and ecological impacts must be considered
3. Decisions must be made on best available information but absence of, or any uncertainty in, information should not be used as a reason for delaying or failing to make a decision.
4. A harvest level for each fishery should be determined.
6. The total harvest across all sectors should not exceed the allowable harvest level.
7. If this occurs, steps consistent with the impacts of each sector should be taken to reduce the removal.
8. Management decisions should aim to achieve the optimal benefit to the community and take account of economic, social, cultural and environmental factors.

In keeping with the integrated nature of fisheries ecosystems, these principles cannot be considered in isolation in considering how best to manage fisheries: their implications and consequences overlap, complement and confound each other which is what makes fisheries management so demanding and challenging.

Different Types of Management

Wider examination of fisheries management framework currently existing in different countries shows that the following three approaches are being adopted:

(i) Rights-based approach

(ii) Ecosystem approach

(iii) Precautionary approach

(i) Rights-based approach

In well managed fisheries, Maximum Sustainable Yield (MSY) or Maximum Economic Yield (MEY) or yield-per Recruit (Y/R) is used as biological reference points (BRPs) to derive thresholds and targets to arrive at sound fisheries management decisions (FAO, 2006). Spawning-recruitment relationship (S-R) is used as a key element for formulating fisheries management advice. A few other empirical reference points such as long-term mean size at capture also can be used as BRPs. By using the MSY approach and BRPs, countries like the USA, Canada, New Zealand, and a few countries in the Europe are following advanced rights-based management approach to limit the catch equal to or within the total allowable catch by following catch quotas. In these countries, Total Allowable Catch (TAC) is set with reference to maintaining the biomass at or above a level that can produce maximum sustainable yield (MSY).

(ii) Ecosystem approach

In the last ten years, it has been recognized that effective fisheries management could be achieved by following ecosystem approach, in which multiple regulatory measures and management actions could be applied in full consideration of aquatic species, the ecosystems in which they live and the developmental systems that degrade the ecosystems.

Applying an ecosystem approach to fisheries management (EAFM) is considered the preferred option and the best practice for long-term sustainability of fisheries and the services that fisheries ecosystems provide to the society.

(iii) Precautionary approach

Although MSY is an appropriate basis for reference points, there are limitations of applying MSY approach in fisheries management in the absence of key BRPs like the S-R. However, non-availability of a whole range of scientific information should not deter taking management decisions. In this situation, precautionary approach should be the backbone of fisheries management. The UN Conference on Straddling Fish Stocks and Highly Migratory Stocks (UN 1995) first articulated the principle for fisheries under the following definition:

"The absence of scientific data shall not be used as a reason for postponing or failing to take conservation and management measures".

The precautionary approach requires, *inter alia*, maintenance of a flexible, resilient fishery system including the fish stock, the associated species, the fleet and the management agency regulating it. The precautionary approach emphasizes that, greater the information gaps and the amount of uncertainty, the management measures should be more cautious to avoid risks.

Whatever is the approach, stakeholder engagement in various levels of fisheries management and co-management systems are becoming popular in many parts of the world and demonstrating considerable levels of success. In its simplest form, co-management can be described as fisheries management where roles and responsibilities are shared between the government and resource users (Pomeroy, 1994).

Breadth of Stock Assessment

Stock assessment is sometimes viewed as a rather narrow biological discipline that might be summarized as "the interpretation of commercial catch to estimate potential yields". However, stock assessment is much more than this. First and foremost, stock assessment involves understanding the dynamics of fisheries. This recognizes that fisheries are dynamic entities that will respond over time to management regulations, and to extrinsic factors. Modern stock assessment is not just the task of making static predictions about sustainable yields. It should also involve making predictions about how policies should be structured in order to deal with the unpredictable changes that will inevitably occur.

Fisheries are also much more than fish catch. Fishermen are an important component of fisheries, and stock assessment must take into account how fishermen will respond, and also make predictions about things important to fishermen such as catch per unit effort. Processing and marketing are also very important components of the fishery system.

Importance of Stock Assessment to Fisheries Management

Scientists strive to increase the types and amounts of data collected from fisheries and research projects in order to improve the accuracy of stock assessments. Fisheries managers then consider results of the stock assessment when taking management action, which in turn may affect stock abundance or productivity (Fig. 1). If a stock is overfished, actions need to be taken to reduce fishing pressure. This allows the stock to rebuild to an acceptable level and promotes a healthy fishery in the future. On the other hand, if a stock is healthy, managers take steps to ensure the stock is harvested at a level allowing for long-term sustainability. Because stock assessments are directly linked to management actions, it is important to understand appropriate uses of data, different options for analyses, and how to apply assessment results.

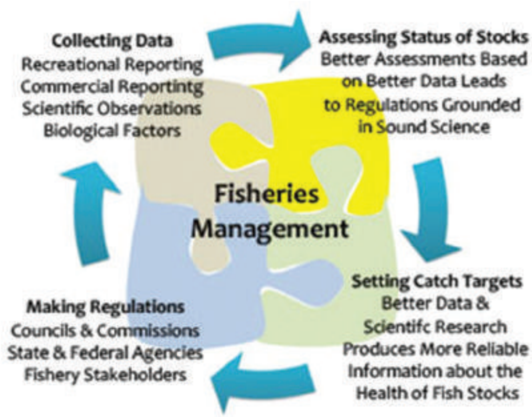

Fig. 1. Importance of stock assessment to fisheries management

The results of stock assessments serve as the basis for long-term and short-term fishery management decisions. First, the assessment provides the basis for status determinations, which entails the following:

(1) Determining whether underfishing or overfishing is occurring and determine the level that would produce maximum sustainable yield; and

(2) Comparison of current reproductive potential (usually measured as spawning biomass) to a limit level (usually set to approximately half the level that would produce maximum sustainable yield) as a measure of stock depletion and a trigger for development of a rebuilding plan.

Second, assessments provide forecasts of the expected future catch and stock abundance associated with proposed harvest policies. Thus they provide scientific information for implementation of the harvest policy that will produce optimum yield from the fishery. Finally, the time series of abundance, mortality, and productivity produced by single-species stock assessments provide input to ecosystem food web models.

Changing Role of Assessment in Fisheries Management

Commercial fisheries usually develop initially through a dynamic process that involves several distinct stages. A generalized diagram of these stages is shown in Figure 2.

(i) First, there is discovery of a valuable stock. This is the predevelopment of the fishery.

(ii) Second, there is a period of rapid growth of fishing effort.

(iii) Next, the fishery reaches full development, where yields are near or perhaps a little above a long-term sustainable level.

(iv) The rapid development results in fish stock reduction and more fishermen compete for the remaining fish.

(v) The fishery often then enters an overexploitation stage, which is followed by a collapse. The stock may or may not recover on its own during this period.

On a longer time scale, technological innovations may result in increased fishing success and attraction of more fishing pressure and hence a repetition of stages four and five of development, unless fishing effort is carefully managed through each technological transition. The extent to which the collapse is severe, or the fishery does not collapse at all will depend on the price of the fish product, the delays in investment, the extent to which fishing success declines as abundance declines, and whether regulatory agencies act to reduce effort or catch before a collapse occurs.

Fisheries management should consider quantification of these different phases of fisheries for taking decisions. (i) The most important management as well as assessment question is, what level of fishing pressure should be permitted at an initial stage of fisheries development. On a sustainable basis, is the stock likely to support 10 boats or 100 or 1000? In the early development phase, an order of magnitude of assessment, even if it is a rough estimate, will be of considerable value. This will permit precise estimates of assessment later in the development.

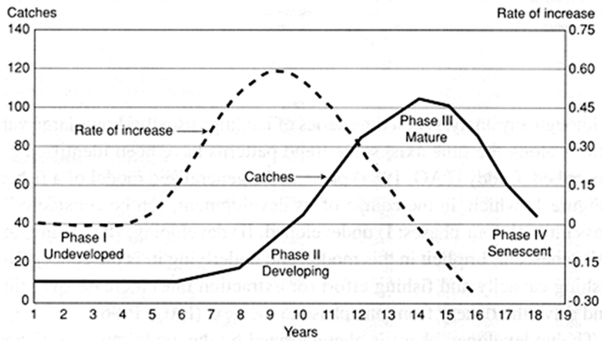

Fig. 2. An example of different phases of fisheries development (Source: FAO)

(ii) A key role of stock assessment during fisheries development is to provide regular updating and feedback of population parameters and estimated potential into the decision making process. Systematic and regular assessments will provide good early warnings of overfishing and help avoid overcapitalisation. A simple method of assessment as the fishery develops is to monitor the relationship between the fishing effort and catch and plot a graph as shown in Figure 2. As the catch reaches the top of the curve and starts to drop, it shows that the MSY has been reached and it is time to reduce the fishing effort.

(iii) When the fish stocks are overexploited, the key role of stock assessment is to quantify the choices as precisely as possible. How to rebuild the stocks? Should it be through reducing fishing effort, if so how much? How long it will take for the fisheries to rebuild? In this situation, it is important to predict how the stocks will respond to new management initiatives. A classic role of stock assessment would be to provide, based on available information, reasonable prediction about such circumstances.

Uncertainty in Stock Estimates Affects Fisheries Management Decisions

Through stock assessments, scientists aim to determine parameters such as stock size and fishing mortality rate. In reality, the estimates are not precise and they are the most "likely" values. In fact, a wide *range* of values may exist. In order to make sense of the range of possible values, assessment models produce an estimate of the uncertainty about these values. Often, uncertainty is simply a range within which the true value may lie. That range is called a confidence interval or confidence bound. The wider the confidence interval, the more uncertainty exists about where the true value lies. For example, a stock assessment might determine that the current year's biomass equals 100,000 tonnes with a 95 percent confidence interval of 80,000-120,000 metric tonnes.

Uncertainty often exists in the information being input into a stock assessment model. What is the true natural mortality rate? Are catches fully accounted for or some might be missing? Are there errors in the way a fish's age or weight is estimated based on its length? Are fish migrating into or out of the stock?

Other uncertainties arise from the choice of stock assessment model. No model can fit the data perfectly because no model can possibly capture the true complexity of the system. Is there a relationship between stock size and recruitment? Does a fish's vulnerability to the fishing gear change each year? Does natural mortality vary from year to year? The goal is to capture the general trends as accurately as possible. Some statistical or estimation uncertainty is inevitable.

Estimating uncertainty allows decision makers to know how accurate the point values may be, and allows them to choose their actions appropriately. For stocks with greater uncertainty, the true status of the stock will not be clear. A stock with greater uncertainty cannot be managed like the one with lesser uncertainty. This is because it is more likely that the stock with greater uncertainty is already close to or even below its biomass threshold. Formally incorporating this uncertainty to predict the results of management actions is called risk assessment.

As with stock assessments, the goal of risk assessment is not to provide a single solution to stock management, but rather to provide decision makers with the information necessary to effectively compare various choices. Such risk assessments are often included within a stock assessment to predict a stock's response to different levels of fishing pressure. While a stock assessment cannot remove or incorporate all uncertainty, it should explain how uncertainty is incorporated and why it may be ignored. It should also test the sensitivity of the model to any assumptions that were made.

Stock assessments are merely tools. They cannot produce concrete decisions about how to manage a stock. They cannot tell a decision maker which management options are right and which are wrong. Rather, the stock assessment is designed to give managers and decision makers information about the current status of a stock relative to its biological reference points. It provides them with information about how the stock might respond to future management actions. Choosing between management options is ultimately the role of the manager. Ideally, a careful and complete stock assessment will provide the manager with the necessary information to manage the stock successfully into the future.

Summary

The choice of fisheries management is not whether to do stock assessment, but how best to do it. Stock assessment involves understanding and making predictions about the response of fisheries systems to management actions. Stock assessment helps managers to make choices in the dynamic fisheries systems in the fact of uncertainty (Hilborn and Walters, 1992). The role of stock assessment is not to make the best guess on MSY, but rather help design a fisheries management system to understand the dynamics and respond to the variabilities.

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STOCK ASSESSMENT MODELS AND METHODS

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Introduction

Fish stocks have an important role in providing cheap protein food, income and employment to millions of people in the world. Judicious management and exploitation of the renewable fish resources is important for sustained production over years. Over fishing leads to disappearance of the renewable fish stocks. Assessment of fish stocks is the first step to determine the level of exploitation necessary for arriving at maximum sustainable yields from the fish resources. Assessment of stocks and study of impact of present level of exploitation on exploited stocks are necessary for maintenance of stocks at maximum sustainable level. Many mathematical and statistical models have been developed and used for fish stock assessment studies. The unique features of fish stocks are, they do not come under visual horizon for direct evaluation of stock sizes, their distribution over space, time and species varies at higher dimension and fish stocks are affected by fishery dependent factors such as effort exerted, size at first capture and fishery independent factors like salinity, temperature, water current etc. The models to study fish stocks should consider the three aspects namely, size of the stock, level of exploitation and effect of fishery independent factors. Multi species and multi gear situation adds to the problem of assessing the fish stock. Stock assessment models satisfying some of these requirements have been developed and successfully used for management of the fishery.

The fish stock assessment models can be categorized as deterministic models and stochastic models. Deterministic models form the major category which is further divided into two class as Macro-analytical models and Micro-analytical models. Stochastic models incorporate random elements into the stock assessment models and deterministic models do not allow chance fluctuations in its construction. Macro-analytical models are used for rough approximation of the existing status of the stocks and these models are simple, require only catch and effort data for different years/time and analysis is straight forward.

Macro-analytical models

Other names for macro-analytical model are synthetic model and global models. Here the overall net effect of all the factors that control the biomass is considered simultaneously.

In macro-analytical models the change in biomass is expressed as

$B_1 - B_0 = R + G - D$

where B_0 and B_1 are the initial and final biomass in a year, R is the recruitment, G is the growth and D is the mortality. The relationship of change in biomass (B_1-B_0) with the biomass B, instantaneous rate of fishing mortality F and the yield Y are considered. Different models under this category are

Swept Area Method: In this method the biomass is estimated based on the area swept by experimental trawling and the total area inhibited by the stock taking into consideration the quantity caught and the escapement factor.

Biomass Approach: In biomass approach the biomass and MSY are calculated using instantaneous rate of fishing (F), natural mortality rate (M) and intrinsic rate of increase of population (r).

Surplus Production Model: This is under the assumption that when a stock is exploited the change in its biomass depends on its intrinsic rates of natural growth and the catch.

1. Schaefer model: When a stock is exploited its biomass decreases and Scheafer used a linear representation for the relationship (biomass function) and obtained the famous logistic growth curve. He thus obtained MSY and corresponding effort by equating the derivative of the equation to zero.

2. Exponential model: Here the functional relationship is taken as non-linear (exponential) relationship.

3. Pella and Tomlinson model: This is a generalization of the surplus production model by proposing a general functional relationship for the biomass function.

Successive Removal Methods: These models are under the assumption that the change in stocks is only due to catch removals and during fishing no other change takes place in the stocks.

1. Leslie method: Assuming catch per unit of effort as an index of the stock abundance he took catch per unit effort as proportional to the stock size.

2. De Lury method: This is a slight modification of Leslie method. By assuming that the fraction of stock removed by a unit of effort is very small he obtained an approximation for stock size.

3. Ricker method:

Capture-Recapture Methods: In capture-recapture methods the method of estimation of stock is based on probability distribution of the situation especially the hypergeometric probability distribution for single release of marked ones. Also, there are methods covering multiple release and recapture for both closed and open sytems.

1. Hypergeometric model: This is based on the conditional probability distribution of recovery of m_2 marked ones in n_2 number of fish caught with a total of n_1 fish marked and released.
2. Bailey-inverse sampling method: In this method the sampling of animals is continued till a prefixed number of marked fish are recaptured. The probability distribution of the particular situation is then used to estimate the stock size.
3. The generalized hypergeometric method: In this case the joint distribution of a set of random variables are derived and based on the structure of the model the stock size is estimated.
4. Inverse Schnabel census: This is an extension of the inverse sampling procedure combining the generalized hypergeometric method.

Relative Response Model: This model depends on successive cathes to predict the maximum catch that the fishery can sustain under the assumptions that, stocks existing in a particular area are exploited by various types of gears that are not species specific, the fishing is increased over a period of time till the optimum level is achieved and when the effort is increased the catch also increase till a maximum level is reached.

Quick Estimates: In the absence of earlier history, when the fishery is in progress, it is desirable to have quick estimates based on known statistics.

1. Comparison method: On the basis of yield gradients based on catch or primary productivity of known areas, production in other areas having similar characteristics can be estimated.
2. Indicator method: If an indicator or potential yield that is easily and quickly measurable is available then that indicator can be profitably used for assessing yield.
3. Productivity approach: Knowledge on production at successive trphic levels is required in this approach. Due to the complexity of the trophic relationships the results vary widely.

Micro-Analytical Models

Micro-analytical models otherwise known as dynamic pool models take into account recruitment, mortality, age, growth and all other factors affecting stock. These models are based on the assumptions that the stock under study is in a steady state (recruitment, growth and mortality are constant) and the yield is directly related to the recruitment. Under this assumptions yield-per-recruitment (Y/R) will be and index of stock. Different models under this category are

1. Beverton and Holt model
2. Jones method
3. Ricker model: He proposed a simple method with no assumptions on the form of growth. The average biomass is obtained first from the successive biomass estimates and substituted it in the yield equation to obtain the final equation for the yield.
4. Cohort analysis: In cohort analysis estimates of stock sizes for different age/size classes are made recursively starting from the terminal class back words to finally end at the initial size assuming a constant fraction for the terminal class exploitation rate. Also, the instantaneous rates of fishing and natural mortalities are assume to be known for this exercise.
5. Thompson and Bell model

COMPUTATIONAL OPTIONS FOR MARINE FISHERIES RESEARCH AND MANAGEMENT

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Introduction

Marine fisheries research and management including its core domains like stock assessment and resource simulation and forecasting has of late been driven by the explosion in the computational power and designing and development of tailor-made software. Though the activities on the computational front have peaked in the last five years or so, the seeds were sown way back in eighties with the introduction of personal computing. Here it is relevant to record that digitization of fisheries related information and datasets were much older than these software developments. Although it is nearly impossible to prepare an exhaustive list of software and routines which are presently in use by researchers and planners in Marine Fisheries Management, it is possible to categorise the computational options on a perspective note. This paper would attempt doing that.

Generic grouping of computational tools

For enhancing objectivity, the software options under focus can be grouped into the following four categories:

(i) Custom made software for specific fishery related issues

(ii) General purpose software routines which are of high relevance to fisheries research

(iii) Software and digital options for information and data processing in fisheries research and

(iv) Miscellaneous options

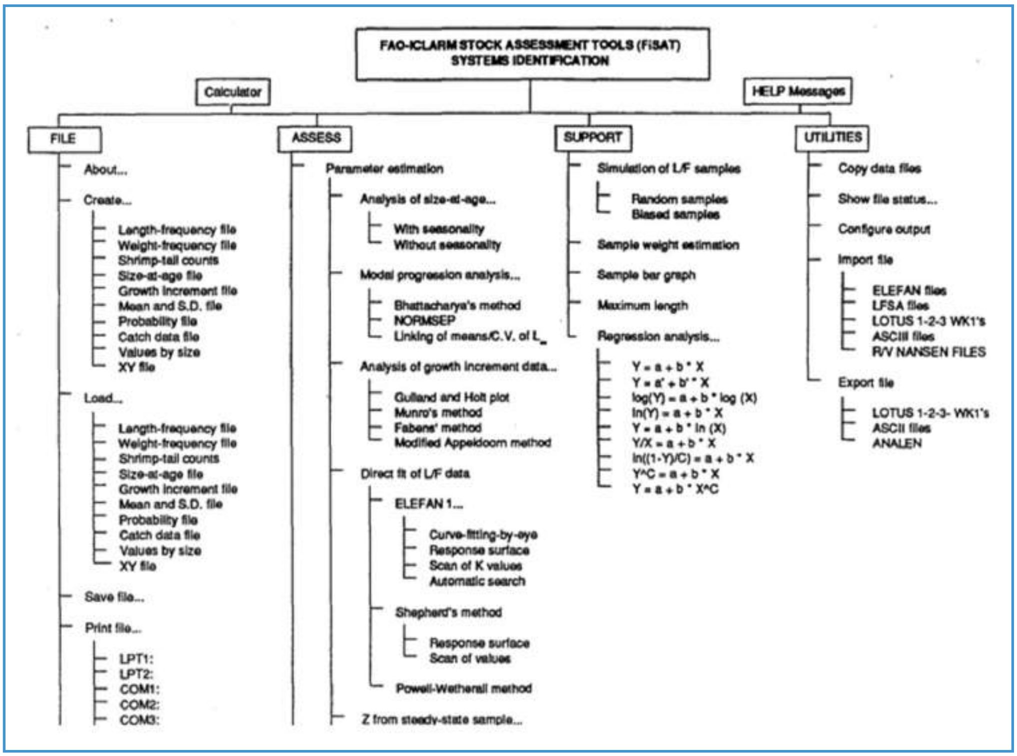
Custom Made Software

This group is the most important and diversified one amongst all computations tools available. These include very specific tools like Electronic Length Frequency Analysis (ELEFAN) and the routines of similar nature used in quantitative fish stock assessment which have later been enshrined in the FAO- ICLARM Stock Assessment Tools (FiSAT).

FiSAT

A beautiful introduction to the thought process that preceded the creation of this software has been given in Pauly and Sparre (1991). The software was the major first such effort in the field of fish stock assessment that brought the various possibilities arising out of established conceptualisations that could throw light on the quantification of the growth and reproductive performance of an average fish of a species and stock under one roof with a common data initialization. The spreadsheet based data feeding was fully focused upon and the tools were further grouped under a bouquet titled ASSESS wherein VBGF type growth, LCC based mortality, spawning stock- recruitment to yield per recruit to Thompson and Bell models could be applied on suitable datasets which can be fed in half a dozen formats. The major standout feature of this software is the ease of performance of modal progression analysis to separate out the cohorts from a mixed bag of length-weight data using the linearized differentiation of normal densities. This process again has been simplifies almost to the spreadsheet level with added advantage of letting the researcher to select and omit the possible candidate data points.

The arrangement of options and tools under the software is best depicted by the tree chart (partially reproduced here) by Pauly and Sparre (1991).



This probably is the most deployed software for any fish population dynamic analytics and till date serves as the benchmark for other new age software. The ease of use of this software partially stems from the non-stochastic approach to the analysis and thereby ensuring replication of results on even datasets. This deterministic approach is the one which has lead to myriad of more comprehensive and broad based analytical framework for the data sampled.

Marine Resources Assessment Group (MRAG) Initiative Under Fishery Management Science Programme (FMSP)

LFDA Version 5.0

The Length Frequency Distribution Analysis (LFDA) package is a PC-based computer package for estimating growth parameters and mortality rates from fish length frequency distributions. Version 5.0 of LFDA includes methods for estimating the parameters of both non-seasonal and seasonal versions of the von Bertalanffy growth curve. It includes three methods for estimating growth parameters. These are Shepherd's Length Composition Analysis (SLCA) method, the projection matrix (PROJMAT) method, and a version of the Elefan method. A facility is provided that allows conversion of length frequencies to age frequencies using the estimated growth curves. In addition to methods for estimating growth parameters, the package also includes three methods for estimating the total mortality rate Z, given estimates of the von Bertalanffy parameters. A function allowing simulation of length frequency data under a variety of assumptions is also included. As with previous versions of LFDA, the package includes a comprehensive context-sensitive Help system and a detailed example analysis. The download file also includes the graphics server programme required to plot the data.

CEDA Version 3.0

The Catch Effort Data Analysis package (CEDA) is a PC-based software package for analysing catch, effort and abundance index data. Version 3.0 allows calculation of estimates of current and unexploited stock sizes, catchability and associated population dynamics parameters. Both depletion and several types of stock production (biomass dynamic) models can be fitted, using one of three different assumptions about the distribution of residuals. Both point estimates and bootstrap confidence intervals for the estimated parameters can be calculated. CEDA also includes the facility to do projections of stock size into the future under various scenarios of catch or effort levels, so that different management strategies can be investigated. Output is presented both graphically and textually, and can be printed or saved to disk for further use. As with previous versions of CEDA, the package includes a comprehensive context-sensitive Help system and a detailed example analysis. The download file also includes the graphics server programme required to plot the data.

Yield Version 1.0

Yield Version 1.0 is a program for calculating fishery yields and stock biomasses, on an absolute or per-recruit basis, and for calculating biological reference points associated with these. On starting the program, users are asked to enter values of biological parameters (e.g. growth, mortality, age at maturity and stock-recruitment relationship) and fishery parameters (e.g. length at first capture, fishing season). For each parameter, either a single value can be entered, or a probability distribution can be specified to allow for uncertainty. When calculating yields and yields per recruit, the program takes explicit account of specified parameter uncertainties, presenting results in terms of histograms. Transient projection and reference point calculations can also be made, once the extent of stochastic recruitment variability has been specified. As with CEDA and LFDA, the package includes a comprehensive context-sensitive Help system and a detailed example analysis. The download file also includes the graphics server programme required to plot the data.

ParFish Version 2.0

Participatory Fisheries Stock Assessment (ParFish) Software is a PC-based software package that uses Bayesian Statistics and Decision Theory to assess the state of a fishery stock and estimate limit and target control levels. The software supports the overall approach which is described in the accompanying ParFish Guidelines. The guidelines provide an overview of all six steps in the approach including: i) understanding the context; ii) engaging stakeholders; iii) undertaking the stock assessment; iv) interpreting the results and giving feedback; v) initiating management planning and vi) evaluating the process. The ParFish software is currently based on the logistical biomass growth model and requires information on four parameters: Current Biomass, Unexploited Biomass, Catchabilty and Growth rate. Interview data from fishers are used to construct 'priors' for the model parameters which can be combined with other available information to provide best estimates. This information is then used, together with preference data from fishermen, to calculate the current stock level and the control levels that will provide the most preferred catch rates for fishers. The programme takes explicit account of uncertainty in the data, presenting results as probability density functions (with accompanying mean, median, mode and confidence intervals). The Software is accompanied by a manual which gives step-by-step guidance on inputting data and running the analysis. There area also additional reference sheets which assist with the interviews and other data collection methods.

RAPFISH- A Rapid Analysis Tool for Fishery Sustainability

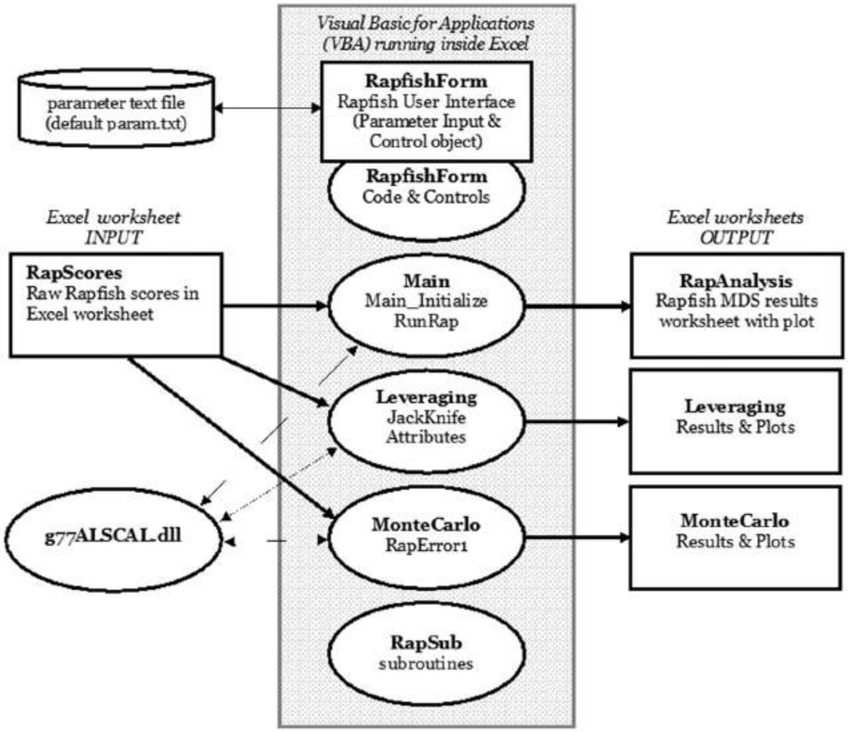
This is an unique but important software tool, which could be tagged under research as well as management of fisheries, wherein Multi Dimensional Scaling, a multivariate statistical dimension reduction tool, has been put to use to rank fisheries simultaneously on biological, technological, economic, ethical and sociological fronts by ranking different fisheries under various contributory aspects falling under these five dimensions. Visual Basic for Applications (VBA) codes have been developed which would guide through the data entered through Excel spreadsheet to the development of report on the status of sustainability of the fisheries under focus and their combined unidirectional ranking. The framework of the software has been described by Patricia, K and Tony J. Pitcher (2004) as follows:

The original rationale for developing for *Rapfish* was toevaluate sustainability, and examples from that modality are largely used in this document. Fisheries scientists grade fisheries according to a large set of 'attributes'. Attributes are grouped in ecological, economic, social, technological, and ethical categories, or 'evaluation fields', so that 'sustainability' can be considered from various points of view. The *Rapfish* technique is flexible such that other modalities of status may be used, such conformity with a set of specified objectives or compliance with a code of conduct . *Rapfish* applies a statistical ordination technique called Multi-Dimensional Scaling (MDS) to reduce the NxM matrix of fisheries statistics for N fisheries and M attributes into a N x 2 dimensional space which has similar distance properties as the N x M statistics. In this 2D attribute space, one dimension (x-axis) is the score representing the status (degree of sustainability) from 'bad' to 'good', and the other dimension (y-axis) represents other factors, unrelated to sustainability (or whatever status is being scored), which distinguish fisheries. The MDS routine ALSCAL in the statistical package SPSS was used in the development and testing of the *Rapfish* technique. SPSS batch programming facilities software were written (Kavanagh 1999) to automate the *Rapfish* procedure, including routines for attribute leveraging and Monte Carlo error analysis. Problems with this software were inflexibility and awkwardness in re-configuring parameters due to limitations in the SPSS command language.

This report describes a more portable and easy-to-use *Rapfish* software implementation, implemented in Microsoft Excel and its programming language, Visual Basic for Applications (VBA). Excel is a popular and low-cost application and the majority of fisheries scientists are familiar and comfortable using it for statistical data analysis. The original ALSCAL FORTRAN code for multi-dimensional scaling has been re-written and built as a dynamic link library routine (DLL) called from an Excel/VBA program. This Excel/VBA/FORTRAN implementation of *Rapfish* is portable (users need only Excel and not SPSS), is easy to programme for various repeat analyses such as leveraging and Monte Carlo, and has a handy graphical user interface to control processing and visualize results.

The Rapfish software architecture can be diagrammatically explained as follows:

General purpose software routines which are of high relevance to fisheries research. Under this category fall the analysis environments like R, WinBUGS, GAMS etc. which have



many customization options of very direct and high utility value in the area of fisheries management. Of these the open source R software stands out in dishing out half a dozen routines referred to as libraries which have been.

TropFishR

The TropFishR package uniquely adds further data-limited method capacity (Table 1) by including tradi- tional and updated versions of the Electronical LEngth Fre- quency ANalysis (ELEFAN) method, used in growth parameter estimation, with new optimisation techniques (Tay- lor & Mildenberger 2017), Millar's nonlinear selectivity mod- els (Millar & Holst 1997), and a complete set of methods for fisheries analysis with LFQ data. This compilation allows a stock assessment routine to derive reference levels (e.g. FMSY, F0 1) by means of yield per recruit modelling, which may be based on a single year of LFQ data. Until now the preferred software for single species stock assessment with length-fre- quency data has been the windows-based programme FiSAT II (Gayanilo, Sparre & Pauly 1996) due to its user-friendly, click-based interface. The software is, however, limited in its ability to import data and perform automated analyses. The TropFishR package aims to remedy these shortcomings by allowing further expansion and flexibility. Although wider in scope, the main methods follow those outlined in the FAO manual 'Introduction to tropical fish stock assessment' (Sparre & Venema 1998). Many of the same examples and datasets featured therein are included in the package (Table 1) and documented in accompanying help files, which facilitates use in training and teaching. Finally, output from various functions can be passed to plotting functions, allowing for export as publication-quality figures.

For historical reasons, and the link to the above-mentioned book by Sparre & Venema (1998), the package's name reflects the fact that the methods have often been applied to tropical fisheries, although they are equally applicable to other regions with data-poor stocks for which LFQ data is available. Typically, the workflow of a data-poor stock assessment with LFQ data would include: (i) estimation of biological stock characteristics (growth and natural mortal- ity), (ii) fisheries performance aspects (exploitation rate and selectivity), and (iii) stock size and status. The order of the methods is important as they build upon each other in a sequential way. If some or all of the vital parameters for stock assessment are already known, the user may skip the data-poor approaches for their assessment and can directly proceed with yield modelling applications.

CatDyn: Fishery Stock Assessment by Generalised Depletion Models

As a recourse to viewing the stock dynamics through catch rather than the population, which is of course used as an index for the latter, routines have been developed to assess, model and predict stock health using Generalised Depletion models. The entire gamut of parametrisation, modelling and forecasting has been made handy by the R library CatDyn. As per the introduction given by the author(s) of CatDyn, the library is capable of the following:

Based on fishery Catch Dynamics instead of fish Population Dynamics (hence CatDyn) and using high-frequency or medium-frequency catch in biomass or numbers, fishing nominal effort, and mean fish body weight by time step, from one or two fishing fleets, estimate stock abundance, natural mortality rate, and fishing operational parameters. It includes methods for data organization, plotting standard exploratory and analytical plots, predictions, for 77 types of models of increasing complexity, and 56 likelihood models for the data.

The concept of depletion modelling is set into motion using the following parametrization. The process equations in the Catch Dynamics Models in this package are of the form

$$C_t = ke^{-\frac{M}{2}}E_t^a N_t^b$$

$$N_t = N_0 e^{-Mt} - e^{\frac{M}{2}} \sum_{i<t} C_{t-1} e^{-M(t-i-1)} + \sum_j P_j e^{-M(t-j)}$$

where C is catch in numbers, t, i are time step indicators, j is perturbation index (j=1,2,...,100), k is a scaling constant, E is nominal fishing effort, an observed predictor of catch, a is a parameter of effort synergy or saturability, N is abundance, a latent predictor of catch, b is a parameter of hyperstability or hyperdepletion, and M is natural mortality rate per time step. The second summand of the expanded latent predictor is a discount applied to the earlier catches in order to avoid an M-biased estimate of initial abundance. Perturbations to depletion represent fish migrations into the fishing grounds or expansions of the fishing grounds by the fleet(s) resulting in point pulses of abundance. In transit models (limited to one fleet) there are also emigration events happening at specific time steps for each perturbation. In 2 fleet cases the fleets contribute complementary information about stock abundance, and thus operate additively; any interaction between the fleets is latent and affects the estimated values of fleet dependent parameters, such as k, a, and b.

The observation model can take any of the following forms: a Poisson counts process or a negative binomial counts process for catch recorded in numbers, an additive random normal term added to the continuous catch (in weight) predicted by the process (normal and adjusted profile normal), a multiplicative exponential term acting on the process-predicted catch such as the logarithm of this multiplier distributes normally (lognormal and adjusted profile lognormal), and Gamma (shape and scale parameterization).

The library CatDyn takes care of almost all the parameterisation issues and dishes out the type of output which would magnify the status of fisheries as seen from the macro dynamic level in such a way to aid the policy makers.

Other R Libraries

There are a few more libraries in R viz. FSA, Fishery Libraries in R (FLR), fishMod etc. which have specific routines or functions that could be applied under one type of assessment protocol. Amongst these FLR seems to be a multifaceted effort wherein almost all aspects of fishery including bycatches, discards as well as economics of fishery are being simulated/ analysed. Most of these libraries have explicit or derived leads to the arriving at of crucial Biological Reference Points (BRP), like MSY, F0.1 etc. which would help the fishery manager to take a call on the precautionary or knife edge type calls on effort moderation so that the stock health is saved.

Software and Digital Options for Information and Data Processing in Fisheries Research

This third type of software are basically data driven and hence could be basically front-ends of huge data repositories. Let us have a look at a few of them:

FAO's FishStatJ

The FishStatJ application provides users with access to a variety of fishery statistical datasets. Any data having yearly time series and coded dimensions can potentially be stored and processed by **FishStatJ**. The system consists of a main application module and workspaces which include the datasets and can be loaded by the user.FishStatJ is a Java-based desktop application. This is quite helpful in getting data on global capture fisheries and aquaculture fish production on aggregated and disaggregated at various levels of granularity.

R language- Rfishbase

This is a library provided interface to various types of customised data tapping from the repositories of fish biology related information on the lines of Fishbase. Despite functioning as the programmatic interface to Fishbase <http://www.fishbase.org>, re-written based on an accompanying 'RESTful' API. Access tables describing over 30,000 species of fish, their biology, ecology, morphology, and more. This package also supports experimental access to <http://www.sealifebase.org> data, which contains nearly 200,000 species records for all types of aquatic life not covered by 'FishBase.'

R language- rfisheries

This yet another database interface in R which gives updated landings of various countries. It is a programmatic interface to 'openfisheries.org'. This package is part of the 'rOpenSci' suite (http://ropensci.org).

Apart from these there are many more open access digital repositories like ICOADS, APDRC, SeaWIFS (NOAA), which dish out various bio- geo- chemical and oceanographic datasets on spatio-temporal tagging base which are of high relevance in climate based modelling of Fishery dynamics.

Miscellaneous

Apart from these types of end to end solution providing software or coding platforms, there are quite a few general purpose routines which have immense use in the field of analysing fishery information. A few of them are listed below:

(i) WinBUGS: A Windows based Bayesian analysis tool using Gibbs Sampler which supports Markov Chain Monte Carlo (MCMC) algorithms is a great tool, wherein fishery growth models can be analysed with additional information on the trends observed in the estimated trajectories of important parameters like virgin biomass, carrying capacity, intrinsic rate of growth, which were otherwise considered as constant unique valued functionals in frequentist concept.

(ii) Generalised Algebraic Modelling System (GAMS) / Data Envelopment Analysis (DEA) for performing optimisation of bioeconomic models on the lines of constraint shored minimisation/ maximisation goal followed in Linear Programming.

(iii) Routines and libraries which could carry out Automatic Differentiation Model Building (ADMB), which by far has been recorded as the most suited one for complicated fishery optimisation issues using which crucial pre- BRP parameters could be estimated with more precision.

(iv) There are quite a few comprehensive packages which could analyse marine communities on multivariate biotic and abiotic variables over a series of sampling points, thereby comparing the diversity gradient and the spacio-temporal innuendos thereof. The most prominent one is Plymouth Routines in Multivariate Ecological Research (PRIMER), Clark and Warwick (2001).

(v) Other advancements like the analysis of slope of size spectra, which has a very high level of application in assessing marine ecosystem especially under the realms of the average trophic levels is another addition to the analysis tools basket. Size spectrum models have emerged from 40 years of basic research on how body size determines individual physiology and structures marine communities. They are based on commonly accepted assumptions and have a low parameter set, making them easy to deploy for strategic ecosystem-oriented impact assessment of fisheries. They are rooted on the fundamental principle of food encounter and the bioenergetics budget of individuals. Within the general framework, three model types have emerged that differ in their degree of complexity: the food-web, the trait-based, and the community models. The implementations of size spectrum models on these lines flag important variations concerning the functional response, whether growth is food-dependent or fixed, and the density dependence imposed on the system.

(vi) Another booming area of research armoured by computational power is Stock Synthesis. Stock Synthesis (SS) provides a statistical framework for calibration of a population dynamics model using a diversity of fishery and survey data. It is designed to accommodate both age and size structure in the population and with multiple stock sub-areas. Selectivity can be cast as age specific only, size-specific in the observations only, or size-specific with the ability to capture the major effect of size-specific survivorship. The overall model contains subcomponents which simulate the population dynamics of the stock and fisheries, derive the expected values for the various observed data, and quantify the magnitude of difference between observed and expected data. Some SS features include ageing error, growth estimation, spawner-recruitment relationship, movement between areas. SS is most flexible in its ability to utilize a wide diversity of age, size, and aggregate data from fisheries and surveys. The ADMB C++ software in which SS is written searches for the set of parameter values that maximize the goodness-of-fit, then calculates the variance of these parameters using inverse Hessian and MCMC methods. A management layer is also included in the model allowing uncertainty in estimated parameters to be propagated to the management quantities, thus facilitating a description of the risk of various possible management scenarios, including forecasts of possible annual catch limits. The structure of Stock Synthesis allows for building of simple to complex models depending upon the data available.

Conclusion

The options thrown up by the giant strides made by computational advance are immense in recent times and so are the opportunities and new challenges posed by unravelling the more and more complicated facets of intricate dynamics of oceanic flora and fauna. Though any one software or method can be singled out as THE SOLUTION, the adoption of more than one for same set of data would give an idea about the sensitivity/ robustness of the inferences, thereby making forecasting a more reassuring assignment.

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AN INTRODUCTION TO R PROGRAMMING

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Introduction

R language is the GNU arm of S language, which has taken the computational world by storm in the last decade. Starting as a compendium of statistical tools, this language has grown up into a canopy lording over a research analysis environment thereby subsuming many hitherto complicated manoeuvres onto the realms of syntactical simplicity. As this an exponentially expanding field of development with ever exploding information downpour, it would be a near impossible task to frame it onto a short simple foundational discourse. However in the subsequent sections we would try to view the potential and the extent of practicality we would unravel the hidden features of the software through a GUI envelop also apart from the regular console and syntax based one. To get its power more understandable we would visualize its forays into the field of analytics using medium scale examples from marine fisheries data.

R is "GNU S" — A language and environment for data manipulation, calculation and graphical display.

- R is similar to the award-winning S system, which was developed at Bell Laboratories by John Chambers et al.
- a suite of operators for calculations on arrays, in particular matrices,
- a large, coherent, integrated collection of intermediate tools for interactive data analysis,
- graphical facilities for data analysis and display either directly at the computer or on hardcopy
- a well developed programming language which includes conditionals, loops, user defined recursive functions and input and output facilities.

The core of R is an interpreted computer language.

- It allows branching and looping as well as modular programming using functions.
- Most of the user-visible functions in R are written in R, calling upon a smaller set of internal primitives.

It is possible for the user to interface to procedures written in C, C++ or FORTRAN languages for efficiency, and also to write additional primitives

R, S and S-plus- a brief time line

- S: an interactive environment for data analysis developed at Bell Laboratories since 1976
  - 1988 - S2: RA Becker, JM Chambers, A Wilks
  - 1992 - S3: JM Chambers, TJ Hastie
  - 1998 - S4: JM Chambers
- Exclusively licensed by *AT&T/Lucent* to *Insightful Corporation*, Seattle WA. Product name: "S-plus".
- Implementation languages C, Fortran.
- See:http://cm.bell-labs.com/cm/ms/departments/sia/S/history.html
- R: initially written by Ross Ihaka and Robert Gentleman at Dep. of Statistics of U of Auckland, New Zealand during 1990s.
- Since 1997: international "R-core" team of ca. 15 people with access to common CVS archive.

What R does and does not

o data handling and storage: numeric, textual o matrix algebra o hash tables and regular expressions o high-level data analytic and statistical functions o classes (Object Oriented "OO") o graphics o programming language: loops, branching, subroutines	o is not a database, but connects to DBMSs o has no graphical user interfaces, but connects to Java, TclTk o language interpreter can be very slow, but allows to call own C/C++ code o no spreadsheet view of data, but connects to Excel/MsOffice o no professional / commercial support

R and statistics

- Packaging: a crucial infrastructure to efficiently produce, load and keep consistent software libraries from (many) different sources / authors, which are updated at a best possible refresh rate
- Statistics: most packages deal with statistics and data analysis and there are many conduit and value addition libraries which augment the statistical inference

- State of the art: many statistical researchers provide their methods as R packages

Statistical Analysis

Data Analysis and Presentation happen to be the core strength of R software environment and the ease with which this is performed makes the environment as the ultimate winner. Faster computational routines and amenability of access and modification to interim steps and results makes the programming environment a winner.

- The R distribution contains functionality for large number of statistical procedures.
    - linear and generalized linear models
    - nonlinear regression models
    - time series analysis
    - classical parametric and nonparametric tests
    - clustering
    - smoothing
- R also has a large set of functions which provide a flexible graphical environment for creating various kinds of data presentations.

References

- **For R**,
    - The basic reference is The New S Language: A Programming Environment for Data Analysis and Graphics by Richard A. Becker, John M. Chambers and Allan R. Wilks (the "Blue Book") .
    - The new features of the 1991 release of S (S version 3) are covered in Statistical Models in S edited by John M. Chambers and Trevor J. Hastie (the "White Book").
    - Classical and modern statistical techniques have been implemented.
        - Some of these are built into the base R environment.
        - Many are supplied as packages. There are about 8 packages supplied with R (called "standard" packages) and many more are available through the cran family of Internet sites (via http://cran.r-project.org).
- All the R functions have been documented in the form of help pages in an "output independent" form which can be used to create versions for HTML, LATEX, text etc.
    - The document "An Introduction to R" provides a more user-friendly starting point.

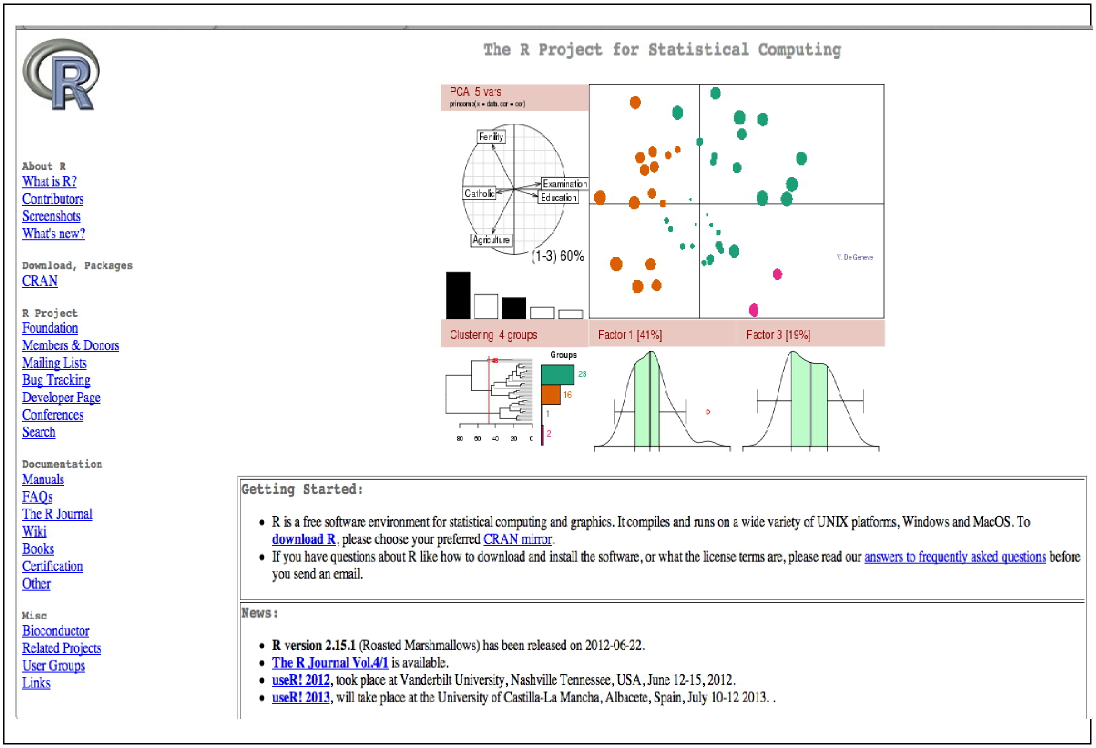
– An “R Language Definition” manual

– More specialized manuals on data import/export and extending R.

R installations

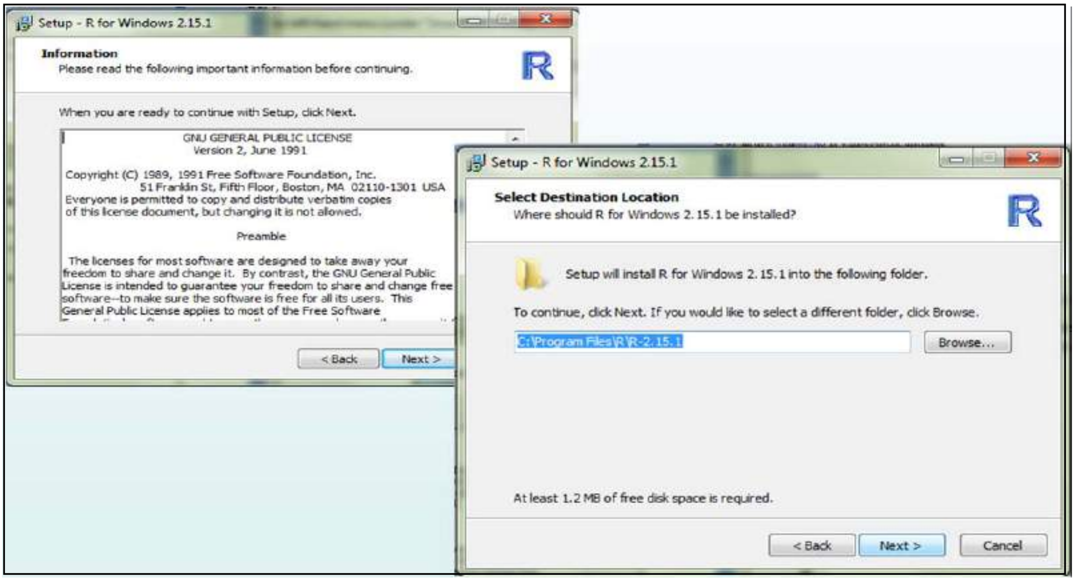
Getting Started

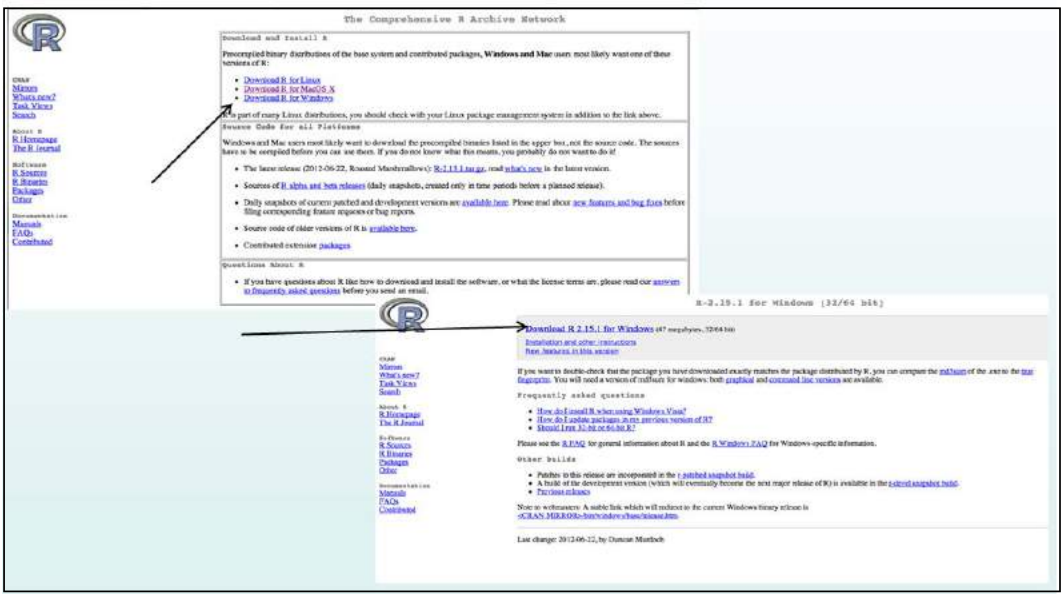
To install R on your MAC or PC the starting point has to behttp://www.r-project.org/.



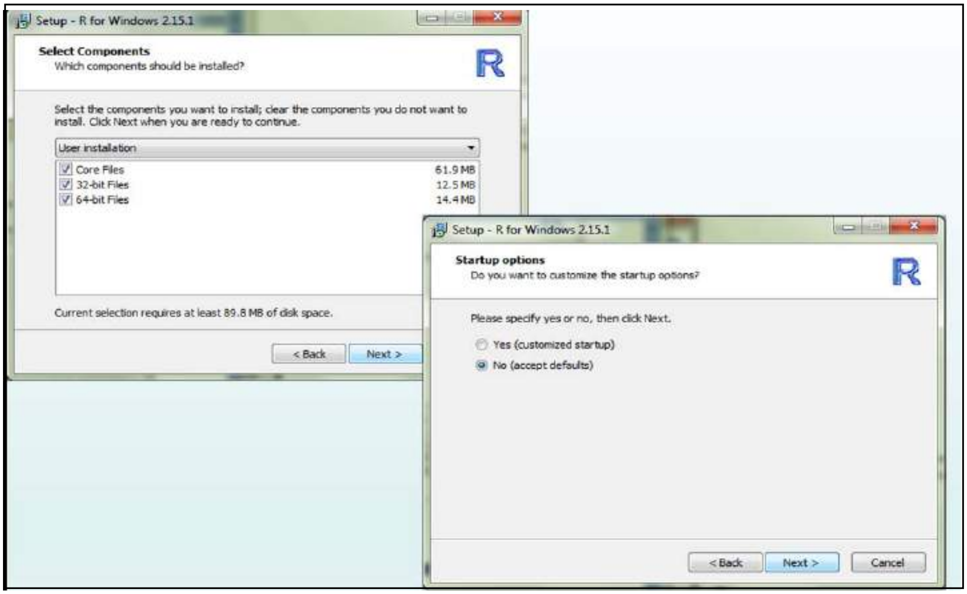
Depending on the choice of operating system the installer/ zip file with checksum may be downloaded and verified.

An effort to download R for Windows would have the following sequence of interactions with the portal, whose snapshots are given below:

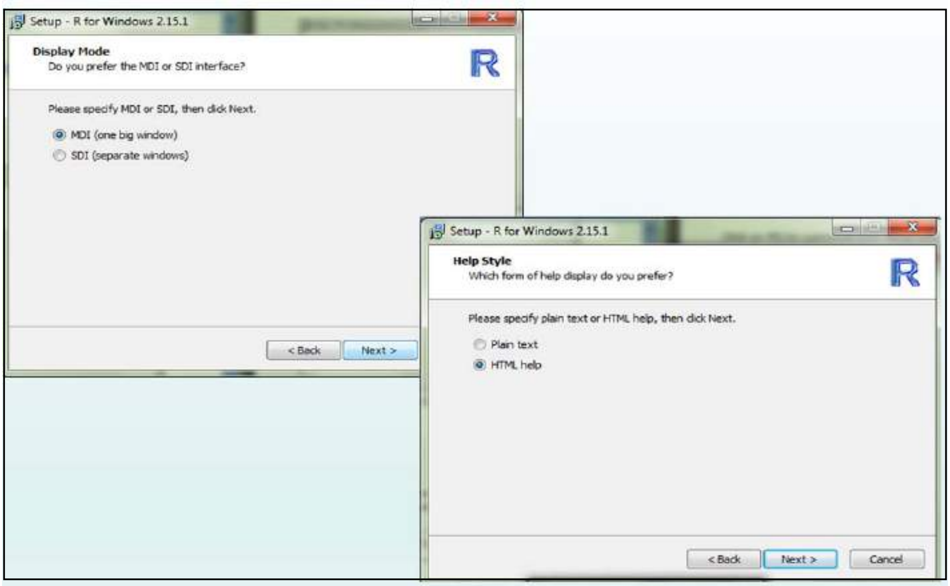

Setup - R for Windows 2.15.1
Information
Please read the following important information before continuing.
When you are ready to continue with Setup, click Next.
GNU GENERAL PUBLIC LICENSE
Version 2, June 1991
Copyright (C) 1989, 1991 Free Software Foundation, Inc.
51 Franklin St, Fifth Floor, Boston, MA 02110-1301 USA
Everyone is permitted to copy and distribute verbatim copies
of this license document, but changing it is not allowed.
Preamble
The licenses for most software are designed to take away your
freedom to share and change it. By contrast, the GNU General Public
License is intended to guarantee your freedom to share and change free
software--to make sure the software is free for all its users. This
General Public License applies to most of the Free Software
< Back
Next >
Setup - R for Windows 2.15.1
Select Destination Location
Where should R for Windows 2.15.1 be installed?
Setup will install R for Windows 2.15.1 into the following folder.
To continue, click Next. If you would like to select a different folder, click Browse.
C:\Program Files\R\R-2.15.1
Browse...
At least 1.2 MB of free disk space is required.
< Back
Next >
Cancel


The Comprehensive R Archive Network
Download R 2.15.1 for Windows

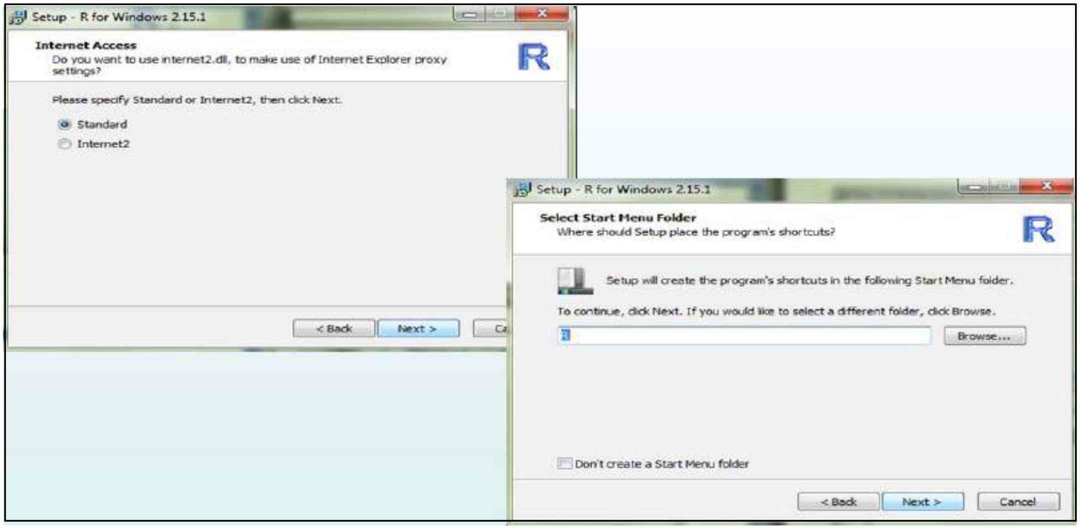
It's always a good idea to download all the files.

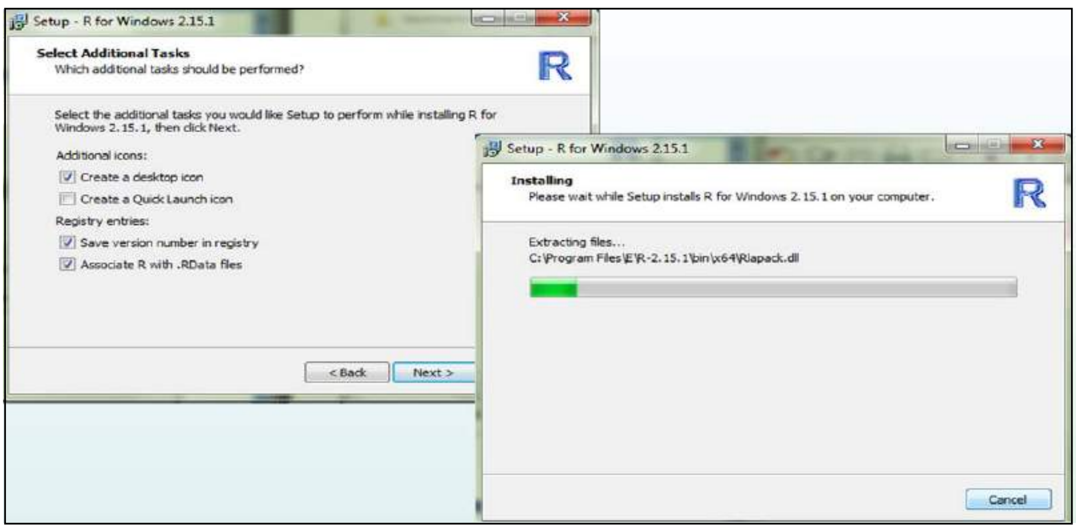


MDI is when the windows will be contained within one large window.



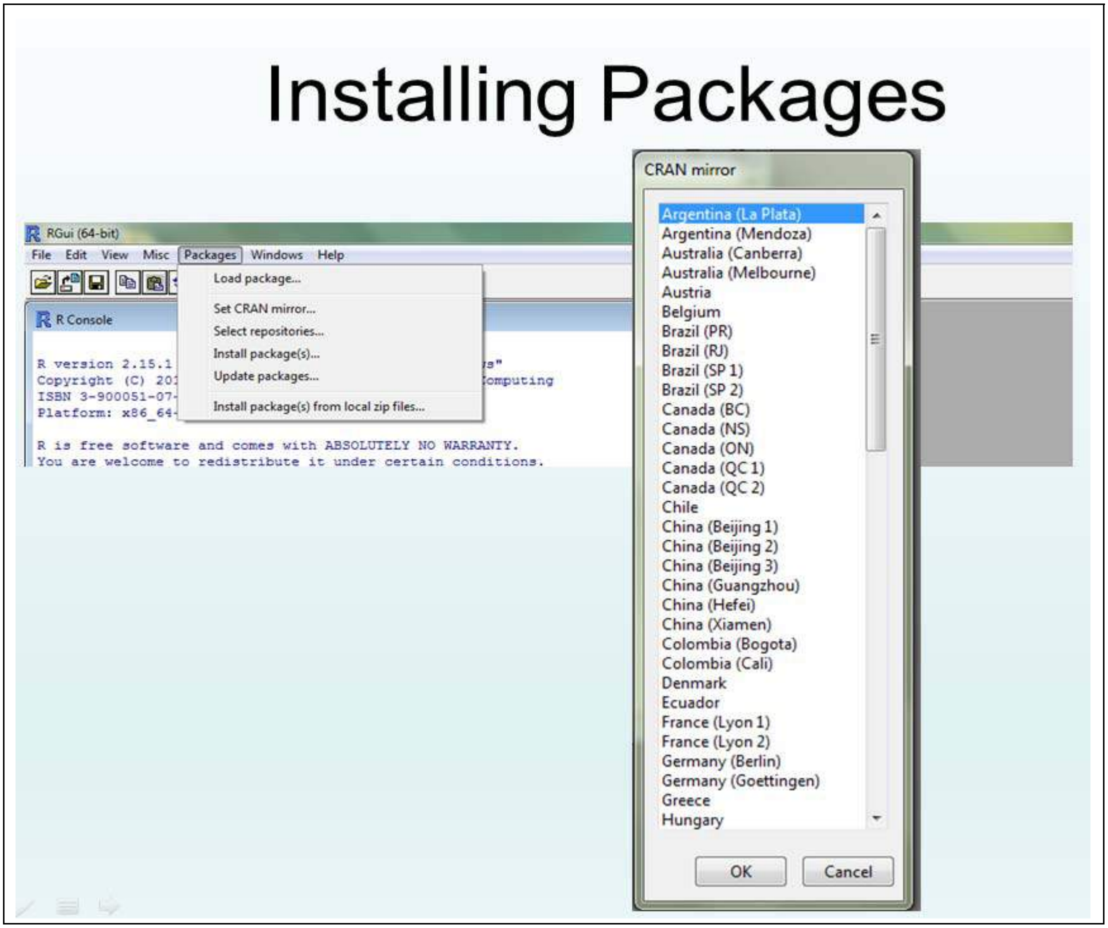
This is similar to how Excel is setup. SDI is a single document interface where every item will get its own window. This is similar to how SPSS is set up where it has separate data editor, viewer, and syntax windows. Once you choose which your prefer click next.Choosing either html or plain text and clicking is the next step.The installation may take awhile





To install packages on Windows, clicking on packages and install packages will be the next step.

Scrolling down to country nearest and choosing a "mirror" that is close is the next step

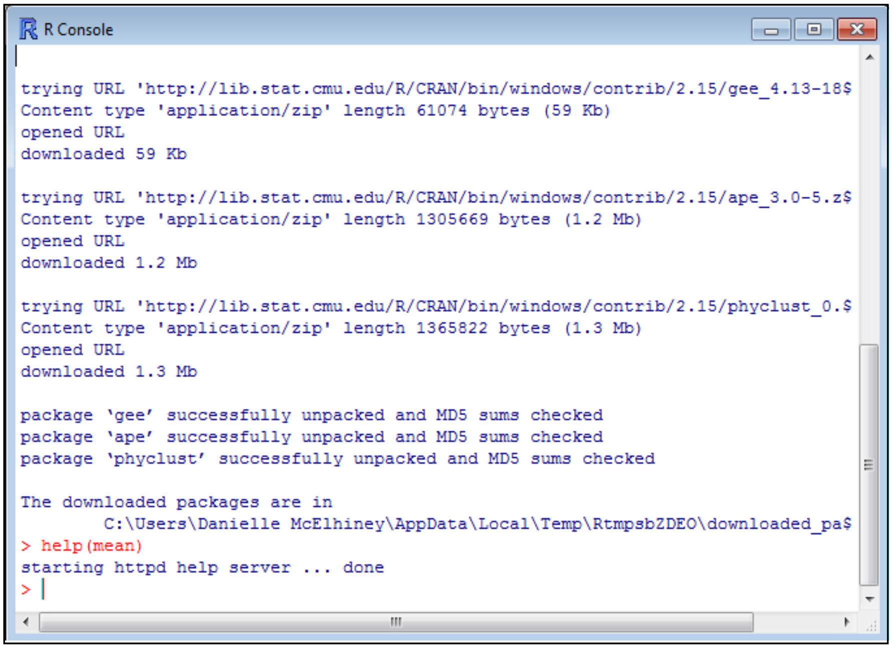


Scrolling down list until the requisite package is the next step, keeping in mind that R lists things in alphabetical order and by uppercase than lowercase. Once a package is clicked to load, R will install not only the package but all of the packages needed to run the package, including the dependencies.

To actually use the package, one has to go back to the package tab and click on load package.

Using Help Command

?solve translates on to giving details of help information about “solve” function whilst help.search or ?? allows searching for help in various ways

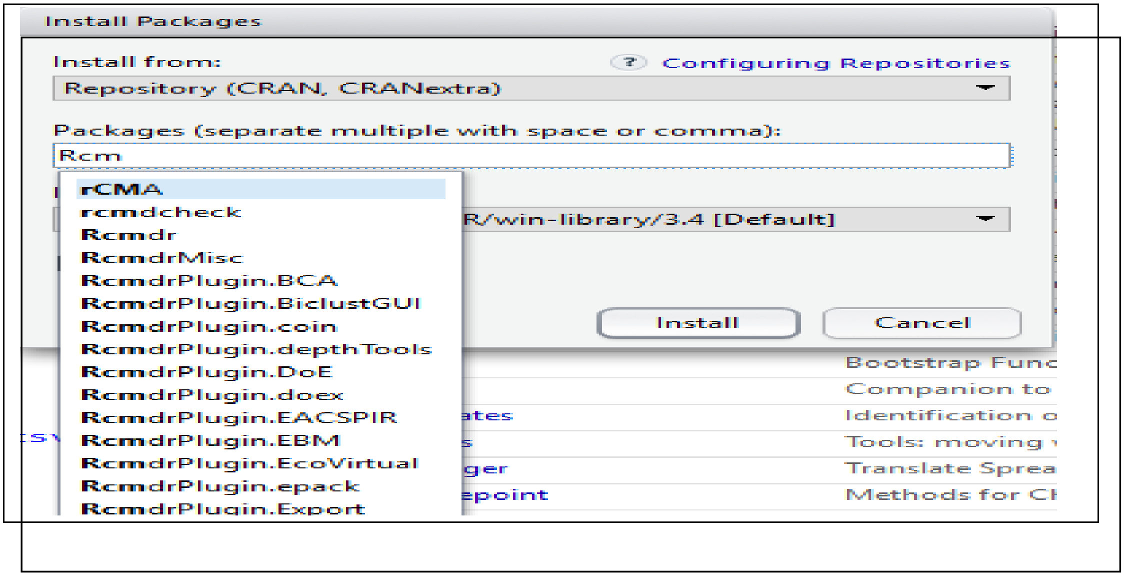


Rcommander – A graphical interaction “skin” for R

R provides a powerful and comprehensive system for analysing data and when used in conjunction with the R-commander (a graphical user interface, commonly known as Rcmdr) it also provides one that is easy and intuitive to use. Basically, R provides the engine that carries out the analyses and Rcmdr provides a convenient way for users to input commands. The Rcmdr program enables analysts to access a selection of commonly-used R commands using a simple interface that should be familiar to most computer users. It also serves the important role of helping users to implement R commands and develop their knowledge and expertise in using the command line --- an important skill for those wishing to exploit the full power of the program.(http://www.rcommander.com/)

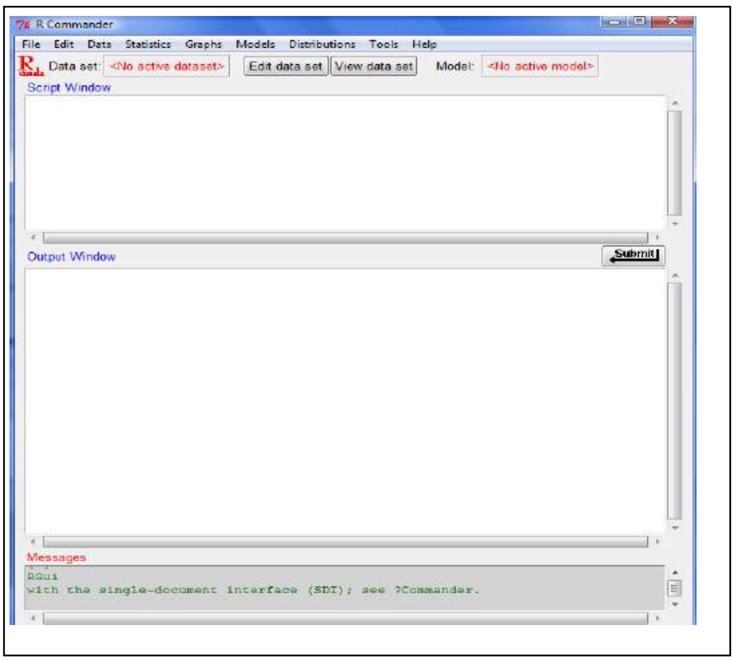
a) Loading R Commander

– Packages -> Install Packages -> Cran Mirror Selection -> Rcmdr



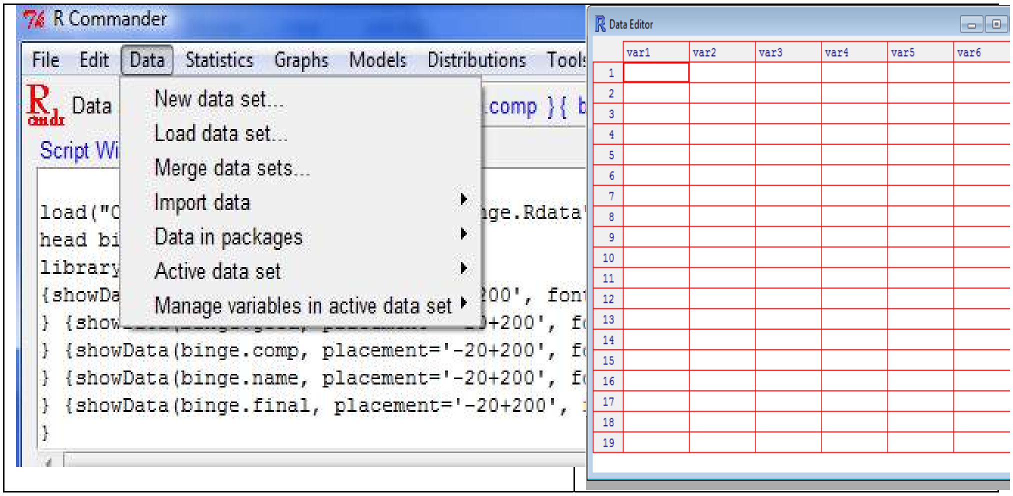
b) Opening R Commander

Open R -> Packages -> Load Packages -> Rcmdr



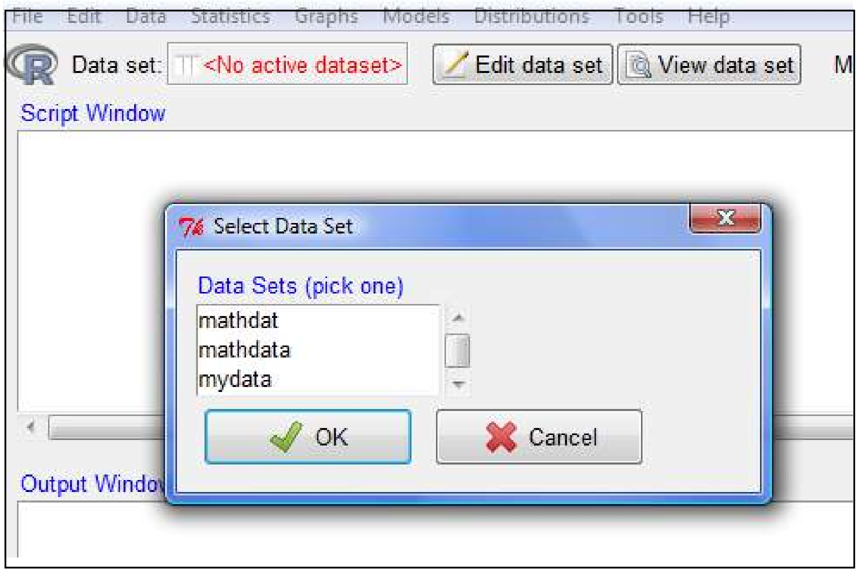
c) Loading Data

Data->Load data

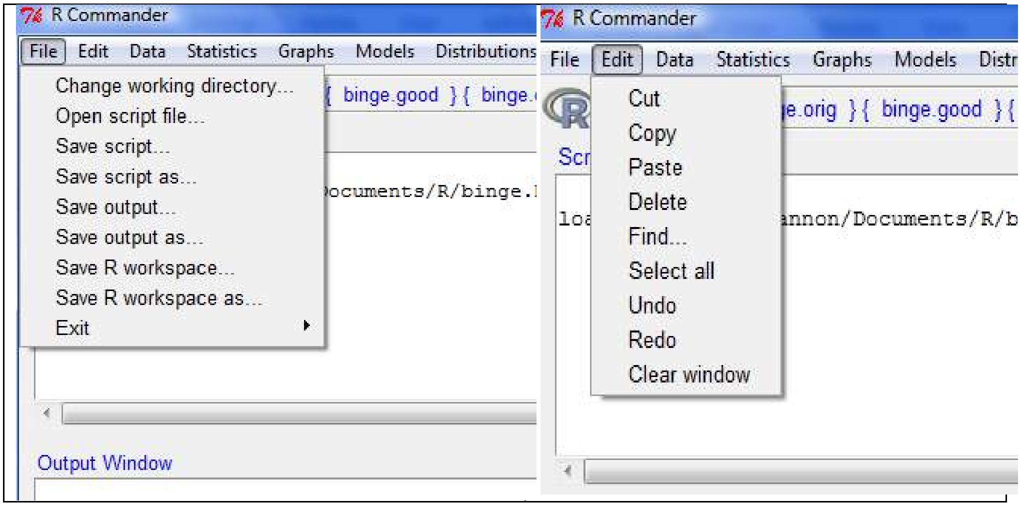


d) Active Data selection

Data ->Active data set -> Select active data set



e) Menu driven File edit options

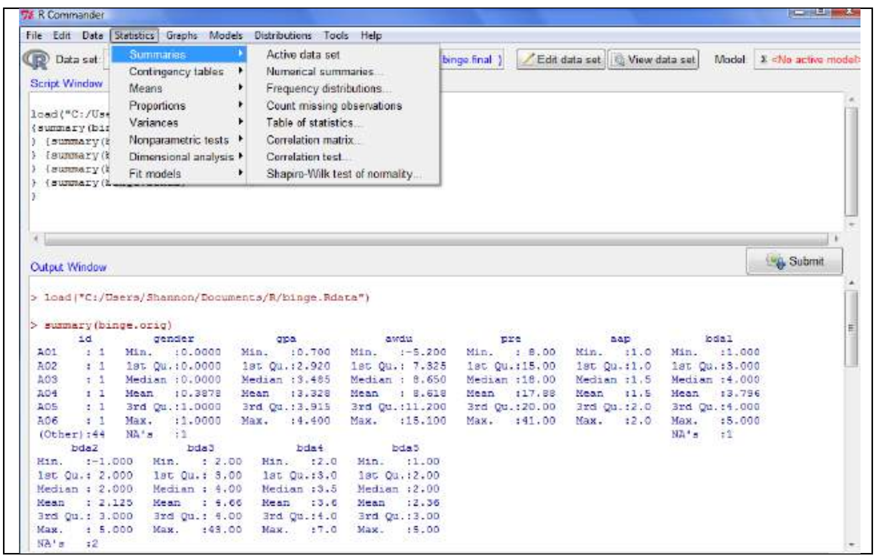


Script will save it as an R file .R and Output will save it as a text file. .txt

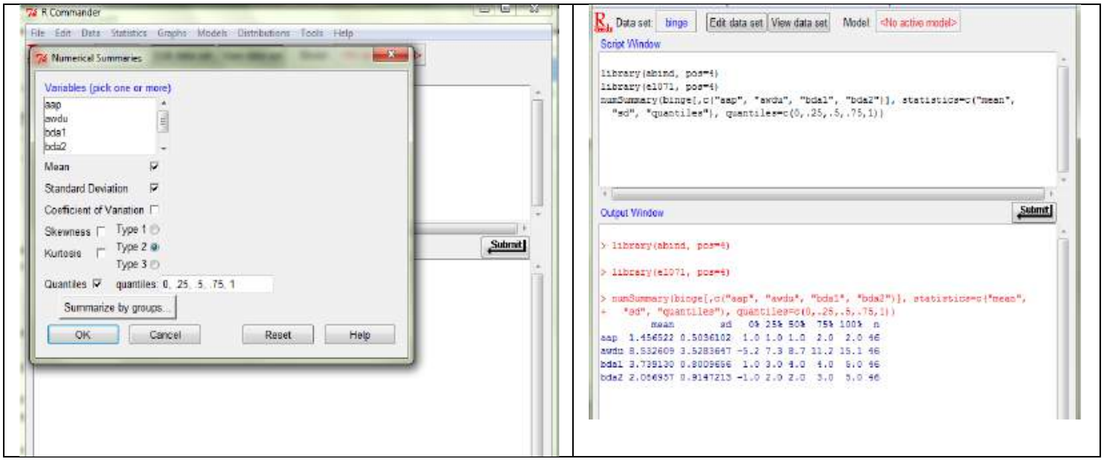
f) Summary of the data

Statistics -> Summaries

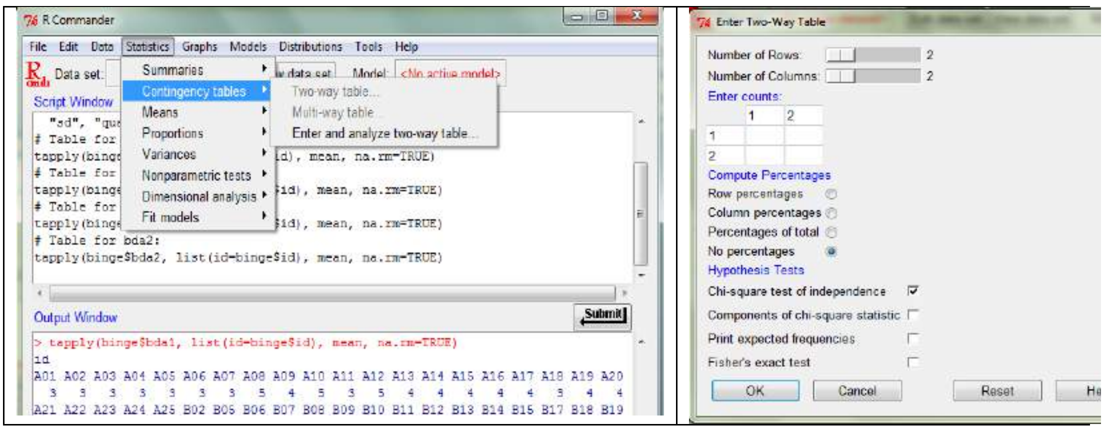
Numerical Summaries – can also provide mean, standard deviation, skewness, kurtosis etc..



g) Mean, Standard Deviation, Skewness, Kurtosis



h) Contingency Tables

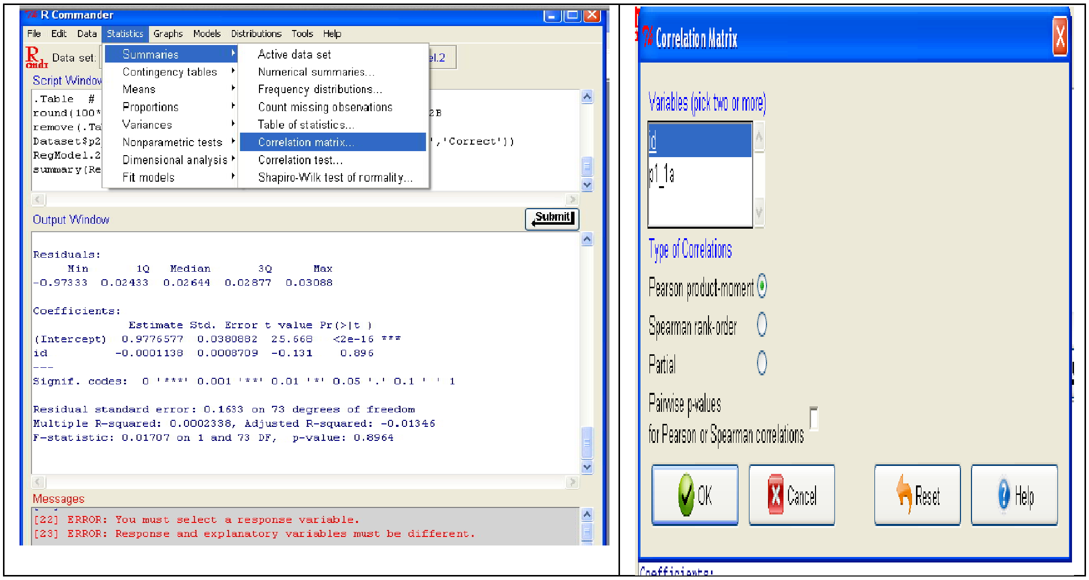


i) Correlations in R Commander

Correlation analysis can be done with R as follows.

Correlation is a bivariate analysis that measures the strengths of association between two variables and the direction of the relationship. In terms of the strength of relationship, the value of the correlation coefficient varies between +1 and -1. When the value of the correlation coefficient lies around ± 1, then it is said to be a perfect degree of association between the two variables. As the correlation coefficient value goes towards 0, the relationship between the two variables will be weaker. the direction of the relationship is simply the + (indicating a positive relationship between the variables) or - (indicating a negative relationship between the variables) sign of the correlation.

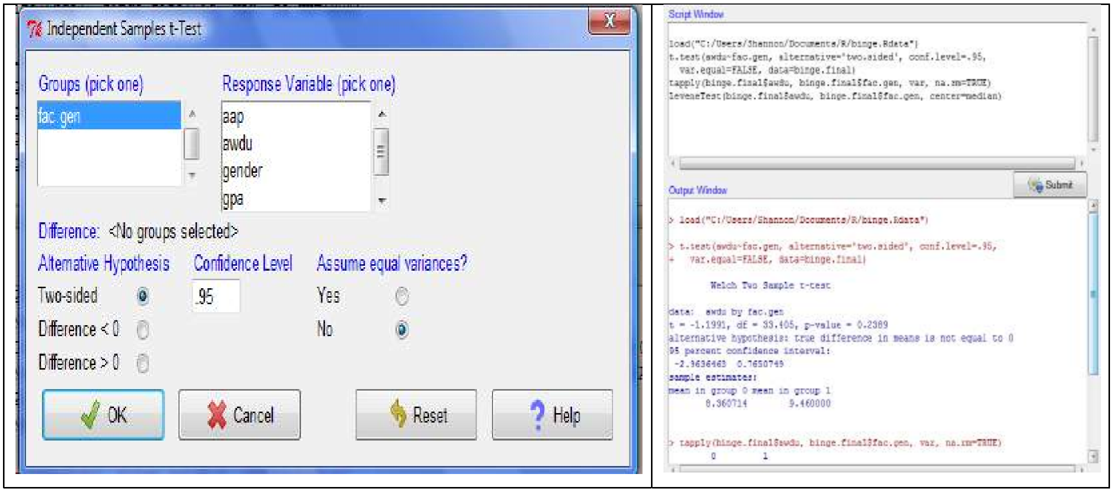
Usually, in statistics, we measure four types of correlations: Pearson Correlation,Kendall rank correlation, Spearman correlation, and the Point-Biserial correlation. The software below allows you to very easily conduct a correlation.



j) Independent T-Test

The independent t-test, also referred to as an independent-samples t-test, independent measures t-test or unpaired t-test, is used to determine whether the mean of a dependent variable (e.g., weight, anxiety level, salary, reaction time, etc.) is the same in two unrelated, independent groups (e.g., males vs females, employed vs unemployed, under 21 year olds vs those 21 years and older, etc.). Specifically, you use an independent t-test to determine whether the mean difference between two groups is statistically significantly different to zero.

Statistics->Independent T Test



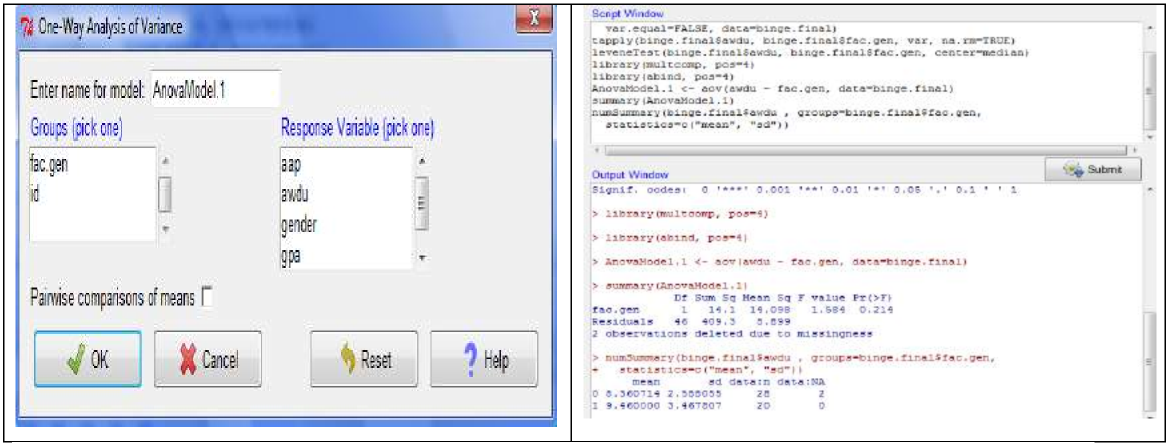
k) One Way ANOVA

ANOVA(Analysis of Variance) is a statistical technique that assesses potential differences in a scale-level dependent variable by a nominal-level variable having 2 or more categories. For example, an ANOVA can examine potential differences in IQ scores by Country (US vs. Canada vs. Italy vs. Spain). The ANOVA, developed by Ronald Fisher in 1918, extends the *t* and the *z* test which have the problem of only allowing the nominal level variable to have just two categories. This test is also called the Fisher analysis of variance.ANOVAs are used in three ways: one –way Anova, two-way ANOVA, and N-way Multivariate ANOVA.

One-Way ANOVA

A one-way ANOVA refers to the number of independent variables--not the number of categories in each variables. A one-way ANOVA has just one independent variable. For example, difference in IQ can be assessed by Country, and County can have 2, 20, or more different Countries in that variable. The software below allows you to easily conduct an ANOVA.

Statistics->One Way ANOVA



I) Factor Analysis

Factor analysis is a technique that is used to reduce a large number of variables into fewer numbers of factors. This technique extracts maximum common variance from all variables and puts them into a common score. As an index of all variables, we can use this score for further analysis. Factor analysis is part of general linear model(GLM) and this method also assumes several assumptions: there is linear relationship, there is no multicollinearity, it includes relevant variables into analysis, and there is true correlation between variables and factors. Several methods are available, but principle component analysis is used most commonly.

Types of factoring:

There are different types of methods used to extract the factor from the data set:

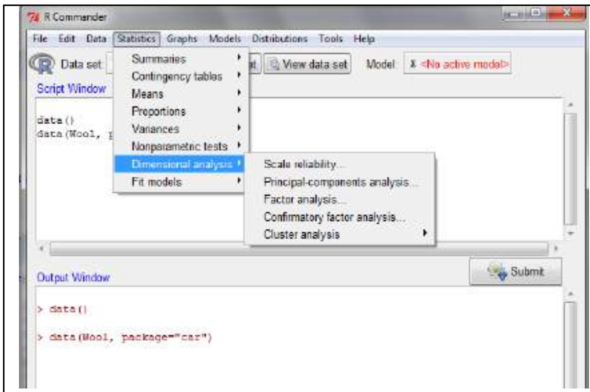
1.**Principal component analysis**: This is the most common method used by researchers. PCA starts extracting the maximum variance and puts them into the first factor. After that, it removes that variance explained by the first factors and then starts extracting maximum variance for the second factor. This process goes to the last factor.

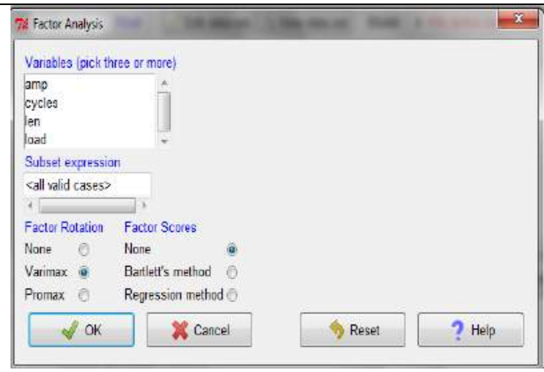
2. **Common factor analysis:** The second most preferred method by researchers, it extracts the common variance and puts them into factors. This method does not include the unique variance of all variables. This method is used in SEM.

3. **Image factoring:** This method is based on correlation matrix. OLS Regression method is used to predict the factor in image factoring.

4. **Maximum likelihood method:** This method also works on correlation metric but it uses maximum likelihood method to factor.

5. **Other methods of factor analysis:** Alfa factoring outweighs least squares. Weight square is another regression based method which is used for factoring.



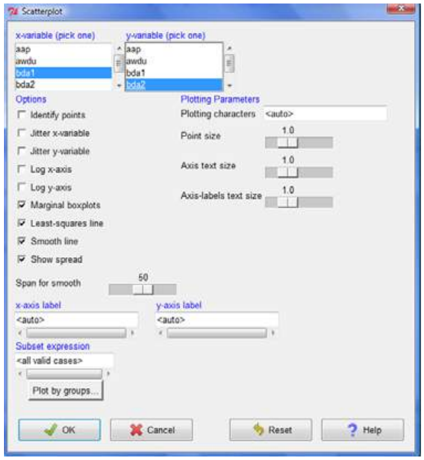


Result are shown as follows

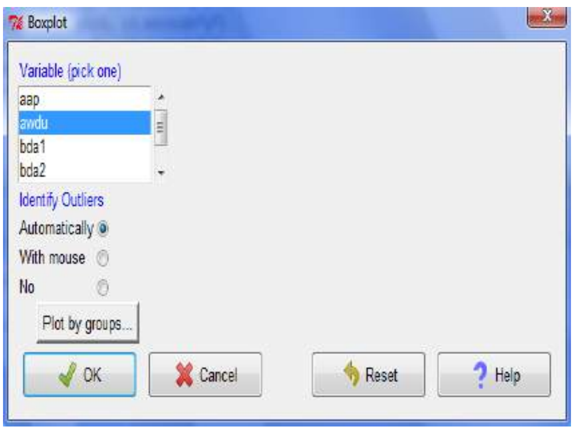
```
Script Window
.FA <- factanal(~aap+awdu+bda1, factors=1, rotation="varimax",
  scores="none", data=binge.orig)
.FA
remove(.FA)
library(sem, pos=4)

> .FA <- factanal(~aap+awdu+bda1, factors=1, rotation="varimax",
+   scores="none", data=binge.orig)

> .FA

Call:
factanal(x = ~aap + awdu + bda1, factors = 1, data = binge.orig,     scores = "none", rotation = "varimax")

Uniquenesses:
  aap  awdu  bda1
0.849 0.324 0.596

Loadings:
     Factor1
aap  0.388
awdu 0.822
bda1 0.636

               Factor1
SS loadings      1.231
Proportion Var   0.410

The degrees of freedom for the model is 0 and the fit was 0

> remove(.FA)

> library(sem, pos=4)
```

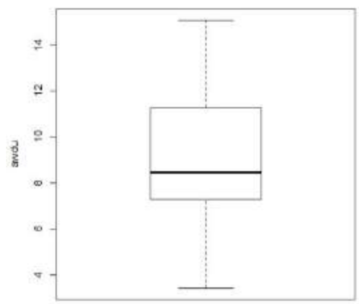
J) Graphs

Graphs->Scatter plot



Graphs->Box plot





Chapter4:-R Basics

R is object base

Types of objects (scalar, vector, matrices and arrays Assignment of objects)

Building a data frame

Operation Symbols

Symbol	Meaning
+	Addition
-	Subtraction
*	Multiplication
/	Division
%%	**Modulo (estimates remainder in a division)**
^	Exponential

R as a Calculator

```
1550+2000

## [1] 3550
```

or various calculations in the same row

```
2+3; 5*9; 6-6

## [1] 5

## [1] 45

## [1] 0
```

AsMathematics

```
1+1

## [1] 2

2+2*7

## [1] 16

(2+2)*7

## [1] 28
```

AsVariables

```
x<-2
x
```

```
## [1] 2

y<-3
y

## [1] 3

5->z

(x*y)+z

## [1] 11
```

Numbers in R: NAN and NA

NAN (not a number) NA (missing value) -Basic handling of missing values

Missing values are noise to statistical estimations. We are going to learn a basic command for handling missing values.

```
x<-c(1,2,3,4,5,6,NA)
mean(x)

## [1] NA

mean(x,na.rm=TRUE)

## [1] 3.5
```

Objects in R

Objects in R obtain values by assignment.
This is achieved by the gets arrow, <-, and not the equal sign, =.
Objects can be of different kinds.

Built in Functions

R has many built in functions that compute different statistical procedures.

Functions in R are followed by ( ). Inside the parenthesis we write the object (vector, matrix, array, dataframe) to which we want to apply the function.

```
# Create a sequence of numbers from 32 to 44.
print(seq(32,44))

##  [1] 32 33 34 35 36 37 38 39 40 41 42 43 44

# Find mean of numbers from 25 to 82.
print(mean(25:82))
```

```
## [1] 53.5
# Find sum of numbers frm 41 to 68.

print(sum(41:68))
## [1] 1526
```

Vectors

Vectors are variables with one or more values of the same type. A variable with a single value is known as scalar. In R a scalar is a vector of length 1. There are at least three ways to create vectors in R: (a) sequence, (b) concatenation function, and (c) scan function.

Create two vectors of different lengths.

```
vector1 <-c(5,9,3)
vector2 <-c(10,11,12,13,14,15)
vector1
## [1] 5 9 3
vector2
## [1] 10 11 12 13 14 15
```

Arrays

Arrays are numeric objects with dimension attributes. The difference between a matrix and an array is that arrays have more than two dimensions.

```
# Take the above  vectors as input to the array.
result <-array(c(vector1,vector2),dim =c(3,3,2))
print(result)
## , , 1
##
##      [,1] [,2] [,3]
## [1,]    5   10   13
## [2,]    9   11   14
## [3,]    3   12   15
##
## , , 2
##
##      [,1] [,2] [,3]
## [1,]    5   10   13
## [2,]    9   11   14
## [3,]    3   12   15
```

Matrices

A matrix is a two dimensional array. The command colnames

```
# Elements are arranged sequentially by row.
M <-matrix(c(3:14), nrow =4, byrow =TRUE)
print(M)

##      [,1] [,2] [,3]
## [1,]    3    4    5
## [2,]    6    7    8
## [3,]    9   10   11
## [4,]   12   13   14
```

String Characters

In R, string variables are defined by double quotation marks.

```
letters<-c("a","b","c")
letters

## [1] "a" "b" "c"
```

Subscripts and Indices

Select only one or some of the elements in a vector, a matrix or an array. We can do this by using subscripts in square brackets [ ].
In matrices or dataframes the first subscript refers to the row and the second to the column.

Dataframe

Researchers work mostly with dataframes . With previous knowledge you can built dataframes in R Also, import dataframes into R.

```
# Create the data frame.
emp.data <-data.frame(
emp_id =c (1:5),
emp_name =c("Rick","Dan","Michelle","Ryan","Gary"),
salary =c(623.3,515.2,611.0,729.0,843.25),

start_date =as.Date(c("2012-01-01", "2013-09-23", "2014-11-15", "2014-05-11",
"2015-03-27")),
stringsAsFactors =FALSE
)
```

```
# Print the data frame.
print(emp.data)

##   emp_id emp_name salary start_date
## 1      1     Rick 623.30 2012-01-01
## 2      2      Dan 515.20 2013-09-23
## 3      3 Michelle 611.00 2014-11-15
## 4      4     Ryan 729.00 2014-05-11
## 5      5     Gary 843.25 2015-03-27
```

A journey wading through the amazing summarizing and analytical capabilities of R- a case study.

Let the presumed data pertain to landings and standardized effort of a maritime state estimated by ICAR-CMFRIduring the interregnum 1997 to 2013

Calling file in R

```
klm<-read.csv("C:/Users/cmfri/Desktop/cpue_spcode_kldata.csv",header=TRUE)
```

To know header portion of the data set

```
head(klm)

##   year month species    raised   nomeff   stdcpue
## 1 1997     1      40  20595.35 122.0811  3.634042
## 2 1997     2      40  24201.10 114.3719  4.532246
## 3 1997     3      40  23497.64 255.0315  3.926130
## 4 1997     4      40  50176.75 154.7663  6.762821
## 5 1997     5      40 137626.24 314.6413 13.805531
## 6 1997     6      40  38149.38 649.1328 16.071358
```

To check the last few rows of the dataset

```
tail(klm)

##        year month species raised   nomeff  stdcpue
## 245815 2013     7    4580      0 0.000000 0.000000
## 245816 2013     8    4580   1674 2.059835 1.667304
## 245817 2013     9    4580      0 0.000000 0.000000
## 245818 2013    10    4580      0 0.000000 0.000000
## 245819 2013    11    4580      0 0.000000 0.000000
## 245820 2013    12    4580      0 0.000000 0.000000
```

to know the observations in the data

```
length(klm)
```

```
## [1] 6
```

to know the structure of the dataframe

```
str(klm)
## 'data.frame':    245820 obs. of  6 variables:
##  $ year   : int  1997 1997 1997 1997 1997 1997 1997 1997 1997 1997 ...
##  $ month  : int  1 2 3 4 5 6 7 8 9 10 ...
##  $ species: int  40 40 40 40 40 40 40 40 40 40 ...
##  $ raised : num  20595 24201 23498 50177 137626 ...
##  $ nomeff : num  122 114 255 155 315 ...
##  $ stdcpue: num  3.63 4.53 3.93 6.76 13.81 ...
```

Descriptive statistics analysis

```
summary(klm)
##       year          month          species         raised
##  Min.   :1997   Min.   : 1.00   Min.   :   0   Min.   :       0
##  1st Qu.:2001   1st Qu.: 3.75   1st Qu.: 867   1st Qu.:       0
##  Median :2005   Median : 6.50   Median :1513   Median :       0
##  Mean   :2005   Mean   : 6.50   Mean   :2201   Mean   :   42699
##  3rd Qu.:2009   3rd Qu.: 9.25   3rd Qu.:4016   3rd Qu.:       0
##  Max.   :2013   Max.   :12.00   Max.   :9999   Max.   :71536031
##                                                NA's   :30
##      nomeff            stdcpue
##  Min.   :     0.0   Min.   :   0.000
##  1st Qu.:     0.0   1st Qu.:   0.000
##  Median :     0.0   Median :   0.000
##  Mean   :   154.2   Mean   :   7.112
##  3rd Qu.:     0.0   3rd Qu.:   0.000
##  Max.   :119100.1   Max.   :5600.000
##
```

If further enhanced list of summary statistics information about the data like third and fourth order moments, then the describe function of psych or summary function would come in handy.

```
library(psych)
describe(klm[,3:6])

##         vars      n     mean        sd median trimmed     mad min
## species    1 245820  2201.15   1951.83   1513 1941.16 1257.24   0
## raised     2 245790 42699.02 719150.48      0   62.52    0.00   0
## nomeff     3 245820   154.25   1543.66      0    0.16    0.00   0
## stdcpue    4 245820     7.11     52.38      0    0.11    0.00   0
##                max      range  skew kurtosis      se
## species     9999.0     9999.0  1.40     1.91    3.94
## raised  71536030.7 71536030.7 44.70  2681.18 1450.57
```

```
## nomeff    119100.1   119100.1 22.83   770.70    3.11
## stdcpue     5600.0     5600.0 21.65   971.06    0.11
```

If one wants to study monthly catch grouped information so that an idea about issues like which month (used as a group) would have etched up maximum landings/ catch, then simple literally rooted commands like describeBy (psych) or aggregate would come in handy.

```
library(psych)
describeBy(klm$raised,klm$month)

##
##  Descriptive statistics by group
## group: 1
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20485 41379.48 784622.6      0  146.65   0   0 51193526 51193526
##     skew kurtosis      se
## X1 46.55  2497.42 5482.05
## --------------------------------------------------------
## group: 2
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20485 32904.06 535506.3      0  113.45   0   0 45468199 45468199
##     skew kurtosis      se
## X1 49.62  3259.68 3741.51
## --------------------------------------------------------
## group: 3
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20485 39087.37 569052.1      0  162.51   0   0 31762665 31762665
##    skew kurtosis      se
## X1 38.4  1796.15 3975.89
## --------------------------------------------------------
## group: 4
##    vars     n     mean     sd median trimmed mad min      max    range
## X1    1 20471 33795.18 477389      0   64.13   0   0 31931384 31931384
##     skew kurtosis      se
## X1 42.59  2353.01 3336.59
## --------------------------------------------------------
## group: 5
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20485 37566.67 469275.5      0    96.2   0   0 30492626 30492626
##     skew kurtosis      se
## X1 33.18  1478.99 3278.76
## --------------------------------------------------------
## group: 6
```

```
##    vars     n    mean       sd median trimmed mad min      max    range
## X1    1 20485 34552.2 655525.6      0   30.67   0   0 65432961 65432961
##     skew kurtosis      se
## X1 61.23  5239.89 4580.07
## --------------------------------------------------------
## group: 7
##    vars     n    mean       sd median trimmed mad min      max    range
## X1    1 20485 32621.2 643003.1      0       0   0   0 49428947 49428947
##     skew kurtosis      se
## X1 42.19  2362.03 4492.57
## --------------------------------------------------------
## group: 8
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20484 57397.86 713381.8      0   31.03   0   0 38795185 38795185
##     skew kurtosis      se
## X1 26.21   920.16 4984.42
## --------------------------------------------------------
## group: 9
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20485 55833.65 901880.9      0    34.3   0   0 71536031 71536031
##     skew kurtosis      se
## X1 41.11  2415.63 6301.32
## --------------------------------------------------------
## group: 10
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20484 57071.88 915432.9      0   89.05   0   0 55973676 55973676
##     skew kurtosis      se
## X1 34.05  1453.38 6396.16
## --------------------------------------------------------
## group: 11
##    vars     n     mean     sd median trimmed mad min      max    range
## X1    1 20485 51210.52 915220      0  133.56   0   0 49127745 49127745
##     skew kurtosis      se
## X1 36.33  1488.92 6394.51
## --------------------------------------------------------
## group: 12
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20471 38960.92 830555.4      0  134.37   0   0 66844967 66844967
##    skew kurtosis      se
## X1   56  3639.25 5804.96
```

Selecting subsets of data:

```
#to know the whole species entries
t<-klm$species
length(t)

## [1] 245820

# to know the june species entries
d<-klm$species[klm$month=="6"]
length(d)

## [1] 20485
```

to exclude some data

```
#exclude june catch and know the entries
e<-klm$species[klm$month!="6"]
length(e)

## [1] 225335
```

correlation of the data

```
# correlation between catch and effort for the whole period
attach(klm)
cor.test(raised,nomeff,method="pearson")

##
##  Pearson's product-moment correlation
##
## data:  raised and nomeff
## t = 434.94, df = 245790, p-value < 2.2e-16
## alternative hypothesis: true correlation is not equal to 0
## 95 percent confidence interval:
##  0.6572472 0.6617152
## sample estimates:
##       cor
## 0.659487
```

##multiple correlation

```
##Here we select the oilsardine catch.
The oil sardine species code as 362
##we pick all the years monthly  oil sardine
sp362<-klm[(klm$species=="362"),]
cordat<-sp362[,4:6]
cor(cordat)
```

```
        raised     nomeff    stdcpue
raised  1.0000000 0.45713639 0.61135090
nomeff  0.4571364 1.00000000 0.06860281
stdcpue 0.6113509 0.06860281 1.00000000
```

Linear regression & ANOVA

```
fit <-lm(raised~year +month +nomeff, data=sp362)

# show results
summary(fit)

##
## Call:
## lm(formula = raised ~ year + month + nomeff, data = sp362)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -24406856  -5945766   -838374   4725596  40857882
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept) -2.148e+09  2.787e+08  -7.706 5.93e-13 ***
## year         1.072e+06  1.389e+05   7.716 5.59e-13 ***
## month        7.997e+05  1.969e+05   4.062 6.97e-05 ***
## nomeff       3.997e+02  4.493e+01   8.897 3.44e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9689000 on 200 degrees of freedom
## Multiple R-squared:  0.4275, Adjusted R-squared:  0.4189
## F-statistic: 49.78 on 3 and 200 DF,  p-value: < 2.2e-16

# model coefficients
coefficients(fit)

##   (Intercept)          year         month        nomeff
## -2.147604e+09  1.072090e+06  7.997178e+05  3.997276e+02

# CIs for model parameters
confint(fit, level=0.95)

##                     2.5 %        97.5 %
## (Intercept) -2.697162e+09 -1.598046e+09
## year         7.980987e+05  1.346082e+06
## month        4.115344e+05  1.187901e+06
## nomeff       3.111348e+02  4.883205e+02
```

```
# predicted values
fitted(fit)

##       10609       10610       10611       10612       10613       10614
## -3789651.96   -75345.54 15111313.36 13412874.31 17168949.26   120681.70
##       10615       10616       10617       10618       10619       10620
## 11475956.42  2176177.37  4491241.24 20281254.70 10248865.43  6278101.08
##       10621       10622       10623       10624       10625       10626
## -1848628.97  -945019.58 10648970.16 18599757.89  1915100.95  4945529.10
##       10627       10628       10629       10630       10631       10632
##  1844457.32  4524979.63  8480021.57 27270345.64 26410785.24  7449598.25
##       10633       10634       10635       10636       10637       10638
##  8195286.59 18056830.84 12504031.29  4797286.88   690139.61  7333241.94
##       10639       10640       10641       10642       10643       10644
##  9086615.20 12777192.22 16114211.77 21825496.12 23957847.88 30125417.82
##       10645       10646       10647       10648       10649       10650
## 16794955.21  8159428.15 18423291.70 38539644.49 22526843.37 15428828.71
##       10651       10652       10653       10654       10655       10656
## 19942372.43  8463199.11 16820433.97 16852255.88 19772511.73 16832240.83
##       10657       10658       10659       10660       10661       10662
##  6812947.52  2187489.33  3280344.12 24388104.43 18000977.41 15107404.98
##       10663       10664       10665       10666       10667       10668
## 11071325.90  8804492.99 11659447.99 15882452.30 13614255.15 14360781.30
##       10669       10670       10671       10672       10673       10674
##  4963345.25  3874425.71  8638896.83 15820079.63  9947652.94 10608928.30
##       10675       10676       10677       10678       10679       10680
## 11831223.68 10715678.08 18370843.69 18033007.59 24787443.71 20792659.27
##       10681       10682       10683       10684       10685       10686
## 10734553.89 14786524.50 23586068.72 15174415.81 14696669.45 21641645.35
##       10687       10688       10689       10690       10691       10692
## 16169395.71 12954237.15 18327299.72 26652093.45 23775360.33 20813243.93
##       10693       10694       10695       10696       10697       10698
## 21399224.55 14748593.10 17040545.01 16656182.65 24538822.27 12033993.05
##       10699       10700       10701       10702       10703       10704
## 19365173.86 13378906.14 16135355.04 20944717.11 22152925.25 23350707.08
##       10705       10706       10707       10708       10709       10710
## 12137727.49 12362516.34 15647882.15 17728272.88 25610912.49 11483182.33
##       10711       10712       10713       10714       10715       10716
## 16228410.19 14066458.06 21735642.49 16489766.28 22863440.68 25217568.20
##       10717       10718       10719       10720       10721       10722
## 14835803.84 16495146.39 22063158.91 16594990.87 22768308.44 15220954.75
##       10723       10724       10725       10726       10727       10728
## 17405975.76 16749989.07 21071396.44 26135139.19 34594122.49 25311911.45
##       10729       10730       10731       10732       10733       10734
```

```
## 16213850.04 18560659.25 20910497.95 17148441.29 23064011.08 11548843.47
##       10735       10736       10737       10738       10739       10740
## 19107866.87 25146512.87 23611984.56 42060769.69 32661334.03 33443082.46
##       10741       10742       10743       10744       10745       10746
## 26843089.98 15219653.93 27987085.90 25288610.68 27765987.37 14731658.59
##       10747       10748       10749       10750       10751       10752
## 17559758.01 21155741.90 25500961.51 24405053.32 39326020.64 25050900.94
##       10753       10754       10755       10756       10757       10758
## 19830935.26 14206507.84 14964046.91 16055186.14 17867665.14 13526068.97
##       10759       10760       10761       10762       10763       10764
## 17068671.46 25656764.37 20949202.17 25406915.94 27419616.94 18691846.63
##       10765       10766       10767       10768       10769       10770
## 19797610.39 12647096.61 14383437.39 14983527.60 19213873.26 20770627.04
##       10771       10772       10773       10774       10775       10776
## 16985410.38 15938248.25 21060373.50 34082753.83 40548912.21 30156164.56
##       10777       10778       10779       10780       10781       10782
## 29631248.55 19454957.10 19789660.52 20025809.52 21633117.75 17439149.02
##       10783       10784       10785       10786       10787       10788
## 20005697.35 24040773.06 21080888.19 26283510.76 26352521.83 31706623.55
##       10789       10790       10791       10792       10793       10794
## 24439494.21 27241932.83 22930440.38 23641969.90 27794243.34 19988084.70
##       10795       10796       10797       10798       10799       10800
## 21491465.81 25726079.40 30678149.02 31537346.13 36756187.66 34532571.26
##       10801       10802       10803       10804       10805       10806
## 26224188.37 24391818.16 20675677.20 23963221.50 20784503.22 18502261.85
##       10807       10808       10809       10810       10811       10812
## 19268540.54 18341131.67 23102919.88 26747332.20 27817053.16 27904369.27
```

```r
# residuals
residuals(fit)
```

```
##        10609        10610        10611        10612        10613
##   5952459.84  12255563.09  -3371411.14  -4445741.27  -8889076.47
##        10614        10615        10616        10617        10618
##    986134.71  -5748266.48   -336390.21   2807133.26   1645172.74
##        10619        10620        10621        10622        10623
##  -3629105.70  -4577842.81   3072907.21   3243308.73  -5672890.07
##        10624        10625        10626        10627        10628
## -15696727.40    289232.12   2042122.32   1117366.99   2926082.40
##        10629        10630        10631        10632        10633
##   5230228.43 -20382271.56  -5264124.44  -5075967.51   1491577.71
##        10634        10635        10636        10637        10638
##  -9837151.49  -6712232.19   -764792.30   -437886.38   2231690.27
##        10639        10640        10641        10642        10643
```

```
## -1443831.23 -2440345.04 14926587.99 -6794617.92  2635516.43
##       10644       10645       10646       10647       10648
## -17311907.92 -5709093.26  4952910.28 -6048902.56 -6642668.40
##       10649       10650       10651       10652       10653
## -9406029.73 11491464.13 29486574.30  2963737.40  3482526.36
##       10654       10655       10656       10657       10658
##   764926.90  5721591.58 -8014761.85  -334238.52  5160023.79
##       10659       10660       10661       10662       10663
##  3802703.26 -10108379.25 -2107670.27 -3238790.51  6520269.00
##       10664       10665       10666       10667       10668
##  6117951.47  3707721.08  4118584.97   744008.66 -2535146.08
##       10669       10670       10671       10672       10673
##  5587891.61   247621.47 -2882708.00   800991.54  -911955.00
##       10674       10675       10676       10677       10678
##  -655352.63  5390336.84  4162722.58 18880213.59 11462880.43
##       10679       10680       10681       10682       10683
## 24340300.82 -5444209.40  6331098.26  2063500.35  8101582.03
##       10684       10685       10686       10687       10688
## -1076762.56 -1485004.62  1129099.86 -3023048.68  1233356.51
##       10689       10690       10691       10692       10693
##  4825705.45 29321582.28 12866219.97 -8588656.22 -3474768.56
##       10694       10695       10696       10697       10698
## -3342387.93 -1561293.84 -7985942.92 -13492569.39 -6264977.56
##       10699       10700       10701       10702       10703
##  7369859.10 -2554169.18  8312707.30 10394757.30  7502086.94
##       10704       10705       10706       10707       10708
##  8077227.47 -2014108.57   -95116.07 16114782.51 -9058033.14
##       10709       10710       10711       10712       10713
## -14564659.61 -2664396.26 -4418287.27 -1765118.25  8881219.38
##       10714       10715       10716       10717       10718
## -5440633.74  4224442.28 19111300.40  6924490.79  3747711.16
##       10719       10720       10721       10722       10723
## -9990097.04 -6651295.63 -5039648.82    -6308.56  2483670.82
##       10724       10725       10726       10727       10728
## -5713224.42 -2679256.50  6910723.16 -3562131.49 -9394292.44
##       10729       10730       10731       10732       10733
## 12292491.48  4692225.99 -9441901.08 -2161564.02 -5911665.98
##       10734       10735       10736       10737       10738
## -4985852.10  7434834.02 -6325219.34 -9242339.89  2630232.74
##       10739       10740       10741       10742       10743
##  2220095.43 -24406855.54 19131720.29 -3262974.07 -10889120.28
##       10744       10745       10746       10747       10748
## -10903121.99 -17763414.88 -6822302.77 -6103458.03  4173221.59
##       10749       10750       10751       10752       10753
```

```
##   1798780.05  -2210622.30 -11946665.58 -13681047.30  -2168599.28
##        10754        10755        10756        10757        10758
##  -6048066.31  -2150199.30 -13368549.99 -13612130.58  -5616599.80
##        10759        10760        10761        10762        10763
##  -8493152.82  13138420.47   5906816.91  -5632275.23 -14413805.47
##        10764        10765        10766        10767        10768
## -11756970.84  13432590.65  -4590320.74  11802983.94 -11719864.10
##        10769        10770        10771        10772        10773
##  -5872175.91  -6074743.34  -1524686.00 -11526464.03    588741.05
##        10774        10775        10776        10777        10778
##  -6270584.46   3002161.46  17526668.12  21562277.07   4623242.69
##        10779        10780        10781        10782        10783
##   -574423.50   -461153.44   8859508.60  -6850722.29     20410.18
##        10784        10785        10786        10787        10788
##   1833438.73  -6721423.87   -120768.46   6155767.42  16332840.98
##        10789        10790        10791        10792        10793
##  11567778.03  -5252033.21   7628370.24 -14204807.69  -8731475.08
##        10794        10795        10796        10797        10798
##  -3574565.94   3934677.40   -701966.67  40857881.71   3374642.37
##        10799        10800        10801        10802        10803
##   6228081.96  32312395.41  18534222.08  21076380.64  -3225724.08
##        10804        10805        10806        10807        10808
##   7968162.75  -5060877.16  -8144023.17  -9024300.07 -16068197.43
##        10809        10810        10811        10812
## -15246302.20  -2792914.14  -5883562.15 -13014993.94
```

```
# anova table
anova(fit)
```

```
## Analysis of Variance Table
##
## Response: raised
##            Df     Sum Sq    Mean Sq F value    Pr(>F)
## year        1 4.6080e+15 4.6080e+15  49.083 3.663e-11 ***
## month       1 1.9813e+15 1.9813e+15  21.104 7.689e-06 ***
## nomeff      1 7.4316e+15 7.4316e+15  79.159 3.445e-16 ***
## Residuals 200 1.8776e+16 9.3882e+13
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# covariance matrix for model parameters
vcov(fit)
```

```
##              (Intercept)          year         month        nomeff
## (Intercept)  7.767104e+16 -3.872335e+13 28849322448.9 -1.085409e+09
```

```
## year       -3.872335e+13  1.930661e+10  -132736938.4  5.147853e+05
## month        2.884932e+10 -1.327369e+08 38753042588.4 -5.204691e+05
## nomeff      -1.085409e+09  5.147853e+05     -520469.1  2.018502e+03

# regression diagnostics
influence(fit)

## $hat
##       10609       10610       10611       10612       10613       10614
## 0.042348953 0.032174152 0.030947216 0.024014063 0.027363125 0.031587019
##       10615       10616       10617       10618       10619       10620
## 0.018101845 0.031744185 0.029944584 0.028749417 0.028915850 0.042004060
##       10621       10622       10623       10624       10625       10626
## 0.036951680 0.032836278 0.020628210 0.029105061 0.025090117 0.020127986
##       10627       10628       10629       10630       10631       10632
## 0.028928511 0.025311220 0.021317185 0.041136744 0.038894083 0.038442958
##       10633       10634       10635       10636       10637       10638
## 0.024751425 0.032951924 0.018613317 0.018864207 0.027982400 0.015391058
##       10639       10640       10641       10642       10643       10644
## 0.014401572 0.013346093 0.015061997 0.022355644 0.027879390 0.046154691
##       10645       10646       10647       10648       10649       10650
## 0.031627027 0.018558780 0.023833019 0.112821017 0.025427226 0.010871644
##       10651       10652       10653       10654       10655       10656
## 0.014936315 0.016434376 0.012730547 0.015052097 0.018993675 0.022811653
##       10657       10658       10659       10660       10661       10662
## 0.021590355 0.025598024 0.021891454 0.030677847 0.012303026 0.008431467
##       10663       10664       10665       10666       10667       10668
## 0.010270283 0.015731396 0.014200211 0.013621161 0.019758522 0.024082289
##       10669       10670       10671       10672       10673       10674
## 0.023275260 0.022651222 0.013566370 0.010244787 0.009973309 0.009427607
##       10675       10676       10677       10678       10679       10680
## 0.009064497 0.012642349 0.009371723 0.011822949 0.018824179 0.019203515
##       10681       10682       10683       10684       10685       10686
## 0.018230843 0.014847325 0.025124352 0.008429436 0.006662158 0.010162920
##       10687       10688       10689       10690       10691       10692
## 0.005886809 0.009761653 0.008305723 0.017501582 0.015513961 0.018205378
##       10693       10694       10695       10696       10697       10698
## 0.028403775 0.013710461 0.011213122 0.007992116 0.015776039 0.008437031
##       10699       10700       10701       10702       10703       10704
```

```
## 0.005524255 0.009895498 0.009330121 0.010167001 0.013503398 0.017684780
##       10705       10706       10707       10708       10709       10710
## 0.017555766 0.013732230 0.009968803 0.007831239 0.015806655 0.010548861
##       10711       10712       10713       10714       10715       10716
## 0.005897979 0.010109522 0.007643304 0.013336595 0.013258812 0.017830567
##       10717       10718       10719       10720       10721       10722
## 0.017580339 0.013641063 0.014828321 0.007707093 0.009130653 0.007002906
##       10723       10724       10725       10726       10727       10728
## 0.005964200 0.008107635 0.007712046 0.011939769 0.030339564 0.017690478
##       10729       10730       10731       10732       10733       10734
## 0.018267899 0.014779064 0.012677183 0.008396088 0.008933566 0.015077042
##       10735       10736       10737       10738       10739       10740
## 0.006182481 0.008291578 0.008441482 0.057347133 0.023330100 0.027175075
##       10741       10742       10743       10744       10745       10746
## 0.034145133 0.015598509 0.024922266 0.014620930 0.015971049 0.011818535
##       10747       10748       10749       10750       10751       10752
## 0.009166620 0.007953467 0.009838765 0.011779321 0.041442536 0.019370448
##       10753       10754       10755       10756       10757       10758
## 0.021496796 0.018615226 0.015482224 0.012810535 0.010316345 0.017445774
##       10759       10760       10761       10762       10763       10764
## 0.012517804 0.009671274 0.012428820 0.013209037 0.016669564 0.030352449
##       10765       10766       10767       10768       10769       10770
## 0.022778573 0.024013621 0.019359402 0.017364762 0.011868764 0.010639665
##       10771       10772       10773       10774       10775       10776
## 0.016097657 0.020932289 0.015185078 0.023064462 0.042076891 0.022982715
##       10777       10778       10779       10780       10781       10782
## 0.039314848 0.020642852 0.017495861 0.015307288 0.013370033 0.017670901
##       10783       10784       10785       10786       10787       10788
## 0.015229820 0.013478258 0.018677831 0.017442482 0.021062576 0.025585033
##       10789       10790       10791       10792       10793       10794
## 0.029795969 0.028346084 0.020069570 0.017557692 0.017992944 0.017991668
##       10795       10796       10797       10798       10799       10800
## 0.017279735 0.015915981 0.018925877 0.021355814 0.030908716 0.029985740
##       10801       10802       10803       10804       10805       10806
## 0.033882901 0.027040425 0.023711906 0.020546316 0.021026489 0.024976776
##       10807       10808       10809       10810       10811       10812
## 0.025242356 0.030110086 0.024279989 0.023872198 0.027053249 0.031774203
##
```

```
## $coefficients
##       (Intercept)          year         month        nomeff
## 10609  2.217824e+07 -1.095925e+04 -1.325088e+04  -3.148198546
## 10610  4.411931e+07 -2.183848e+04 -2.228032e+04  -4.498752468
## 10611 -1.067489e+07  5.318300e+03  5.379473e+03  -1.436946526
## 10612 -1.430707e+07  7.125744e+03  5.005198e+03  -1.244058740
## 10613 -2.792623e+07  1.393898e+04  6.644383e+03  -3.898604484
## 10614  3.637567e+06 -1.803856e+03 -6.792737e+01  -0.548821439
## 10615 -1.912700e+07  9.531031e+03 -1.168978e+03  -0.136134257
## 10616 -1.236679e+06  6.142401e+02 -2.614444e+02   0.182574103
## 10617  1.017484e+07 -5.060185e+03  3.311361e+03  -1.300911103
## 10618  5.221933e+06 -2.616049e+03  2.285340e+03   0.594874799
## 10619 -1.269309e+07  6.332354e+03 -7.146199e+03   0.885644012
## 10620 -1.689093e+07  8.416379e+03 -1.142621e+04   2.385068449
## 10621  9.988869e+06 -4.931698e+03 -6.845283e+03  -1.449495213
## 10622  1.048887e+07 -5.182988e+03 -5.814728e+03  -1.523215775
## 10623 -1.631084e+07  8.103095e+03  8.519957e+03  -0.699865368
## 10624 -4.218674e+07  2.105372e+04  1.871018e+04  -8.082331986
## 10625  9.242638e+05 -4.579190e+02 -1.489350e+02  -0.132336511
## 10626  6.358893e+06 -3.155937e+03 -2.504379e+02  -0.691128004
## 10627  3.641035e+06 -1.805648e+03  3.989493e+02  -0.629386219
## 10628  9.337116e+06 -4.637748e+03  2.201757e+03  -1.355018464
## 10629  1.613545e+07 -8.032158e+03  5.891577e+03  -1.534779365
## 10630 -5.312552e+07  2.673259e+04 -2.690472e+04 -14.346919347
## 10631 -1.395324e+07  7.020519e+03 -9.319379e+03  -3.177538009
## 10632 -1.646696e+07  8.204834e+03 -1.260786e+04   2.577627287
## 10633  3.760187e+06 -1.861128e+03 -3.473579e+03   0.051669502
## 10634 -2.234622e+07  1.112837e+04  2.018246e+04  -5.245393316
## 10635 -1.628359e+07  8.088006e+03  1.014416e+04  -1.151932610
## 10636 -2.047850e+06  1.013844e+03  7.423967e+02   0.229688220
## 10637 -1.247581e+06  6.168874e+02  2.124380e+02   0.254137855
## 10638  5.894615e+06 -2.925287e+03 -3.169306e+02  -0.578830806
## 10639 -3.769840e+06  1.873573e+03 -3.804838e+02   0.307087073
## 10640 -6.158875e+06  3.068716e+03 -1.564194e+03   0.147604594
## 10641  3.662943e+07 -1.829673e+04  1.530656e+04   1.079832230
## 10642 -1.581303e+07  7.932421e+03 -9.414976e+03  -2.292732097
## 10643  6.064794e+06 -3.048607e+03  4.741647e+03   1.073663875
## 10644 -3.778883e+07  1.909829e+04 -3.788386e+04 -12.327285258
```

```
## 10645 -1.077920e+07  5.352968e+03  1.401354e+04  -2.618544383
## 10646  1.060570e+07 -5.242426e+03 -9.252015e+03  -0.347635974
## 10647 -1.132823e+07  5.641363e+03  9.615886e+03  -2.693177220
## 10648 -9.507136e+06  4.843114e+03  1.053421e+04 -10.992044696
## 10649 -1.695109e+07  8.482417e+03  7.344435e+03  -5.387675286
## 10650  2.306200e+07 -1.148565e+04 -2.772593e+03   1.485708039
## 10651  5.621407e+07 -2.811061e+04  3.670604e+03   9.641509106
## 10652  6.729828e+06 -3.341545e+03  2.126468e+03  -1.036254290
## 10653  7.108220e+06 -3.551032e+03  3.575657e+03   0.201266255
## 10654  1.582467e+06 -7.910911e+02  1.116079e+03   0.007929597
## 10655  1.152837e+07 -5.779663e+03  1.061769e+04   0.692447633
## 10656 -1.710168e+07  8.560121e+03 -1.874231e+04   0.721627113
## 10657 -5.929103e+05  2.917234e+02  7.601162e+02   0.049510964
## 10658  1.002366e+07 -4.923779e+03 -9.198676e+03  -2.342143138
## 10659  7.327219e+06 -3.604714e+03 -5.164301e+03  -1.679766149
## 10660 -1.353175e+07  6.778596e+03  1.248477e+04  -6.827556929
## 10661 -3.213203e+06  1.600485e+03  1.461190e+03  -0.560386836
## 10662 -5.268267e+06  2.619912e+03  7.210039e+02  -0.190793353
## 10663  1.154913e+07 -5.730482e+03  1.707015e+03  -1.365261647
## 10664  1.144985e+07 -5.676987e+03  4.440678e+03  -2.347823170
## 10665  6.705866e+06 -3.334416e+03  4.132369e+03  -1.025737232
## 10666  7.032453e+06 -3.511565e+03  6.112911e+03  -0.393054841
## 10667  1.345926e+06 -6.713397e+02  1.456790e+03  -0.200903934
## 10668 -4.611241e+06  2.303236e+03 -6.060086e+03   0.709429363
## 10669  8.053249e+06 -3.938302e+03 -1.250602e+04  -1.696860825
## 10670  3.705611e+05 -1.813324e+02 -4.426178e+02  -0.102288769
## 10671 -3.939973e+06  1.936750e+03  4.059715e+03   0.572834588
## 10672  9.419679e+05 -4.666418e+02 -8.618175e+02   0.114659646
## 10673 -1.250211e+06  6.167518e+02  5.154677e+02   0.205175878
## 10674 -9.007893e+05  4.451602e+02  9.586014e+01   0.155957310
## 10675  7.341548e+06 -3.636302e+03  1.425342e+03  -1.188810295
## 10676  5.924946e+06 -2.935061e+03  2.957010e+03  -1.379088741
## 10677  2.301099e+07 -1.150280e+04  1.942244e+04   0.687768760
## 10678  1.439071e+07 -7.198515e+03  1.679264e+04  -0.355463468
## 10679  2.651039e+07 -1.340312e+04  4.410324e+04   7.047794792
## 10680 -6.703334e+06  3.371961e+03 -1.252879e+04  -0.114757586
## 10681  5.541159e+06 -2.697350e+03 -1.452595e+04  -0.247387790
## 10682  1.603446e+06 -7.856451e+02 -3.948057e+03   0.274442552
```

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## 10683  4.441413e+06 -2.216849e+03 -1.315567e+04  4.618659090
## 10684 -8.700043e+05  4.284249e+02  1.132074e+03 -0.059475986
## 10685 -1.253417e+06  6.181170e+02  9.149269e+02  0.029129447
## 10686  7.539905e+05 -3.770922e+02 -3.244721e+02  0.348491682
## 10687 -2.562626e+06  1.271214e+03 -6.547688e+02  0.113695338
## 10688  1.194618e+06 -5.910220e+02  8.516612e+02 -0.322441202
## 10689  4.025099e+06 -2.010676e+03  5.027373e+03 -0.089717606
## 10690  1.819959e+07 -9.292996e+03  4.003722e+04 11.363767502
## 10691  9.363500e+06 -4.747078e+03  2.359376e+04  2.319518098
## 10692 -7.222097e+06  3.641319e+03 -1.986024e+04  0.265940573
## 10693 -6.056861e+05  2.898511e+02  8.536768e+03 -1.727667047
## 10694 -1.305227e+06  6.257896e+02  6.340178e+03 -0.260270335
## 10695 -5.404923e+05  2.614907e+02  2.335034e+03 -0.239252458
## 10696 -3.033790e+06  1.475310e+03  8.449588e+03 -0.662450304
## 10697 -2.362064e+06  1.199732e+03  1.007671e+04 -6.274776280
## 10698 -3.521929e+06  1.715006e+03  8.703304e+02  1.664513748
## 10699  2.733217e+06 -1.358053e+03  1.366920e+03  0.610078755
## 10700 -1.458547e+06  7.165223e+02 -1.783467e+03  0.743524545
## 10701  4.271917e+06 -2.117273e+03  9.037041e+03 -1.581853695
## 10702  4.131753e+06 -2.087052e+03  1.506093e+04  0.226903260
## 10703  2.904535e+06 -1.479497e+03  1.400255e+04  0.289243941
## 10704  3.048377e+06 -1.566427e+03  1.848898e+04  0.443212896
## 10705 -1.143376e+05  3.516276e+01  4.602683e+03  0.137875177
## 10706 -7.011967e+03  2.551064e+00  1.759407e+02  0.010002868
## 10707  1.826903e+04  1.014222e+02 -2.353720e+04  0.397682389
## 10708  3.251151e+05 -2.043634e+02  9.595275e+03 -0.801320482
## 10709  3.554089e+06 -1.748180e+03  1.089865e+04 -6.854712077
## 10710 -5.167254e+05  2.371035e+02  3.141253e+02  0.929696189
## 10711 -3.470363e+05  1.570767e+02 -1.072941e+03  0.615906683
## 10712 -2.925253e+05  1.379845e+02 -1.239762e+03  0.541044957
## 10713 -3.072306e+05  1.381465e+02  9.063973e+03  0.541680208
## 10714 -7.765932e+05  3.799752e+02 -8.323130e+03  1.489904557
## 10715 -8.593698e+04  2.628041e+01  7.898327e+03  0.103047003
## 10716 -1.259419e+06  5.068377e+02  4.351076e+04  1.987339499
## 10717 -2.845605e+06  1.485801e+03 -1.599330e+04  0.181059556
## 10718 -1.627264e+06  8.403740e+02 -7.098327e+03  0.252218086
## 10719  5.738343e+06 -2.891791e+03  1.542928e+04 -3.217688027
## 10720  2.575890e+06 -1.325706e+03  6.849368e+03  0.170024856
```

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## 10721  2.743464e+06 -1.373642e+03  3.476782e+03  -1.312834809
## 10722  1.891144e+03 -9.794033e-01  9.849642e-01   0.001247668
## 10723 -8.431059e+05  4.291345e+02  5.959896e+02  -0.318369889
## 10724  1.699317e+06 -8.661153e+02 -3.867812e+03   1.216859700
## 10725  1.070784e+06 -5.326297e+02 -2.795782e+03   0.073939846
## 10726 -3.634180e+06  1.778932e+03  9.715614e+03   1.373827064
## 10727  2.721464e+06 -1.315127e+03 -6.229100e+03  -2.214626452
## 10728  4.293151e+06 -2.087533e+03 -2.150113e+04  -0.526242586
## 10729 -1.033050e+07  5.266972e+03 -2.848234e+04   0.596359927
## 10730 -4.140989e+06  2.097702e+03 -8.969896e+03   0.596746653
## 10731  8.740758e+06 -4.401930e+03  1.426929e+04  -1.942572590
## 10732  1.704127e+06 -8.639063e+02  2.214883e+03   0.104151101
## 10733  5.543927e+06 -2.774150e+03  4.021768e+03  -1.323301838
## 10734  2.900244e+06 -1.491977e+03  4.589080e+02   2.258154884
## 10735 -5.746351e+06  2.887983e+03  1.708556e+03  -0.658799504
## 10736  5.863621e+06 -2.911538e+03 -3.625998e+03  -1.200248796
## 10737  7.936993e+06 -3.943310e+03 -9.448384e+03  -0.532097381
## 10738 -3.799404e+06  1.852009e+03  3.297152e+03   2.792589403
## 10739 -2.424007e+06  1.187533e+03  3.945937e+03   1.015428594
## 10740  2.673316e+07 -1.306522e+04 -5.391394e+04 -11.044007437
## 10741 -2.998799e+07  1.500246e+04 -4.771143e+04  11.234460799
## 10742  3.826148e+06 -1.940949e+03  6.044669e+03   0.353303805
## 10743  1.675273e+07 -8.356773e+03  1.760887e+04  -5.936400688
## 10744  1.547598e+07 -7.733429e+03  1.234295e+04  -3.738592715
## 10745  2.611850e+07 -1.300653e+04  1.310536e+04  -7.628145733
## 10746  7.224511e+06 -3.654449e+03  8.377321e+02   2.258058551
## 10747  6.805481e+06 -3.423328e+03 -1.621965e+03   1.376820132
## 10748 -4.986467e+06  2.493240e+03  2.680961e+03  -0.330865273
## 10749 -2.339139e+06  1.162491e+03  1.818326e+03   0.193486833
## 10750  2.757010e+06 -1.370125e+03 -3.221227e+03   0.002231249
## 10751  2.044704e+07 -1.003019e+04 -2.065058e+04  -9.384825508
## 10752  1.680124e+07 -8.323089e+03 -3.179199e+04   0.884179476
## 10753  3.751150e+06 -1.888552e+03  5.092878e+03  -0.305438599
## 10754  9.283990e+06 -4.699767e+03  1.106898e+04   1.314300194
## 10755  3.286791e+06 -1.661185e+03  3.019905e+03   0.482833713
## 10756  2.048982e+07 -1.033521e+04  1.318982e+04   2.856629756
## 10757  2.120923e+07 -1.066864e+04  7.912063e+03   2.228364085
## 10758  7.963005e+06 -4.022772e+03  5.211376e+02   2.538605474
```

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## 10759  1.266087e+07 -6.364137e+03 -2.438977e+03   2.598379782
## 10760 -2.251378e+07  1.121529e+04  7.805354e+03   1.476114842
## 10761 -9.195523e+06  4.595975e+03  6.444720e+03  -1.139421617
## 10762  9.377180e+06 -4.664159e+03 -8.216497e+03  -0.004043853
## 10763  2.459176e+07 -1.220144e+04 -2.690524e+04  -0.885468388
## 10764  1.699698e+07 -8.491030e+03 -2.886275e+04   5.548338501
## 10765 -2.849576e+07  1.433161e+04 -3.139603e+04   1.152496207
## 10766  8.667243e+06 -4.384161e+03  8.282529e+03   1.642954860
## 10767 -2.250246e+07  1.135701e+04 -1.638369e+04  -3.664811034
## 10768  2.222611e+07 -1.120462e+04  1.127902e+04   3.825802265
## 10769  1.166217e+07 -5.854050e+03  3.449565e+03   0.842605075
## 10770  1.218204e+07 -6.103551e+03  1.094079e+03   0.654610620
## 10771  2.868529e+06 -1.440760e+03 -4.620766e+02   0.555959114
## 10772  2.116036e+07 -1.063087e+04 -8.671706e+03   5.458520491
## 10773 -1.149062e+06  5.744290e+02  6.512743e+02  -0.141506136
## 10774  1.460430e+07 -7.234601e+03 -8.553998e+03  -2.664872208
## 10775 -7.643539e+06  3.771626e+03  5.224049e+03   2.239007014
## 10776 -3.793829e+07  1.880890e+04  4.009159e+04   1.916947871
## 10777 -6.147477e+07  3.071463e+04 -5.402415e+04  12.582237726
## 10778 -1.142963e+07  5.742630e+03 -8.695424e+03  -0.166766045
## 10779  1.407505e+06 -7.066625e+02  8.318138e+02   0.038518304
## 10780  1.119671e+06 -5.617728e+02  4.693291e+02   0.047646704
## 10781 -2.167545e+07  1.085816e+04 -5.392837e+03  -0.573298309
## 10782  1.582477e+07 -7.945378e+03  8.266039e+02   2.357102011
## 10783 -4.808225e+04  2.408581e+01  5.590822e+00  -0.005150303
## 10784 -4.484881e+06  2.239632e+03  1.185089e+03  -0.148714333
## 10785  1.578188e+07 -7.891115e+03 -7.552015e+03   1.971122788
## 10786  2.988220e+05 -1.488566e+02 -1.787522e+02   0.006945175
## 10787 -1.515295e+07  7.543606e+03  1.180438e+04  -0.637321651
## 10788 -4.259410e+07  2.113152e+04  3.732562e+04   2.314337478
## 10789 -3.541430e+07  1.774364e+04 -2.767970e+04   2.732233148
## 10790  1.636634e+07 -8.184845e+03  1.046740e+04  -1.790939131
## 10791 -2.241748e+07  1.123094e+04 -1.130989e+04   0.396006193
## 10792  4.159560e+07 -2.082176e+04  1.502035e+04  -0.586778663
## 10793  2.643894e+07 -1.320083e+04  5.980054e+03  -1.914906596
## 10794  9.916625e+06 -4.969398e+03  5.111495e+02   0.921178949
## 10795 -1.098800e+07  5.499053e+03  1.051415e+03  -0.883903995
## 10796  2.028247e+06 -1.012302e+03 -4.477825e+02   0.029640129
```

```
## 10797 -1.234049e+08  6.141495e+04  4.093550e+04   7.340044191
## 10798 -1.022276e+07  5.083079e+03  4.809996e+03   0.599668816
## 10799 -1.987209e+07  9.854067e+03  1.122356e+04   2.609591178
## 10800 -1.000787e+08  4.964740e+04  7.332152e+04   7.924476981
## 10801 -6.529009e+07  3.268233e+04 -4.475353e+04   5.236688538
## 10802 -7.206740e+07  3.609092e+04 -4.080151e+04   2.726204116
## 10803  1.055969e+07 -5.295507e+03  4.652551e+03   0.405043300
## 10804 -2.658305e+07  1.330478e+04 -8.378138e+03   0.046214950
## 10805  1.629572e+07 -8.165072e+03  2.904723e+03   1.105528974
## 10806  2.558239e+07 -1.282763e+04  8.884004e+02   3.217167593
## 10807  2.834348e+07 -1.420069e+04 -2.841140e+03   3.633854651
## 10808  4.988753e+07 -2.499597e+04 -1.231960e+04   8.133609667
## 10809  4.883875e+07 -2.440287e+04 -1.721099e+04   4.428098543
## 10810  9.177389e+06 -4.576010e+03 -4.219677e+03   0.388898756
## 10811  1.944169e+07 -9.685203e+03 -1.139177e+04   0.767636896
## 10812  4.293545e+07 -2.137868e+04 -3.100402e+04   2.295963898
##
## $sigma
##   10609   10610   10611   10612   10613   10614   10615   10616   10617
## 9704033 9673382 9710573 9708368 9692571 9713348 9704899 9713577 9711506
##   10618   10619   10620   10621   10622   10623   10624   10625   10626
## 9712887 9710099 9707947 9711071 9710794 9705104 9647742 9713585 9712507
##   10627   10628   10629   10630   10631   10632   10633   10634   10635
## 9713275 9711335 9706375 9600885 9706147 9706674 9713017 9687689 9701725
##   10636   10637   10638   10639   10640   10641   10642   10643   10644
## 9713453 9713556 9712299 9713060 9712046 9654918 9701385 9711759 9631991
##   10645   10646   10647   10648   10649   10650   10651   10652   10653
## 9704897 9707140 9703907 9700734 9690097 9679013 9482552 9711297 9710429
##   10654   10655   10656   10657   10658   10659   10660   10661   10662
## 9713454 9704972 9696589 9713578 9706537 9709783 9686303 9712444 9710871
##   10663   10664   10665   10666   10667   10668   10669   10670   10671
## 9702490 9703766 9710000 9709158 9713461 9711904 9705335 9713591 9711428
##   10672   10673   10674   10675   10676   10677   10678   10679   10680
## 9713440 9713390 9713495 9706020 9709067 9620081 9679152 9556146 9705788
##   10681   10682   10683   10684   10685   10686   10687   10688   10689
## 9703041 9712489 9696177 9713305 9713033 9713274 9711229 9713210 9707532
##   10690   10691   10692   10693   10694   10695   10696   10697   10698
## 9484558 9670016 9694154 9710393 9710677 9712970 9696964 9665645 9703363
```

```
##   10699   10700   10701   10702   10703   10704   10705   10706   10707
## 9699470 9711903 9695548 9685330 9698839 9696413 9712539 9713605 9645521
##   10708   10709   10710   10711   10712   10713   10714   10715   10716
## 9692194 9657695 9711752 9708527 9712793 9693026 9705844 9708928 9616936
##   10717   10718   10719   10720   10721   10722   10723   10724   10725
## 9700975 9709924 9687368 9702069 9706975 9713608 9712002 9705092 9711736
##   10726   10727   10728   10729   10730   10731   10732   10733   10734
## 9701097 9710222 9690341 9673713 9707825 9690224 9712389 9704482 9707077
##   10735   10736   10737   10738   10739   10740   10741   10742   10743
## 9699210 9703167 9691298 9711709 9712302 9553906 9615084 9710809 9682102
##   10744   10745   10746   10747   10748   10749   10750   10751   10752
## 9682351 9630307 9701417 9703878 9709066 9712762 9712328 9675017 9664111
##   10753   10754   10755   10756   10757   10758   10759   10760   10761
## 9712364 9703962 9712393 9666666 9665059 9705299 9694694 9668416 9704465
##   10762   10763   10764   10765   10766   10767   10768   10769   10770
## 9705289 9658802 9676664 9665730 9708021 9676792 9677383 9704577 9703955
##   10771   10772   10773   10774   10775   10776   10777   10778   10779
## 9712996 9678443 9713516 9703191 9711173 9631938 9587608 9707961 9713521
##   10780   10781   10782   10783   10784   10785   10786   10787   10788
## 9713552 9693008 9701242 9713607 9712726 9701692 9713604 9703590 9642534
##   10789   10790   10791   10792   10793   10794   10795   10796   10797
## 9677866 9706262 9698235 9660336 9693505 9710241 9709532 9713478 9263021
##   10798   10799   10800   10801   10802   10803   10804   10805   10806
## 9710597 9703249 9431081 9621196 9594785 9710850 9696826 9706838 9695996
##   10807   10808   10809   10810   10811   10812
## 9691973 9644505 9651788 9711540 9704400 9668249
##
## $wt.res
##        10609        10610        10611        10612        10613
##   5952459.84  12255563.09  -3371411.14  -4445741.27  -8889076.47
##        10614        10615        10616        10617        10618
##    986134.71  -5748266.48   -336390.21   2807133.26   1645172.74
##        10619        10620        10621        10622        10623
##  -3629105.70  -4577842.81   3072907.21   3243308.73  -5672890.07
##        10624        10625        10626        10627        10628
## -15696727.40    289232.12   2042122.32   1117366.99   2926082.40
##        10629        10630        10631        10632        10633
##   5230228.43 -20382271.56  -5264124.44  -5075967.51   1491577.71
```

```
##       10634       10635       10636       10637       10638
##  -9837151.49  -6712232.19   -764792.30   -437886.38   2231690.27
##       10639       10640       10641       10642       10643
##  -1443831.23  -2440345.04  14926587.99  -6794617.92   2635516.43
##       10644       10645       10646       10647       10648
## -17311907.92  -5709093.26   4952910.28  -6048902.56  -6642668.40
##       10649       10650       10651       10652       10653
##  -9406029.73  11491464.13  29486574.30   2963737.40   3482526.36
##       10654       10655       10656       10657       10658
##    764926.90   5721591.58  -8014761.85   -334238.52   5160023.79
##       10659       10660       10661       10662       10663
##   3802703.26 -10108379.25  -2107670.27  -3238790.51   6520269.00
##       10664       10665       10666       10667       10668
##   6117951.47   3707721.08   4118584.97    744008.66  -2535146.08
##       10669       10670       10671       10672       10673
##   5587891.61    247621.47  -2882708.00    800991.54   -911955.00
##       10674       10675       10676       10677       10678
##   -655352.63   5390336.84   4162722.58  18880213.59  11462880.43
##       10679       10680       10681       10682       10683
##  24340300.82  -5444209.40   6331098.26   2063500.35   8101582.03
##       10684       10685       10686       10687       10688
##  -1076762.56  -1485004.62   1129099.86  -3023048.68   1233356.51
##       10689       10690       10691       10692       10693
##   4825705.45  29321582.28  12866219.97  -8588656.22  -3474768.56
##       10694       10695       10696       10697       10698
##  -3342387.93  -1561293.84  -7985942.92 -13492569.39  -6264977.56
##       10699       10700       10701       10702       10703
##   7369859.10  -2554169.18   8312707.30  10394757.30   7502086.94
##       10704       10705       10706       10707       10708
##   8077227.47  -2014108.57    -95116.07  16114782.51  -9058033.14
##       10709       10710       10711       10712       10713
## -14564659.61  -2664396.26  -4418287.27  -1765118.25   8881219.38
##       10714       10715       10716       10717       10718
##  -5440633.74   4224442.28  19111300.40   6924490.79   3747711.16
##       10719       10720       10721       10722       10723
##  -9990097.04  -6651295.63  -5039648.82     -6308.56   2483670.82
##       10724       10725       10726       10727       10728
##  -5713224.42  -2679256.50   6910723.16  -3562131.49  -9394292.44
```

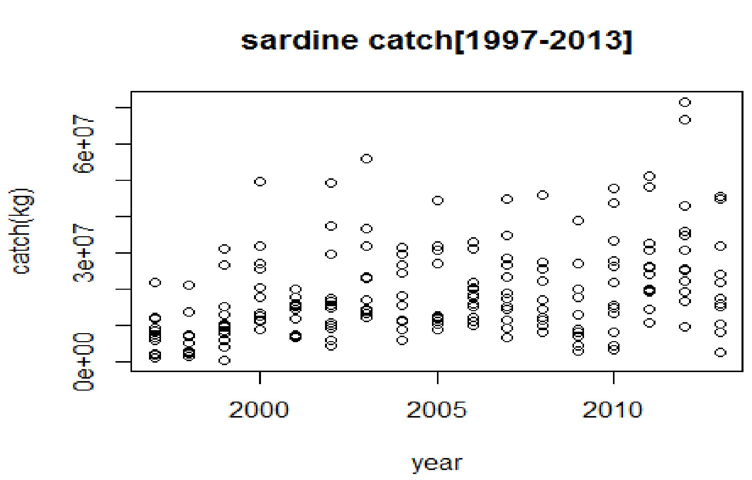
```
##       10729        10730        10731        10732        10733 
##  12292491.48   4692225.99  -9441901.08  -2161564.02  -5911665.98 
##       10734        10735        10736        10737        10738 
##  -4985852.10   7434834.02  -6325219.34  -9242339.89   2630232.74 
##       10739        10740        10741        10742        10743 
##   2220095.43 -24406855.54  19131720.29  -3262974.07 -10889120.28 
##       10744        10745        10746        10747        10748 
## -10903121.99 -17763414.88  -6822302.77  -6103458.03   4173221.59 
##       10749        10750        10751        10752        10753 
##   1798780.05  -2210622.30 -11946665.58 -13681047.30  -2168599.28 
##       10754        10755        10756        10757        10758 
##  -6048066.31  -2150199.30 -13368549.99 -13612130.58  -5616599.80 
##       10759        10760        10761        10762        10763 
##  -8493152.82  13138420.47   5906816.91  -5632275.23 -14413805.47 
##       10764        10765        10766        10767        10768 
## -11756970.84  13432590.65  -4590320.74  11802983.94 -11719864.10 
##       10769        10770        10771        10772        10773 
##  -5872175.91  -6074743.34  -1524686.00 -11526464.03    588741.05 
##       10774        10775        10776        10777        10778 
##  -6270584.46   3002161.46  17526668.12  21562277.07   4623242.69 
##       10779        10780        10781        10782        10783 
##   -574423.50   -461153.44   8859508.60  -6850722.29     20410.18 
##       10784        10785        10786        10787        10788 
##   1833438.73  -6721423.87   -120768.46   6155767.42  16332840.98 
##       10789        10790        10791        10792        10793 
##  11567778.03  -5252033.21   7628370.24 -14204807.69  -8731475.08 
##       10794        10795        10796        10797        10798 
##  -3574565.94   3934677.40   -701966.67  40857881.71   3374642.37 
##       10799        10800        10801        10802        10803 
##   6228081.96  32312395.41  18534222.08  21076380.64  -3225724.08 
##       10804        10805        10806        10807        10808 
##   7968162.75  -5060877.16  -8144023.17  -9024300.07 -16068197.43 
##       10809        10810        10811        10812 
## -15246302.20  -2792914.14  -5883562.15 -13014993.94
```

Chapter 5: Plots in R

##scatter plot

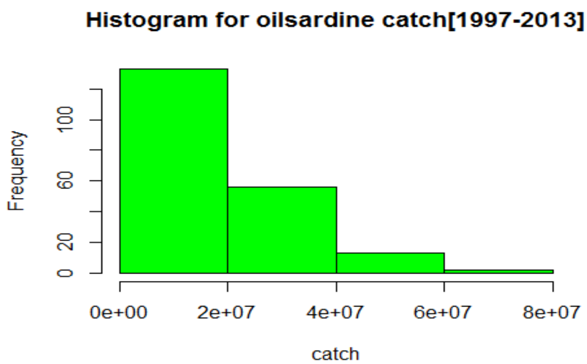
```
sp3621<-sp362[c(1:2,4)]
attach(sp3621)

## The following objects are masked from klm:
##     month, raised, year
plot(year,raised,main="sardine catch[1997-2013]",xlab="year",ylab="catch(kg))
```



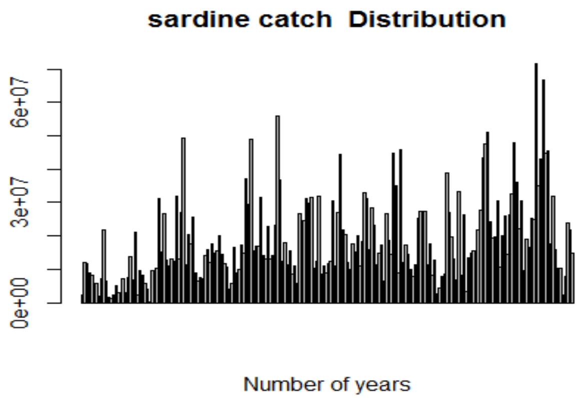
##Histogram

```
hist(raised,main="Histogram for
oilsardine catch[1997-2013]",
xlab="catch",
col="green",
breaks=5)
```



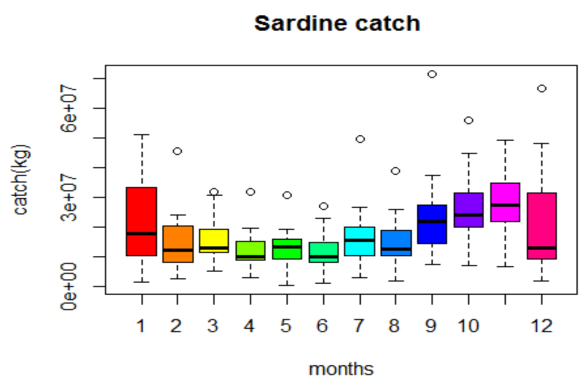
##Bar plot

```
barplot(raised, main="sardine catch
Distribution",
xlab="Number of years")
```



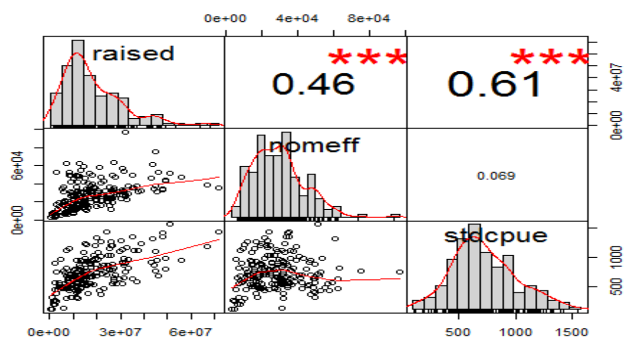
Boxplot in r

```
# Boxplot of catch vs month
boxplot(raised~month,data=sp3621,
main="Sardine catch ",
xlab="months",
ylab="catch(kg)",col=rainbow(length
(unique(month))))
```



to plot a correlation in r

```
##we select sardine  correlations
cordat<-sp362[,4:6]
library(PerformanceAnalytics)
chart.Correlation(cordat,method=
"pearson")
```



Suggested Reading

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ESTIMATION OF GROWTH PARAMETERS

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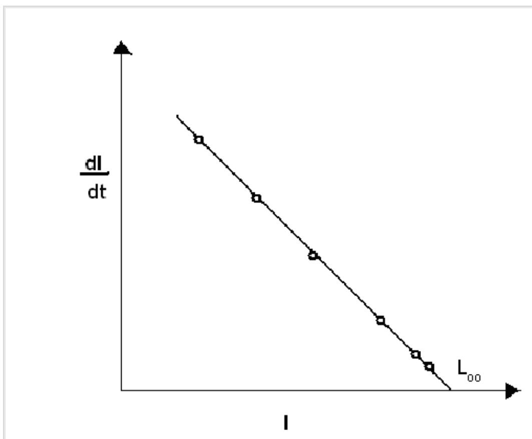
ICAR- Central Marine Fisheries Research Institute

15

A growth curve is an empirical model of the evolution of a quantity over time. Some growth curves for certain biological systems display periods of ***exponential growth***. **A Gompertz curve,** named after Benjamin Gompertz, is a sigmoid function. It is a type of mathematical model, where growth is slowest at the start and end of a time period. In biology, a growth model is a depiction of length or weight of animals as a function of age. In the case of fish populations, the study of growth is to determine the body size as a function of its age. The growth model developed by **von Bertalanffy** (1934) has been found to be suitable for the observed growth of most of the fish species. This model expresses length as a function of age of the animal.

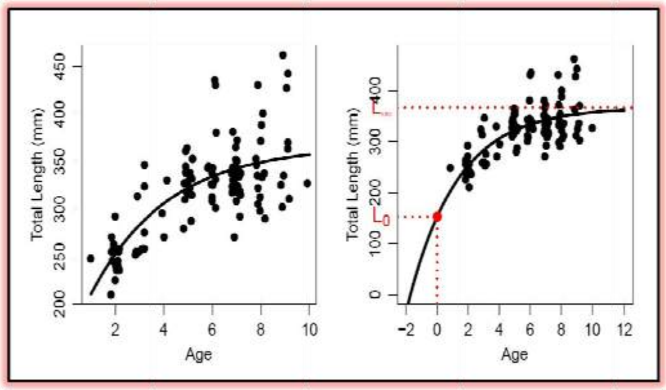
Fish increases in length as they grow older but their growth rate which is the increment in length per unit time decreases as they grow old. When the rate of growth is plotted against the length, in most cases it will look almost like a straight line with descending limb (negative slope). This line will cut the x-axis at a point where the rate of growth is zero. This is the point beyond which the fish will not grow further and the length of the fish at this point is known as the asymptotic length denoted by L_∞ .

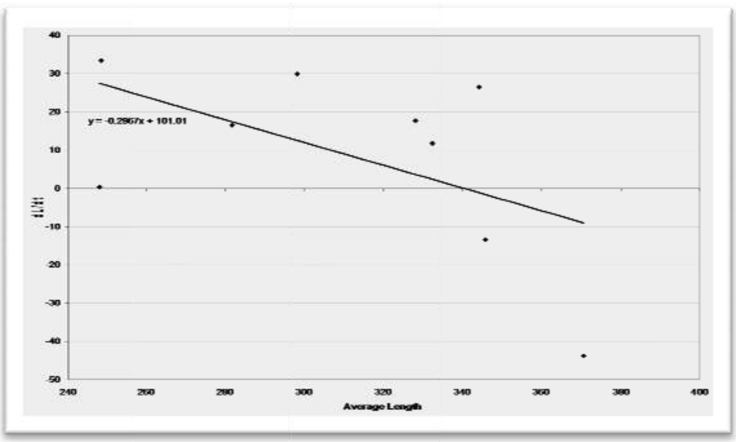


Example: Length-at-age for a portion of a sample of male Atlantic croakers (left) and average length-at-age are given in the following table. The figures show plots of the growth curve and growth rates.

Reprinted from the CMFRI, FRAD. 2014. Training Manual on Fish Stock Assessment and Management, p.150.

Indiv	*Age*	*Length*	*AvgAge*	*AvgLength*
1	1	248	1	248.0
2	2	210	2	248.4
3	2	225	3	281.8
4	2	236	4	298.3
5	2	240	5	328.2
6	2	245	6	345.9
7	2	255	7	332.5
8	2	258	8	344.3
9	2	263	9	370.8
10	2	270	10	327.0
11	2	292		
⋮	⋮	⋮		





To develop the growth model the above phenomenon can be represented by means of a differential equation

$$\frac{dl}{dt} = K(L_\infty - l)$$

This can be rewritten as

$$\frac{dl}{L_\infty - l} = K\,dt$$

The required growth model is then obtained by integrating the above differential equation to yield,

$$-\log(L_\infty - l) = K\,t + C$$

where C is a constant to be determined.

Expressing this equation for the length l we get,

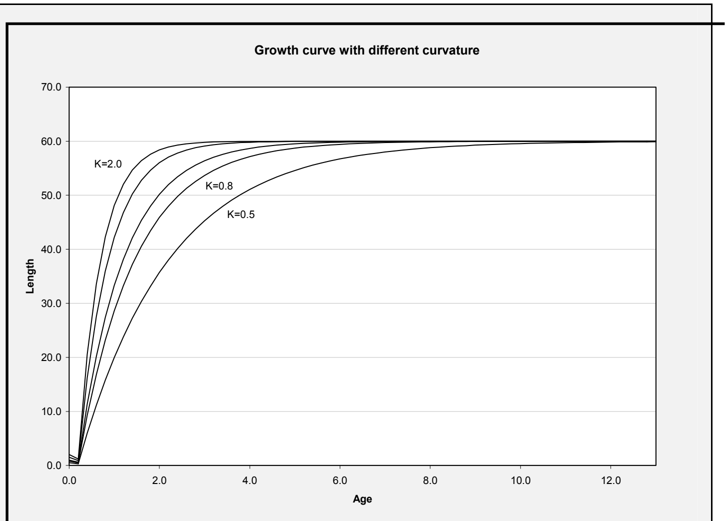
$$l = L_\infty - Ce^{-K\,t}$$

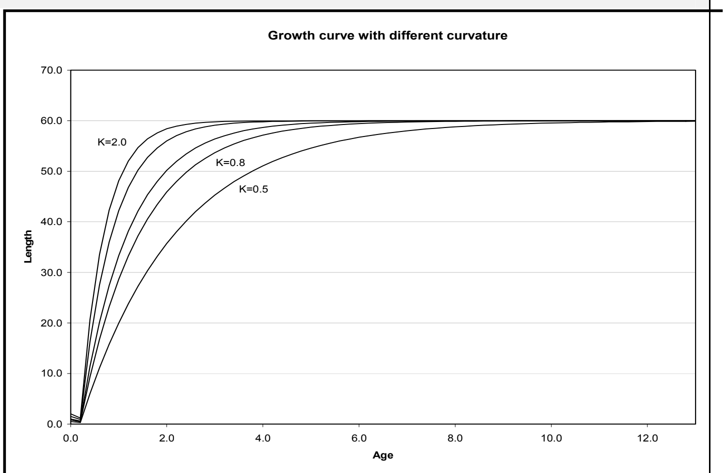
When $t = 0$ the length l also will be zero so that we get,

$$0 = L_\infty - C.$$

Hence $C = L_\infty$ and we get the equation as

$$l = L_\infty(1 - e^{-K\,t})$$





But usually the length will be zero at a different point $t = t_0$ so that we get the solution for the constant as

$$C = L_\infty\, e^{K\,t_0}$$

Hence the general growth equation is obtained by substituting the above value for C as $l = L_\infty(1 - e^{-K(t - t_0)})$

Parameters of the model are K, L_∞ and t_0. Here K is termed as the curvature, L_∞ is known as the asymptotic length and t_0 is the age at birth.

The data commonly used for fish stock assessment is the length frequency data collected periodically by sampling from commercial catches. The data so obtained will consist of animals of different age group. The animals born on same day (single spawning) is termed as a cohort and the animals of the same age will not have same length rather it will vary with a mean and variance. If we make a histogram of their length most of the animals will fall at the middle and it will have the well known bell shape. The sample collected at a time will be a mixture of such bell shaped distributions corresponding to different age groups. If we are able to trace the length distributions of each cohort separately from its initial age up to its life span then we would be able to work out its growth and growth model parameters. As the sample collected by us from commercial catch will be a mixture of cohorts of different age groups the problem reduces to resolution of individual components (known as normal distributions or Gaussian components) from the mixture.

Resolution of Gaussian Components from Polymodal Distributions

The frequency distribution of length obtained from a sample of fish is usually skew and polymodal. The modes corresponding to individual age groups are very useful in separating the different Gaussian components of which it is assumed to be composed off. Here the problem is to resolve a distribution into Gaussian components. Different procedures are available for resolution of a mixture into Gaussian components. These are probability paper method, parabola method and Bhattacharya's method. Among this the last method is most popular.

Probability Paper Method: Decomposition of polymodal frequency distributions using probability paper method was introduced by Harding (1949) and later modified by Cassie in 1950. This involves dissection of the distribution at points of inflexion of the probit plot, followed by correction for over lap of components. In this method, the cumulative percentages of the frequency distribution are first plotted against the mid points of the classes on a probability graph paper and the point of inflexion are marked. Cumulative percentages of these points are the keys for separation of the components and each segment between them are due to separate distributions. Each of these components is then extracted by adjusting the original cumulative percentages within in segments so that the total is 100. These adjusted values if plotted on the same probability paper will be linear. The means of each separated component are estimated from the actual frequencies falling in the corresponding region.

Parabola Method: If the frequency distribution of random variable distributed as normal has *y* as the frequency for a class with mid value *x* then we can express y as

$$y = N \int_{x-c/2}^{x+c/2} f(x)\, dx$$

where *f(x)* is the probability distribution of a normal random variable with mean μ, standard deviation σ, *c* the class interval and *N* the total frequency. An approximation for the relation is

$$y \approx \frac{(N c e^{-(x-\mu)^2})/2\sigma^2}{\sqrt{2\pi\sigma}}$$

$$\ln(y) \approx \ln(\frac{Nc}{\sqrt{2\pi\sigma}}) - \frac{(x-\mu)^2}{2\sigma^2}$$

The above equation is of the form which is a quadratic equation representing a parabola. The axis of symmetry of the above parabola will be at $x = \mu$. Hence, if we plot the natural logarithm of the class frequencies against the mid values of the classes we can represent the different peaks with different parabolas each corresponding to a normal distribution whose mean is the point where the axis of symmetry intersects the *x*-axis.

Bhattacharya's Method: If $y(x)$ denote the observed frequency of the class with *x* as its mid value and *h* the class width, then

$$y = \int_{x-h/2}^{x+h/2} \sum_{i=1}^{k} N_i f(x, \mu_i, \sigma_i)\, dx$$

$$\approx \int_{x-h/2}^{x+h/2} N_r f(x, \mu_r, \sigma_r)\, dx$$

$$\approx \int_{x-h/2}^{x+h/2} N_r \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{1}{2\sigma^2}(x-\mu_r)^2}\, dx$$

$$\ln(y) = \ln(\frac{hN_r}{\sigma_r\sqrt{2\pi}}) - \frac{h^2}{24\sigma^2} - \frac{\sigma_r^2 - (h^2/12)}{2\sigma_r^2} t^2$$

by ignoring terms with higher orders in *h* and

$$t = \frac{(x-\mu_r)}{\sigma}$$

$$\Delta t^2 = 2h(x - \mu_r + \frac{h}{2}\sigma_r^2 \text{ and}$$

$$\Delta \ln(y) = -h(\sigma_r^2 - h^2/12) - (x - \mu_r + h/2)/\sigma_r^4$$

That is, the graph of $\Delta \ln(y)$ against the mid value of the class will be linear. If denote the x intercept and the angle the line makes with the –ve direction of the x-axis then the mean and standard deviationof the Gaussian component corresponding to this region are estimated as a plot of $\Delta \log y(x) = \log(y(x+h)) - \log(y(x))$ against *x* is to be made first. Then the number of regions where the graph look like straight lines with–ve slope, indicate the number of components (under certain conditions). By connecting the points in the regions fit straight lines for these regions. If θ_r is the angle it makes with the *x* axis and λ_r is the *x* intercept for the r^{th} region for $r = 1,\cdots,k$ then the mean and variance of the r^{th} component is estimated as

$$\mu_r = \hat{\lambda}_r + h/2$$

$$\hat{\sigma}_r^2 = (dh\ Cot\hat{\theta}_r / b) - h^2/12$$

where *b* and *d* denote the relative scales for *x* and $\angle \log y(x)$ respectively. The proportions of the mixture can be estimated as

$$\hat{p}_i = \hat{N}_i \Big/ \sum_{i=1}^{k} \hat{N}_i$$

where $\hat{N}_i$ is the total frequency of the i^{th} class and it is estimated by

$$\hat{N}_r = \sum y(x) \Big/ \sum \hat{p}_r$$

Here, the summation being restricted to the region under consideration and

$$\hat{p}_{ri} = P\left(\frac{x + h/2 - \hat{\mu}_i}{\hat{\sigma}_i}\right) - P\left(\frac{x - h/2 - \hat{\mu}_i}{\hat{\sigma}_i}\right)$$

where *P(x)* is the distribution function of standard normal variate.

Estimation of Growth Parameters

Once we have data on age and corresponding length obtained from the above procedure we may use any one of the following methods as per the situation to estimate the growth parameters.

Gulland and Holt Plot: For small values of Δt (need not be kept constant), the required expression is

$$\frac{\Delta L}{\Delta t} = K\,L_\infty - K\,\overline{L}_t \text{ where } \Delta L = L_{t+\Delta t} - L_t \text{ and } \overline{L}_t = \frac{(L_{t+\Delta t} + L_t)}{2}$$

By regressing $\frac{\Delta L}{\Delta t}$ on $\overline{L}_t$ (of the type $y = a + b\,x$)we can get estimates of the growth parameters as

$$\hat{K} = -\hat{b} \text{ and } \hat{L}_\infty = -\frac{\hat{a}}{\hat{b}}$$

Example: The first two columns of the following table pertain to the age and corresponding average length of animals of a cohort. The growth parameters can be estimated by calculations in the remaining columns and a followed regression. The steps followed are

1. Generate column dL as the increment in length (difference of consecutive values of L(t)
2. Generate column dt as the increment in age (difference of consecutive values of Age(t)
3. Compute values in column dL/dt as the ratio of values in dL and dt)
4. Compute the mean length Lbar(t) as the average of consecutive values of L(t)

Age (t)	L(t)	dL	dt	dL/dt	Lbar(t)
1	25.7	10.3	1	10.3	30.85
2	36.0	6.9	1	6.9	39.45
3	42.9	4.6	1	4.6	45.20
4	47.5	3.2	1	3.2	49.10
5	50.7	2.1	1	2.1	51.75
6	52.8	1.4	1	1.4	53.50
7	54.2				

Now regress the values in column dL/dt with the values in Lbar(t). That is carryout regression analysis with values in column dL/dt as Y values and values in Lbar(t) as X values and obtain the regression coefficients *a* and *b*.

Regression Statistics	
Multiple R	0.999922
R Square	0.999844
Adjusted R Square	0.999804
Standard Error	0.046844
Observations	6

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	22.36353	0.11182	199.9952	3.75E-09
Lbar(t)	-0.39163	0.00245	-159.872	9.18E-09

The estimates of coefficients in the regression model obtained through the regression analysis are a = 22.36353 and b = -0.39163 and the estimates of growth parameters are

$$\hat{K} = -\hat{b} = 0.39163 \text{ and } \hat{L}_\infty = -\frac{\hat{a}}{\hat{b}} = -\frac{22.36356}{-0.39163} = 57.1$$

Ford-Walford Plot: The growth equation can be brought into the form

$$L_{t+\Delta t} = a + b\,L_t \text{ where } a = L_\infty(1-b) \text{ and } b = e^{-K\,\Delta t}$$

When Δt is constant we can get estimates of a and b by regressing $L_{t+\Delta t}$ on L_t and the estimates of growth parameters can be obtained as

$$\hat{K} = -\frac{\ln(\hat{b})}{\Delta t} \text{ and } \hat{L}_{\infty} = \frac{\hat{a}}{(1-\hat{b})}$$

Example: For the same set of data the column L(t+1) is made with the next value of L(t). As per the Ford-Walford plot we regress the values in L(t+1) with values in L(t) and find the regression coefficients a and b.

Age (t)	L(t)	L(t+1)
1	25.7	36.0
2	36.0	42.9
3	42.9	47.5
4	47.5	50.7
5	50.7	52.8
6	52.8	54.2
7	54.2	

Regression Statistics	
Multiple R	0.999987
R Square	0.999974
Adjusted R Square	0.999968
Standard Error	0.039173
Observations	6

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	18.7018	0.074708	250.3308	1.53E-09
L(t)	0.672493	0.001713	392.5672	2.53E-10

The estimates of coefficients in the regression model obtained through the regression analysis are a = 18.7018 and b = 0.672493. Thus the estimates of growth parameters are

$$\hat{K} = -\frac{\ln(\hat{b})}{\Delta t} = -\frac{\ln(0.672493)}{1} = 0.3968 \text{ and } \hat{L}_{\infty} = \frac{\hat{a}}{(1-\hat{b})} = \frac{18.7018}{(1-0.672493)} = 57.1$$

Method of Chapman and Gulland: When Δt is constant, using the growth equation we can make the relation

$$L_{t+\Delta t} - L_t = c\, L_{\infty} - c\, L_t \text{ where } c = 1 - e^{-K\,\Delta t}$$

Through a regression of $(L_{t+\Delta t} - L_t)$ on L_t we can arrive at a regression relation of the form $y = a + b\,x$ and using the estimates of coefficients of this regression equation we can estimate the growth parameters as

$$\hat{L}_{\infty} = -\frac{\hat{a}}{\hat{b}} \text{ and } \hat{K} = -\frac{\ln(1+b)}{\Delta t}$$

Example: For the given data first we generate a column with values L(t+1)-L(t) and regress these values on L(t) to obtain the constants a and b in the linear regression equation.

Regression Statistics	
Multiple R	0.999945
R Square	0.999891
Adjusted R Square	0.999863
Standard Error	0.039173
Observations	6

	Coefficients	Standard Error	t Stat	P-value
Intercept	18.7018	0.074708	250.33083	1.528E-09
L(t)	-0.32751	0.001713	-191.182	4.49E-09

The estimates of a and b from the regression analysis are a = 18.7018 and b = -0.32751. The corresponding estimates of growth parameters are

$$\hat{L}_\infty = -\frac{\hat{a}}{\hat{b}} = -\frac{18.7018}{-0.32751} = 57.1 \text{ and } \hat{K} = -\frac{\ln(1+b)}{\Delta t} = \frac{-\ln(1-0.32751)}{1} = 0.3968$$

ELEFAN – Electronic Length Frequency Analysis

The first component ELEFAN-I in the system of ELEFAN is the program for estimation of growth parameters from length frequency data. It was first developed in 1978 and it consisted of (i) component for separation of samples into normally distributed components (ii) estimation of growth parameters by generating the growth curve and minimizing the sum of squared deviations from the means of the component distributions. Later versions incorporated an algorithm which by passes the sample separation step and fits the growth curve to peaks defined independently of any assumed underlying distribution.

- Data pre-processing: ELEFAN-I uses a simple high-pass filter to identify peaks and troughs in length frequency data. The high pass filter used is a running average over 5 classes which leads to the definition of peaks as those parts of the length frequency distribution that are above the corresponding moving average and those below the corresponding running average are the thoughs separating peaks.
- Steps involved in fitting of the growth curve in ELEFAN-I are
  i. Calculate the maximum sum of points available in a set of length frequency samples. These are points which can be accumulated by one singe growth curve. It is termed as available sum of peaks (ASP).
  ii. Trace through the set of length frequency tables sequentially arranged in time for any arbitrary input of growth parameters L_∞ and K. A series of growth curves starting from the base of each of the peaks are then projected forward

and backward in time to meet all other samples or the same sample again and again.

iii. Accumulate points obtained by each growth curve when passing through the troughs separating peaks.

iv. Select the curve which pass through most peaks and avoid most troughs and accumulate the largest number of points called Explained Sum of Peaks (ESP).

v. Decrement or increment the values of L_∞ and K until the ratio ESP/ASP reaches a maximum.

The growth model used in ELEFAN-I is the seasonally oscillating version of the generalized von Bertalanffy Growth Function (VBGF) of the form

$$L_t = L_\infty[1 - \exp(-KD(t - t_0) + \frac{CKD}{2\pi} Sin(2\pi(t - t_s))]^{\frac{1}{D}}$$

where

L_t is the predicted length at age t.

L_∞ is the asymptotic length

K is the growth constant – stress factor by Pauly 1981.

D is another growth constant – termed as surface factor by Pauly 1981

C is a factor that express the amplitude of the growth oscillations.

t_0 is the age at which the fish would have had zero length

t_s sets the beginning of the sinusoidal growth oscillation with respect to t = 0

In ELEFAN-I the model is used with two of the original parameters replaced (i) t_s with winter point WP and (ii) t_0 is described as a factor used to adjust a growth curve to an absolute age scale. Here a parameter "T0" is internally used to fulfil the role of t_0. Winter point WP designates the period of the year, expressed as a function of a year when growth is slowest. In northern hemisphere WP is often found to be near 0.2 (February) while for the southern hemisphere WP is often a value close to zero. The relation between WP and t_s is

$$t_s + 0.5 = WP$$

When D = 1 and C = 0 the model will take the form of the normal VBGF used for fisheries research. When 0 < C < 1 growth oscillates seasonally and when C > 1 growth oscillates strongly.

ESTIMATION OF MORTALITY

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Fish as a natural resource follows most of the established behavior expected of ay similar animal. The birth and ensuing recruitment, growth, reproduction and death, technically referred to as mortality are well defined phases of any animal's life time and fishes are no exceptions to this. As is evident from its logic, fish populations increase in their abundance, popularly termed as biomass, by birth of animals or by growth apart from occasional immigrations. The loss of animals is mostly through death (mortality) which could occur due to ageing, natural mortality, or due to fishing, fishing mortality apart from the predation inflicted by larger animals in the sea. Hence mortality phenomenon happens to be the single most important cause of change in abundance of fish in any defined population or technically referred to as stock. By its sheer importance as the leveling force in face of animals with varying degrees of reproduction, mortality assumes an important position in the study of dynamics or fluctuations in the biomass of a given resource. Like its growth counterparts mortality too has well laid conceptualization coupled with clearly defined procedures of measurement or technically termed as estimation. Thus the phenomenon of rate of loss of animals in a particular population is a parameter to be estimated with the sampled animals. The measurements taken from the sampled individuals help an assessor to find out the composition of fish available at various ages and such information collected over a period of time will enable the observer to find out the rates at which fish of a particular age die due to natural and unnatural causes.

The inevitability of the mortality phenomenon can be understood by the fact that for a group of contemporarily hatched fish the number can only dwindle over time. The contemporaries or those individuals who were hatched almost at the same epoch are technically termed as cohorts. The phenomenon of mortality applies to each such group of cohorts and how they decline in number through time. To clearly delineate this process of decline in numbers it is essential to follow the fate of the cohort. As mentioned earlier cohort is a batch of fish of all of approximately the same age and belonging to the same stock. (Sparre and Venema 1998). All fish of a cohort are assumed to have the same age at given time so that they all attain the recruitment age at the same time. In the context of mortality one is interested in the number of survivors from a cohort as a function of age. As mortality is split into natural and fishing induced ones, estimating the mortality entails the determination of total mortality (natural

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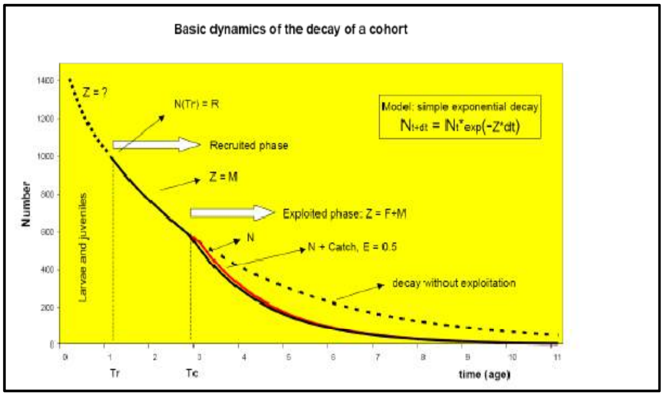
mortality + fishing mortality) first and then splitting this into natural and fishing mortalities as appropriate.

The progress of a cohort over time is displayed below in figure. In a cohort model it is assumed that R individuals are recruited into the fishery at the age t_r (denoting age at recruitment). From this age fish are exposed to some degree of natural mortality ,M. After certain time these fish are exposed to fishing at age t_c (age at first capture) denoted by F for fishing mortality. At some point tmax the older fish are not vulnerable to fishing. This setup assumes an all or none type of selection popularly referred to as knife edge selection, whereby at tc either none or all fish in an age class are either recruited or not or vulnerable or not, and once vulnerable all age classes are vulnerable. (Sparre and Venema 1992)



Dynamics of a Cohort

The dynamics of similarly aged fish of a stock are assumed to follow the model of natural decay, whereby the reduction in numbers due to total mortality is an exponential function of the number of cohorts at the beginning of the period. Notationally the rate of change in numbers or number of losses or number of animals died in a small epoch is given by the following equation

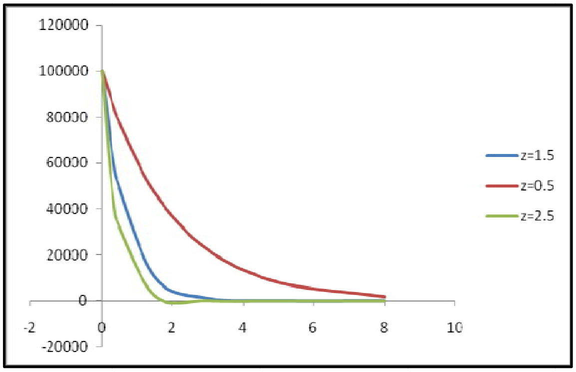
$$\frac{\Delta N(t)}{\Delta t} = -Z * N(t)$$

where the deltas indicate the change in numbers and a small interval of time, say one day or week etc. Z is the coefficient of reduction or popularly known as rate of annual instantaneous mortality usually scaled to account for one year. N(t) indicates the number of individuals alive at time t, preferably converted to years. This total mortality is supposed to be the arithmetic sum of natural mortality M and fishing mortality F. Notational depiction is as follows.

$$Z=M + F$$

A gentle mathematical juggling would yield the number of individuals alive at time t which follows the time of recruitment of the cohorts into the fishery at Tr could lead to an equation

N(t)=N(Tr)*exp(-Z(t-Tr)). That is the number of individuals available at the present time in years is a function of the difference between the time at recruitment and the present



time and also the number of live individuals at the time of recruitment. Of course this whole relationship assumes that the rate of instantaneous mortality Z remains constant throughout. As a corollary it can be said that higher the value of Z the faster would be the decline in numbers and the lower would be the maximum age.

As an example let us look at a case where the recruitment number N(Tr) of a cohort is 1,00,000 and total instantaneous mortality Z = 1.5 per year. Assuming Δt as one day that is 1/365th of a year then, the number of survivors at different time intervals is given in the table.

Age of cohorts (t years)	Time interval in years	Number of survivors (N(Tr)*exp(-Z*(t-Tr)))
tr	0	100000
tr+ one day	0.00274	99590
tr+0.2	0.2	74082
tr+0.3	0.3	63763
tr+0.4	0.4	54881
tr+0.4+one day	0.40274	54656
tr+1.5	1.5	10540
tr+3.0	3	1111
tr+5.0	5	55
tr+8.0	8	1

As it can be seen that the loss is very severe in the initial phases as compared to the last stage like 8 years whereby the cohorts effectively vanish. The steepness depends upon the value of Z and it is better depicted in the following chart.

As is evident the decline is the steepest in the z=2.5 case and it is the slowest in z=0.5 case. The X axis indicates the time gap after Tr in years and the Y axis entries indicate the number of surviving animals.

After the animals obtain age of first capture they are most vulnerable to fishing mortality, whereas upto the age of recruitment the decline in numbers is mostly due to predation or disease ie natural mortality. Assuming that Z=F+M, the number of cohorts caught in a period from t1 to t2 in years is expressed as the function of total and fishing mortality as follows.

$$C(t1,t2)=F/Z*[(N(t1)-N(t2)]$$

Wherein N(t1) and N(t2) are the animals available at time periods t1 and t2. This equation is of extreme importance in fish stock assessment and is famously referred as Baranov's equation or Catch Equation. The fraction F/Z is also very important from assessment point of view and is popularly referred to as "Exploitation Rate". At the same period the number of animals dying due to natural causes is

D(t1,t2)= M/Z*[N(t1)-N(t2)]

The catch equation can be rewritten by involving the number of individuals at the beginning ie t1 as follows:

C(t1,t2)= N(t1)*F/Z*(1-exp(-Z(t2-t1)))

One major assumption which is the soul of this entire conceptualization is the fact that during the time interval (t1,t2) the situation at the ground is not fluctuating enough to influence the mortality rates, F and M. But criticisms are always possible on the count that natural mortality rates tend to differ with aging and younger fishes which are possibly smaller in size are less prone to fishing mortality as compared to their older counterparts.

Another conceptualization based on catch equation is the "Average number of survivors during the time period (t1,t2)" which is given by

$$\bar{N}(t1,t2) = N(t1) * \frac{1 - e^{-Z*(t2-t1))}}{Z * (t2 - t1)}$$

Estimation of Total Instantaneous Mortality (Z)

a) From Catch Rates

There are very many ways of estimating Z from the data collected from research fishery. One such method is the method based on catch rates or Catch Per Unit Effort (CPUE) which is the ratio of total quantity of fish caught to the total number of units of gear utilized to catch the same. When the fish are caught with the same gear whose catchability coefficient (q) with respect to a particular resource is constant, the proportion of surviving members of the cohorts at two time periods (t1,t2) is equal to the ratio of the catch rates at the two time periods recorded by exploratory survey. That is

$$\frac{N(t2)}{N(t1)} = \frac{CPUE(t1)}{CPUE(t2)}$$

A slight modification of the catch equation would lead to the following relationship when the number of cohorts available at the time limits vizN(t1) and N(t2) are known.

$$Z = \frac{1}{t2 - t1} * \log\left(\frac{N(t1)}{N(t2)}\right)$$

Using the previous two relationships it can be derived

$$Z = \frac{1}{t2 - t1} * \log\left(\frac{CPUE(t1)}{CPUE(t2)}\right)$$

When the data available pertains to commercial fisheries, where the time series is on quarterly or annual basis, the equation used could be similar to the one described previously and the CPUE is calculated as the catch of cohort during the period (t1,t2) divided by the effort during that period. The catch rate can then be expressed as the product of average number of survivors in the period (t1,t2) and the catchability coefficient of the gear.

b) Heincke's method

Assuming that mortality rate (Z) is constant throughout the life of an individual, the following equation holds based on certain algebraic norms.

$$Z = -\ln\ (\textstyle\sum_{t=1}^{\infty} N(t) / \sum_{t=0}^{\infty} N(t)$$

which is called the Heincke's equation. In plain words the mortality rate is the negative value of the ratio between the number of surviving individuals from age 1 to those surviving from age 0. Substituting CPUE's at each year in the place of N(t)'s this equation assuming that they are proportional the same reads as

$$Z = -ln\frac{CPUE(1) + CPUE(2) + CPUE(3\ and\ above)}{CPUE(0) + CPUE(1) + CPUE(2) + CPUE(3\ and\ above)}$$

c) Robson- Chapman Method

Another estimate of Z is proposed by Robson and Chapman (Sparre&Venema, 1992) and the formula is

$$Z = -ln\frac{N(1) + 2 * N(2) + 3 * N(3) + \cdots}{N(0) + 2N(2) + 3N(2) + 4(N3) + \cdots - 1}$$

d) Linearised Catch Curve Method

Ideally for estimating most of the parameters including the mortality rate, the type of data required is the number of sampled and raised animals belonging to a cohort at various age categories. However in fishery sampling age determination is a time and manpower consuming exercise and invariably aging is done by using the length of the animals sampled and their categories thereof. Here length is used as an alibi for age. Further it is worth recalling that age and length are functionally linked through the Von Bertalanffy Growth Function (VBGF). Using the inversion of the VBGF length can be converted into age. The specific relationship is as follows:

$$t(L)Z = t_0 - \frac{1}{K} * \ln\left(1 - \frac{L}{L_\infty}\right)$$

where t(L) is the age at length L units (cm or mm) and t_0, L_∞ and K are the classical VBGF parameters. Using this in the equation relating the logarithm of catch rate over a small time interval and the mid –time interval which is as follows:

$$\ln\left(\frac{C(t,t+\Delta t)}{\Delta t}\right) = c - Z * (t + \frac{\Delta t}{2})$$

which in turn can be rewritten using the catch and length information as

$$\ln\frac{C(L_1, L_2)}{\Delta t} = c - Z * t\left(\frac{L_1 + L_2}{2}\right).$$

Here the change in time

$$\Delta t \text{ isgiven by } \frac{1}{K} * \ln\left(\frac{L_\infty - L_1}{L_\infty - L_2}\right)$$

Thus from this linear function, the total instantaneous rate of mortality can be estimated as the negative slope. It can be noted that in the previous equations c is a term which is made of constant terms or in other words by terms which are not involving either time or length at different classes.

To put this linearised catch curve method into action, a plot of

$$\ln\frac{C(L_1,L_2)}{\Delta t}\text{against}t\left(\frac{L_1+L_2}{2}\right)$$

has to be made. Only the stable range of t values which are in the fully exploited range of the animal's life and which also is not close to t_∞ (age at maximum length of the animal) must be included for the computation of the coefficients of regression. This procedure is partially subjective which must be given due care.

Example

A worked out example of estimating total instantaneous mortality rate Z from length frequency data is given below.

The case is that of Upeneusvittatus from Manila Bay, Philippines (quoted in Sparre and Venema 1992) and the length intervals and catch numbers of the pseudo cohorts is given below. The VBGF parameters are K=0.59 per year; L_∞=23.1 cm; and t_0=0

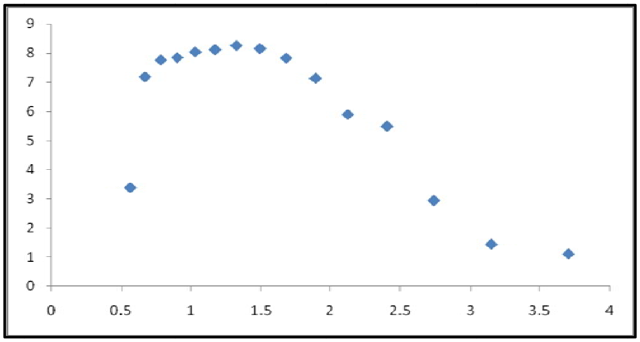
L1-L2	C(L1,L2)	t(L1)	Δt	t(L1+L2)/2	ln(C(L1,L2)/Δt)
6-7	3	0.51	0.102	0.56	3.381395
7-8	143	0.612	0.109	0.665	7.179252
8-9	271	0.721	0.116	0.778	7.756284
9-10	318	0.837	0.125	0.898	7.841493
10-11	416	0.961	0.135	1.027	8.033166
11-12	488	1.096	0.146	1.168	8.114464
12-13	614	1.242	0.16	1.32	8.252576
13-14	613	1.402	0.177	1.488	8.14997
14-15	493	1.579	0.197	1.675	7.825061
15-16	278	1.776	0.223	1.884	7.128205
16-17	93	2	0.257	2.123	5.891279

17-18	73	2.257	0.303	2.402	5.484482
18-19	7	2.56	0.37	2.735	2.940162
19-20	2	2.93	0.474	3.151	1.439695
20-21	2	3.404	0.66	3.702	1.108663
21-22	0	4.064	1.096	4.525	-
22-23	1	5.16	4.064	6.188	-1.40217
23-24	1	-	-	-	-

To select the most appropriate portion of the length intervals a plot of

$\ln \frac{C(L_1,L_2)}{\Delta t}$ against $t\left(\frac{L_1+L_2}{2}\right)$

is made and in the above case it looks like this:



As is evident from the scatter the first 7 observations and the last two observations do not follow the steady fall pattern and hence can be avoided. So only the points in the mean time range 1.5 to 3.15 are considered for estimating the regression coefficients. In this present case the estimated slope is -4.19433 and hence the estimated Z rate is 4.19.

e) The cumulated catch curve method

Another approach to estimate Z from length frequency data is the Cumulated Catch Curve method propounded by Jones and Van Zalange. The main difference here is in the time range (t1,t2) t2 is assumed to be very large to be near ∞ and that would lead the linearised catch curve equation to become

LnC(t, ∞)=d- Z*t where C(t, ∞) is called cumulated catch curve equation. Then the Jones and Van Zalinge equation for length converted catch curve would be

$$\ln\left(C(L, L_\infty)\right) = a + \frac{Z}{K}\ln\left(L_\infty - L\right)$$

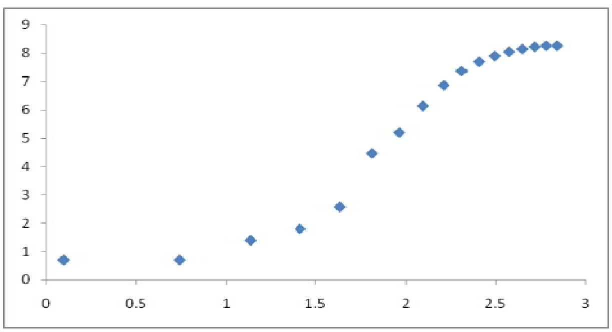
After selecting the appropriate portion of the scatter between

$$\ln\big(C(L, L_\infty)\big) \text{and } \ln\left(L_\infty - L\right).$$

Then from the slope the Z is estimated as slope * K. For the previous example the cumulated catch curve approach is done as follows:

L1-L2	C(L1,L2)	C(L1,L∞)	ln(C(L1,L∞))	ln(L∞-L1)
6-7	3	3816	8.246958	2.839078
7-8	143	3813	8.246172	2.778819
8-9	271	3670	8.207947	2.714695
9-10	318	3399	8.131237	2.646175
10-11	416	3081	8.033009	2.572612
11-12	488	2665	7.887959	2.493205
12-13	614	2177	7.685703	2.406945
13-14	613	1563	7.354362	2.312535
14-15	493	950	6.856462	2.208274
15-16	278	457	6.124683	2.091864
16-17	93	179	5.187386	1.960095
17-18	73	86	4.454347	1.808289
18-19	7	13	2.564949	1.629241
19-20	2	6	1.791759	1.410987
20-21	2	4	1.386294	1.131402
21-22	0	2	0.693147	0.741937
22-23	1	2	0.693147	0.09531
23-24	1	1	0	-2.30259

The plot based on the last two columns is shown here. From the plot it can be seen that the most appropriate range to be used for estimating the slope is the x range from 1.41 to 2.31 and the corresponding slope value is 6.51. Hence the estimated Z rate = Slope*K= 6.51* 0.59= 3.84.



f) Beverton and Holt's Z-equation based on length data

Beverton and Holt (Sparre and Venema 1992) have shown that there exists a functional relationship between Z and the average length of fish $\bar{L}$ which is given by

$$Z = K * \frac{L_\infty - \bar{L}}{\bar{L} - L'}$$

where L′ is some length for which all fish of that length and longer are under full exploitation and it is the lower limit of the class interval of lengths from which point full exploitation is presumed.

For example if the VBGF parameters of a cohort are K=0.45 per year and L_∞ = 100 cm and if it is assumed that L′=45 cm then the Z estimates for the following data are as given below:

Length Group	Mid Length	N(1960)	N(1970)	N(1980)	N(1960)*Mid Length	N(1970)*Mid Length	N(1980)*Mid Length
45-50	47.5	256	268	212	12160	12730	10070
50-55	52.5	237	226	161	12442.5	11865	8452.5
55-60	57.5	211	180	116	12132.5	10350	6670
60-65	62.5	187	141	79	11687.5	8812.5	4937.5
65-70	67.5	161	105	52	10867.5	7087.5	3510
70-75	72.5	138	76	31	10005	5510	2247.5
75-80	77.5	113	50	17	8757.5	3875	1317.5
80-85	82.5	87	30	8	7177.5	2475	660
85-90	87.5	62	15	3	5425	1312.5	262.5
90-95	92.5	36	6	1	3330	555	92.5
95-100	97.5	12	1	0	1170	97.5	0
	Sum	1500	1098	680	95155	64670	38220
	$\bar{L}$				63.43667	58.898	56.20588

Where N(1960) indicates numbers caught in year 1960 and so on. The mean length here is a weighted average of the lengths detailed.

Based on these figures the Z values for various years are as follows:

$$Z(1960)=0.3 * \frac{100-63.44}{63.44-45} = 0.6 \text{ per year}$$
$$Z(1970)=0.3 * \frac{100-58.90}{58.90-45} = 0.9 \text{ per year}$$
$$Z(1980)=0.3 * \frac{100-56.21}{56.21-45} = 1.2 \text{ per year}$$

g) Power- Wetherall method

As a special application of the Beverton- Holt's Z- equation it can be expressed that

$\bar{L}$=a + b*L′ where Z/K=-(1+b)/b and L_∞=-a/b or alternatively

b=-K/(Z+K) and a=-b* L_∞

This means that plotting $\bar{L}$ -L′ against L′ gives the estimates of a and b and from them the parameters L_∞ and Z can be estimated.

h) Pauly's empirical equation for Natural Mortality Estimation

Pauly (Sparre and Venema 1992) made regression analysis to functionally link natural mortality M with VBGF parameters and climatic parameters and the empirical formula arrived by him is given below:

Rate of Natural Mortality per Year (M)= $-0.0152-0.279*\ln L_{\infty}+0.6543*\ln K+0.463*\ln T$
where T is the average annual temperature at the surface in degrees centigrade.

The following table gives the estimates of natural mortality for various combinations of T and VBGF parameters.

T=5°C					T=25°C			
L∞	K=0.1	0.5	1.0	2.0	0.1	0.5	1.0	2.0
10	0.24	0.7	1.1	1.7	0.51	1.5	2.3	3.6
80	0.14	0.38	0.6	1.0	0.29	0.8	1.3	2.0
200	0.10	0.30	0.47	0.7	0.22	0.6	1.0	1.6

Method of Computing

The above discussed methods of estimating rates of mortalities can be implemented practically either by manual means (highly exhausting) or by using computer based spread sheets or by software custom made for this purpose.

Suggested Reading

Sparre, P and Venema, S.C (1992) Introduction to Tropical Fish Stock Assessment. Part 1.Manual, FAO Fisheries Technical Paper No. 306.1, Rev. 1., Rome.376 p.

ESTIMATION OF LENGTH WEIGHT RELATIONSHIP IN FISHES

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17

Organisms generally increase in size (length, weight) during development. The key factors that influence the growth of fish are the quantity of food available, the number of fish utilizing same food source, temperature, oxygen and other water quality factors besides the size, age and sexual maturity of the fish. Every animal in its life exhibit growth both in length and in weight and the relationship between these two has both applied and basic importance. The length-weight relationship is one of the standard methods that yield authentic biological information and is of great importance in fishery assessments. It establishes the mathematical relationship between the two variables, length and weight, and helps in assessing the variations from the expected weight for the known length groups. This is particularly useful for computing the biomass of a sample of fish from the length-frequency of that sample. The parameter estimates of the relationship for a population of fish can be compared to average parameters for the region, parameter estimates from previous years, or parameter estimates among groups of fish to identify the relative condition or robustness of the population. Relationship between length and weight is required for setting up yield equation and sometimes it may be useful as a character to differentiate "small taxonomic units". It also helps in converting one variable into another. Of the two, length is easier to measure and can be converted into weight in which the catch is invariably expressed. The length weight relationship also provides means for finding out the "condition factor" and the seasonal changes in the condition factor are useful to determine the biological changes in the fish.

Length-weight relationship -uses

- to convert growth-in-length equations to growth-in-weight, for stock assessment models;
- for the estimation of the biomass of a species from length frequency distributions
- to calculate an estimate of the condition of fish; and
- for life history and morphological comparisons of life histories of a certain population from different regions

The relationship between weight (W) and length (L) in fishes has the form:

$W=aL^b$

Reprinted from the CMFRI, FRAD. 2014. Training Manual on Fish Stock Assessment and Management, p.150.

In this equation, the parameters ***a*** and ***b,*** usually termed as length weight parameters are to be estimated with the available length-weight data. Each species of fish will have a specific length-weight relationships or specific length - weight parameters. It may also differ between sexes and between stocks or those belonging to different geographical regions. The parameter ***a*** is a scaling coefficient for the weight at length of the fish species. The parameter ***b*** is a shape parameter for the body form of the fish species.

The length of a fish is often measured more accurately than the weight.

In theory, one might expect that the exponent ***b*** would have a value of roughly ***b*** = 3 because the volume of a 3-dimensional object is roughly proportional to the cube of length for a regularly shaped solid. Length is one dimensional whereas weight which depends on volume is three dimensional. Hence, there is thinking that weight of a fish is proportional to cube of the length of the fish. That is, there exists cubic relationship between weight and length of a fish. For an ideal fish which maintains the same shape b=3. Most species of fish do change their shape as they grow and so a cube relationship between length and weight would hardly be expected. It has also been found that while b may be different for fish from different localities, of different sexes, or for larval, immature and mature fish, it is often constant for fish similar in these respects. The length-weight relationship may thus be a character for the differentiation of small taxonomic units, like any other morphometric relationship. It may also change with metamorphosis or the onset of maturity.

In practice, fish that have thin elongated bodies will tend to have values of ***b*** that are less than 3 while fish that have thicker bodies will tend to have values of ***b*** that are greater than 3. Thus this also help to determine whether somatic growth is isometric (b=3) or allometric. Values of b smaller, equal and larger than 3 indicate isometry, negative allometry and positive allometry respectively. When $b>3$, large specimens increase in height or width faster than in length, either as the result of a change in body shape with size, or because the large specimens in the sample are in better condition than the small ones. Conversely, when $b<3$, either the large specimens have changed body shape, i.e., become more elongated, or the small specimens were in better nutritional condition at the time of sampling.

Thus the growth of fish length and weight is not proportionate or the relationship between length and weight is not linear. This means that when the length is increased the increase in weight is not proportionate to it. It is rather non-linear type of relationship. The estimation procedure for length – weight relationship is through linear regression. Since the above model of length-weight relationship is not linear it has to be transformed into linear type by applying logarithmic transformation.

If we take logarithm (*natural logarithm with base e*) the above model will become linear as

In (W) = In (a) + b In (L) or $Y = A + b X$

where ln(a) is the intercept and (b) the slope or regression coefficient.

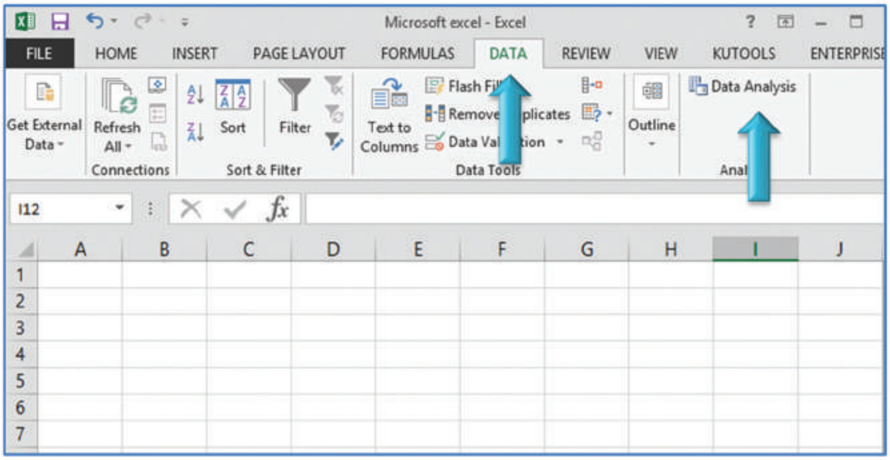
The above relationship is now linear and we can use the ordinary linear regression method for estimating the parameters of the relationship.

Data for fitting the length-weight relationship is collected randomly from the commercial catches and should represent fishes of all sizes, smallest to the biggest, and there should be enough samples for the analysis and estimation through regression. If our aim is to examine difference in length weight relationship between different sexes then data should be collected separately for males and females.

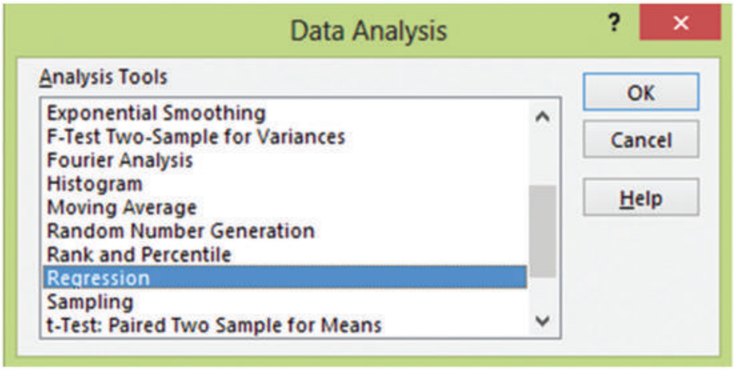
Regression Analysis for Estimation of Length Weight Parameters

We can use Microsoft Excel to do the analysis using the regression analysis tool.

Select Data from the Main Menu and Select Data Analysis

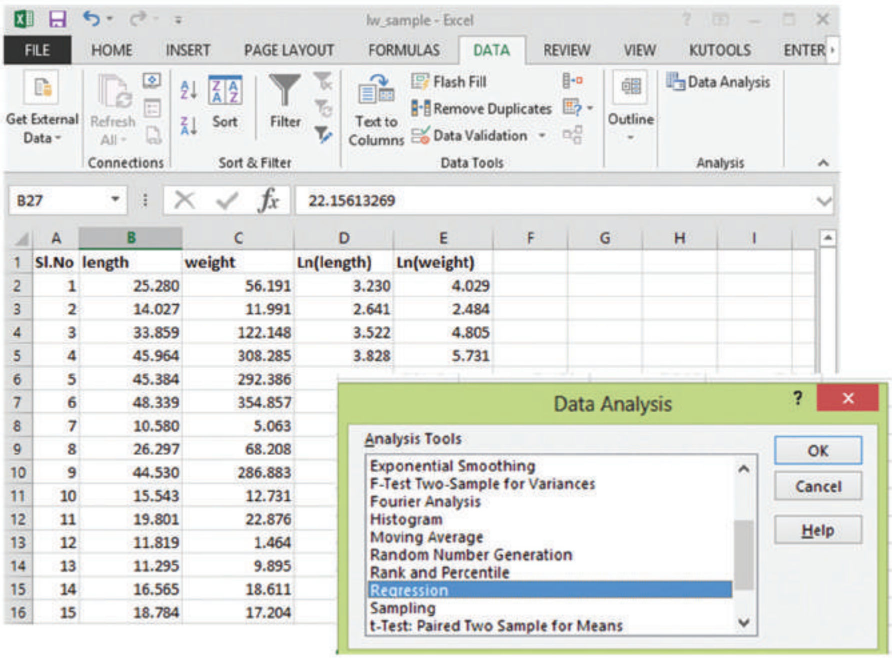


Select 'Regression' from the 'Data Analysis' dialog box and click OK.



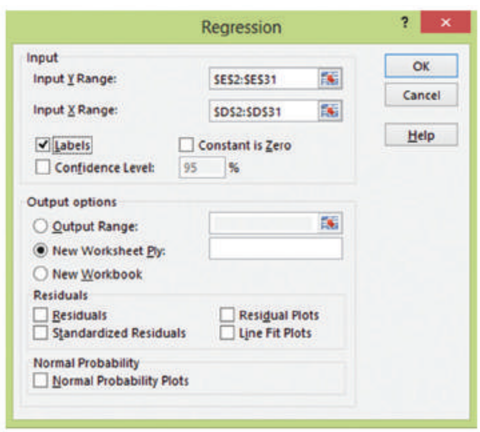
The following example demonstrates the use of this tool for estimation of length weight parameters.

Enter the data on length and weight of samples in two columns as shown in below. Generate two columns as the logarithmic values of the length and weight by using the natural logarithm function 'ln'. The transformed data will be used for estimation of parameters. To run the regression routine select **Data** from the main menu, and select **Data Analysis**. Again select Regression from the dropdown menu.

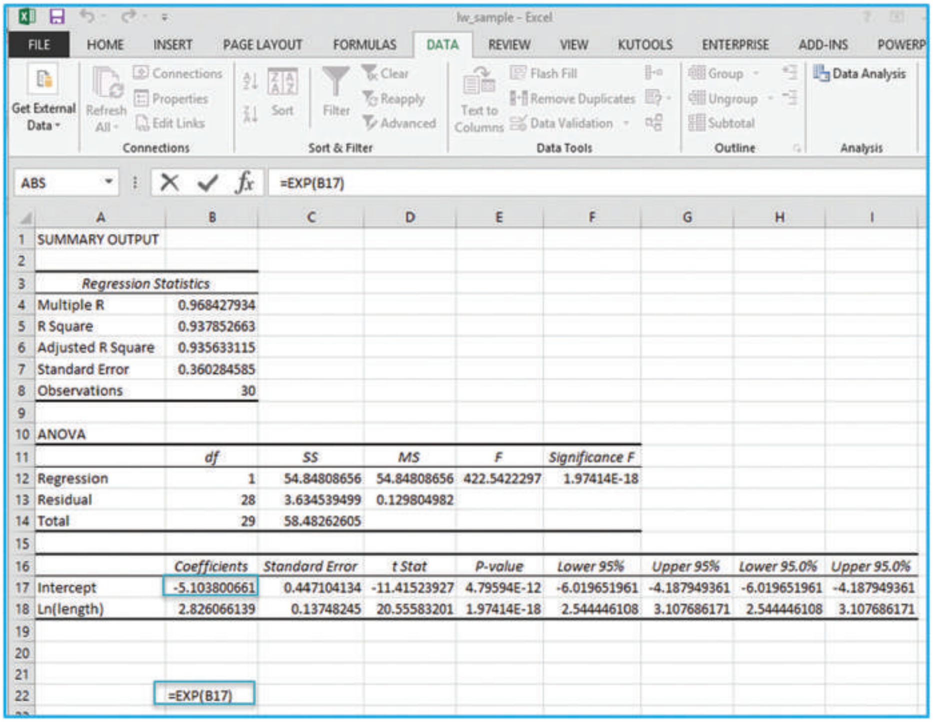


You will be presented with the following dialog box:

Specify the cells containing log transformed weight data and label for "Input Y Range:" (E21:E31). For "Input X Range:" specify the cells containing log transformed length data and label (D21:D31). Check the "Labels" box (since you included data labels in your input ranges), select the New Worksheet Ply under "Output options" and click OK.



The output will be obtained in a new sheet as given below.



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.968427934
R Square	0.937852663
Adjusted R Square	0.935633115
Standard Error	0.360284585
Observations	30

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	54.84808656	54.84808656	422.5422297	1.97414E-18
Residual	28	3.634539499	0.129804982		
Total	29	58.48262605			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-5.103800661	0.447104134	-11.41523927	4.79594E-12	-6.019651961	-4.187949361	-6.019651961	-4.187949361
Ln(length)	2.826066139	0.13748245	20.55583201	1.97414E-18	2.544446108	3.107686171	2.544446108	3.107686171

=EXP(B17)

The output will give regression statistics, ANOVA and the estimates of coefficients. The estimate of parameter 'a' is calculated from the value given against intercept and the estimate of parameter 'b' is that given against Ln(length) coefficient (here it is the value against 'ln(Length)' which is 2.826). The estimate of 'a' is calculated as the exponent of the intercept value which can be obtained by using the '**exp'** function. For example here the intercept value is in cell B17 and to obtain the estimate of 'a' in a blank cell use the function '=exp(B17)' and we get the value of a as 0.00607.

The goodness of fit of the regression model is indicated by the 'R square' value in the output. It should be high for the relationship fitted to be good. In the example it is 0.96 indicating a good fit. The maximum value of 'R square' is 1.0 and the minimum is zero.

Using the estimated values of the parameters and the original data we can calculate the expected values of weight for the lengths in the sample data. This is done by substituting the estimated values in the relationship $W = a\,L^b$ and calculating the weights corresponding to each length in the sample.

Statistical Test for b=3 (Isometric Relationship)

In statistical test of hypothesis this is testing for the null hypothesis H_0 : b =3 against the alternative hypothesis H_1 : $b \neq 3$. The test criterion for this statistical test is a Student's t statistic with (n-2) degrees of freedom where n is the total number of observations.

Since this test criterion is for a linear regression, for the length-weight relationship situation we should use the log transformed values for the X and Y variables. Therefore, X values are the log transformed values of length and Y values are the log transformed values of the weights.

The test statistics for this is

$$t_{n-2} = \frac{(b-3)\sqrt{(n-2)\sum_{i=1}^{n}(x_i-\bar{x})^2}}{\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2 - b^2\sum_{i=1}^{n}(x_i-\bar{x})^2}}$$

This value has to be compared with the table value of t for n-2 d.f for making inferences about the null hypothesis.

If the value of Student's t is higher than the calculated value, we accept the null hypothesis that b=3. In that case we infer that the length weight relationship is said to be isometric or there is cubic relationship between length and weight.

The length-weight relationship in fishes can be affected by a number of factors including season, habitat, gonad maturity, sex, diet, and stomach fullness, health and preservation techniques, and differences in the length ranges of the specimen caught. The exact relationship between length and weight differs among species of fish according to their inherited body shape, and within a species according to the condition (robustness) of individual fish. Condition sometimes reflects food availability and growth within the weeks prior to sampling. But, condition is variable and dynamic. Individual fish within the same sample vary considerably, and the average condition of each population varies seasonally and yearly.

THOMPSON & BELL PREDICTION MODEL

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Prediction or predictive models predict the effect of different levels of fishing effort on the fish stocks in the future. Two prediction models that are widely applied are Thompson and Bell (1934) model and the Yield per recruit model developed by Beverton and Holt (1957). These models provide a direct link between fish stock assessment and fishery resource management. The Thompson & Bell Model is a widely used prediction model in assessing the optimum factor for increase or decrease of fishing effort to achieve maximum sustainable and economic yield of a commercially exploited species. This model builds on the output of age (as conceived in the original model) or length-based Virtual Population Analysis (VPA). The equations used for the VPA and cohort analysis can be transformed to predict future yields and biomass at different levels of fishing efforts; *i.e.*, the knowledge of the past fishery can be used to predict the future yields.

While predicting the impact of fishing intensity on yield and standing stock biomass of an exploited species in a geographic area, the Thompson and Bell model can add a third dimension – price – to the assessment profile through bioeconomic analysis, which can be done if value of the catch is provided as an input. The input parameters required for this model are

- L_1, L_2...L_n (length groups)
- K (annual growth coefficient – VBGF parameter)
- t_0 (age at zero length – VBGF parameter)
- L_∞ (asymptotic length – VBGF parameter)
- M (Natural mortality)
- Terminal F/Z (assumed to be 0.5)
- a (intercept of LWR)

- b (slope of LWR)
- Catch (in numbers) for each length group
- Yield and biomass output of Virtual Population Analysis
- Price

The output of the Thompson & Bell analysis are the predictions of catch in numbers, total deaths in numbers, the mean biomass and yield for a combination of different F and M values. The prediction made by length converted Thompson and Bell analysis is a prediction of the average long-term catches assuming recruitment to remain constant. The impact of changes in F on the yield, average biomass and value of the catch can be calculated to arrive at the Maximum Sustainable Yield (MSY) and Maximum Economic Yield (MEY). The assumption in this method is that the stock remains in a steady state and all parameters, including recruitment remain constant.

The FiSAT package contains the Thompson and Bell yield and stock prediction for single/multispecies fisheries, and is perhaps the most widely used programme in India.

The LFSA package has two programmes, the TBYR and MIXFISH. The TBYR uses a special version of the Thompson and Bell yield and stock prediction model for the single stock, single fishery situation. The TBYR converts the stock estimates (in numbers) for length groups derived through LCOHOR analysis into age group stock estimates. This programme is better suited for long-lived species of 5 years or more since conversion of length groups to age groups in short-lived species is not easily done. MIXFISH is a length-based Thompson and Bell model with options for analysis of a mixed fishery. An advantage over the TBYR is that there is no need for conversion of length groups to age groups, and therefore it can be used for long-lived as well as short-lived species. Although designed for analysis of a mixed fishery, the MIXFISH also contains the single species analysis options as well as an option for mesh assessment. The output of MIXFISH indicates the total yield for various combinations of effort and L_{50}%.

Using the length-based Thompson & Bell model

Taking off from the output of length-based VPA, the steps involved in the Thompson & Bell analysis are –

- The i^{th} length class is

  $(L_i - L_{i+1})$

- Total mortality sequence is

  $Z_i = M + xF_i$, , where x is the multiplier used to raise or reduce the fishing mortality rates sequence, x = 1 for the current level of exploitation

- Population size of successive classes is

$$H_i = \left[\frac{L_\infty - L_i}{L_\infty - L_{i+1}}\right]^{\frac{M}{2K}}$$

$$N_{i+1} = N_i \left[\frac{\frac{1}{H_i} - x\frac{F_i}{Z_i}}{H_i - x\frac{F_i}{Z_i}}\right]$$

- Catch for each class is

$$C_i = [N_i - N_{i+1}]x\left(\frac{F_i}{Z_i}\right)$$

$$\overline{w_i} = a\left[\frac{L_i + L_{i+1}}{2}\right]^b$$

- Average weight for each length class is

$$Y_i = C_i\overline{w_i}$$

- Yield for each different length class is

$$V_i = Y_i\overline{v_i}$$

- Value for each length class is

$$\overline{N_i} = \frac{N_i - N_{i+1}}{Z_t \Delta t_i}$$

Using Excel for Thompson & Bell Analysis through Length-based Cohort Analysis

Vivekanandan (2002) discusses an example of the length-based Thompson and Bell analysis by using the data on the goatfish *Upeneus sulphureus* off Chennai and the price of different length groups of *U. sulphureus* in the landing center. In a later publication (Vivekanandan, 2005) uses the same example, but with more details on the method of analysis. The use of excel for Thompson & Bell analysis using the same data set is shown here –

The sample data set is **Length groups of goatfish *U. sulphureus* off Chennai during 2000.** The input data for Thompson & Bell analysis will be the output from length-based Virtual Population Analysis:

Length group (mm)	Fishing mortality	M factor	Total mortality	Mean body weight (g)	Number of survivors (000s)	Number caught (000s)	Yield (tonnes)	Mean biomass (tonnes)
50-59	0.6310	1.0498	1.5310	2.3	79073	4972	11.4	18.1
60-69	1.1775	1.0541	2.0775	3.7	67009	8218	30.4	25.8
70-79	1.4788	1.0592	2.3788	5.7	52510	8587	48.9	33.1
80-89	1.3861	1.0654	2.2861	8.3	38697	6476	53.8	38.8
90-99	1.2681	1.0729	2.1681	11.6	28016	4731	54.9	43.3
100-109	1.1779	1.0825	2.0779	15.6	19928	3477	54.2	46.0
110-119	1.0506	1.0950	1.9506	20.4	13794	2426	49.5	47.1
120-129	0.9217	1.1119	1.8217	26.2	9290	1648	43.2	46.8
130-139	0.7202	1.1361	1.6202	33.0	6032	992	32.7	45.5
140-149	0.6545	1.1737	1.5545	40.8	3801	684	27.9	42.6
150-159	0.3087	1.2404	1.2087	49.7	2176	245	12.2	39.4
160-169	0.2226	1.3911	1.1226	59.9	1217	136	8.1	36.6
170-179	0.2041	2.0884	1.1041	71.3	531	83	5.9	29.0
180-L_∞	0.9000	-	1.8000	84.2	82	41	3.5	3.8
Total							436.7	496.1

Step 1

Estimate Value of yield for each length class from per unit price data:

Length group (mm)	Fishing mortality	M factor	Total mortality	Mean body weight (g)	Number of survivors (000s)	Number caught (000s)	Yield (tonnes)	Mean biomass (tonnes)	Value (Rs/kg)	Value of yield (000 Rs)
50-59	0.6310	1.0498	1.5310	2.3	79073	4972	11.4	18.1	5	57.0
60-69	1.1775	1.0541	2.0775	3.7	67009	8218	30.4	25.8	5	152.0
70-79	1.4788	1.0592	2.3788	5.7	52510	8587	48.9	33.1	5	244.7
80-89	1.3861	1.0654	2.2861	8.3	38697	6476	53.8	38.8	5	268.8
90-99	1.2681	1.0729	2.1681	11.6	28016	4731	54.9	43.3	5	274.4
100-109	1.1779	1.0825	2.0779	15.6	19928	3477	54.2	46.0	15	813.6
110-119	1.0506	1.0950	1.9506	20.4	13794	2426	49.5	47.1	15	742.4
120-129	0.9217	1.1119	1.8217	26.2	9290	1648	43.2	46.8	15	647.7
130-139	0.7202	1.1361	1.6202	33.0	6032	992	32.7	45.5	15	491.0

Length group (mm)	Fishing mortality	M factor	Total mortality	Mean body weight (g)	Number of survivors (000s)	Number caught (000s)	Yield (tonnes)	Mean biomass (tonnes)	Value (Rs/kg)	Value of yield (000 Rs)
140-149	0.6545	1.1737	1.5545	40.8	3801	684	27.9	42.6	15	418.6
150-159	0.3087	1.2404	1.2087	49.7	2176	245	12.2	39.4	25	304.4
160-169	0.2226	1.3911	1.1226	59.9	1217	136	8.1	36.6	25	203.7
170-179	0.2041	2.0884	1.1041	71.3	531	83	5.9	29.0	25	147.9
180-L_∞	0.9000	-	1.8000	84.2	82	41	3.5	3.8	25	86.3
Total							**436.7**	**496.1**		**4852.5**

Step 2

Estimate the yield, biomass & value for varying Fishing mortality factors (F-factor). For example, the output shown under Step 1 is for F-factor = 1. The output for F-factor = 0.5 (*obtained by multiplying the fishing mortality of all length classes with 0.5*) will be

Length group (mm)	Fishing mortality	M factor	Total mortality	Mean body weight (g)	Number of survivors (000s)	Number caught (000s)	Yield (tonnes)	Mean biomass (tonnes)	Value (Rs/kg)	Value of yield (000 Rs)
50-59	0.3155	1.0498	1.2155	2.3	79073	2527	5.8	18.4	5	29.1
60-69	0.5888	1.0541	1.4888	3.7	69339	4390	16.2	27.6	5	81.2
70-79	0.7394	1.0592	1.6394	5.7	58238	4971	28.3	38.3	5	141.7
80-89	0.6931	1.0654	1.5931	8.3	47216	4129	34.3	49.4	5	171.4
90-99	0.6341	1.0729	1.5341	11.6	37725	3331	38.6	60.9	5	193.2
100-109	0.5890	1.0825	1.4890	15.6	29667	2711	42.3	71.8	15	634.4
110-119	0.5253	1.0950	1.4253	20.4	22813	2103	42.9	81.7	15	643.4
120-129	0.4608	1.1119	1.3608	26.2	17107	1592	41.7	90.5	15	625.6
130-139	0.3601	1.1361	1.2601	33.0	12407	1067	35.2	97.8	15	528.1
140-149	0.3272	1.1737	1.2272	40.8	8674	820	33.5	102.3	15	502.1
150-159	0.1544	1.2404	1.0544	49.7	5597	325	16.2	104.7	25	404.1
160-169	0.1113	1.3911	1.0113	59.9	3376	195	11.7	104.9	25	292.0
170-179	0.1021	2.0884	1.0021	71.3	1604	132	9.4	92.5	25	235.9
180-L_∞	0.4500	-	1.3500	84.2	304	101	8.5	19.0	25	213.6
Total							**364.7**	**959.8**		**4695.6**

Similarly, the output for F-facto r = 1.5 will be

Length group (mm)	Fishing mortality	M factor	Total mortality	Mean body weight (g)	Number of survivors (000s)	Number caught (000s)	Yield (tonnes)	Mean biomass (tonnes)	Value (Rs/kg)	Value of yield (000 Rs)
50-59	0.9465	1.0498	1.8465	2.3	79073	7340	16.9	17.8	5	84.4
60-69	1.7663	1.0541	2.6663	3.7	64754	11549	42.7	24.2	5	213.7
70-79	2.2182	1.0592	3.1182	5.7	47321	11139	63.5	28.6	5	317.5
80-89	2.0792	1.0654	2.9792	8.3	31662	7619	63.2	30.4	5	316.2
90-99	1.9022	1.0729	2.8022	11.6	20745	5035	58.4	30.7	5	292.0
100-109	1.7669	1.0825	2.6669	15.6	13328	3337	52.1	29.5	15	780.8
110-119	1.5758	1.0950	2.4758	20.4	8291	2091	42.7	27.1	15	639.9
120-129	1.3825	1.1119	2.2825	26.2	5006	1273	33.3	24.1	15	500.1
130-139	1.0803	1.1361	1.9803	33.0	2905	686	22.7	21.0	15	339.8
140-149	0.9817	1.1737	1.8817	40.8	1646	424	17.3	17.6	15	259.4
150-159	0.4631	1.2404	1.3631	49.7	834	137	6.8	14.7	25	169.7
160-169	0.3339	1.3911	1.2339	59.9	432	70	4.2	12.6	25	105.0
170-179	0.3062	2.0884	1.2062	71.3	173	38	2.7	9.0	25	68.6
180-L_{∞}	1.3500	-	2.2500	84.2	21	13	1.1	0.8	25	26.8
Total							**427.6**	**288.0**		**4113.9**

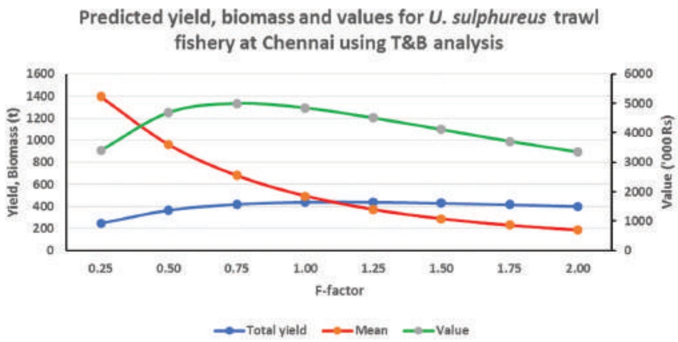
<u>Step 3</u>

Tabulate the predicted total yield, mean biomass and value obtained for a range of F-factors, starting from F-factor = 0. The yield and value will show continuous increase and then a steady decline, while the biomass will show a decline in quantity for increasing F-factors.

F factor	Total yield (tonnes)	Mean biomass(t)	Value (000 Rs)
0	0		0
0.25	245.2	1395.5	3400.9
0.50	364.7	959.8	4695.6
0.75	418.2	680.0	5001.5
1.00	436.7	496.1	4852.5
1.25	436.7	372.6	4513.2
1.50	427.6	288.0	4113.9
1.75	414.1	228.7	3717.8
2.00	399.2	186.3	3353.1

Step 4

The graph generated from the output data is given below. It can be observed that the yield increases from 245.2 t at F-factor of 0.25 to 436.7 t at F = 1.00-1.25 but decreases to 399.2 t at F = 2.00. The Maximum Sustainable Yield, the MSY (436.7 t) is obtained at the current fishing mortality level (F factor = 1.0). The mean biomass drastically decreases from 1395.5 t at F-factor 0.25 to 496.1 t at F-factor 1.00 and further to a mere 186.3 t at F-factor 2.00. The Maximum Sustainable Economic Yield, MEY is obtained at the F-factor 0.75 (Rs.50 lakhs). The interpretation of the results is that the present fishing level provides the MSY and increase in fishing effort will decrease the yield and drastically reduce the biomass. However, since the MEY is obtained at 75% of the present fishing effort, it is advisable to reduce the fishing effort to that level to realise better revenue.



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BEVERTON AND HOLT'S YIELD PER RECRUIT MODEL

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Yield per Recruit (Y/R) is the expected life time yield per fish recruited into the stock at a specified age. The Beverton and Holt's Yield per Recruit model (1957), is a predictive model that can be used by fishery managers to understand the biological / economical effect of fishing on the stocks and helps them to take suitable measures to ensure sustainable yields from the fishery. In the Beverton and Holt (1957) yield equation, the response of a population to fishing mortality on a per-recruit basis depends on natural mortality (*M*), fishing mortality (*F*),growth rate (*K*, from the von Bertalanffy growth equation) and the age (*tc*) at first capture (depends on gear selectivity). A fishery manager will aim at arriving at a combination of measures that will ensure that the fish stocks are exploited at such a level that there is neither growth nor recruitment overfishing, and predictive models employing the Y/R concept enable these decisions. Maximum yield from a cohort can be realised only by exploiting it at an age or size (optimum age or length) at which the cohort's biomass reaches its maximum. Thus, ideally fishery managers should be implementing exploitation strategies that do not harvest fish too early (by restricting catches of juvenile fishes) or too late when most of them would die due to "senility" or similar reasons operated through natural mortality.

The Yield per Recruit model of Beverton and Holt is in principle a "Steady State Model" implying that the model is describing the state of the stock and yield in a situation when the fishing pattern has remain unchanged for a sufficiently long period of time and all the fishes alive have been exposed to it since they recruited. Hence this is based on certain assumptions which are listed below

- Recruitment is constant, though not specified
- All fish in a cohort have hatched on the same day

- knife edge Recruitment (Tr, All fish from a cohort recruit to the fishing ground at the same time) and knife edge Selection (Ts) is (Experiencing only natural mortality (M) upto the time of recruitment it is suddenly exposed to Fishing (F) mortality, which remain constant in the entire life span of the cohort after it enters the fishery)
- Complete mixing occurs within the stock
- length –weight relationship has exponent 3

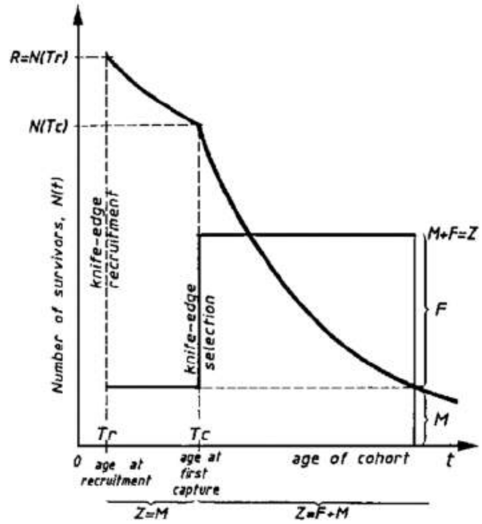

Fig. 1. Depiction of some of the assumptions in the yield per recruit model

Mathematical expression of the Beverton and Holt's Y/R model uses the total yield per recruit for the entire life span of the cohort using the equation

$Y/R = F * \exp[-M * (T_c - T_r)] * W_\infty * [1/z - 3S/(z+k) + 3S^2/(z+2K) - S^3/(z+3K)]$

where $S = \exp[-K * (T_c - t_0)]$

K and t_0 = von Bertalanffy growth parameters

T_c = Age at first capture

T_r = Age at recruitment

W_∞ = Asymptotic body weight

F = Fishing mortality

M = Natural mortality

Z = Total mortality (F+M)

Mortality which is divided as due to natural causes (M) and fishing (F) is a continuous process in time where the number of individuals is constantly reduced from the initial number R (number of recruits). In the Y/R model the yields are relative to recruitment and it is possible to calculate Y/R by varying the input parameters such as F (proportional to effort) and T_c (function of gear selectivity) which are possible to be controlled by a fishery resource manager.

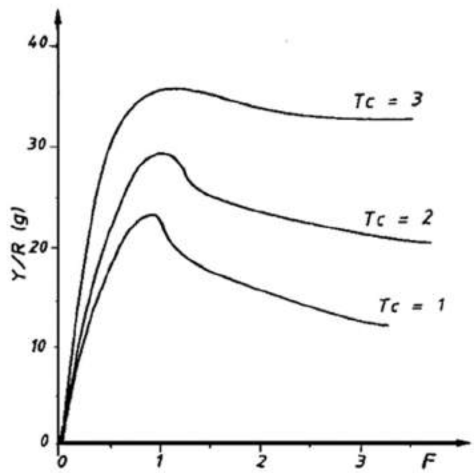

Fig. 2. Yield per recruit curves with different ages of first capture (T_c)

The Y/R curve has a maximum point known as the ' Maximum Sustainable Yield' which in turn depends on the age at first capture which in turn is influenced by the mesh size of the gear or other gear technology related factors. By combining a range of values of T_C and F and assuming that other conditions operating in the fishery are not changing, the long term sustainable yield is arrived. Originally an age based model, it can also be converted into a length based one applying certain principles, in fisheries where the data is mainly of length frequencies of the catch of particular species which has not been aged.

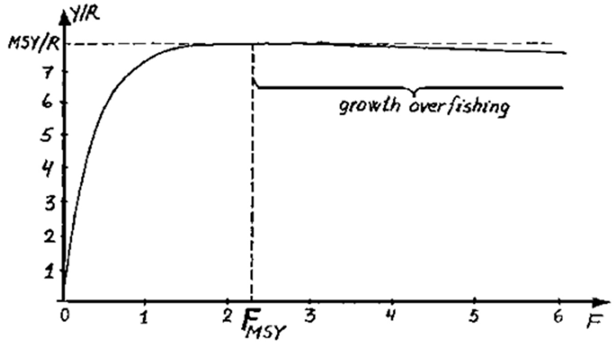

Fig. 3. A typical Y/R curve as a function of Fishing mortality

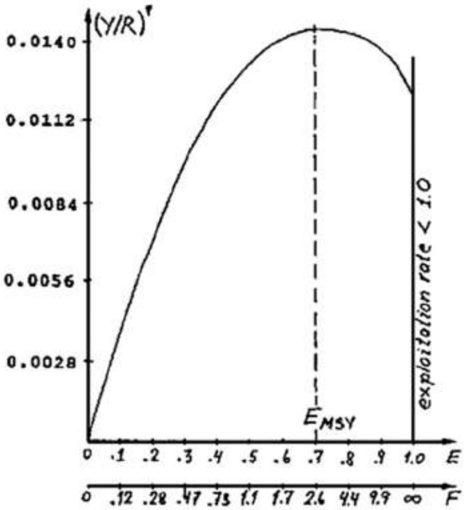

Fig. 4. Beverton and Holt's relative yield per recruit (Y/R)' curve for a given species and known length at first capture

Y/R relationships are important in arriving at two biological reference points (BRP) commonly used by fishery managers such as F_{max} (or F_{msy}) and $F_{0.1}$. The F_{max} BRP being highly sensitive to changes in growth, natural mortality and selectivity parameters adopted, its use as a target reference point is not encouraged. A more conservative estimate of $F_{0.1}$ which is the fishing mortality rate for which slope of the yield-per-recruit curve is only 10% (rather than 0%) of its value at the origin is preferred. In certain cases, Y/R curve does not have a maximum and can lead to the wrong conclusion that effort can be increased indefinitely. In such cases, often common in tropical fisheries, it is recommended to look into biomass/ recruit curves also along with the Y/R curves.

In fisheries management, frequently there is need to understand how much the yield per recruit will change in response to changes in fishing effort. In such situations, rather than the absolute values of Y/R expressed as grams per recruit, Beverton and Holt (1966) developed the Relative Yield per Recruit Model, denoted as (Y/R)' which used the life history invariants (dimensionless ratios). The (Y/R)' can be calculated for given input values of M/K, L_∞ and L_c for values of E ranging from 0 to 1 and corresponding to F values of 0 to $_\infty$. This has been used for assessing effect of mesh size regulations effectively.

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VIRTUAL POPULATION ANALYSIS

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Introduction

Virtual population analysis (VPA) is a modeling technique commonly used in fisheries science for reconstructing the historical population structure of a fish stock using information on the deaths of individuals in each time step. The time steps are typically annual (though not necessarily) and the deaths are usually partitioned into mortality due to fishing and natural mortality. VPA therefore looks at a population in an historic perspective. The advantage of doing a VPA is that once the history is known it becomes easier to predict the future catches, which is usually one of the most important tasks of fishery scientists. Virtual population analysis calculates the number of fish alive in each cohort for each past year. It is also called cohort analysis because each cohort is analysed separately. VPA relies on a very simple relationship for each cohort. VPA or Cohort analysis was first developed as age-based methods in temperate regions further developed as length-based methods for tropical regions.

Virtual Population Analysis

Virtual population analysis is basically an analysis of the catches of commercial fisheries, obtained through fishery statistics, combined with detailed information on the contribution of each cohort to the catch, which is usually obtained through sampling programmes and age readings. The word “virtual”, introduced by Fry is based on the analogy with the “virtual image”, known from physics. A “virtual population” is not the real population, but it is the only one that is seen. It is virtual in the sense that the population size is not observed or measured directly but is inferred or back calculated to have been a certain size in the past. The idea behind the method is to analyse that what can be seen, the catch, in order to calculate the population that must have been in the water to produce this catch. The total landings from a cohort in its lifetime is the first estimate of the numbers of recruits from that cohort. The basic equation for VPA is

Number alive at beginning of this year	=	Number alive at beginning of next year	+	Catch of this year	+	Natural mortality of this year

VPA is based on three equations;

1.1. $C(y,t,t+1) = N(y,t) * \left[\frac{F(y,t,t+1)}{M+F(y,t,t+1)} * \{1-\exp(-z)\}\right]$

1.2. $C(y,t,t+1) = N(y,t) * \frac{F(y,t,t+1)}{M+F(y,t,t+1)} [\exp\{F(y,t,t+1)+M\}-1]$

1.3. $N(y,t) = N(y+1,t+1) * \exp\,[F(y,t,t+1)+M]$

Where,

C (y, t, t+1) = number caught between age 't' and age 't+1' in 'y' year

N (y, t) = No. of survivors in the sea with 't' age in starting of 'y' year

N (y+1, t+1) = No. of survivors in the sea with 't+1' age in starting of 'y+1' year

F = Fishing mortality coefficient

M = Natural mortality coefficient

Calculation procedure

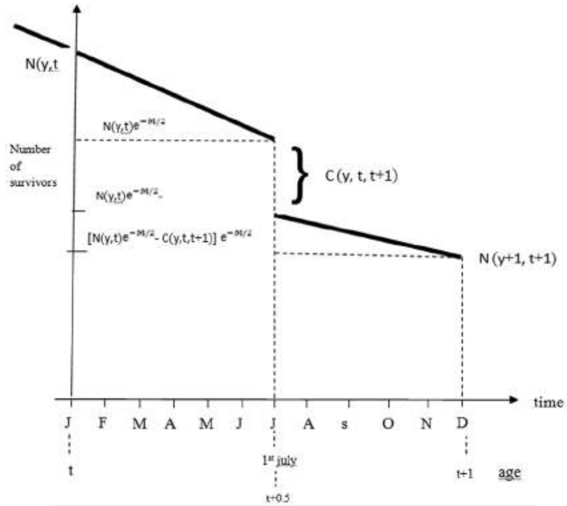
The calculation can be started from the bottom i. e. year of oldest age group for VPA analysis (for example, if VPA analysis is carried out for the time period from 1978 to 1980, the starting of VPA analysis can be begun from the year 1980) using equation-1.1. At first step, the fishing mortality can be chosen on the basis of guess. Second step onward, fishing mortality cannot be taken simply on the basis of guess, but it can be calculated with help of equation-1.2 by some trial and error method. Once, fishing mortality has been estimated, the number of fish in the sea for preceding year can be calculated by using equation-1.3.

Computer Programs

Mensil (1988) presents a package of microcomputer programs, 'ANACO' (ANAlysis of COhort) which can perform the VPA calculations. 'COMPLEAT ELEFAN' package (Gayanilo, Soriano and Pauly, 1988) and FiSAT contain also routines for VPA analysis.

Age-based Cohort Analysis (Pope's Cohort Analysis)

As derived from the catch equation, the VPA implied the solution by some numerical techniques (some trial and error method). This is a minor technical problem when one has access to a computer. However, the problem can be circumvented in an easy way, so that VPA can also be carried out on a pocket calculator. The version of VPA suitable for pocket calculators is the "cohort analysis" developed by Pope (1972). Cohort analysis is conceptually identical to VPA, but the calculation technique is simpler. It is based on an approximation, illustrated which shows the number of survivors of a cohort during one year. The catch is taken continuously during the year, but in cohort analysis the assumption is made that all fish are caught on one single day. Consequently in the first half year the fish suffer only natural mortality so the number of survivors on 1 July becomes:



Diagrammatic representation of age-based cohort analysis

2.1. $$N(y,t+0.5) = N(y,t) * \exp\left(-\frac{M}{2}\right)$$

Then, instantaneously, the catch is taken and the number of survivors becomes:

2.2. $$N(y,t) * \exp\left(-\frac{M}{2}\right) - C(y,t,t+1)$$

This number of survivors then suffers further only natural mortality in the second half year and finally the number of survivors at the end of the year is:

2.3. $$N(y+1,t+1) = \left(N(y,t) * \exp\left(-\frac{M}{2}\right) - C(y,t,t+1)\right) * \exp\left(-\frac{M}{2}\right)$$

For convenience of calculation this equation is rearranged as:

2.4. $$N(y,t) = \left(N(y+1,t+1) * \exp\left(\frac{M}{2}\right) + C(y,t,t+1)\right) * \exp\left(\frac{M}{2}\right)$$

Now from the N's, fishing mortality can be obtained with the help of equation:

2.5. $$F(y,t,t+1) = \ln\left[\frac{N(y,t)}{N(y+1,t+1)}\right] - M$$

Note that the F that caused computational problems in the VPA equation does not occur here.

Since catch may be considered for any time period i. e. t to t+Δt. Therefore, the general equation for age-based cohort analysis can be express as:

2.6. $$N(t) = \left[N(t+\Delta t) * \exp\left(M * \frac{\Delta t}{2}\right) + C(t,t+\Delta t)\right] * \exp\left(M * \frac{\Delta t}{2}\right)$$

Similarly, the general equation to obtain fishing mortality can be express as:

2.7. $$F(t, t+\Delta t) = \frac{1}{\Delta t} * \ln\left[\frac{N(t)}{N(t, t+\Delta t)}\right] - M$$

Calculation procedure

The calculation of cohort analysis can be started similar to VPA analysis by assuming the fishing mortality for the oldest age group. After first step, the number of survivors in the sea in preceding year can be calculated for any time period by using the general equation for age-based cohort analysis given above (equation-2.6). The fishing mortality during the year can also be calculated by using above general equation of fishing mortality (equation-2.7).

Jones' Length-Based Cohort Analysis

Keeping in view the difficulty in determination of ages for certain resources and also the fact that it is rather difficult to obtain age-frequency data for most of the tropical fish, cohort analysis described above is modified to make use of the length frequency data (length composition data for the total fishery are available for one year or the average length composition for a sequence of years). The name "length based cohort analysis" is somewhat misleading, as we are not dealing with real cohorts in the present analysis. The real cohort is replaced by a "pseudo-cohort" which is based on the assumption of a constant parameter system. Thus, it is assumed that the picture presented by all length (or age) classes caught during one year reflects that of a single cohort during its entire life span. Example for length-based cohort analysis is length composition of total catch of hake (*Merluccius merluccius*):

Length group (cm) (L1-L2)	Number caught ('000) C (L1, L2)	Length group (cm) (L1-L2)	Number caught ('000) C (L1, L2)
6-12	1823	48-54	653
12-18	14463	54-60	322
18-24	25227	60-66	228
24-30	8134	60-72	181
30-36	3889	72-78	96
36-42	2959	78-84	16
42-48	1871	84-∞	46

Here length group is converted into age intervals by the inverse Von Bertalanffy equation:

3.1. $$t(L1) = t_0 - \frac{1}{K} * ln\left[1 - \frac{L1}{L\infty}\right]$$

3.2. $$\Delta t = t(L2) - t(L1) = \frac{1}{K} * ln\left[\frac{L\infty - L1}{L\infty - L2}\right]$$

To convert the cohort analysis equation into a length-based version, only the term exp [(M* Δt)/2] has to be changed. This is done by substituting Δ t with following equation:

3.3. $$\exp\left[M * \frac{\Delta t}{2}\right] = \exp\left[\frac{M}{2} * \frac{1}{K} * \ln\left(\frac{L\infty - L1}{L\infty - L2}\right)\right] = \exp\left[\ln\left(\frac{L\infty - L1}{L\infty - L2}\right)^{\frac{M}{2K}}\right] = \left(\frac{L\infty - L1}{L\infty - L2}\right)^{\frac{M}{2K}}$$

It is convenient to use a symbol instead of this complicated term, therefore we introduce the symbols:

N (L1) = N [t (L1)]	=	the number of fish that attain length L1
	=	the number of fish that attain age t (L1) (also called the number of survivors)
N (L2) = N (t (L1 + Δt)	=	the number of fish that attain length L2
	=	the number of fish that attain age t (L2)
		[= t (L1) + Δt]
C (L1, L2) = C (t, t + Δt)	=	the number of fish caught of lengths between L1 and L2
	=	the number of fish caught of ages between t (L1) and t (L2)

3.4. $$H(L1, L2) = \left(\frac{L\infty - L1}{L\infty - L2}\right)^{\frac{M}{2K}}$$

Now equation can be rewritten using these length-based symbols, as:

3.5. $$N(L1) = [N(L2) * H(L1, L2) + C(L1, L2)] * H(L1, L2)$$

The equation for length-based cohort analysis for last group:

3.6. $$C(L1, L2) = N(L1) * \frac{F}{Z}[1 - \exp(-z * \Delta t)]$$

The equation for calculation of fishing mortality in length-based cohort analysis can be written as:

3.7. $$F(L1, L2) = M + \frac{F(L1,L2)/Z(L1,L2)}{1 - \left[\frac{F(L1,L2)}{Z(L1,L2)}\right]}$$

Calculation Procedure

The calculation for length-based cohort analysis is similar to age based cohort analysis. It can be started with last group with the help of equation-3.6. After first step, the number of survivors in the sea in preceding year can be calculated by using equation-3.5. The fishing mortality can also be calculated by using equation of fishing mortality given in equation-3.7.

Limitation

1. Natural mortality of cohort at age 't' (M) is constant.
2. It deals with the population dynamics of single species, whereas natural fish populations almost always interact among themselves and with others.

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MULTISPECIES VIRTUAL POPULATION ANALYSIS

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Introduction

Fisheries are the major driver for the changing in properties of both fished and unfished species, through direct and indirect effects. Direct effects can include reductions in population abundance, age and size structure, biodiversity, community composition and habitat destruction. Indirect effects, including incidental mortality, are transmitted through the ecosystem by trophic interactions and competition, and may result in increased or decreased abundance of prey or predator species, altering community composition. In recognition of the complex, interconnected nature of marine ecosystems, ecosystem approaches have been promoted as a way to improve fisheries assessment and management. There is a wide-range of multi-species and ecosystem modelling approaches. They range from extended single species models to multi-species minimum realistic models, food web models to whole ecosystem models with age and spatial structure. All models have their strengths and weaknesses: simplicity may entail missing key processes, whereas complexity requires more data, time and resources.

Multispecies Virtual Population Analysis

Multispecies virtual population analysis (MSVPA) is an approach to quantifying predator–prey interactions and estimating the rates of predation mortality for exploited fish populations. This approach was developed within International Council for the Exploration of the Sea (ICES) as a multispecies by extension of VPA or cohort analysis. MSVPA is a computation technique by which, one can calculate the amount of fish there must have been in the sea to account for the observed catches in fisheries and the observed stomach contents of predators. MSVPA provides useful insight into the role of predator-prey interactions by quantifying food consumption of major predators. Therefore, to perform MSVPA, detailed food-habit information is required. Thus, MSVPA requires input data as the natural mortality (non-predation), an estimate for fishing mortality in the last year (terminal F), abundance index for all groups, suitability estimates, weight-at-age, predator ration estimates and diet data.

The basic approach was derived from the model of Andersen and Ursin (1977) and subsequently described by Pope (1979), Helgason and Gislason (1979), and Gislason and Helgason (1985). Finally, this approach was reviewed by Sparre (1991) and Magnusson (1995). The main conclusions from applications to this system, summarized by Pope (1991), are that the rates of natural mortality are higher than typically assumed and are annually variable. The model is derived from the basic age-structured VPA approach with the addition of resolving natural mortality (M) into two components *i.e.* predation (M_2) and residual natural mortality (M_1), e.g. competition, disease, starvation and other natural causes. Predation mortality rates are calculated using the model that consists two primary terms, one for the total biomass of food consumed by the predator and other is suitability index that determines the predator's diet composition. In practice, the suitability coefficients can be calculated by incorporating diet information for all predator and prey age classes for at least 1 year in MSVPA time-series. Suitability coefficient measures the relative suitability of one species as prey for predators. These parameters must be estimated inside the model and this estimation requires data on the stomach contents of the predators in the model. MSVPA makes two key assumptions; one is constant ration size (*i.e.* independent of time for each species-age combination), hence fixed weights-at-age and other is prey selection which leads to a type II functional feeding response. Thus, suitability coefficients are constant in time and independent of prey abundance. In single species VPA, each cohort can be treated separately, the results being independent of the results of the other cohorts. The usual procedure for VPA is to work backwards in time, starting with the oldest age group and ending with the recruits. But, this procedure would not work for MSVPA. All cohorts of all species have to be dealt with simultaneously, as the value of the predation mortality depends on the abundances of predators and prey. Thus, MSVPA works on a "by-year basis" rather than on a by-cohort basis. MSVPA is a recursive algorithm and advantage of this model is the estimation the annual consumption of prey by predators.

Natural Mortality (M)

$M = M1 + M2$

Where, M1 is the residual mortality and *M2* is the predation mortality.

Predation Mortality Coefficient (M_2)

Predation mortality coefficient can be calculated using the model that consists two primary terms such as total biomass of food consumed by the predators and suitability coefficients of predators. Therefore, Predation mortality coefficient has been estimated by following formula:

$$M2_{p,a} = \sum_i \sum_j \frac{\bar{N}_{i,j}\ R_{i,j}\ S_{p,a,i,j}}{\sum_{p,a} \bar{N}_{p,a}\ W_{p,a}\ S_{p,a,i,j}}$$

$M_{2p,a}$ = Predation mortality of prey *'p'* at age *'a'*

$\bar{N}_{i,j}$ = Average abundance of predator *'i'* at age *'j'*

$R_{i,j}$ = Annual ration (total annual food consumption, kg) for the predator species

$S_{p,a,i,j}$ = Suitability coefficient for each predator - prey combination

$\bar{N}_{p,a}$ = Average abundance of prey *'p'* at age *'a'*

$W_{p,a}$ = Weight of the prey *'p'* at age *'a'*

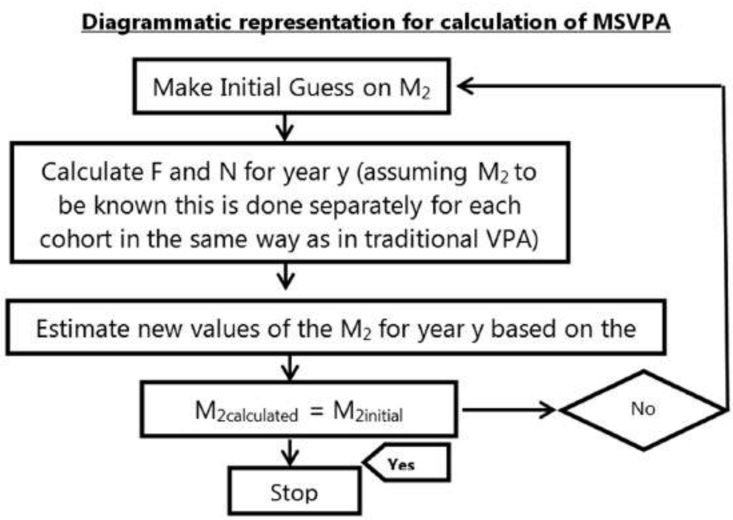
Here Numerator reflects the diet composition of the predator relative to the available food. The denominator of equation represents the total suitable biomass available to the predator.

Computation of MSVPA

The computation of MSVPA is started by assuming that the suitability coefficients are known. If the 'N' is known, then 'M_2' can be calculated by using predation mortality coefficient equation. Other hand, once the 'M_2' is known; again 'N' can be calculated using single species VPA techniques. However, 'N' is not known, this problem can only be solved using iterative techniques.

Suitability Coefficient

The factor determining the availability of prey as food for predator is called a "(food) suitability coefficient". Suitability coefficient is the most important parameters estimated in a MSVPA model. It reflects predator preferences, vulnerability, and availability of prey, which is influenced by the spatial overlap of predators and prey. There are two assumptions for



calculation of suitability coefficient, it is independent with change time and also independent with prey abundance *i.e.* type II predator-prey feeding response. The suitability coefficients are estimated iteratively in the MSVPA model with the following equation by incorporating diet information for all predator and prey at age classes.

$$S_{p,a,i,j} = \frac{U_{p,a,i,j} / \bar{N}_{p,a} \, W_{p,a}}{\sum_p \sum_a U_{p,a,i,j} / \bar{N}_{p,a} \, W_{p,a}}$$

$U_{p,ja,i,j}$ = Observed food composition in the predator's stomach contents; *a* is the age of prey *p*; and *j* is the age of predator *i*

$\bar{N}_{p,a}$ = Average abundance of prey *p* at age *a*

$W_{p,a}$ = Weight of the prey *p* at age *a*

Input data for MSVPA

The following are the input data for MSPVA:

1. Stomach content data
2. Annual predator ration (kg)
3. Residual mortality coefficient (M_1)
4. Number of catch at age (C)
5. Terminal fishing mortality coefficient ($F_{terminal}$)

Outputdata for MSVPA

The following are the output for MSPVA:

1. Fishing mortality coefficient (F)
2. Stock numbers (N)
3. Suitability coefficient (S)
4. Predation mortality coefficient (M_2)

Advantages

MSVPA uses data inputs (e.g. fishery catch-at-age) that are similar to those used in single species fishery models. The model outputs of MSVPA are directly comparable with those of single-species approaches. MSVPA can be use in fishery management plans. If parameters are stable, MSVPA models can include trophic interactions in the development of management advice.

Limitation

1. It concerns over the type II of functional feeding response
2. MSVPA models typically include only exploited species, and all other components of the ecosystem (e.g. zooplankton, benthic secondary production, apex predators) are either omitted from the model or are includedas fixed inputs of biomass
3. If parameters vary from year to year, trophic MSVPA models may have little value for managers

Extended MSVPA

Extended MSVPA (MSVPA-X) is represented as an alternative to existing MSVPA approaches. It is an improvement over previous approaches by increasing the flexibility to model seasonal and interannual dynamics in the strength of prey – predator interactions. It includes an alternative functional feeding response with the implementation of type III feeding response. MSVPA-X uses index-tuned VPA methods for estimation of terminal fishing mortality (F_t). It also incorporates a more complex expression of predator feeding and consumption rates by more explicit formulation of prey size and type selection.

MSVPA assumes that food consumption is a constant proportion of body weight across seasons and years. In reality, food consumption rates in fish can vary strongly, particularly between seasons as a function of changing temperatures and metabolic demands. Therefore, a modified functional relationship between food availability and predator consumption rates is included in MSVPA-X. The total consumption for a predator 'i' age 'a' in year, '*y*', season,'*s*' can be calculated by following equation:

$$C_s^{ia} = 24E_s^{ia} * \overline{SC_{ias}} * D_s^{ia} * W_{ys}^{ia} * \overline{N_{iays}}$$

Where,

SC_{ias} = Stomach contents weight relative to predator body weight in a season

D^{ia}_s = Number of days in the season

w^{ia}_{ys} = Average weight at age for the predator species

N^{ia}_{ys} = Abundance of the predator age class

E^{ia}_s = Evacuation rate (hr^{-1})

Evacuation rate (E^{ia}_s) = $\alpha_{ia} \exp(\beta_{ia}.Temp_s)$

Where,

$Temp_s$ = Seasonal temperature (°C)

α_a & β_{ia} = Parameters based upon laboratory feeding experiments

Again, stomach contents across years for predator

$$\left(SC_y^{ia}\right) = \overline{SC_{ias}} + \left(log\frac{SB_{iays}}{SB_{ias}}\right).\overline{SC_{ias}}$$

Where,

$\overline{SC}_{ias}$ = Average stomach contents across years for predator *i,* age class *a*, in season '*s*'

SB = Average biomass available to the predator

Suitability in MSVPA-X

Suitability in MSVPA-X is calculated by defining selectivity equation rather than relying on back-calculating suitability in iteration method as MSVPA. Predation is based on "density risk" and "prey vulnerability". Density risk reflects the relative encounter rate of the predators and prey driven by spatial overlap. Prey vulnerability combined probabilities of attack, capture, and ingestion. Therefore, suitability equation components are represented by the product of spatial overlap, a type preference or electivity parameter, and size-selection parameter.

Suitability $S_{jb}^{ia} = O_j^{ia}A_j^{ia}B_{jb}^{ia}$

Where,

S^{ia}_{jb} = Suitability for a given prey species ' j' and age class 'b' for predator species 'I'

O^{ia}_{j} = Spatial overlap index

A^{ia}_{j} = Vulnerability

B^{ia}_{jb} = Size selection

Spatial Overlap Index

Spatial overlap index (O_{ij}) can be calculated by using following equation,

$$O_{ij} = \frac{\sum_{Z=1}^{m}\left(N_{jz}N_{iz}\right).m}{\sum_{z=1}^{m}N_{jz}\sum_{z=1}^{m}N_{iz}}$$

Where,

N. z is the abundance of each predator or prey in each of 'm' spatial cells. It ranges between 0 and 1. It represents horizontal overlap of the predator and prey.

Type Preferences

Type preference reflects selection for a particular species relative to all others based upon ease of capture, energy content, or other factors that result in a preferred prey type. For each prey type (or species), a preference rank is assigned for a given predator age class. If a prey species is not consumed by that predator age class, then it is given a rank of zero. It can be calculated by Proportionalized rank index (A^{ia}_j);

$$A_j^{ia} = \frac{m - r_j^{ia}}{\sum_{j=1}^{m} r_j^{ia}}$$

where,

m = Number of prey species and r^{ia}_j = Preference rank for each prey species

Size Selection

Size selection uses a flexible unimodal function (the incomplete beta integral) to describe size selection. The function can be fitted to data on the length distribution of fish prey in stomach data by maximum likelihood estimation. This assumes that the length distribution of prey in the diet reflects selection rather than availability.

Program Implementation for MSVPA

The MSVPA is implemented as a MS Windows application written in Visual Basic 6.0. The program includes interface screens for the entry and management of species data, model inputs, and both graphical and data outputs. All data and outputs are stored and managed within a relational database, created by the program termed a "project file". The project file is stored, where catch and other biological data for individual species are entered that can be included within MSVPA executions. The project file also allows development and storage of MSVPA-X runs.

Application of MSVPA

MSVPA has demonstrated that an increase in mesh size can result in lower long-term yields, an effect opposite to what is predicted if species interactions are ignored. Such insights into the dynamics of the system are useful and MSVPA may therefore have an important role in fisheries management.

Suggested Reading

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MACRO ANALYTICAL MODELS

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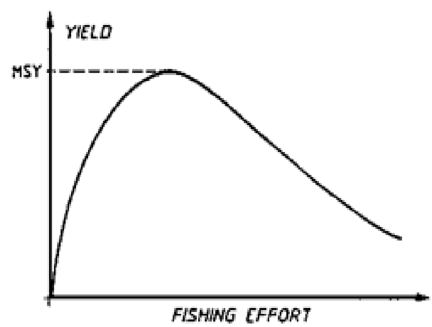
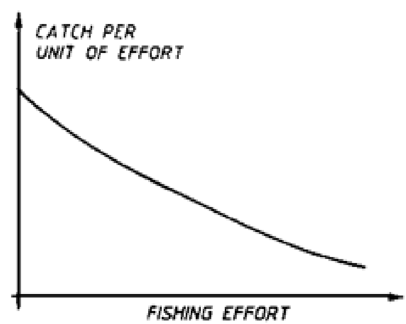
Introduction

Production models form one of the two groups of models used in studying fish population and assessing the state of the fish stocks. Unlike the analytical models, they do not consider the events within a population, and particularly ignore the growth and mortality of the individuals forming the population. These models view population as one unit of biomass, with all individuals having the same growth and mortality rates. The surplus production models deal with the entire stock, the entire fishing effort and the total yield obtained from the stock, without entering into any details such as the growth and mortality parameters or the effect of the mesh size on the age of fish capture etc. Surplus production models were introduced by Graham (1935), but they are often referred to as Schaefer-models.





The objective of the application of surplus production models is to determine the optimum level of effort that is the effort that produces the maximum yield that can be sustained without affecting the long-term productivity of the stock, or the maximum sustainable yield (MSY). Surplus production models assume that variation in population biomass results from increases due to growth and reproduction (termed production), and decreases from natural and fishing mortality.

Surplus production models use catch per unit effort as input. The data, which represent a time series of years, are usually collected from commercial fishery. The model is based on the assumption that the biomass of the fish in the sea is proportional to the catch per unit effort. Surplus production models are concerned with four basic quantities.

They are

- The population biomass B
- The catch
- The fishing effort
- The net natural rate of increase

The basic information used in surplus production models is catch-per-unit-effort (CPUE) data and records of landed catches. In this approach, consistent with most other stock assessment techniques, CPUE is regarded as an index of resource biomass or resource abundance.

The problem is to estimate

- the constant of proportionality linking CPUE to resource biomass, referred to as the catchability coefficient, and
- to estimate the resource carrying capacity and the scale of the surplus production curve.

Since the surplus production and hence the resource biomass cannot increase indefinitely (resource biomass is assumed to achieves a maximum level known as the resource carrying capacity), surplus production is zero both at a resource biomass level of zero (when there is no biomass then it cannot produce any surplus production) and at a resource biomass level equal to the carrying capacity. Somewhere between these two extreme resource biomass levels (zero and the resource carrying capacity) the surplus production must reach a maximum value. Most surplus production models assume that the relationship between surplus production and resource biomass is bell shaped, that is it is fairly symmetrical with a maximum about halfway between a resource biomass of zero and the carrying capacity In practice surplus production curves are seldom symmetrical and there are a variety of surplus production models which accommodate virtually all possible asymmetrical relationships that may be required for different situations. For example, in many finfish stocks the maximum is assumed to occur at a biomass smaller than the halfway point, whereas for whale stocks it is assumed to lie at a biomass larger than the halfway point.

The basic assumptions in Schafer's model are

- The net natural rate of growth is a decreasing function of the biomass
- The relationship is linear
- We are dealing with a unit stock.
- The population reacts instantaneously to any change in effort.
- The population has no size or age structure. There is no growth or ageing of individuals.
- Any loss is mortality
- No interaction with other species.
- No spatial and environmental variation.
- The stock is closed, no immigration and emigration.

The model can be applied for the fisheries which have undergone substantial increase or decrease in fishing effort over a long time series.

All discrete surplus production models are of the form

$B_{t+1} = B_t + g(B_t) - C_t$

where

Bt	the exploitable biomass at the start of the year t
g(Bt)	biomass dynamic as a function of current biomass
Ct	catch during the year t

The three most common forms for the function g(B) are

1.	rB (1 – B/K)	Schafer
2.	rB {1 – (In B)/(In K)}	Fox
3.	r/p B{1 – (B/K)p}	Pella Tomlinson

where

B	is the current biomass
r	the stocks intrinsic rate of increase in proportion to unit time.
K	carrying capacity or the maximum population size
p	the shape parameter

The Schafer form of the biomass dynamic function is equivalent to the Pella Tomlinson form with p=1. The fox form is the limit of Pella Tomlinson form as $p \rightarrow 0$

The Schaefer and Fox Models

The Schaefer model expresses the yield per unit effort (Y/f) as a function of the effort (f) in the simplest way as

$$Y/f = a + bf$$

In this model the catch per unit effort is considered as a linear function of effort and the linear relationship has negative slope and positive intercept. The catch per unit effort (Y/f) decreases for increasing effort (f); but the intercept (a) must be positive.

In this method,

The Maximum Sustainable Yield $MSY = \frac{-a^2}{4b}$

Optimum effort $f_{MSY} = \frac{-a}{2b}$

Yield for a given effort = af – bf^2

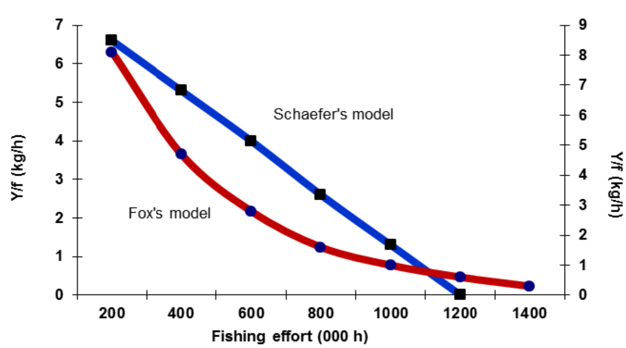
Using time series data on catch and effort by a linear regression of catch per unit effort (Y_t / f_t) (CPUE) on effort f_t, we can estimate the coefficients *a* and *b* and calculate MSY using this estimates.

In Fox model, an exponential relationship between *CPUE* and effort is assumed. The model is given by

$$\frac{Y(i)}{f(i)} = e^{c+d*f(i)} \quad \text{or} \quad \ln \frac{Y(i)}{f(i)} = c + d * f(i)$$

This function will have maximum value for the yield when $f_t = \frac{-1}{d}$ and the maximum value of yield (*MSY*) is given by $MSY = \frac{-1}{d} e^{c-1}$

Using time series data on catch and effort through a linear regression of logarithm of catch per unit effort $\ln(Y_t / f_t)$ on effort f_t, we can estimate the coefficients *c* and *d* and calculate MSY using these estimates.



Though the models of Schaefer and Fox conform the assumption that Y/f declines as effort increases, the straight line of Schaefer model implies that Y/f reaches zero for certain f value but the curved line in the Fox model implies that the Y/f never approaches zero, even at very high levels of effort.

Because holistic models are much simpler than analytical models, the data requirements are also less demanding. There is no need to determine cohorts and therefore no need for age determination. This is one of the main reasons for the relative popularity of surplus production models in tropical fish stock assessment. Surplus production models can be applied when data are available on the yield (by species) and of the effort expended over a certain number of years. This method is simpler since it makes no assumptions about the size and/or age composition of the catch or of the broader population. It is one of the simplest ways to deal with multispecies/multifleet system by pooling the catch of all species and the effort by all fleets. Application of the Schaefer model to the catch of all species by all types of fleets would give an estimate of MSY for the area in consideration. However, the problem of exploitation of the same stock by gear with different efficiencies has to be addressed by standardising the fishing efforts of all the gear that are engaged in the fishery.

MAXIMUM ECONOMIC YIELD AND ITS IMPORTANCE IN FISHERIES MANAGEMENT

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Introduction

Fishery resources are renewable natural resource but are liable to become extinct (as witnessed in many cases across the globe) if continuous and indiscriminate harvest is adopted Here the size of the stock (population) depends on the biological, economic and social considerations. Since fisheries resources are mostly coming under common property resources, its management becomes a complex issue (due to which a comprehensive management measure could not be exercised) and we have to resort to various management intervention options to ensure sustainable harvest as well as to maintain inter and intra generational equity. The management issue gains more significance in India wherein species diversity is very high and so the diversity among the fishing communities involved in fishing operations. "In an open access regime like fishery, negative externalities are many, which implies that uncontrolled fishery will bound to end up in what is called tragedy of commons.' (Grafton et.al, 2006).

There are many fishery management indicators, or reference points, which are estimated based on the systematic landing data and stock assessment studies. These indicators form the basis for formulation of various management measures in the country. Among such reference points, maximum economic yield (MEY) is one. The concepts, estimation of MEY and its significance in fishery management are dealt with in the following sections.

Sustainable Yield

Before actually proceeding to MEY, it will be better to have an understanding on the concepts of sustainable yield for a better understanding**.**

Fisheries are classified under renewable natural resources. However such resources are also liable to become extinct if the rate of harvest or exploitation is higher than the rate of regeneration or reproduction. Here the size of the stock (population) depends on the biological, economic and social considerations.

The sustainable yield in fishing commonly referred to as "Maximum Sustainable Yield (MSY) is a biological phenomenon. MSY means that level of fish catch or yield that can be harvested from a given system in perpetuity without affecting the stock of the system (or the sea). In other words, a catch level is said to be sustainable whenever it equals the growth rate of the population since it can be maintained for ever. As long as the population size remains constant, the growth rate will remain constant as well.

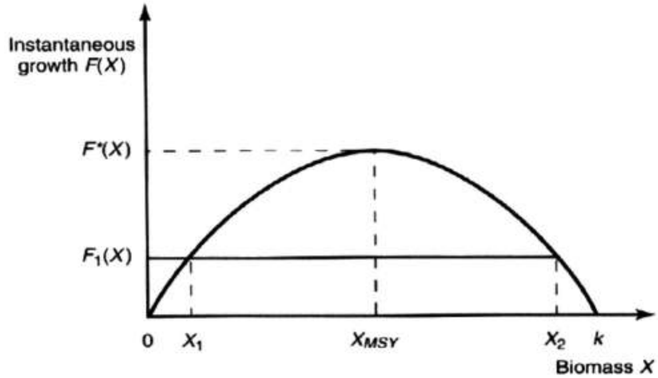


Fig. 1. Sustainable Yield Curve

Source John A. Dixon, Fisheries and Aquatic Resources World Bank Institute

What is MEY?

Maximum economic yield is that yield level, which coincides with the level of harvest or effort that maximized the sustainable net returns from fishing. A MEY harvest is desirable because it is the catch level that enables society to do the best it can with what nature has provided. (Grafton et al, 2006). Maximum Economic Yield (MEY) which includes the monetary terms of the effort and returns in sustainable yield formulation.

In fisheries terms, maximum sustainable yield (MSY) is the largest average catch that can be captured from a stock under existing environmental conditions. Relating to MSY, the maximum economic yield (MEY) is the level of catch that provides the maximum net economic benefits or profits to society.

MEY is a long-run equilibrium concept which refers to the level of output and the corresponding level of effort that maximize the expected economic profits in a fishery. In most cases, this scenario results in yields and effort levels that are less than at maximum sustainable yield (MSY) and in stock biomass levels greater than at MSY (Mardie 2002, Bromley,2009)

Earlier only biological aspects were considered in fisheries management. But they were aimed at controlling fishing effort and they did not consider the economic or social aspects of fishing methods. The net income from fishing and the subsequent use of income for the livelihood of fishers is also of vital importance. Besides the cost and returns in fishing plays a significant role as incentives for engaging in fishing as an occupation. This thought gave way for the economics to be included in fisheries management.

Economists have long argued that a fishery that maximizes its economic potential also usually will satisfy its conservation objectives (Walters 1993; Mardie 2002). This scenario is encapsulated in the concept of maximum economic yield (MEY), a long-run equilibrium concept that refers to the level of output and the corresponding level of effort that maximize the expected economic profits in a fishery. In most cases, this scenario results in yields and effort levels that are less than at maximum sustainable yield (MSY) and in stock biomass levels greater than at MSY (Mardie 2002, Bromley,2009). Lower levels of fishing effort also generally result in fewer adverse environmental impacts. Developed initially in the context of single-species fisheries (Walters, 1993), MEY was extended to multispecies fisheries under the assumption that the species are caught in fixed proportions. The optimal catch and biomass for any single species in a multispecies fishery may be greater or less than at MSY (Bromley, 2009).

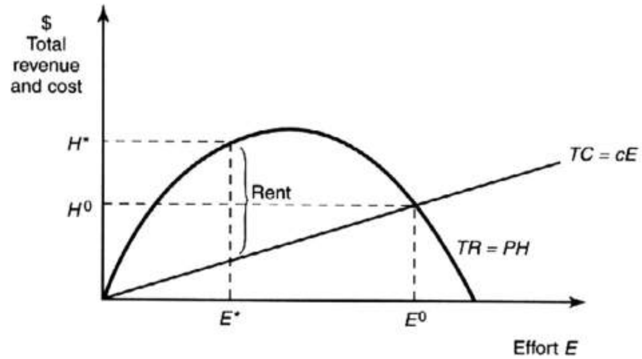


Fig. 2. Maximum Economic Yield

When the relationship between effort and money are measured, it was observed that when stock is low, effort must be high.

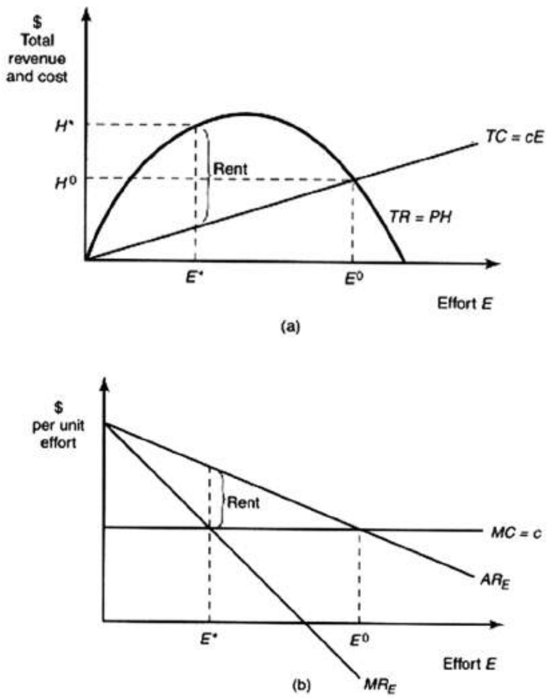
- Total revenue (TR) = Price (P) × Catch (H)
- TC = Unit cost (c) × Effort
- Rent = TR – TC

The rent is maximized at the point E*.Please note that here,

- MEY is left of MSY
- Optimal harvest (H*) is less than the MSY harvest
- But rent is larger than at MSY

The point E* is that effort level at which the MEY occurs. At this point of effort only the difference between the total revenue from fishing and total cost of fishing is the maximum. **This difference is also referred to as resource rent.**

The marginal analysis can show that the MEY occurs at the point where MC =MR. It is observed that for marginal unit of effort, marginal rent is = 0 and average rent >1.



Source: John A. Dixon, 2005

Dixon concludes that the "Goal of traditional fisheries management: achieve MSY. However the economists aim for MEY in contrast to MSY. AT MEY, compared to MSY, the fish catch is lower, fishing profit is higher, fishing effort is lower and the fish stock is higher. Thus the author concludes that MEY is where more fish is conserved. (Dixon, 2005)

Steps in estimation of MEY

p = a -by..(1)

Where,

p is the price per unit weight of fish
y is the annual yield

The average price per unit weight of fish (p) is generally a monotonically decreasing function of annual yield (y)

The profit is obtained as a difference between total revenue (TR) and total cost (TC), i.e.,

Π = TR – TC = (p-c)y ....(2)

Where

'c' is the cost of harvesting one unit weight of fish. From this, a cost function will be fit from the data collected

MEY = (a – c) / 2b ....(3)

f_{mey} = [a +/- (a^2 – 4 b MEY)]$^{1/2}$ / 2b ...(4)

where, a = intercept; b, c =regression coefficients

From f_{mey}, the optimum fleet size is obtained by dividing 'b' by the average annual fishing days. Based on this the excess capacity and thus the capital investment (over and above the optimum fleet size) can be worked out

Factors Affecting MEY

While estimating the MEY, three assumptions have been made such as zero discount rate; cost of fishing is a simple linear function of stock size; fishing costs rise proportionately with effort

The cost of fishing is an important component that decides the MEY. Generally the cost of fishing increases with a decrease in stock size at an increasing rate. This is the characteristics of the fishing practice. Under such a situation, it will be desirable to have a catch and effort level further to the left of the bionomic equilibrium

If the discount rate is very high or large, the MEY will correspond to a bionomic equilibrium (Clark, 1990), because it will be profitable to harvest the stock today itself if the loss of future net returns are very heavily discounted. Maximizing economic viability of fisheries is compatible with economic sustainability of the fisheries.

Estimation of MEY becomes complicated due to biological interactions; apportioning of the cost of fishing; value of target versus by catches and splitting the efforts and related aspects; lack of complete biological data to calculate the stock-recruitment relationship; inability to accurately measure the actual catch and effort of fishers and the current size of the fish stock; price of fish and the precise cost of fishing**.** A fall in fish price or an increase in cost of fishing will lead to lower harvest with a less fishing effort and a larger stock size in order to maximize the economic profits (Grafton et.al. 2006)

Importance of MEY Fisheries Management

MEY is a good target reference point for fisheries management despite the assumptions made. MEY ensures that the stock levels in many fisheries are larger than those associated with the traditional MSY target. MEY also ensures that the major inputs like fuel and labour are optimally utilized to maximize the profit. MEY helps to estimate the excess fishing capacity in the sector, which provides one of the strong bases for recommending optimum fleet size. If the resources are used beyond the MEY target, it will result in excess fishing capacity, lower returns and thus lower profits. Hence it pays rich dividend to follow the MEY as an important component for aiming at a sustainable fishery.

Conclusion

MEY acts an important link between the biological and economic implications of fisheries management. Taking cue from tragedy of commons that unmanaged natural resources are depleted completely and some sort of regulation measures are need to ensure sustainable utilization. In case of fisheries the economics of fishing operations (cost and returns) determine not only the profitability of the profession but also the driving force for remaining in the sector. In this context, the MEY which incorporates the costs of fishing the revenue earned into the sustainable yield models, provide an acceptable method for formulating fishery management plants. As reported by a few studies, the biological reference point (MSY) and the economic reference point (MEY) are always compliments to each other and they should be employed in formulation of any fishery management policies in the country.

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GEAR SELECTIVITY

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Most of the fishing gears are selective for certain length range of fish thus excluding very small and very big fish. This property of fishing gears is termed as gear selectivity. Thompson and Ben-Yami (1984) considered selectivity as the capacity of any method of gear type to capture certain fractions or sections of the fish population whether grouped by species, age, size or behaviour and to exclude others. Gear selectivity needs to be considered when we go for estimation of size composition of fish. The ultimate aim of studies on size selection is to suggest suitable mesh sizes to catch fish of either economically optimum size or an optimum size for the judicial exploitation of the stock. It is an important tool for fisheries managers for regulating the minimum mesh sizes of fishing fleet by determining the minimum sizes of the target species in certain fisheries. Mesh sizes are regulated to conserve the spawning stock and to increase the long term sustainable yield. Estimation of total mortality and prediction of future yield using prediction models etc. will be affected by selectivity of gears.

It is well known that the complete length/age ranges of fish and shell fish are not under full exploitation. Trawl gears are selective for larger sizes of length while gillnets are selective for an intermediate length range; the smaller ones escape through the mesh and very large ones are not gilled. This property of fishing gear is called gear selectivity with regard to size selection. According to Lagler (1968), the selectivity of a gear may be defined by a curve giving for each size of fish the proportion of the total population of that size which is caught and retained by a unit operation of the gear. This leads to the definition of selectivity as the proportionality constant s_{ij} in the equation for catch per unit operation of a gear for fish of length j by mesh size i given by

$$c_{ij} = s_{ij} N_j$$

Selectivity of trawl gears

The fine meshed end of the net where the catch is collected is known as codent. The mesh size of the codent determines the gear selectivity of trawl gear. By covering the codent with a larger bag with very fine meshes we can determine the amount and sizes of fish that escapes through the codent meshes. Selectivity of the gear can then be determined by comparing the sizes of the fish in the codent with those of the fish in the cover. This experimental method is known as "covered codent method".

Using data from such experiments on numbers in codent and numbers in cover for different length classes a logistic curve given in the following form is fitted after working out the fraction retained.

$$y_i = \frac{1}{1+\exp(a-bx_i)}$$

Here y_i is the proportion of fish retained in the codent for the i^{th} length class and x_i is the mid-length of the i^{th}class. The parameters a and b are obtained through a regression analysis using the expression

$$\ln(\frac{1}{y_i}-1) = a - b\,x_i$$

Lengths corresponding to 25%, 50% and 75% retention are then obtained using the estimated values of a and b as

$$L_{25\%} = \frac{a-\ln(3)}{b}$$

$$L_{50\%} = \frac{a}{b}$$

$$L_{75\%} = \frac{a+\ln(3)}{b}$$

The length range from $L_{25\%}$ to $L_{50\%}$ which is symmetrical about $L_{50\%}$ is called as the selection range. As the probability that a fish will escape through a mesh depends on its shape and in particular on its body depth compared to the mesh size it is assumed that the body depth at which 50% of the fish are retained is proportional to the mesh size. That is

$D_{50\%}$= *A (mesh size)*

where A is a constant. As body depth is proportional to body length it implies that similar expression holds for length of the fish also.

$L_{50\%}$= *SF (mesh size)*

The constant SF is known as the selection factor.

Example:

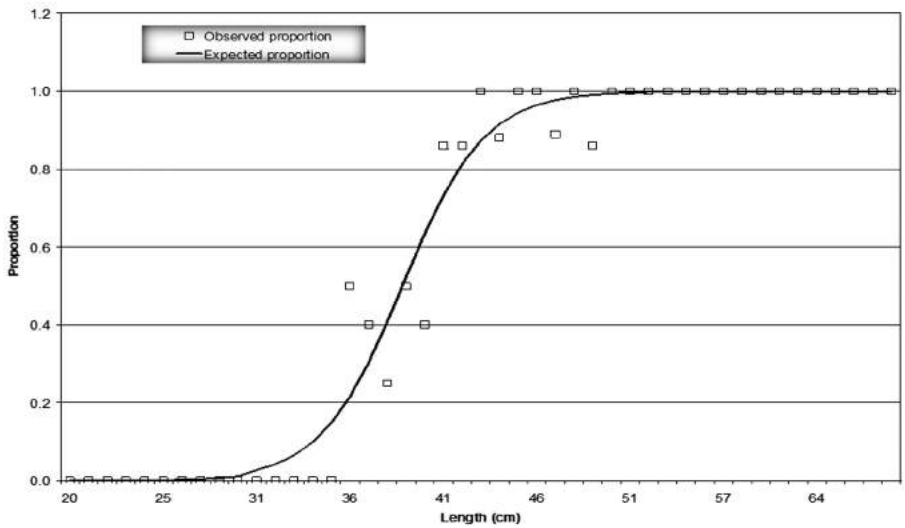
The following data is from an experiment that deals with threadfin breams (Nemipterus japonicus) that are caught with a trawl net with codent mesh size 4 cm and a cover of much small meshes.

Length Interval	Number in Codent	Number in Cover	Total Number	SI-obs fraction retained	ln(1/SI-1) (y)	Mid length (x)	SI-est fraction retained
9-10	0	1	1	0.000			
10-11	1	6	7	0.143	1.792	10.5	0.129
11-12	2	7	9	0.222	1.253	11.5	0.232
12-13	2	4	6	0.333	0.693	12.5	0.383
13-14	7	5	12	0.583	-0.336	13.5	0.559
14-15	30	13	43	0.698	-0.836	14.5	0.722
15-16	61	8	69	0.884	-2.031	15.5	0.842
16-17	27	3	30	0.900	-2.197	16.5	0.916
17-18	7	0	7	1.000		17.5	0.957
18-19	4	1	5	0.800		18.5	0.979

Regression analysis done with x on y gave the following results

Summary Output					
Regression Statistics					
Multiple R	0.991298				
R Square	0.982672				
Adjusted R Square		0.979206			
Standard Error		0.225186			
Observations		7			
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	14.37835	14.37835	283.5482	1.35E-05
Residual	5	0.253543	0.050709		
Total	6	14.63189			
	Coefficients	*Standard Errort Stat*		*P-value*	*Lower 95%*
Intercept	9.436398	0.580778	16.24786	1.61E-05	7.94346
X Variable 1	-0.7166	0.042556	-16.8389	1.35E-05	-0.82599

The gear selection ogive for trawl net with 4cm codent mesh size is given below.



Estimates of parameters of the logistic curve are a = 9.436398 and b = -0.7166. The lengths at which the fish are retained 25%, 50% and 75% are calculated as

L25%	11.6352
L50%	13.1683
L75%	14.7014

$L_{50\%}$ = *SF (mesh size)*

13.1683 = SF X 4

SF = 3.292

That is selection factor for the trawl net used with mesh size 4 is 3.292. These are useful for prediction of the effects of changes of mesh size using the Thompson and Bell method.

EXPLORATORY SURVEY FOR BIOMASS ESTIMATION

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Introduction

Bottom trawl surveys are widely used for monitoring demersal stocks when a simple index of abundance is required for scientific and related work. From unfished stocks (or stocks for which no or few data on the fishery are available), preferably the unexploited stocks, biomass and annual yield estimates may also be derived by undertaking bottom trawl surveys. The estimation of total biomass from the catch per unit of effort (or unit area) using a trawl survey, however, involves several crucial assumptions, leaving such estimates rather imprecise. But we can resort to this method when we require an immediate input to be generated and the methodology is less time consuming and easy to carry out.

Various studies have reported that the mean catch (either in weight or in numbers) per unit of effort or per unit of area is an index of the stock abundance (i.e. assumed to be proportional to the abundance). This simple index may be converted into an absolute measure of biomass using the so-called "swept area method" which is followed universally in all trawl survey methods. This method falls under the so-called holistic methods of assessing fish stock abundance.

Various theories were propounded as we trace back the research related to trawl survey stock assessment and the prominent among them are that of the Gulland (1975), Saville (1977), Troadec (1980), Doubleday (1980) and Grosslein and Laurec (1982). These reviews also give guidelines for conduct of trawl surveys (planning, design, data collection, data recording, analysis and reporting), and the steps followed can be referred in Butler et al. (1986), ICOD (1991) and Strømme (1992).For more detailed descriptions of these subjects the reader is referred to, among others, Alverson and Pereyra (1969), Alverson (1971), Mackett (1973), FAO/UNDP (1975), Gulland (1975), Saville (1977), Flowers (1978), Doubleday (1981), Grosslein and Laurec (1982) and Fogarty (1985).

Structure of a Bottom Trawl

The bottom trawl (Fig. 1) is a conical bag netwith a wide opening mouth fitted with weights (sinkers) on the ground-rope and floats on the head-rope. When the vessel is under taking a trawl operation, the net is kept open by two otter boards (wooden or iron structures) which are towed the help of warps attached forward in their centre so they tend to diverge. The towing is done with the mechanical power of an engine in the vessel. The two otter boards are connected to the net by bridles. These may be up to 200 m long and sweep the sea bed over a wide area depending upon the size of the gear used in the operation. They frighten the fish towards the advancing net (a behavioral advantage utilized by the trawl operators) and so increase its effectiveness. The shape, size and mesh of the trawl gear used varies depending on the variety of fish targeted and on the type of the trawling ground. The ground-rope may be fitted with roller gear (bobbins) so that the trawl can be used on stony bottom (rough bottoms) without being damaged. The tail end of the gear from which the captured fish are removed is called the "codend". This is where most of the size selection takes place. In most cases a relatively small mesh size is required in the codend, in order to obtain a representative sample for the entire size range of the species under investigation.

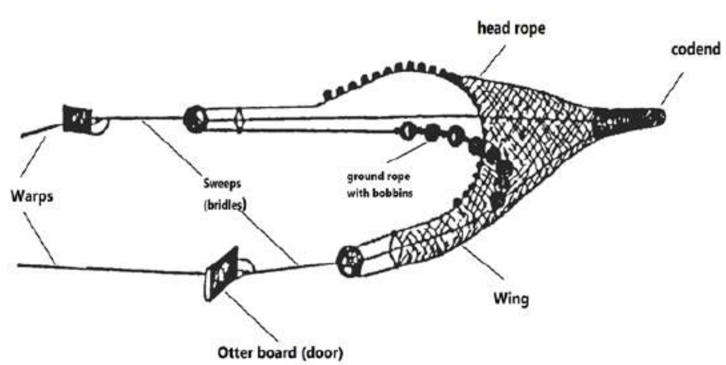


Fig. 1. Structure of bottom trawl

Exploratory Survey for Biomass Estimation

Estimates of biomass and annual yield can be derived from bottom trawl surveys, especially for monitoring demersal fish stocks. But the estimation of total biomass from this based on catch per unit effort estimates involves some crucial assumptions. The mean catch per unit area is an index of the stock abundance. This is on the assumption that it is proportional to the abundance. Using swept area method this index of stock abundance can be converted into an absolute measure of biomass.

The objectives of bottom trawl survey are:

- Estimation of the total biomass and catch rates.
- Estimation of biomass of selected species.
- Collection of biological data such as length frequency data for estimation of growth and mortality parameters.
- Collection of environmental data.

The bottom trawl is a conical net bag with wide mouth fitted with weights on the ground rope and floats on the head rope. The net is kept open by tow otter boards which are wooden or iron structures towed by the warps attached forward of their centre so that they tend to diverge. These may be very long and sweep the sea bed over a wide area. They frighten the fish towards the advancing net and increases its effectiveness. The shape of the net varies depending on the kinds of fish targeted and the types of bottom. The ground rope is fitted with roller gear so that the trawl can be used on stony bottom without any damage. The tail end of the gear from which the captured fish are removed is called the codend where most of the size selection takes place. In order to obtain a representative sample of all the size ranges of the species the mesh size should be relatively small at the codend.

For estimation of stock sizes a completely randomized design or a stratified random sampling design is preferred and in most cases stratified sampling design is preferred. Strata are constructed in accordance with the density distribution of the fish so that areas with high/ medium/low densities are separated. For stratification some prior information is required which is obtained in a first survey following simple random sampling design and the variability obtained is used for stratification. The distribution of hauls within strata should be random taking into account the practical difficulties. The number of hauls possible in a given period can be calculated as:

Number of hauls per day = T / (t2+t3+t4)

where T is the number of hours available per day, t2 is the duration of one haul, t3 is the time used for shooting and hauling the trawl and t4 is the average time taken to cover distance between stations. It is important to standardize the length of the haul throughout the survey, since the catchability of species and sizes often depends on the duration of haul. Following are the important points to be remembered while recording data from a trawl survey:

- The objective of the survey determines the data items to be recorded, e.g. biomass estimation, length frequency analysis, mortality estimation.
- Data items include specification of gear, haul duration, position at start and end of haul, wire length, wing spread, bottom type, depth, etc.
- Catch record should include total weight, species composition, length frequencies for selected species.
- Data should be well organized to facilitate processing.
- There should be a log summarizing the whole cruise.
- There should be fishing log that provides information on vessel's position, time of start, end of haul gear rigging, etc. Summary information on catch should also be recorded in the fishing log.
- Detailed information on catch in terms of length, weight, sex, maturity stage, etc. for each specimen should be recorded along with length frequency distributions.

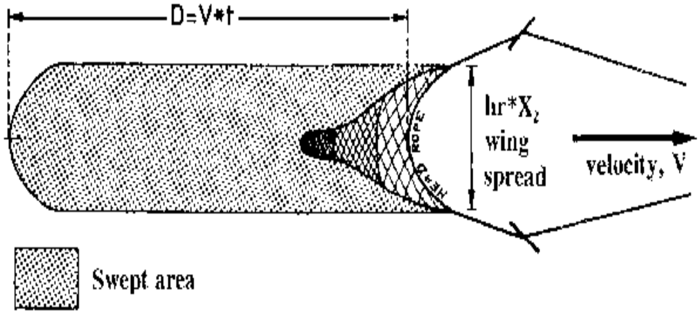
Swept Area Method

From Fig. 13.5.1, Trawl sweeps a well defined path, the area of which is the length of the path times the width of the trawl which $D = v \times t$ is called the swept area. It is estimated as:

$a = D \times h \times X_2$

Where, 'v' is the velocity of the trawl over the ground when trawling, 'h' is the length of the head-rope, 't' is the time spent for trawling and X_2 is the fraction of the head-rope length, 'h', which is equal to the width of the path swept by the trawl and the wing spread is $h \times X_2$. Different values of X_2 in use are 0.4 to 0.6 for Southeast Asian bottom trawls, 0.5 as a compromise suggested by Pauly and 0.6 in the Caribbean suggested by Klima. Catch per unit area estimated by dividing the catch by the swept area is used for the estimation of biomass. When exact positions of the start and end of the haul are available, the distance covered in nautical miles is estimated as:

$$D = 60 * \sqrt{(Lat1 - Lat2)^2 + (Lon1 - Lon2)^2 * Cos^2(0.5(Lat1 - Lat2))}$$



where Lat1, Lat2 are the latitude at start and end of haul in degrees, Lon1,Lon2 are longitude at start and end of the haul in degrees. When the velocity of the vessel and its course together with direction and speed of the current are available, then the distance covered per hour is calculated as:

$$D = \sqrt{VS^2 + CS^2 + 2VS * CS * Cos(dirV - dirC)}$$

where VS is the velocity of the vessel in knots (nautical miles per hour), CS is the velocity of current in knots, *dirV* is the course of vessel in degrees and *dirC* is the direction of current in degrees.

If cw is the catch in weight of a haul and 't' the time spent in hauling (in hours), the cw/t is the catch in weight per hour. If 'a' is the swept area then a/t is the swept area per hour. Then the catch per unit of area is obtained as:

$$CPUA = \frac{cw/t}{a/t} = \frac{cw}{a}\ kg/nm^2$$

If X_1 is the fraction of the biomass in the effective path swept by trawl, which is actually retained in the gear and cw / a is the mean catch per unit area of all hauls, then an estimate of the average biomass per unit area is:

$$\bar{b} = \frac{\overline{(cw/a)}}{X1}\ kg/nm^2$$

Let Anm^2 be the total area under investigation, then the estimate of total biomass for this area is obtained as:

$$B = \frac{\left(\overline{cw}/a\right)^{A}}{X1}\ kg$$

An example of biomass estimate from commercial trawl data off Saurashtra coast in western India is given here. A trawler (overall length: 17.5 m) conducted fishery survey during 1985-1989. During the 5-year period, the survey was conducted in eighty-eight 10′ squares between the latitude zones 20°N and 70°E (off Veraval) and 23°N 68°E (off Jakhau) at depth range of 12 to 70 m. The area of each 10′ square in the survey area was considered as 326.6 km^2.

The total area considered (A) for the survey was estimated as (326.6 * 88) 28,740.8 km^2. The area swept (a) by the gear during one hour of trawling was calculated considering the trawling speed (v) as 2.5 knots/h (= 4.3 km/h), the headrope length (h) of the trawlnet as 24 m, and X2 as 0.5. The area swept was calculated as 0.052 km^2/h for the entire period of the survey.

The biomass was calculated by pooling the catch from each 10′ square during the 5-year period. The total catch was 205.2 t and the CPUE was 43.9 kg/h.

Biomass = (43.9 * 28740.8)/(0.052 * 0.5) = 48528 t

Density = Biomass/Area considered

= 48528 / 28740.8 = 1.688 t/km^2.

Precision of the estimate of biomass in the swept area method can be achieved by increasing the number of hauls. Another way of increasing precision is to apply stratified sampling by considering depth and bottom type. Suitable stratification may improve precision for the same number of hauls.

However, estimation of biomass and density from the CPUE involves several crucial assumptions, such as (i) the CPUE is proportional to the biomass abundance, and (ii) the proportion of detainment in gear, etc. It has been observed that for some stocks, the observed CPUE is only related to stock size, and in such cases, there may be no CPUE data that are satisfactory. For example, the CPUE from purseseine fisheries for shoaling pelagics may lead to erroneous estimates. For pelagic trawling, avoidance can be very great. Moreover, survey by any gear provides an estimate of only the target stocks of that gear and not the totalbiomass of the considered area. Due to this reason, the biomass is usually underestimated by the swept area method. This method has its main application to gears hauling non-selectively along the seabed.

For a meaningful estimate, surveys have to be conducted for several weeks every year, for which the estimation cost could be high.

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AGE DETERMINATION IN FISHES

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Fisheries management relies on the proper understanding the fish population dynamic. It includes determining the biological parameters, including size at maturity, duration of spawning season, mortality estimates, age and growth. Accurate information on age of fish is an important pre-requisite for extracting precise information on growth, mortality, recruitment and other fundamental population parameters of fishes for stock assessment. The outcome of conventional age estimates using length frequency data depends upon the sample quality, selectivity of the fishing gear etc. The stock assessment results may therefore be affected and sometimes give results which is having no bearing on reality. The hard parts of the fishes also grow with the fish and the growth process may left some inscription on such parts and if that can be interpreted properly, will get precise idea on growth. These inscriptions may result from either changes in the environment which the fish inhabits, or food availability, or physiological states of the fish. However, free swimming fishes always lives in ideal conditions and do not leave any environment related markings in their skeletal structures. So interpretation of hard part inscriptions need utmost care.

Ageing Techniques

There are four approaches to age the fish.

i. Direct observation of fish in confinement or marking/tagging recapture technique

This is the oldest technique described initially by the fish culturists. Tagging and marking experiments are conducted as the data collected are useful in estimating the population size, mortality rates and migration. Tagging does not enable individual fish to be aged unless the age of the fish at tagging is known. The method is very useful for fish living in areas where the growth is continuous throughout the year. It is useful when large numbers of fish recaptured at annual intervals are available. However, cultivated or tagged fish seldom have the same growth rate as that of the wild or untagged fish. Tagging or marking of fish usually involves considerable time and recapturing is not assured.

ii. Injection (chemical marker) technique

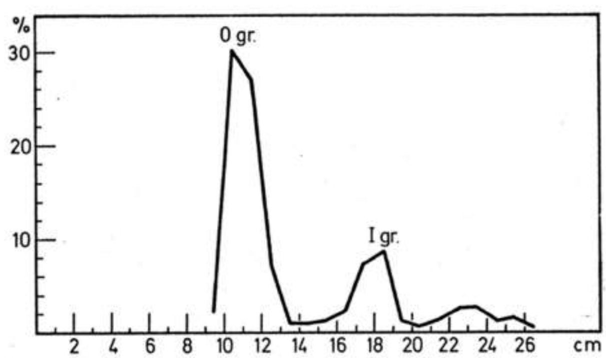
Artificial time markers can be introduced into skeletal structures by injecting chemicals into fish. The initial works were based on the use of lead acetate but this is toxic and tetracycline is now commonly used. It has the advantage of being an antibiotic drug, stable in solid form. Tetracycline is readily absorbed by vertebrate animals and deposited in bony structures where calcification is taking place. In teleost fish, the tetracycline is laid down as a narrow ring timing the point of injection. The areas in which tetracycline is deposited in skeletal tissue appears fluoresce yellow under ultraviolet light, enabling them to be detected easily. However this is not a popular technique.

iii. Analysis of length frequency data of fish

Length frequency data are used in various analytical, graphical and software assisted techniques to estimate the age, growth and other population parameters. The common methods employed are:

1. Petersen method

This is a single sample method and is very simple, fastest but most inaccurate method of ageing fishes. This method can be used only with species which have a restricted spawning season so that the fish bred in a single season can be identified as a single mode in a polymodal length distribution. The mode with the lowest value is identified as 0-year group fish. Subsequent modes will be 1-year group, 2-year group fish and so on. The method can be very good for young fish but becomes increasingly less useful for older fish as the growth rate slows down and the modes merge. In practice length-frequency distributions of fish caught over the shortest time period possible are plotted; the shorter the time period the more precisely the modes will be defined. A regular sequence of such length frequency distributions enables the progression of the modes to be followed.



2. Monthly modal progression analysis

Length frequency data collected at random from the commercial and experimental fishing are used to estimate the age of the age and growth of the fish.

3. Scatter diagram technique of monthly modal length

By plotting the monthly modal values of the length frequency data of fish as a scatter diagram, growth as well as the number of broods recruiting per year can be estimated.

4. Bhattacharya method

This is a graphical method of splitting a composite distribution into separate normal distributions, i.e. when several age groups or cohorts of fish are represented in the same sample. (For details consult FAO Fisheries Technical Paper No. 306.1 ,Rev.)

5. Probability paper/plot method

This method aims to resolve the normally distributed components of a length frequency distribution.

iv. Age determination using hard parts of fish

Fishes grow continuously, but growth rate varies over time and season and also depending on the characteristics of the habitat they lives. Hard parts like bones, spine, otoliths, scales etc. also increase in size with the fish. Hard part grows by deposition of different minerals in a biological matrix. Any changes in growth rates may be reflected as zones or bands in the hard parts. By tracking down these inscriptions age of the fishes can be determined. During slow growth phase rings/bands will be laid close together, whereas during fast growth phase they will be laid far apart.

Among skeletal structures, otoliths and scales are most widely used as they are easy to collect and store. The opercular bones of the head, pectoral and pelvic girdles dorsal spine etc. were also widely used.

Otoliths

There are three pairs of otoliths in teleost fishes. These are three-dimensional structures but do not necessarily grow at the same rate equally in all dimensions. But there will be some species specific pattern in otoliths, which consists of number of concentric shells with different radii. Depending on the amount of organic material in each shell or zone, its appearance will vary from extremely opaque to completely hyaline. For reading otoliths it is usually preferable to identify and count the opaque zones, as characteristic growth patterns if any will usually appear and also more visible in the opaque zones. Among the three, Sagittal otoliths are generally used for age determination as they are the largest and easy to collect and process. They are located in the sacculus of the inner ear.

Scales

Scales vary in shape depending on the fish and body shape. Scales at the shoulder of the fish between the head and the dorsal fin is best suited for age determination. Scales are almost two-dimensional structures. The anterior part is formed of a series of sclerites which should extend in a regular pattern from the centre of the scale. The structural discontinuities used for age determination result from irregularities in the pattern of the sclerites; they may be slightly distorted or they may be slightly closely spaced than the majority of the sclerites; usually the discontinuities are narrow and they are usually called 'rings'.

Scales are thin structures they need no preparation before viewing; the scales should be cleaned before they are stored. For reading, the slide with mounted scales is placed on the stage of a low-power microscope. The magnification used depends upon the size of the scale; in general, the lowest possible magnification is the best because it enables the whole scale pattern to be seen.

Estimation of Growth Parameters

Growth parameters estimated from the age-length data developed from hard part imaging and will be used in the conventional length based stock assessment for precision.

TRUSS NETWORK ANALYSIS

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Classification problems exists in numerical taxonomy in biology and many other branches of Science. The interest here is to classify objects into one of many existing classes and is based on measurements taken on a set of characteristics (called variables). Hence classification is a multivariate problem which can be divided into two broad categories.

- We have multiple measurements data from a number of individuals belonging to known groups. Also we have data collected on individuals whose group membership is not known and is to be determined using the measurements made on them. This problem in statistical terminology comes under Discriminant Analysis.
- Another type is the case when the groups are them selves unknown and a primary purpose of the analysis is to find groups so that those belonging to same group are similar than those belonging to different groups. This in statistics come under the heading of cluster analysis or pattern recognition.

Cluster Analysis:

This involves the search through multivariate data for observations that are similar enough to each other to be usefully identified as part of a common cluster. Clusters consist of observations that are close together and that the clusters themselves are separated. If each observation is associated with only one cluster, then the clusters form a partition of the data. Finding the partition into clusters is not always easy. There are numerous methods for clustering. Some methods of making clusters starts with models like mixture models of clusters. Examples of application of cluster analysis are studying genetic diversity within and between populations of and endangered fish species, clustering species of bees into higher-level taxonomic groups, developing clusters of patients based on physiological variables, constructing a speaker-independent word recognition system etc. Numerical methods of clustering with out any model can be into three major types; *hierarchical, partitioning* and *over lapping*.

Principal Component Analysis

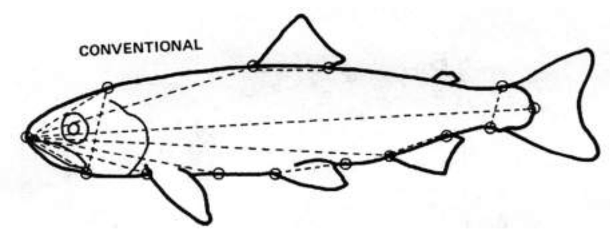
In principal component analysis we have a sample of observations taken on a set of variables and the objective is to find linear combinations of the variables so that the first linear combination accounts for maximum possible variation in the data, the second linear combination accounts for the next highest possible variation and so on. By this we get another set of transformed variables which are linear combinations of the original variables and they new set will have the property that by considering few of them we will be able to explain a major portion of the variability in the population. The approach in principal component analysis is to reduce dimensions by calculating the eigen values and eigen vectors of the covariance or correlation matrix and project the data orthogonally into the space spanned by the eigen vectors belonging to the largest eigen values. These projections are interesting due to the following reasons

- If projection is an aggregate of several clusters, then these can become individually visible only if the separation between clusters is larger than the internal scatter of the clusters. Thus, if there are only a few clusters, the leading principal axes will tend to pick projections with good separations.
- It tend to act as a variation reducing technique relegating most of the random noise to the trailing components and collecting the systematic structure into the leading ones.

Suppose that we have measurements on k variables $x_1, x_2, \cdots, x_k$ made on n individuals. Then we have *n* x *k* matrix of data and we can work out means for these variables which we can treat as a mean vector of length *k*. Also we can compute the variance covariance matrix **S** matrix using this data set. This matrix will be then used to compute the k principal components, say $z_i = a_{1i}x_1 + a_{2i}x_2 + \cdots + a_{ki}x_k$ for $i = 1,2,\cdots,k$ and the amount of variation explained by each of them will be available as $\lambda_1, \lambda_2, \cdots, \lambda_k$ where $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_k$.

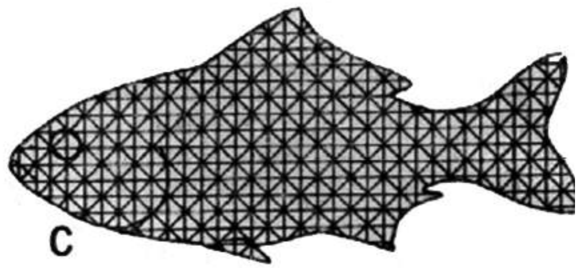
Truss Network Analysis

In systematics the interest is often in quantifying differences in form among different species or conspecific populations. When these are studied using conventional measurements (shown below) the amount of information available for analysis are repetitious and lack variation in oblique directions.



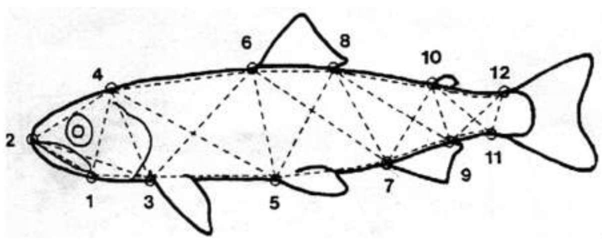
There are several biases and weaknesses inherent in traditional character set used to study stock differences in systematics.

- They tend to be in one direction only (longitudinal) lacking information of depth and breadth.
- Coverage is highly uneven both by region and orientation.
- Some landmarks like tip of the snout and posterior end of vertebral column are used repeatedly.
- Many landmarks are external rather than anatomical and their placement may not be homologous placement may not be homologous from form to form.
- Many measurements extends over much of the body.
- When measurements are taken on soft bodied organisms, the amount of distortion due to preservation can not be easily estimated.



The most ideal measurements which overcomes these problems is as in the picture C.

Truss is a geometric protocol for character selection which largely overcomes the disadvantages of conventional data sets and it leads to certain style of analysis. In *truss* system, homologous landmarks on the boundary of the form are divided into two tiers and paired. The distance measures connect these landmarks into an over determinate truss network which is a series of quadrilaterals each having internal diagonals. Each quadrilateral shares one side with each succeeding and preceding quadrilaterals (see figure).

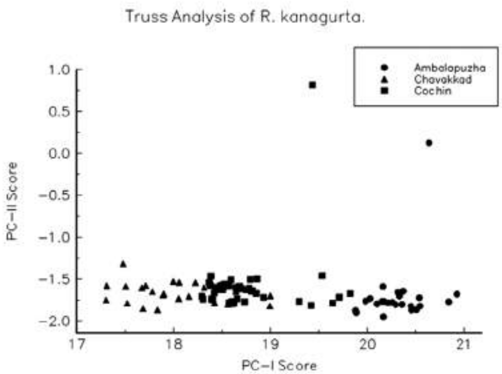


The following are the properties of a truss network measurements.

- It enforces systematic coverage across the form
- It exhaustively and redundantly archives the form
- The degree of measurement error in data can be measured and corrected
- Forms may be standardized to one or more common reference sizes by representing measured distances on some composite measure of body size and reconstructing the form using the distance values predicted at some standard body size.

- Principal components can be given geometrical interpretations. Component scores are measures of configuration while loadings are descriptors of shape change.
- Composite mapped forms are suitable for biorthogonal analysis of shape differences between forms.

In the analysis of multivariate data collected through truss network measurements the concept is that ***size*** and ***shape*** are the two factors which account for the association among the distance measures. *Size* is not considered as a single variable but as a factor which is obtained as a linear combination of the distance measures. *Shape* is considered as the geometry of the organism after information about position, scale and orientation has been removed. The *shape* discriminator should be independent of *size*, for it to be free from the effect of growth. Principal component (PC) analysis which does not require any prior information about groups is used in the analysis of truss data. A logarithmic transformation is first applied to the measurements before performing the PC analysis to reduce variance due to size variation and also because according to an allometric model diverse distance measures relate log linearly in a homogeneous population. The first component factor of the PC analysis is then interpreted as size component (which is not fully free from shape) and subsequent component factors are designated as shape variable (not fully free from size). Then a plot of the first principal component scores against the second principal component scores will more of less show clustering for different groups. The percentage of variation explained by this two factors also should be considered before making conclusions.



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TROPHIC LEVELS AND METHODS FOR STOMACH CONTENT ANALYSIS OF FISHES

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Investigation of food and feeding of fishes has traditionally been an important field of activity in fisheries biology, but it is one in which there are great difficulties in correlating the results with the research made in the other fields (FAO, 1974). Investigations of the food of the fish cannot be considered in isolation but have to be discussed in relation to the whole marine environment, of which the fish constitute single elements.

Food Chains and Trophic Levels

The production of organic substances (food) by photosynthesis is a process involving transformation of light energy into potential chemical energy. The transfer of this food energy from the producers through a series of consumers is called a food chain, each organism through which it is passed being a link in the chain.

Three different food chains may be recognized.

1	2	3
• The carnivore chain, where the energy is passed from smaller to larger organisms	• The parasite chain, where the energy is passed from larger to smaller organisms	• The saprophyte chain, where the energy is passed from dead organic matter to micro-organism in most cases

In reality food may be passed through parts of all three chains before it is finally decomposed into inorganic nutrients by the bacteria and fungi found at the end of every food chain. In other words, the species population within a community or ecosystem form many food chains which interconnect, anastomose or cross each other in a complex pattern, which is usually referred to as the **food web.**

Organisms which belong to the same link of the food chain as counted from the producer level are said to belong to the same trophic level. Thus the plants constitute the first trophic level, the herbivores the second, and the carnivores feeding on herbivores the third trophic level. Secondary

Reprinted from the CMFRI, FRAD. 2014. Training Manual on Fish Stock Assessment and Management, p.150.

carnivores feeding on third level carnivores belong to the fourth trophic level and so forth. However, there is a very definite limit to the number of possible links in a food chain, and consequently also to the number of trophic levels in any ecosystem. The reason for this is that only about 10 percent of the available energy is assimilated in passing from one trophic level to the next. At the top of the food chain there are usually only one or two major predators. The number of species in each trophic layer increases with approach to the first layer, giving rise to what is called a pyramid of numbers. For the major predators introduction of small amounts of pollutants into the first trophic layer can have fatal consequences because it is eventually concentrated in them.

Gross Production and Net Production

Only a very small portion of the light energy absorbed by green plants that is transformed into food energy (gross production) because most of it is dispersed as heat. Furthermore, some of the synthesized gross production is used by the plants in their own respiratory processes, leaving a still smaller amount of potential energy (the net production) available for transfer to the next trophic level.

The Loss of Energy

True production of organic matter takes place only in the chlorophyll-possessing plants and certain synthetic bacteria, and this has been referred to as the primary production. Copepods and euphausids, convert plant material into protein that can be assimilated by the animals which eat them but which themselves could not exist on plant material. In reality, of course, they only assimilate and store energy derived from the primary producers. They are called secondary producers, a term which of course fits animals at higher trophic levels just as well because they too - although indirectly - utilize the primary production of the plants. The loss of energy is generally referred to as the respiratory loss because the organisms utilize the food energy by oxidizing it. Because of the respiratory losses the food chains cannot be very long and the number of trophic levels in natural communities is therefore seldom more than four or five and often only three. It also means that the total amount of food available decreases with increasing trophic level. For this reason, the largest animals are found feeding on either plants or other animals which are in a low trophic level as, for example, whales on krill and elephants on plants.

Studying Food and Feeding of Fishes

The study of the feeding habits of fish and other animals based upon analysis of stomach content has become a standard practice (Hyslop 1980). Stomach content analysis provides important insight into fish feeding patterns and quantitative assessment of food habits is an important aspect of fisheries management. Lagler (1949) pointed out that the gut contents only indicate what the fish would feed on. Accurate description of fish diets and feeding habits also provides the basis for understanding trophic interactions in aquatic food webs. Diets of fishes represent an integration of many important ecological components that included behavior, condition, habitat use, energy intake and inter/intra specific interactions. A food habit study might be conducted to determine the most frequently consumed prey or to determine the relative importance of different food types to fish nutrition and to quantify the consumption rate of individual prey types. Each of these questions requires information on fish diets and necessitates different approaches in how one collects and analyzes data. Here, we outline qualitative and quantitative techniques used to describe food habits and feeding patterns of fishes. For a better understanding of diet data and for accurate interpretation of fish feeding patterns, time of day, sampling location, prey availability and even the type of collecting gear used need to be considered before initiating a diet study or analyzing existing diet data.

Stomach contents can be collected either from the live or fresh died fish. Regardless of the method, investigators should ensure that the removal technique effectively samples all items in the gut. Other wise data will be skewed toward items that are more easily displaced from the stomach. Alternatively, live fish can be sacrificed and stomach contents removed for analysis. If fish are to be sacrificed, they should be preserved immediately either by freezing or by fixing in formalin. Stomach contents will continue to digest, rendering rapid preservation of the fish or removed contents necessary to prevent loss of resolution. As in most fish groups feeding behavior of juveniles and adults vary distinctly attention should be taken to encounter more samples which will include all size groups of the particular fish. The specimens either from live or preserved should be measured to its total length to the nearest 1mm and weight to the nearest 0.1 g. Cut open the fish and record the sex and maturity stage of the fish. Remove the stomach and preserve them in 5% neutralized formalin for further analysis. For the analysis, a longitudinal cut must be made across the stomach and the contents are transferred into a petri dish. The contents then keep for five minutes to remove excess formalin and then examine under binocular microscope. Identify the gut content up to the genus and if possible up to species level depending up on the state of digestion. Various taxa digest at different rates. As such, all recently consumed taxa may be present in the foregut but only resistant items remain in the hindgut. To avoid bias when both easily digested prey and resistant prey are present, only the immediate foregut (e.g., stomach) should be sampled.

Prey items in fish stomachs are often not intact. Hard parts such as otoliths, scales, cleithra or backbones have diagnostic, species specific characteristics useful for identifying prey. Alternatively, partially digested prey may be identified using unique biochemical methods such as allozyme electrophoresis, or immunoassays. An important fact assessed by the examination of the stomach is the state or the intensity of feeding. This is judged by the degree of distension of the stomach or by the quantity of food that is contained in it. The distension of the stomach is judged and classified as ‘gorged or distended’, ‘full’, ‘3/4full’, ‘1/2full’ etc by eye estimation.

Fish diets can be measured in a variety of ways. Methods of gut contents analysis are broadly divisible into two, viz., qualitative and quantitative. The qualitative analysis consists of a complete identification of the organisms in the gut contents. Only with extensive experience and with the aid of good references it is possible to identify them from digested, broken and finely comminuted materials. Quantitative methods of analysis are three types, viz., numerical, gravimetric and volumetric. All these types of analysis are widely employed by different workers. The following outline of methods is based mainly on the reviews by Hynes (1950), Pillay (1952), Windell(1968), Hyslop (1980) and Chipps et al (2002).

1. Numerical Methods

The numerical methods are based on the counts of constituent items in the gut contents. The numerical methods have been adapted in different ways to assess the relative importance of food items and these can be classified under four distinct heads, viz., a) Occurrence, b) Dominance, c) Number and d) Point (Numerical) methods.

a) Frequency of Occurrence: Stomach contents are examined and the individual food organisms sorted and identified. The number of stomachs in which each item occurs is recorded and expressed as a percentage of the total number of stomachs examined.

Frequency of Occurrence, = $O_i = \frac{J_i}{P}$, where, J_i is number of fish containing prey i and P is the number of fish with food in their stomach.

This method demonstrates what organisms are being fed upon, but it gives no information on quantities or numbers and does not take in to consideration the accumulation of food organisms resistant to digestion. For instance, three organisms in a stomach, say, prawn, rotifers and diatoms, present in the ratio of 1:200:2000 would all be treated by this method as 1:1:1 with reference to the stomach in question. This method holds good even when there is differential distribution of various food organisms in the water for the same reason that it is not biased by size or numbers of organism comprising the food. Many have used this method as an indicator of inter-specific competition while some utilized this method to illustrate the seasonal changes in diet composition.

b) Number Method: The number of individual of each food type in each stomach is counted and expressed as a percentage of the total number of food items in the sample studied, or as a percentage of the gut contents of each specimen examined, from which the total percentage composition is estimated.

Percent by number, $N_i = \frac{N_i}{\sum_{i1}^{Q} N_i}$, where, N_i is the number of food category i

This method has been employed successfully by several workers in studies on the food of plankton feeding fishes where the items can be counted with ease. In the basic number method, no allowance is made for the differences in size of food items. So in the studies on the food of fishes other than plankton feeders, the number method has very limited use. The counting of comminuted plant matter in the stomach of fish is impracticable and will not yield correct evaluations. So also in the analysis of the gut contents of a carnivore which may consist of only one large sized fish and a couple of small larvae, the counting are of little value computations. These are summed to give totals for each kind of food item in the whole sample, and then a grand total of all items. The quotient of these gives the percentage representation, by number, of each type of food item.

c) **Dominance Method**: Essentially the dominance method is a partial improvement of the occurrence method, viz., the lack of consideration of the quantities of the food items present in the stomach, sought to be remedied. The stomach contents comprising the main bulk of the food materials present, is determined and the number of fish in which each such dominant food material is present is expressed as a percentage of the total number of fishes examined. The percentage composition of the dominant food materials can also be expressed by this method as in the occurrence method.

Though in an analysis of dominance the bulk of the food material is taken in to account, it can yield only a very rough picture of the dietary of a fish. Moreover, items which are less dominant due to environmental reasons may escape notice. Though this defect can also be remedied to a certain extent by the examination of large samples spread over a long period of time, a system of assay that takes in to account the relative importance of food constituents will obviously be more suitable in gut content analysis.

d) **Points (Numerical) Method:** The points method is an improvement on the numerical method where consideration is given to the bulk of the food items. The simple form of points method is the one in which the counts are computed falling a certain organisms as the unit. In a more modified form, the food items are classified as 'very common', 'common', 'frequent', 'rare', etc., based on rough counts and judgments by the eye. In this arbitrary classification the size of the individual organisms is also given due consideration. The contents of all stomachs are then tabulated and as a further approximation, different categories are allotted a certain number of points and the summations of the points for each food item are reduced to percentages to show the percentage composition of the diet. This method is essentially a numerical one; the volume being only a secondary consideration and it is only in the counts that a certain amount of accuracy can be claimed.

2. Volumetric Methods

Many workers consider the volume as a more satisfactory method for quantitative analysis of gut contents. As Hynes (1950) pointed out, volume forms a very suitable means of assessment, this is especially so in the case of herbivorous and mud feeding fishes where the numerical methods "become meaningless as well as inaccurate". Even in cases where the numerical methods are suitable, volume has been considered as an essential factor to be reckoned with, and in all improved numerical methods the volume of the food items is taken in to consideration in some way or other.

The chief methods that are employed in assessing the volume of food items in the gut contents of fishes are:

a) **Eye estimation Method:** This is probably the simples and easiest means of determining the volume of food constituents. In this method the contents of each sample is considered as unity, the various items being expressed in terms of percentage by volume as estimated by inspection. This method of analysis is subjective in nature and the investigators personal bias is likely to influence the results very greatly. This defect can be minimized to a great extent by the examination of large samples conducted over a long period.

b) **Points (Volumetric) Method:** This method is a variation of the eye estimation method. Here instead of directly assessing the volume by sight as in the previous method, each food item in the stomach is allotted a certain number of points based on its volume. Certain workers have taken into account both the size of the fish and the fullness of the stomach in the allotment of points. The diet component with highest volume was given 16 points. Every other component was awarded 16, 8, 4, 2, 1 and 0 points depending on the volume relative to the component with the highest volume. Percentage volumes within each subsample were calculated as:

$$\alpha = \frac{\text{Number of points allocated to component a}}{\text{Total points allocated to sub sample}} \text{X } 100$$

where, α is the percentage volume of the prey component a

This method is quite useful for analyzing omnivorous and herbivores where measuring volumes of microscopic organisms such as diatoms and filamentous algae are very difficult.

c) **Displacement Method:** The displacement method is probably the most accurate one for assessing the volume. The volume of each food item is measured by displacement in a graduated container such as a cylinder with the smallest possible diameter for accuracy. This method is eminently suited in the estimation of the food of carnivorous fishes. But the differential rate of digestion of the food items may sometimes affect he accuracy of the observations. However, if the collections are made when the fish are on feed, this defect can be easily overcome. A knowledge of the volumes of the different size groups of the food items ay be of great help in estimating the volume of the whole item form the semi digested fragments

3. Gravimetric Method

The gravimetric method consists of the estimation of the weight of each of the food items, which is usually expressed as percentages of the weight of the total gut contents as in other quantitative methods.

$$\text{Percent by weight, } W_i = \frac{W_i}{\sum_{i=1}^{Q} W_i},$$

Where, W_i is the weight of the prey i

Generally the wet weigh of the food after removing superfluous water buy pressing it dry between filter papers is taken for this purpose. Dry weight estimation is more time consuming and is usually employed where accurate determinations of calorific intake is required. The limitation of weight as a criterion of analysis has already been referred in the consideration of the method of assessing the condition of feed. Besides these, the accurate weighing of small quantities of food matter is extremely difficult and impracticable in studies of large collections. This method is, therefore generally employed only in conjunction with other methods to demonstrate seasonal variations in the intensity of feeding.

Table: Example of results obtained using different methods of estimation of stomach contents for two numbers of *Lactariuslactarius (l.l)*

L. lactarius 1 (Ll1). 1. *Stolephorusbataviensis*, 9 cm long, weight 5 g, volume 7 ml, 6 *Acetes* each 3.0cm long, weight 300mg vol. 2ml, 1 *Bregmaceros* ,4cm, 1 g, vol. 1 ml.

L. lactarius2 (Ll2). 1. *Stolephoursbataviensis*, 7 cm long, weight 3 g, volume 4 ml, 4 *Acetes* 2.5 cm long, weight 250 mg, vol.1 ml.

Food	**Method**	**Fish** Ll1	Ll2		**%**	**Total of which % expressed**
S. bataviensis	Occurrence	1	1	2	40	All food occurrences
Acetes		1	1	2	40	
Bregmaceros		1	0	1	20	
S. bataviensis	Numerical	1	1	2	15.4	All food organisms
Acetes		6	4	10	76.9	
Bregmaceros		1	0	1	7.7	
S. bataviensis	Dominance	1	1	2	100	All fish
Acetes		1	1	2	100	
Bregmaceros		1	0	1	50	
Food	**Method**	**Fish** LL1	LL2		**%**	**Total of which % expressed**
S. bataviensis	Total Volume	7	4	11	73.3	Total food volume
Acetes		2	1	3	20	
Bregmaceros		1	0	1	6.7	
S. bataviensis	% volume	70	80	75	75	Food volume
Acetes		20	20	20	20	
Bregmaceros		10	0	5	5	
S. bataviensis	Gravimetric	5	3	8	67.8	Total weight of food
Acetes		1.8	1	2.8	23.7	
Bregmaceros		1	0	1	8.5	

Food Analysis Indices

A. Simple Indices

1) **Index of Fullness:** This is measured as the ratio of food weight to body weight as an index of fullness, which is very widely employed. (The ratio of corresponding volume can also be used.) This index can be applied to the food in the stomach, or to that in the whole digestive tract. It is usually expressed as parts per 10,000 (%00, or parts per decimile); that is:

$$\text{Fullness index} = \frac{\text{weight of the stomch contents x 10,000}}{\text{weight of fish}}$$

2) **Index of Selection or Forage Ratio:** Most fishes have a scale of preference for the organisms in their environment, so that some are consumed in large numbers, others moderately, some not al all. A quantitative index of such differences called as the forage ratio. A study of the quantities of different organisms available to the fish is made, and also of the various items in their stomachs; then;

$$\text{Selection index = forage ratio} = \frac{s}{b}$$

where, s = percentage representation by weight, of a food organism in the stomach and b = percentage representation of the same organism in the environment. The lower limit for this index is 0; its upper limit is indefinitely large.

3) **Index of Electivity:** Ivlev (1961) proposed a somewhat different quantitative measure of selection which has been widely used as mean of comparing the feeding habits of fishes and other aquatic organisms with the availability of potential food resources in natural habitats. The relationship is defined as

$$\text{Electivity index} = E = \frac{s - b}{s + b}$$

The index has a possible range of -1 to +1, with negative values indicating avoidance or inaccessibility of the prey item, zero indicating random selection form the environment, and positive values indicating active selection.

B. Compound Indices

In an attempt to consolidate the desirable properties of individual diet measures (e.g., Ni, Wi. Foi), compound indices were developed that combine two or more measures into a single index. The belief is that compound indices capture more information than do single component measures (Chipps*et al* 2002).

1) Index of Preponderance: (Natarajan and Jhingran, 1961)

This index gives a summary picture of frequency of occurrence as well as bulk of various food items. It provides a definite and measurable basis of grading the various food elements. The bulk of food items can be evaluated by 1) Numerical 2) volumetric and 3) Gravimetric methods. As the numerical method is not suited to the index with the frequency of occurrence it magnifies the importance of smaller organisms which may appear in enormous numbers. Therefore either volumetric or gravimetric are best to assess the food items quantitatively. If we V_i and O_i are the volume and occurrence index of food item i. then,

$$\text{Index of preponderance } I_i = \frac{V_i O_i}{\sum V_i O_i} X\ 100$$

Example: The 'Index of Preponderance' of food items of *Catlacatla* (Ham.) is given in the table 2 with rankings in brackets.

Table 2 : Index of Preponderance (Natarajan and Jhingran, 1961) of adult *Catlacatla*

Food items	Percentage of Occurrence (O_i)	Percentage of volume (V_i)	$V_i O_i$	$\frac{V_i O_i}{\sum V_i O_i}$ X 100
Crustaceans	24.5	57.1	1398.95	64.50 (1)
Algae	27.3	24.0	655.20	30.06 (2)
Plants	6.4	8.2	52.48	2.41 (3)
Rotifers	10.8	2.4	25.92	1.19 (4)
Insects	3.6	6.0	21.60	0.99 (5)
Protozoa	0.6	0.3	0.18	0.01 (8)
Molluscs	....	....	......	......
Polyzoa	....	....	......	. ....
Detritus	10.0	1.3	13.00	0.60 (6)
Sand and mud	16.8	0.7	11.76	0.54 (7)
$\sum$	**100**	**100**	**2179.09**	**100**

According to the index crustaceans and algae constitute 1 and 2 ranks in *Catla catla*. While third, fourth and fifth places are held by plants, rotifers and insects. In grading the food elements accidental and incidental inclusions like sand, mud, etc., may be left out of consideration.

2) Index of Relative Importance (IRI):- Leo Pinkas et al (1971)

This index is an integration of measurement of number, volume and frequency of occurrence to assist in evaluating the relationship of the various food items found in the stomach. It is calculated by summing the numerical and volumetric percentages values and multiplying with frequency of occurrence percentage value.;

$$\text{Index of relative importance, } \mathrm{IRI_i} = (\%\,\mathrm{N_i} + \%\,\mathrm{V_i})\,\%\,\mathrm{O_i},$$

where, $\mathrm{N_i}$, $\mathrm{V_i}$ and $\mathrm{O_i}$ represent percentages of number, volume and frequency of occurrence prey **i** respectively.

Example: Index of Relative Importance of pelagic preflexion summer flounder, *Paralichthysdentatus* larvae (Grover, 1998) with ranking in brackets

Prey	$\%\,\mathrm{N_i}$	$\%\,\mathrm{V_i}$	$\%\,\mathrm{O_i}$	$(\%\,\mathrm{N_i} + \%\,\mathrm{V_i})\,\%\,\mathrm{O_i}$	%IRI
Tintinnids	28.7	3.3	37.6	1203.2	19.3 (3)
Copepod	20.0	10.2	41.2	1244.24	20.0 (2)
nauplii	16.0	61.4	30.0	2322	37.3 (1)
Copepodites	0.6	4.9	2.0	11	0.2 (8)
Calanoids	0.6	2.0	2.4	6.24	0.1 (9)
Cyclopoids	16.0	1.2	34.8	598.56	9.6 (5)
Copepod eggs	12.1	14.8	28.0	753.2	12.1 (4)
Bivalve larvae	3.7	0.9	11.6	53.36	0.9 (6)
Invertebrate eggs	2.3	1.3	9.2	33.12	0.5 (7)
Other					

In pelagic preflexion summer (*Paralichthy dentatus)* larvae, copepodites composed the bulk of the diet (61.4% Vol, 37.3 % IRI) and formed the most important prey. Copepod nauplii, the second most important prey, composed 20.0% (N and IRI). Tintinnids, despite being the most abundantly ingested prey (28.7% N); ranked third in importance at 19.3% (IRI). Bivalve larvae and copepod eggs were the only other prey that accounted for >1% of the diet, and together they composed 21.7% (IRI).

Suggested Reading

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ROLE OF ENVIRONMENTAL VARIABLES ON SPAWNING AND RECRUITMENT OF SMALL PELAGICS IN AN UPWELLING SYSTEM : THE INDIAN OIL SARDINE - A CASE STUDY

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Introduction

The marine ecosystem is dynamic and the variations several abiotic and biotic factors directly and indirectly affect the fish stocks and their population structure. Spawning and recruitment success is to a large extent linked to these environmental variations. It is well known that resources occupy a particular habitat because of their preference to the environmental variables prevalent there and also due the availability of food. We have large shoal forming small pelagic fishes like the sardines and anchovies and the deep water large pelagic and demersals occupying the marine ecosystem from the upper pelagic zone to the benthic realms. Fishing is one of the major activities directly impacting the fish stocks and fishery records show several cases of overfishing leading to stock collapses. Definitely, fishery management tools have supported revival of several of these stocks but have failed to do so in few others. Almost equally important in inducing the biological changes that control maturation, spawning and recruitment are the some ocean atmospheric processes which change inter-annually in the tropics.

Globally, small pelagics serve as important forage species and support several higher tropic level fisheries. They also support coastal livelihoods and form an important source of low cost and high quality protein to several villagers. In addition to this, they serve as raw material to several post-harvest processing units which prepare canned, smoked and dried products regularly.

One common factor among most of these fishes is their ability to increase in biomass to very high levels and then suddenly decline and collapse. They revive slowly taking to 2 to more than 6 to 8 years depending upon the reason and the intensity of overfishing. All these changes in biomass, like the sudden increase and the low levels are mainly controlled by environmental factors. A recent study on the decline in sardine fishery along the Kerala coast revealed the role played by several abiotic and biotic ecological parameters which determine the recruitment success. The importance of environmental variables on recruitment success is detailed below through the recent investigations on sardine fishery.

Sardine Fishery of Kerala

The Indian oil sardine is a small shoal forming pelagic fish which is caught mainly by seines. Historic records describing the fish and fisheries of Kerala indicate that in the year 1320 Odoric has commented that there were plenty of fishes in coastal waters in Kerala, and this is presumed to be a one of the earliest reference to sardines. Apart from being used as food, sardines were used for oil extraction which was exported from Cochin port. Historic records show that sardine fishery has collapsed several till during the last two centuries and Day (1865) has observed the ill effects of unrestricted in diminished catches in later years. He also thought that oil sardine "*occasionally forsake their haunts for several consecutive seasons, returning again in enormous quantities*"

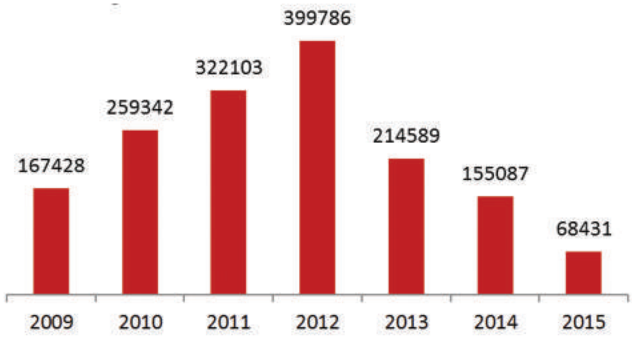


Fig. 1. Kerala Sardine Total Catch in tonnes

The sardine catch in 2012 was 3.9 lakh tonnes which was the highest during the last two centuries and then the decline started. The catch declined by 46 % in 2013 (catch 2.1 lakh tonnes), then by 61% in 2014 (catch-1.6 lakh tonnes) and by 82% in 2015 reaching 68431 tonnes (Fig. 1). Within a span of 5 years, the state witnessed the highest catch and lowest catch. During the period 1960 to 2015, the sardine stock has reached the collapsed status only once (1994.)

Most often, before a fishery collapse, over fishing of the stocks leading to imbalance in the population structure and biomass has been known to occur. As per an estimate of CMFRI based on 2005 to 2007 data the MSY of sardine along Kerala coast, is 2.3 lakhs tonnes. So during the period 2011 and 2012, the stock was fished above the MSY by harvesting nearly 2.5 lakh tonnes.

Excessive harvest of juveniles: About 16,040 tonnes of juveniles (less than 10cm) forming 4% of the total catch were harvested in 2012 and about 4802 tonnes in 2013. This would have affected the spawning biomass of 2013, 2014 and 2015. (16,040 tonnes of less than 10cm sardine would have contributed to a biomass of 5,61,400 tonnes at 30% mortality in the subsequent years . Similarly if the 4802 tonnes of juveniles were allowed to grow, it would have supported a spawning population of 1,68,070 tonnes of sardine)

The Indian oil sardine is known to move to inshore waters for spawning in large shoals. This is the time when the sardines have been fished in large quantities. After spawning, the young ones grow rapidly in the near-shore area (Fig 2). The environmental variations affect all the biological processes.

Role of Fishery dependent factors in reducing fish stocks

Usually age structure in a fish population is balanced. However, due to intense fishing pressure, either due to growth overfishing or due to recruitment overfishing, the fish stocks can be affected and in such instances they become vulnerable to adverse environmental conditions. Less than one year old sardines have always formed a major component of sardine population. However, during the period Oct 2012 to Feb 2013 about 1,17,823 tonnes of 10 to 14 cm size sardines were harvested. The large scale removal of this group also would have affected the potential spawning population of 2013 and 2014. Thus the population of sardine was affected. So by the beginning of 2013, the sardine stock off Kerala was severely affected-low biomass and less number of potential spawners. What followed after that was adverse environmental conditions, though not continuous, affected spawning and recruitment.

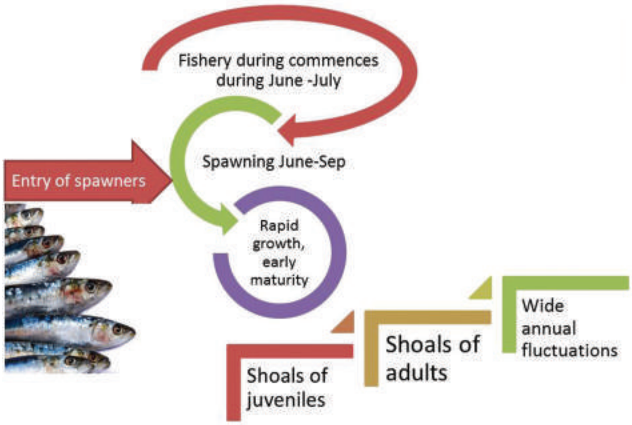
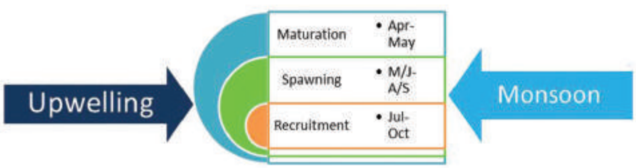


Fig. 3. Time line of reproductive phases and key environmental process

Environmental factors controlling sardine maturation and spawning

Upwelling and monsoon are two major ocean –atmospheric processes which are known to influence sardine maturation and spawning (Fig 3). They are known to mature by April –May and spawn from end of May to August/September. Recruitment is usually from July/ August onwards.



Upwelling and Recruitment

Upwelling is a process in which deep, cold water rises toward the surface. *Upwelling* occurs when winds push surface water away from the shore and are replaced by cold, nutrient-rich water that wells up from below (Fig 4). Deep ocean water is more nutrient-rich than surface water as nutrients, dead and decaying plankton and other fish carcasses sink to the bottom. During upwelling these are brought back to the surface and these fertile systems support blooming of diatoms and zooplankton. This rich food supports growth and maturation of several fishes.

Upwelling is most common along the west coast of continents (eastern sides of ocean basins). In the Northern Hemisphere, upwelling occurs along west coasts (e.g., coasts of California, Northwest Africa, India) when winds blow from the north (causing Ekman transport of surface water away from the shore). Along the Indian west coast, upwelling is strong along Kerala coast and is known to occur in varying intensities.

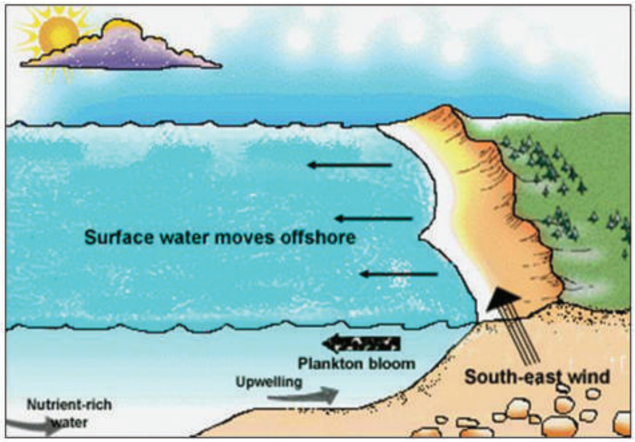


Fig. 4. Schematic diagram of Upwelling

Upwelling and Fish Maturation

As mentioned earlier, upwelling triggers blooming of diatoms and these provide food for the maturing fishes like sardine. Along Kerala coast upwelling sets in by May -June and this suddenly increases the Gonado-Somatic Index of sardine making them ready for spawning. When there is poor upwelling, the major factors supporting gonad development like blooming of diatoms and lowering of ambient temperature does not happen and this can lead to poor maturation or delayed maturation. In 2015, upwelling was poor and maturation was affected.

Upwelling and Dissolved Oxygen

Upwelling can also bring in low oxygen water which can lead to hypoxic conditions. Sometimes along Kerala coast, low oxygen in upwelled waters can be seen in the sardine habitat during August –September. If the dissolved oxygen levels are below one ml /l then this has been found to affect recruitment and the fishery. In the sardine habitat along Kerala coast, the influx of upwelled waters with low oxygen (0.7 to 0.8 mg per litre) was found in the main sardine habitat during August 2013 .Low mixing of waters can cause stratification and along with hypoxic conditions cause stress to the early life stages.

Upwelling and Jellyfishes

Jellyfishes are known to bloom and survive in adverse conditions. When upwelling creates low very oxygen conditions jellyfishes are not affected. Hence they also proliferate in the coastal waters. These can increase the biotic pressures on the larval and juvenile stages through predation.

Timing of Upwelling

If upwelling occurs very early and if the intensity is high with low oxygen waters in the habitat, this can prevent the spawners from entering the coastal waters for spawning. In such cases, spawning may be delayed.

Monsoon-Rainfall and Recruitment

When maturation is largely influenced by upwelling, the onset and intensity of southwest monsoon has a good influence on sardine spawning and recruitment. Though there is no direct affect, the changes triggered by monsoon especially the blooming of plankton in near-shore waters supports early larval development. The high levels of phosphate, nitrate and silicate in the river runoff triggers and supports blooming of diatoms. These support the large shoals of early life stages of sardine. Similarly, there will be negative impacts when the riven runoff is high and there is no proper mixing. This can lead to stratification and adversely affect recruitment.

In 2013 there was good maturation in sardines during pre-monsoon period, but the spawning and recruitment processes were affected by the above normal rainfall during June and July. The rainfall during June and July of 2013 was 60 and 14% more than the normal.

The sardines were exposed to “stress” due to salinity stratification i.e extremely low salinity due to excessive river runoff in the surface waters and higher saline waters in the bottom.

Deficit Monsoon

In 2014 there was good maturation in sardines during pre-monsoon. However, since the monsoon was deficient during June/July it delayed the spawning period._A successful spawning as in normal years was not observed in spite of good maturation. Sporadic spawning was observed from April to Sep/Oct (7 months). Though spawning was observed during third week of June it was not complete.

Excess Rainfall During Late Monsoon

In 2014, monsoon was excess by 74% and 22% during August and September than the normal. This resulted in low saline waters and salinity stratification which affected recruitment.

Ocean Atmospheric Processes

El Niño

El Niño is the warm phase of the El Niño Southern Oscillation (commonly called ENSO) and is associated with a band of warm ocean water that develops in the central and east-central equatorial Pacific . ENSO refers to the cycle of warm and cold temperatures, as measured by sea surface temperature, SST, of the tropical central and eastern Pacific Ocean. El Niño is accompanied by high air pressure in the western Pacific and low air pressure in the eastern Pacific. The cool phase of ENSO is called “La Niña” with SST in the eastern Pacific below average and air pressures high in the El Nino affects the global climate and disrupts normal weather patterns, which as a result can lead to intense storms in some places and droughts in others. At least 26 El Niño events since 1900 have been identified, with the 1982-83, 1997–98 and 2014–16 events among the strongest on records. ENSO is the most important coupled ocean-atmosphere phenomenon to cause global climate variability on inter-annual time scales.

Multivariate ENSO Index

The multivariate ENSO index, abbreviated as MEI, is a method used to characterize the intensity of an El Niño Southern Oscillation (ENSO) event. Given that ENSO arises from a complex interaction of a variety of climate systems, MEI is regarded as the most comprehensive index for monitoring ENSO since it combines analysis of multiple meteorological and oceanographic components such as sea-level pressure (P), zonal (U) and meridional (V) components of the surface wind, sea surface temperature (S), surface air temperature (A), and total cloudiness fraction of the sky (C).

Impacts on Ecosystems and Fisheries

In Peru, the warm water and low food availability that accompany El Nino have led to decline in anchovies that make up the largest fishery on Earth. Global total capture fishery production in 2014 was 93.4 million tonnes, of which 81.5 million tonnes from marine waters and 11.9 million tonnes from inland waters. (FAO, 2016). For the first time since 1998, anchoveta was not the top-ranked species in terms of catch as it fell below Alaska Pollock.

In 2015, it was observed that upwelling was low and the sardine habitat changed considerably. There was no good maturation and spawning during 2015, consequently poor recruitment. Though maturation was observed during May/June, it was not as healthy as in previous years. Globally, 2015 has been considered as a warm year with high temperature and low food. The average seawater temperature in sardine habitat was 29.8° C during 2015, which is nearly 1.1 deg C higher than the average observed (28.6 ° C) for the last 5 years. Positive SSTA exceeding 0.6°C dominated in the tropical Indian Ocean. There was a substantial warming in the tropical Indian Ocean, partially due to influences of the 2015 El Nino. The mean SST in the tropical Indian Ocean was reported to increase by 0.13-0.2°C in 2015. Phytoplankton density was also low during April/May 2015 compared to the high during 2012. This low food availability in the habitat was found to affect maturation which resulted in poor recruitment.

Combined Effects of Overfishing and Environmental Stress

Thus the cumulative effect of overfishing above MSY in 2011 and 2012 including the exploitation of nearly 16,040 tonnes of juveniles in 2012 affected the sardine population/ biomass. This was followed by poor recruitment in 2013 and 2014 due to environmental stress due to salinity stratification (due to excessive rains in late monsoon) and hypoxic condition (due to upwelling) in inshore sardine habitats.

Low food availability and comparatively higher temperature due to poor upwelling led to poor maturation and subsequent recruitment success. In 2015, these changes were compounded mainly by global ocean –atmospheric process like *El nino*. The various factors affecting maturation, spawning and recruitment of oil sardine is given in Table 1.

Table. 1 Factors affecting maturation, spawning and recruitment in oil sardine

Parameter	Maturation	Spawning	Recruitment	Level of impact
Upwelling in April/May	**Favourable**			Very strong
Good diatom bloom				Very strong
Monsoon on-start -May				Mildly strong
Monsoon normal				Very strong
Delayed monsoon		**Unfavourable**		Mildly strong
Excess rainfall (floods)				Mildly strong
Low oxygen in inshore waters	**Unfavourable**		**Unfavourable**	Very strong
Noctiluca /Jellyfish bloom				Mildly strong

Policy Support for Protecting Sardine Stock for Revival

Sardine fishery has collapsed during last century also. To revive the stocks, Government of Madras introduced restricted legislation in Malabar and South Kananra Districts in 1943; then extended to another two years from 1945 to prohibit use of the following nets for immature sardine all throughout the year. Landing of immature oil sardine below 15 cm not exceeding a total weight of one Maund (28 maund =1 ton) was also prohibited. The legislation lapsed in 1947 due practical difficulties encountered in enforcement such as (1) lack of preventive staff all over the coast (2) lack of legislation in adjacent states

The drastic decline after 2012 affected the fishing industry very badly, especially the traditional fishermen and those fishers who had invested heavily on fishing. In a move to protect the resource, the Department restricted fishing of juveniles of fishes based on scientific advisory by CMFRI and the Minimum Legal Size (MLS) was introduced for 14 species. For sardine the MLS was 10 cm.

In almost all major sardine and anchovy fisheries, when the fishery is showing a downward trend, the scientists and administrators join together and introduce Total Allowable Catch or close the fishery for a specific period. The stocks are influenced both by overfishing and by extreme events.

NEW METHODS OF FISH STOCK ASSESSMENT

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1. Multispecies Surplus Production Model

This is a multivariate version of single species surplus production model. Here, the annual surplus production (ASP) is calculated for each stock as:

$$\text{ASP}_{j,t} = B_{j,t+1} - B_{j,t} + \delta_j C_{j,t}$$

where $B_{j,t}$ is the estimated "adult" biomass of stock *j* at the beginning of year *t*, $C_{j,t}$ the catch of stock *j* during year *t*, and δ_j is a stock-specific correction factor that accounts for growth and mortality that would have taken place between the time the catch was taken and the beginning of year *t+1*. Assuming an additive error structure for annual surplus production, the estimating equations take the form of a multiple linear regression for the Graham-Schaefer model and a non-linear regression for the Pella-Tomlinson model (Quinn and Deriso, 1999):

Graham-Schaefer : $ASP_t = \alpha\, \overline{B}_t + \beta\, \overline{B}_t^{\,2} + \varepsilon_t$

Pella-Tomlinson : $ASP_t = \alpha\, \overline{B}_t + \beta\, \overline{B}_t^{\,\nu} + \varepsilon_t$

where α, β, and ν are model parameters and εt are model residuals that are assumed to be normally distributed.

2. Multispecies Virtual Population Analysis (MSVPA) Model

Multispecies virtual population analysis is an extension of the VPA model for simultaneous analysis of data for more than one species that incorporates the predator stomach content data into the virtual population model. In MSPVA through a recursive algorithm the fishing mortality at different age, recruitment, stock size, suitability coefficients and predation mortality are calculated based on catch-at-age data, predator ration and predator diet information. MSVPA allows the estimation of vital population rates used in the management of fishery resources. An additional advantage of the model is the estimation of the predation mortalities produced by predators on preys species and the annual consumption of prey by predators. The MSVPA input data includes the catch-at-age data, percent of maturity-at-age, weight-at-age, terminal fishing mortalities, predator stomach content data and residual mortalities.

3. Dynamic Multispecies Models

These models consider the functional relationships among individual species in a fished system. They build upon single-species theory to understand the dynamics of multispecies fisheries. These models account for interactions among selected species (often exploited fish species) but do not address the ecosystem as a whole. Dynamic multispecies models consider predator–prey interactions and evaluate the interactions between a subset of the species in the ecosystem. They do not model competitive interactions explicitly, but often include constraints such as conservation of total system biomass, or constant input of food from outside the model, which result in changes in abundance of one species indirectly affecting the abundance of species with which it shares prey. Eg: virtual population analysis (VPA) models allowing for cannibalism, multispecies VPA (MSVPA) and statistical assessment models (SAM; single-species with predation).

4. OSMOSE Model

OSMOSE is a multispecies/single species model for fish species. The model assumes predation based on spatial co-occurrence and size and represents fish grouped into school characterized by their size, weight, age, taxonomy and geographical location. The processes considered in the fish life cycle are growth, explicit predation, natural and starvation mortalities, reproduction, migration and a fishing mortality distinct for each species. OSMOSE has been first applied to the Benguela upwelling ecosystem for which 12 fish species have been specified, from small pelagic fish to large demersal species The model needs basic parameters that are often available for a wide range of species. On output, a variety of size-based and species-based ecological indicators can be simulated and converted to in situ survey and catch data at the species level and community level. The model can be calibrated to observe biomass dynamics.

5. Atlantis

Atlantis is an ecosystem model that considers all the components of marine ecosystems namely biophysical, economic and social. It is a deterministic biogeochemical ecosystem model with its overall structure based around the Management Strategy Evaluation (MSE) approach. There are sub-models (or module) for each of the major steps in the adaptive management cycle. deterministic biophysical sub-model is at the core of the model, coarsely spatially-resolved in three dimensions, which tracks nutrient flows through the main biological groups in the system. The primary ecological processes considered in the model are consumption, production, waste production, migration, predation, recruitment, habitat dependency, and mortality. The trophic resolution is typically at the functional group level. The physical environment is represented via a set of polygons matched to the major geographical and bioregional features of the simulated marine system and biological model components are replicated in each depth layer of each of these polygons.

Atlantis also includes a detailed exploitation sub-model. This model is focused on the dynamics of fishing fleets and also deals with the impact of pollution, coastal development, environmental (e.g. climate) change. It allows for multiple fleets, each with its own characteristics of gear selectivity, habitat association, targeting, effort allocation and management structures. It includes explicit handling of economics, compliance decisions, exploratory fishing and other complicated real world concerns.

The sampling and assessment sub-model in Atlantis is designed to generate sector dependent and independent data with realistic levels of uncertainty measurements. These simulated data are based on the outputs from the biophysical and exploitation sub-models, using with a user-specified monitoring scheme. The data are then fed into the same assessment models used in the real world, and the output of these is input to a management sub-model. This last sub-model is a set of decision rules and management actions, which can be drawn from an extensive list of fishery management instruments such as gear restrictions, days at sea, quotas, spatial and temporal zoning, discarding restrictions, size limits, bycatch mitigation, and biomass reference points.

6. Size Spectrum Model

Charles Elton introduced the “pyramid of numbers” in the late 1920s, but this remarkable insight into body-size dependent patterns in natural communities lay fallow until the theory of the biomass size spectrum was introduced by aquatic ecologists in the mid-1960s. They noticed that the summed biomass concentration of individual aquatic organisms was roughly constant across equal logarithmic intervals of body size from bacteria to the largest predators. These observations formed the basis for a theory of aquatic ecosystems, based on the body size of individual organisms, that revealed new insights into constraints on the structure of biological communities. Size spectrum is the distribution of biomass/abundance as a function of individual mass or size. The shape of this function resembles a power function and biomass size spectrums are represented using power functions. Spatial and temporal variability in the community structure can be observed in the shape of biomass size spectra.

7. Stock Synthesis

In the history of fish stock assessment two different approaches dominated. One using time series of an indicator of stock abundance (standardized catch rate as a proxy for stock abundance) along with time series of fish catch (Schaefer, 1954). These models provide inference about current and target fish stock abundance and the maximum sustainable yield. The second approach depend on a time series of detailed fish catch-at-age data in order to reconstruct the virtual abundance of each annual cohort that had been fished (Pope, 1972 – Virtual Population Analysis, VPA). In the last two decades there has been development of a third approach known as Integrated Analysis (IA) that takes a more inclusive approach to modeling fish population dynamics utilizing a wide range of available data. Stock Synthesis (SS), implementation of IA, began during the early 1980s. Synthesis is a term used for development of a new product that is more than an blend of its dissimilar parts. In fish stock assessments, different kinds of data can provide complementary information about the fish stock, but one source may not be sufficient in itself to provide a complete picture of the stock’s abundance and the impact of fishing on the stock. Stock Synthesis inherently blends the population estimation paradigm of VPA with the population productivity paradigm of biomass dynamics models. The observations that can be included in SS are CPUE, effort, survey abundance, discards, length, age, weight composition data and tag-recapture data. It has capability to use time series of environmental and ecosystem factors to influence the poplation dynamics and observation processes over time. Three stages of SS assessment approach are – initial development from northern anchovies (basic concept), re-development as a generalized model for the west coast groundfish and development of the computer code in ADMB (Automatic Differentiation Model Builder).

A CONCEPT FOR ESTIMATION OF SECONDARY AND TERTIARY BIOMASS FROM PRIMARY PRODUCTION

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Global Biogeochemical Cycle

Fixation of inorganic carbon to organic carbon in the ocean is driven purely by phytoplankton. Phytoplankton carbon fixation plays an important role in maintaining the quasi steady state level of atmospheric CO_2. Relative contribution of marine primary productivity to global photosynthetic production is between 10 and 50%. Magnitude ranges from 20 to 55 Gt of C/ year (Ryther 1969, Smith et al., 1983, Walsh 1984 and Martin 1992). Ocean-atmospheric coupled climate models predict changes in the ocean circulation and hypothesize that changes in the ocean circulation will stimulate phytoplankton biomass production in the nutrient depleted areas in the open ocean (Roemmich & Wunch 1985). The effect on atmospheric CO_2 is uncertain because the relationship between the enhanced primary production and air sea exchange of CO_2 is not understood. The challenge is to study the magnitude and variability of Primary productivity, its time scales and changes in atmospheric forcing and upscale it into secondary and tertiary productivity.

Relevance to Northern Indian Ocean (NIO)

The Northern Indian Ocean (NIO) comprises a unique variety of biogeochemical provinces, including eutrophic, oligotrophic, upwelling, and oxygen-depleted zones, all within an area of relatively small geographic extent (Figure 1). Seasonally reversing winds observed in the area influence seasonal fluctuation in plankton richness, which is the resultant of enhanced nutrient supply through the process of coastal upwelling and winter cooling (Prasanna Kumar et al., 2000; de Souza et al., 1996). Enhanced nutrient supply increases

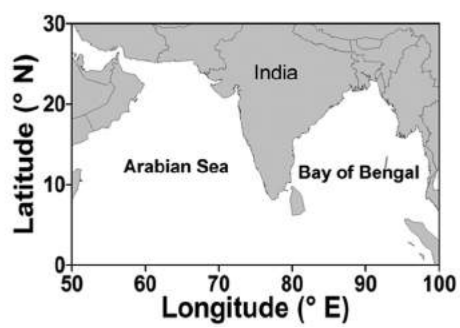

Fig. 1. Northern Indian Ocean comprising of Arabian Sea and Bay of Bengal

primary production in an alarming rate. Both secondary and tertiary production linked with primary production are found to enhance during these periods (Madhupratap et al., 2004). This factor reflects the pronounced semi-annual reversals in regional winds (the seasonal monsoons) that make this region a focus for intense study. Unlike, the seasonal cycle which have a definite periodicity, episodic events such as tropical cyclone which occurs without any periodicity also provides high nutrient supply for primary production, as a consequence of which production increases (Piontkovski and Al-Hashmi, 2014).

Estimation and integration of PP

Integrated *in-situ* column primary production (PP) will be estimated and PP will computed at biome level using *in-situ* and satellite (SRS) remote sensing data by adopting suitable mixed layer PP model. Later SRS methods will be applied for computing primary productivity to integrate at biome level.

Chlorophyll is an important indicator of the quality of aquatic ecosystems that is amenable to in situ and space borne measurement. This property can be retrieved from ocean colour data after removal of the atmospheric signal from the detected radiance. Phytoplankton blooms (indicated by rapid increase in chlorophyll concentration) and spurts in primary productivity are important for maintaining the marine organisms at higher tropic levels, but when associated with eutrophication and harmful algal blooms, as noticed in the coastal waters of India, such events are directly linked (negatively) to the quality of water. Another important measure of water quality in the coastal environment is the suspended sediment load. Together with chlorophyll concentration they determine in water light penetration, and light available for photosynthesis. Optical instruments such as spectral radiometers are able to monitor changes in chlorophyll and suspended sediment load in real time. Furthermore, such measurements can form the basis of local algorithms for application in remote sensing, allowing the results to be extrapolated to the entire study area through remote sensing. Optical methods for monitoring water quality and productivity have been established in other marine environments, for example in the USA. In India, a start in this direction has been established and operationalized by the SATCORE programme of ESSO-INCOIS.

Marine resources, especially fishery resources, have a strikingly important place of prominence in the biodiversity map of the earth. Their dynamics have very important influence; both direct as well as derived, on the wealth, health and eco-balance of many a maritime nation. Indian context to the aforementioned issue can never be overstated with a prominent chunk of future requirement of socio-economic and nutritional sustenance is centered in the marine sector. Towards establishing a scientifically deduced relationship between the marine environment and the resource availability on a realistic basis, there is a need for a focused application of established easy to surveil oceanic, geophysical and physicochemical parameters and their direct or latent influence upon the planktons which happen to be the self-replenishing source of food and nutrition for the fishery resources spread in our EEZ. The spatio-temporal fluctuations of the plankton richness which can be remotely sensed have long been established as a major factor in predicting resource richness in general and congregation and catchable availability in particular. Taking cue from these established models, paradigms can be designed to predict the resource availability from the easy to observe parameters after a thorough validation of the prediction scenarios juxtaposed with the estimated catch attributable to various fishing grounds. The change in the pattern of fishing, period of absence and the composition of fish caught per haul, when analyzed for a range of geo-spatial expanses would help refining and augmenting the existing paradigms resulting in a comprehensive prediction algorithm. Further such models would come in handy in the assessment of marine resource potentials and there periodic revalidation on a homogenous platform with a proper measure of confidence interval. ICAR-CMFRI has come up with a flag ship programme named Chlorophyll based Remote Sensing assisted Indian Fisheries Forecasting System which is operationalizing the primary productivity to biomass model and under the auspice of the Jawaharlal Nehru Science Fellowship, Govt. of India, Prof, Trevor Platt, FRS is coordinating along with Dr. Shubha Sathyendranath, the network on primary production for *in-situ* measurements and modelling the primary production in Indian EEZ.

Nutrient-Phytoplankton-Zooplankton-Detritus Model

Since the mid-20th century, several modelling studies on primary productivity have been carried out over the global ocean. Historically, through the advancement of supercomputing facility this studies have been evolved from simple zero dimensional statistical model to higher order coupled bio-physical model. The compartments of the simple first generation statistical models are expressed by a single differential equation describing the dependence of rate of change of phytoplankton with photosynthesis, respiration and grazing. The functionality of these models are greatly dependent on how efficiently it represents the mixed layer dynamics and its interactions with the euphotic zone. Now a days coupled bio-physical models are come in place and it advances the accuracy and resolution of predicted results. The efficiency of these models have significant contribution from mixed layer dynamics and it incorporates causes from horizontal and vertical advection as well. Most of these models includes phytoplankton, zooplankton, nutrients, detritus and chlorophyll as state variables.

A simple structure of these biological models comprising the sources and sinks of phytoplankton growth rate are represented by the following equation.

$$\frac{\partial P}{\partial t} = \gamma P - G_{zoo} - M_P - £\ (sdet + P)\ P - W\frac{\partial P}{\partial z}$$

Where $(\frac{\partial P}{\partial t})$ represents the rate of change of phytoplankton, γp -phytoplankton growth rate as a source, G_{zoo} – grazing by zooplankton, M_P – mortality of phytoplankton, £ (sdet +P) P represents accumulation of phytoplankton with small detritus and converted in to large detritus and W represents vertical sinking of phytoplankton. Here, first term in the right hand side acts as a source and other four terms indicates sinks of phytoplankton

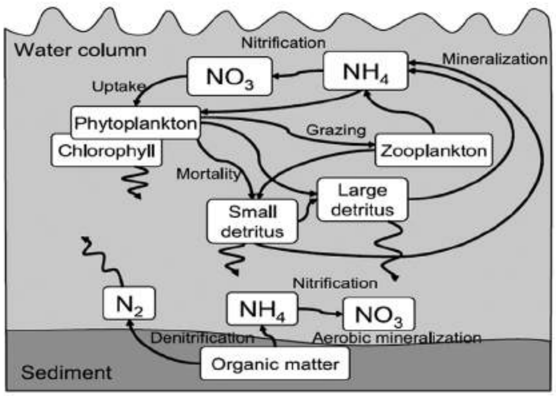

Fig. 2. Schematic representation of biological NPZD model (Figure courtesy: Fennel et al ., 2006)

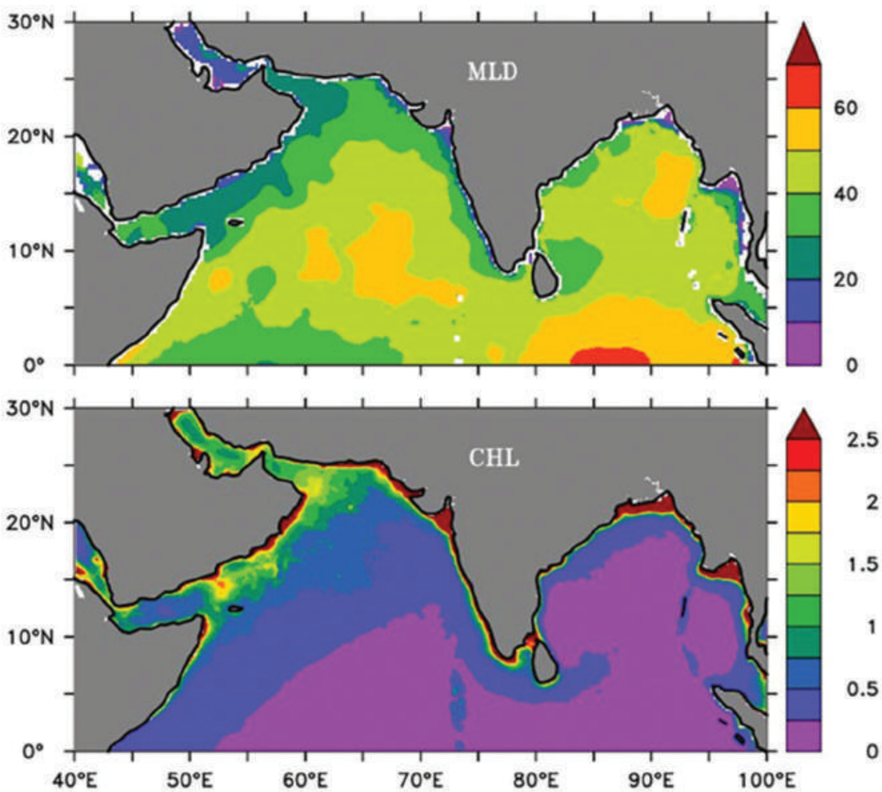

Fig. 3. Annual average of Mixed Layer Depth (MLD) in meter and annual average of Chlorophyll -a (CHL) concentration in mg/m3over the north Indian Ocean. Oceanic provinces of shallow MLD have characterized by high chlorophyll-a concentration.

A simple exercise to estimate biomass from primary productivity for conceptualizing the idea

Indian scenario on potential fish estimates

Authors	Estimated 1^0 productivity	Extrapolated fish production	Remarks
Riley, 1945 Rabinowitch 1945	375 kg C/km2 annually = 3.75 tonnes/ha	15.5 million tonnes (Indian Ocean)	8 times higher than terrestrial productivity
Steeman Nielsen & Jensen, 1967	40% for respiration from net productivity averages globally 1.2-1.5*106 tons	2 million tonnes (Indian Ocean)	Average annual production of hydrosphere similar to terrestrial productivity
Steeman Nielsen & Jensen, 1967	Eutrophic area productivity high	0.2-0.3% of fixed carbon as fish removed annually	High level of efforts in coastal waters with active fishery
Rhyther, 1959	Seasonal maxima also addressed	3 million tonnes (Indian Ocean)	Sea twice as productive as land
Schaefer, 1965	1.9*106 tons of organic carbon for all seas as average	200*106 tonnes for world oceans 40 million tonnes (Indian Ocean)	Fish production 0.03% of potential
Raghuprasad et al., 1969	Compilation of all the above	100 million tonnes (world oceans) 20 million tonnes (Indian Ocean)	0.4% of potential harvested

(All the estimates were based on primary production – Organic carbon biomass generated by the producers)

Calculation of potential estimates of fishery from primary productivity estimates for Indian Ocean basin scale (Raghu Prasad, 1969)

Average annual productivity of Indian Ocean (Anton Brunn survey)	:	3*109 tonnes of Carbon = 0.35 g C/m2
Respiration requirement	:	40% of organic production
Average net production	:	0.24 gC/m2/ day (Western Indian Ocean) 29.19 gC/m2/ day (Eestern Indian Ocean)
Area	:	29*106 km2 (Western Indian Ocean) 22*106 km2 (Eastern Indian Ocean)
Net production of carbon	:	2.3*109 (Western Indian Ocean) 1.6*109 (Eastern Indian Ocean)
Total fish yield (0.03% of net production)	:	12.6 million tonnes In 1967 the production was 2.1 million tonnes. A six fold increase in catch is possible as per the potential estimated

Estimates based on ecological efficiency

- Estimates of potential yield on annual basis is calculated and the potential biomass at the safest level (@10% ecological efficiency level)
- 23 million tons of fish from Western Indian Ocean and
- 15 million tons from Eastern Indian Ocean
- Total of 38 million tons possible from the entire Indian Ocean

Estimation of potential fish yield from zooplankton biomass

Zooplankton biomass estimated for Western Indian Ocean	=	3.25*108 tonnes
Zooplankton biomass estimated for eastern Indian Ocean	=	1.94*108 tonnes
At 10% ecological efficiency level		
Theoretical estimate from carbon production for Western Indian Ocean	=	2.3*109 tonnes
Theoretical estimate from carbon production for eastern Indian Ocean	=	1.6*109 tonnes
Potential fish biomass estimated for Western Indian Ocean	=	18 million tonnes
Potential fish biomass estimated for eastern Indian Ocean	=	11 million tonnes
Total fish biomass estimated for Indian Ocean	=	29 million tonnes

Revised estimates by different authors for Indian EEZ (million tonnes)

Mathew et al., 1989	7.46
Desai et al., 1990	3.66
Moiseev, 1971	3.59
Gulland, 1971	6.55
Prasad, 1970	5.06
Prasad & Nair, 1973	4.60
Quazim, 1976	7.36
Nair & Gopinathan, 1985	5.50

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GENETIC STOCK CHARACTERIZATION OF FISH USING MOLECULAR MARKERS

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Introduction

Accurate Identification of genetic resources is necessary for detecting new species and varieties for products of commercial value. Fish, as a group, apart from their economic value from a biodiversity viewpoint, have the highest species diversity among all vertebrate taxa. They exhibit enormous diversity in size, shape, biology and in the habitats they occupy. In terms of habitat diversity, fishes live in almost all conceivable aquatic habitats, ranging from Antarctic waters to desert springs. Of the 62,305 species of vertebrates recognized world over, 34,090 (nearly 52%) are valid fish species; a great majority of them (97 %) are bony fishes and the remaining (3 %) are cartilaginous (sharks and rays) and jawless fishes (lampreys and hagfishes). Further, on an average, 300 new fish species are described each year, and global surveys indicate that there could well be at least 5,000 species more to be discovered.

Loss of biodiversity is one of the greatest challenges facing modern society. This environmental crisis is increasingly evidenced by the loss or deterioration of genetic resources and habitats, as well as recent attempts to highlight and address the issue at the highest international levels. Appropriate conservation efforts for protection of the natural biological wealth warrant right attention for their sustainable utilization and for posterity. Public concern for biodiversity conservation has risen in the last 50 years and led to national and international policies, legislation, and actions to conserve biodiversity, notably the Convention on Biological Diversity (CBD). To conserve and sustainably utilize the bioresources of the country and for maintaining sovereignty over them, several nations enacted the Biological Diversity Act (BDA). This encompasses guide-lines to address a wide range of issues related to the utilization of bioresources and information within the country as well as by other countries.

Management of Fish Genetic Resources

The objective of management (documentation + conservation + sustainable utilization) of species and their habitats is to maintain the genetic identity and integrity of the species in their natural habitat as well as a genetically sustainable fishery. Hence, documentation of genetic variation and diversity is of vital significance to evolve conservation strategies with long-term impact. Genetic resources can be viewed as genetic differences at three hierarchical levels of organization, viz., species, populations and individuals. At the highest level, species consist of '**populations'** or **'genetic stocks'** that are reproductively isolated from populations of other species. Each species harbours a unique set of genetic material and therefore, conservation, may aim at a specific species, which requires sound knowledge about its biology, biogeography and within species (inter-populational) level genetic diversity. At the population level of organization, the identification of **discrete genetic breeding units** (usually called a '**stock**' in fisheries biology; this is roughly equivalent to a **'population'** or **'genetic stock'** to a geneticist) has been a major theme in fisheries research. The definition of a stock can vary, as the motivations of fishery managers may be influenced by political, economic or biological mandates. **Finally, the largest store of genetic variability in most species exists as genetic differences among individuals within a population**. Hence, the goal of pre-serving genetic variability in a population coincides with the goal of maintaining large ecologically sound natural populations. A fundamental need is to define distinct entities that range from individuals to species to ecosystems and beyond.

Population/Genetic Stock Identification (GSI)

Assessment of genetic variability is important for the management of wild genetic resources of fish. Most species are composed of **populations**, also called **genetic stocks**, between which limited gene flow occurs. These populations maintain their genetic makeup or characteristics distinct from other populations of the same species because of genetic variation within the species. This differentiation depends upon forces such as migration, mutation, selection, and genetic drift, which act on the species/population during its evolution. If such units are overfished, it is unlikely that population sizes will recover because of migration, and hence a collapse of the fishery may occur. Therefore, with the loss of a genetic stock, a species also loses the animals that are adapted to a particular habitat through evolution. Moreover, interbreeding of non-native fish stocks/species with a different make up tends to reduce the genetic variation that naturally exists between genetic stocks. In other words, different natural genetic identities available for a species in different habitats are lost.

A fundamental problem for fisheries management is the identification of populations/ stock of a species and this idea has been brought together with the definition of stock for management. The term stock has been used in various management contexts with little or no genetic content. Several approaches have been advocated to solve this problem.

- Ihssen *et al*. (1981) defines a stock as '*an intra-specific group of randomly mating individuals with temporal or spatial integrity*'.
- Larkin (1972) *defined a stock as 'a population of organisms which share a common gene pool, is sufficiently discrete to warrant consideration as a self-perpetuating system which can be managed'*.
- In fishery management, *a unit of stock is normally regarded as a group of fish exploited in a specific area or by a specific method*.

If fishery managers are to include genetic considerations in their decisions, they will need information on the biological differences between discrete local groups of a species and they will need to understand the genetic and ecological processes that influence discreteness. Thus, the implementation of management strategies based on molecular genetic data can have indirect benefits for population biodiversity, as the main objective of such management plans is to avoid population crashes, which in turn benefits the maintenance of population genetic diversity.

Molecular Genetic Markers: The primary objective of the **genetic stock identification (GSI)** in fish is to assess the distribution and pattern of genetic variability at intra-as well as inter-specific population levels. The first priority for such research is identification of appropriate **molecular genetic markers** to assess genetic diversity. Fish stock identification was initially based solely upon morphological and meristic differences. Because these characters can be influenced by the environment, their variations may not have a genetic basis, and hence do not necessarily provide information on genetic and evolutionary relationships. In the 1950s, dissatisfaction with performance of phenotypic methods for stock identification encouraged early exploration of genetic markers. The markers developed have spurred development of statistical algorithms and revolutionized the analytical power necessary to explore genetic diversity among populations. Methods that take advantage of naturally occurring genetic markers have attracted a good deal of attention because application of physical tags is very labour intensive, and biological markers, such as scale patterns, can vary dramatically from year to year. The first GSI methods using **soluble proteins** and **gene products** such as **allozymes** (enzymes at cellular level) for estimating the contributions of two or more salmon stocks to a mixed harvest were developed in the late 1970s. Since then, the rapidly expanding availability of highly variable genetic markers and refinements in statistical analyses have considerably increased the ability to analyze the stock structure of different fish species; but this has also led to the genetic 'marker wars' among fish geneticists during the past several decades. For many years, allozymes were the universal workhorse genetic makers, and they made many valuable contributions to basic and applied conservation and management. Around 1980, the first applications of **mitochondrial DNA (mtDNA)**

analysis to natural populations were published, and gradually, it replaced allozymes and provided answers to key management questions regarding stock structure. The development of DNA amplification using the **polymerase chain reaction (PCR)** technique has opened up possibility of examining genetic changes in populations over the past 100-years or more even using archive material. In PCR reaction, a DNA sequence can be amplified many thousand folds to provide sufficient product for restriction analysis or direct sequencing. Once appropriate primers are available, large number of individuals can be assayed quickly thus facilitating large population screening for variability. Portions of the mtDNA such as, the ATPase 6 and 8 and hypervariable trans-membrane segments of cytochrome *b* (Cyt*b*) that evolve exceptionally rapidly have been used for high-resolution analysis of genetic stock structure in fish. Although mtDNA has indeed provided a wealth of new insights, it is not a solution and has some limitations with respect to fishery management (*e.g.,* it is maternally inherited, so provides information only about female migration or gene flow, and it is only a single marker and hence has much less power than a full suite of nuclear markers).

In the 1990s, **microsatellites** (**Short Tandem Repeats**— **STRs** or **Simple Sequence Repeats—SSRs**) muscled aside mtDNA and these highly variable **co-dominant markers** have provided greatly increased power and opened up exciting new opportunities (e.g. parentage analysis and individual assignments) that were generally not feasible with allozymes or mtDNA. Microsatellites are repeated DNA sequences having a unit length of 2-6 base pairs tandemly repeated minimum 6 times usually; maximum several times at each locus. They are found in all prokaryote and eukaryote genomes investigated to date. Individual alleles at a locus differ in the number of tandem repeats of the unit sequence owing to gain or loss of one or more repeats and they as such can be differentiated by electrophoresis according to their size.

There are four types of microsatellites

1. Perfect: Perfect tandem repeat sequences.

2. Imperfect: Tandem repeat sequences with intervening sequences.

3. Compound: More than one kind of repeats, adjacent ones.

4. Complex: More than one kind of repeats, with intermediary sequences.

Based on the number of base pairs in a repeat unit, microsatellites can be again classified into *mono* (e.g. C or A), *di* (e.g. CA), *tri* (e.g. CCA), *tetra* (e.g. GATA), *penta* (e.g. CGATA) and *hexa* (e.g. ATGGCA) repeat unit microsatellites. Microsatellites that are used in stock identification studies typically contain di- (AC)n, tri-(ACC)n, or tetra-nucleotide (GATA)n repeats. The most common ones are dinucleotide repeats. Tetra-nucleotide microsatellites are gradually replacing dinucleotide loci as the preferred genetic marker for stock analysis. Microsatellite loci are abundant in all eukaryote genomes and it has been estimated that there are from 10^3 to 10^5 microsatellite loci dispersed at 7 to 10^{10} base pair (bp) intervals or one locus at every 100-300 kilobase pair (kbp) intervals in the eukaryotic genome. Fish genomes may contain more microsatellite loci than most other invertebrate and vertebrate taxa. Mapping studies suggest more or less even distributions of microsatellites throughout genomes, although they are somewhat rarer within coding sequences.

Several features of STR render them invaluable for examining fish population structure. Microsatellites are codominant in nature and inherited in Mendelian fashion, revealing polymorphic amplification products from all individuals in a population. They contain information, which are directly related to the effective number of alleles at each locus. PCR for microsatellites can be automated for identifying simple sequences repeat polymorphism. Small amount of samples of blood or alcohol preserved tissue is adequate for analyzing them. Because they are highly variable in nature, abundant variants are ensured for characterization of populations. However, sample size in excess of 50 may be required to represent the genotype frequencies. The microsatellites are non-coding and therefore variations are independent of natural selection. These properties make microsatellites ideal genetic markers for defining population genetic diversity and distance measures. Because most STR loci are unlinked and inherited independently, the greater the number of loci screened, the greater the likelihood of selecting loci that reveal significant allelic frequency differences among populations and more statistical power is gained in quantifying the extent of genetic differentiation among populations. Additionally, analysis of a larger number of loci may provide a more accurate picture of the evolutionary history of the genetic stocks.

Analysis of microsatellite polymorphisms is a PCR-based approach in which oligonucleotide primers are designed based on unique single-copy sequences flanking the microsatellite repeats. DNA extracted from tissue samples are subjected to PCR reactions. PCR primer pairs are selected such that PCR products are of small molecular size (usually <350bp), providing relative ease in amplification from low-quality DNAs and also allowing for distinguishing small differences in the molecular size of alleles among individuals by using polyacrylamide-gel electrophoresis or automated DNA sequencers. Ideally, each individual shows a single (homozygote) or two-band (heterozygote) DNA pattern, with one band inherited from each parent. Polymorphic alleles at a locus are usually characterized by their molecular sizes. For dinucleotide repeats, these will differ by two base units. Based on the STR allele frequency data, powerful statistical tests are employed to arrive at a decision whether the genetic stocks of a species are significantly different from one another.

However, the field now seems poised to shift towards another type of marker, **single-nucleotide polymorphisms (SNPs)**. Like allozymes, SNPs are generally diallelic, so each marker has less power than a single microsatellite locus. They occur in vast numbers throughout the genome; therefore, eventually large overall increases in power are possible.

Furthermore, once developed, SNPs can be assayed more reliably and cheaply than microsatellites, which could be a considerable advantage in large-scale fishery management applications. However, development of sufficient numbers of SNP markers will be neither easy nor cheap, and analytical issues such as minimizing ascertainment bias remain to be resolved. Despite growing competition from new genotyping and sequencing techniques and latest class of markers, the use of the versatile and cost-effective microsatellites continues to increase, boosted by successive technical advances. Next-generation sequencing (NGS) technologies and the rise of commercial services allow the identification of large numbers of microsatellite loci at reduced cost in non-model species. As a result, more stringent selection of loci is possible, thereby further enhancing multiplex quality and efficiency. Numerous examples also exist where microsatellite analysis is used for fish population analysis and management of Pacific salmon (Fisheries and Oceans Canada website: http://www.pac.dfo-mpo.gc.ca/science/facilities-installations/pbs-sbp/mgl-lgm/proj/ index eng. htm online.) and also for cod where microsatellites have even been used as evidence in a court cases against a fishermen claiming a false origin of his catch. **Use of 20-25 polymorphic microsatellite loci (preferably tetra-nucleotide repeats) and 70–100 individuals from each population has become the standard and scientifically accepted protocol for population genetic analysis of fish along with information on biology and morphometry (*TRUSS*) data. Sequence information of mitochondrial complete ATPase 6/8 and Cytb genes of at least 20 individuals per population are also often generated along with this**.

Genetic Stock Structure in fish:

Distinct population structure has been observed in many fish species across the world indicating that propagation-assisted restoration programmes must be stock-specific to replenish declining populations. Generally, between populations of marine and freshwater species, marked differences exist in the level of genetic differentiation and genetic diversity, with marine species generally exhibiting lower levels of inter-population differentiation and greater genetic diversity. This is mainly due to the higher effective population sizes and/or higher inter-population migration rates in marine environments compared with freshwater. In addition, marine fishes and invertebrates are generally broadcast spawners and hence have large potential for movement between areas by larval drift in currents. In addition, adults of many species are capable of making long distance migrations. Early genetic studies of commercially important marine fishes using allozymes and proteins indicated that they generally had moderate levels of gene diversity and little population subdivision, often covering over several hundred kilometers. However, unexpected fine-scale population sub-structuring and deep genetic lineages have been observed in recent studies with high-resolution markers in many fishes which calls for further in-depth integrated approaches of molecular genetics with life-history traits. This will prove whether the variability is due to isolation or adaptations to particular marine habitats or as a result of non-genetic factors such as large reproductive variation among families. Regular monitoring of populations is also essential to enable a distinction between normal population-size fluctuations and those severe enough to warrant conservation measures.

The greatest genetic threats in the marine ecosystem are the extinction of genetically unique subpopulations and loss of genetic diversity primarily through overfishing and climate change. Illegal unreported and unregulated (IUU) fishing also contributes to this condition, and thus poses a severe threat to marine ecosystems. Controlling for compliance and enforcing fishing regulations is hampered by difficulties in identifying the geographical origin of fish and fish products, at point of landing and further down the food supply chain. Presently, there are no validated genetic methods for identifying the geographical origin of marine fish and investigate commercial fraud. '**FishPop-Trace**'(https://fishpoptrace.jrc.ec.europa.eu/web/fishpop trace/) is an international project, funded by the European Union (EU) framework programme (FP7), aiming to generate forensically validated reference panels of SNP markers for geographical origin assignment in four commercially important fish species, cod (*Gadus morhua*), hake (*Merluccius merluccius*), herring (*Clupea harengus*) and common sole (*Solea solea*). SNP markers are selected these are subsequently genotyped across populations to provide high resolution data to analyze genetic variation. These markers are validated to be used as tags for traceability and enforcement applications leading to a reduction in IUU fishing and conservation of remaining marine resources.

For a successful stocking programme such as sea ranching of endangered seahorse or sacred chank, genetic structure of the original wild population must be determined before any new fish are released into the waters. This information can be used to develop hatchery guidelines for breeding fish for stocking purposes. By ensuring that the stocked population is having the same genetic make-up as the wild population, re-integration of the stocked fish will likely be more successful and deviations from the original genetic structure will be minimal.

Integrating Population Genetics Data into Marine Fisheries Management

Maintaining the maximum level of genetic variations in fish stocks is vital for the preservation of genetic resources. Therefore, excessive loss of genetic variability should be avoided for sustainable management of resources. Application of molecular marker techniques to a number of species has shown that these methods can provide information on genetic stock structure that can be of direct management relevance. However, such information has not always been incorporated into fishery management and policy decisions in several countries. The complex problem requires agreement among scientists, governmental organizations and policy makers to define and implement policies on the sustainable management of these natural resources. Numerous factors (as mentioned below) have contributed to the imperfect integration of genetic data into management of aquatic species.

The fish stock assessment teams generally include quantitative fishery biologists and statisticians. In appropriate situations, the teams should be expanded to include geneticists as well as field biologists. It is always better that fish geneticists fully understand the complexities of the management process so that genetic information can be packaged in the most effective manner, and importance of GSI can be portrayed effectively for the policy makers. Also the managers involved in monitoring of fishery resources should acknowledge that GSI can provide valuable management information. Scientists, managers and policymakers could work together more effectively to foster productive dialogue to link statutory definitions and management or conservation goals.

It is difficult to develop an ideal sampling design for a genetic study without understanding the details of the life history of the target species and physical processes in the aquatic ecosystem. Genetic data can be integrated with other types of biological and oceanographical information. The sampling design of genetic studies does not always match the geographical regions to which management controls are applied. This can rarely result in discrepancy between biological and genetic management units. Implementing GSI over a broad geographical area requires extensive efforts to collect baseline data for populations from different coasts and to standardize laboratory procedures so that comparable data can be obtained by different laboratories. This requires funds, broad collaboration among laboratories and a willingness to share unpublished data.

Most fish geneticists are unfortunately, not exposed to the techniques of statistical model and decision analysis that form the basis for modern stock assessment science. Equally, managers and assessment biologists similarly would benefit from a greater literacy regarding the genetic principles that can profoundly affect the aquatic living resources for which they share stewardship responsibility. Therefore, it might be necessary to develop brief **integrated training courses** to equip geneticists and managers to work on assessment teams.

The purpose of stock assessment in fisheries is to provide timely and appropriate scientific advice on fisheries management for sustained production. Though there are few multi-species models, the assessments are almost mostly conducted for single species, whereas in reality, stocks are influenced by multi-species interactions. In addition, gears mostly harvest many species at a time, leading to difficulty in implementation of the management measures derived from single species stock assessment. Due to the lack of adequate and efficient models for multi-species interactions, stock assessments will generally continue to be based on single species models. Although the main approach in population genetic studies of natural populations still involves collecting individuals from two or more geographical locations and considering them as putative populations, *landscape genetics/seascape genetics*—the study of spatial genetic patterns in continuously distributed species—is rapidly evolving and the methods are beginning to be applied especially to marine species as well. These studies are expected to provide important insights into biological processes leading to effective multi-species stock assessment and management of marine ecosystems. However, considerable dialogue between geneticists, stock assessment scientists and managers, as well as creative thinking on both sides are required to develop effective ways to integrate these insights into fisheries management.

In conclusion, fish genetic stock diversity conservation requires preservation of as much variation as possible at all taxonomic levels and concerted efforts by integrating capture, culture fisheries and environmental programmes using latest technological innovations. The genetic tools will provide innovative means in the future and are an assuring approach for food security of the world and in reducing the fishing pressure on natural resources. Genetic data need to be integrated with other types of biological and oceanographical information for understanding the details of the life history of the target species and physical processes in the marine ecosystem. Although better monitoring of biodiversity, better assessment of risk and a more strategic approach to conserving biodiversity are all essential components to successful risk management, an equally important need is the open dialogue among geneticists, quantitative fishery biologists, statisticians, conservationists and planners that would help sustainable management of stocks of the world's amazingly rich assemblage of fishes.

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ENVIRONMENTAL DNA (eDNA) METABARCODING - BASED ESTIMATION OF MARINE STOCKS

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Abstract

Information on species composition and biomass/abundance of exploited species in coastal fisheries is vital in management of resources. One of the most important mandates of the leading institution is judicious management of coastal and deep sea fishery resources. Traditional methods of identifying species and estimating biomass/abundance have inherent drawbacks which could be ameliorated by DNA marker based approach. Environmental DNA (eDNA) can be obtained from the skin, mucous, gamates, faeces, blood and other cells that are constantly being shed into the immediate environment by the organism. Analysis of this eDNA can give us information on the organisms, their abundance and biomass. Recent advances in next generation sequencing enable simultaneous sequencing of DNA from whole communities known as metabarcoding. Studies carried out in aquaria, large lakes, rivers and marine environment consistently suggest that eDNA metabarcoding outperforms traditional survey methods in terms of non-invasive sampling, sensitivity and cost incurred.

Introduction

Traditional marine fish stock assessment is largely carried out using visual surveys, trawls, seines and tissue biopsies, while they serve as critical sources of data, these monitoring methods are expensive, time consuming, invasive, environmentally destructive and highly prone to misidentification. Use of more efficient, sensitive, non-invasive and cost effective methods is desirable for assessment of the ecosystem as well as in improving baseline ecological data about marine ecosystems. In aquatic environments the eDNA can persist for a day and up to 21 days depending on the environmental conditions. Analysis of this eDNA can give us information on the organisms, their abundance and biomass. Recent advances in next generation sequencing enable simultaneous sequencing of DNA from whole communities known as metabarcoding. There is now increased interest in using eDNA to supplement existing survey methods.

Since 2012 there has been a plethora of studies on eDNA metabarcoding as applied in biodiversity conservation, fish community identification, fisheries management, invasive species, as well as in fish biomass/abundance estimations. eDNA approach became popular because of its non-invasive nature, relatively economy and better results. Thomsen et al (2012) have used eDNA for detection of marine fauna. Pilliod et al (2013) have described eDNA applications in amphibians and fish. The tool has found wide applications in both marine and freshwater environments (Ferguson and Moyer 2014). Miya et al (2015) have developed MiFish primers, which were used to detect more than 230 subtropical species. Largest fish on earth, whale shark was detected from eDNA in water samples (Sigsgaard et al., 2016). Jiang and Yang (2017) have used Scientometric methods have been used to quantitatively assess the current global research status in the eDNA field based on SCI-EXPANDED and Social Sciences Citation Index databases during the period 1992–2016. eDNA can also be used for estimating fish biomass/abundance, and in marine census (Takahara et al., 2012; Kelly et al., 2014; Klymus et al., 2015; Doi et al., 2015; Thomsen et al., 2016; Yamamoto et al., 2016; Roussel and Bernatchez, 2016).

A total 25 research papers related to eDNA metabarcoding/metagenomics by Indian authors have been cited. They are predominantly pertaining to the study of microbial biodiversity from food, soil and deep sea sediments (Jiang and Yang, 2017 for review). Not a single publication related to such study in fish has been cited.

Gap in Knowledge

Metabarcoding is constrained by factors like PCR efficiency, primer tags and sequencing efficacy. Another limitation is lack of comprehensively cured reference databases for certain metazoans for assigning taxon to the OTUS. Future studies are needed to improve sampling strategies (selection of season, sampling location within habitat, etc.) and to understand the relationship between sequence reads and species density. Still there are gaps in knowledge about the dynamic mechanisms relating to shedding of tissue into the environment, metabolism related processes which could also affect quantity of DNA released by an organism into the water. Dynamics of eDNA under field conditions, such as patterns of release, degradation, and diffusion should be taken into consideration to get a better estimate of fish distribution and biomass/abundance based on eDNA.

Technical Approaches

Methodology includes seawater filtration, quantitative real-time PCR, Library preparation, Next Gen Sequencing (NGS) and statistical analysis. Copy number of DNA could be quantitatively interpreted in terms of fish abundance. High throughput sequencing data analysis using the state-of-the art tools could throw light on family level abundance in general and species level abundance of fish in particular.

Expected Utility of Research

Research on eDNA can generated eDNA signatures of exploited pelagic and demersal fish species from Indian coastal fisheries, which would facilitate for accurate estimation of biomass/abundance of fish. Further, India-specific eDNA-linked database on exploited marine species from coastal fisheries could be generated.

DEVELOPMENT OF INDIVIDUAL BASED MODELS IN MARINE FISHERIES RESEARCH

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Setting

Fish population dynamics describe how a stock or a combination of them changes over time as a function of growth, recruitment, mortality, immigration and emigration (Quinn & Deriso, 1999). It is the basis for understanding fish populations and associated fisheries and is the central component of any effort to assess the population dynamics so as to provide quantitative advice for fishery management (Hilborn & Walters, 1992).

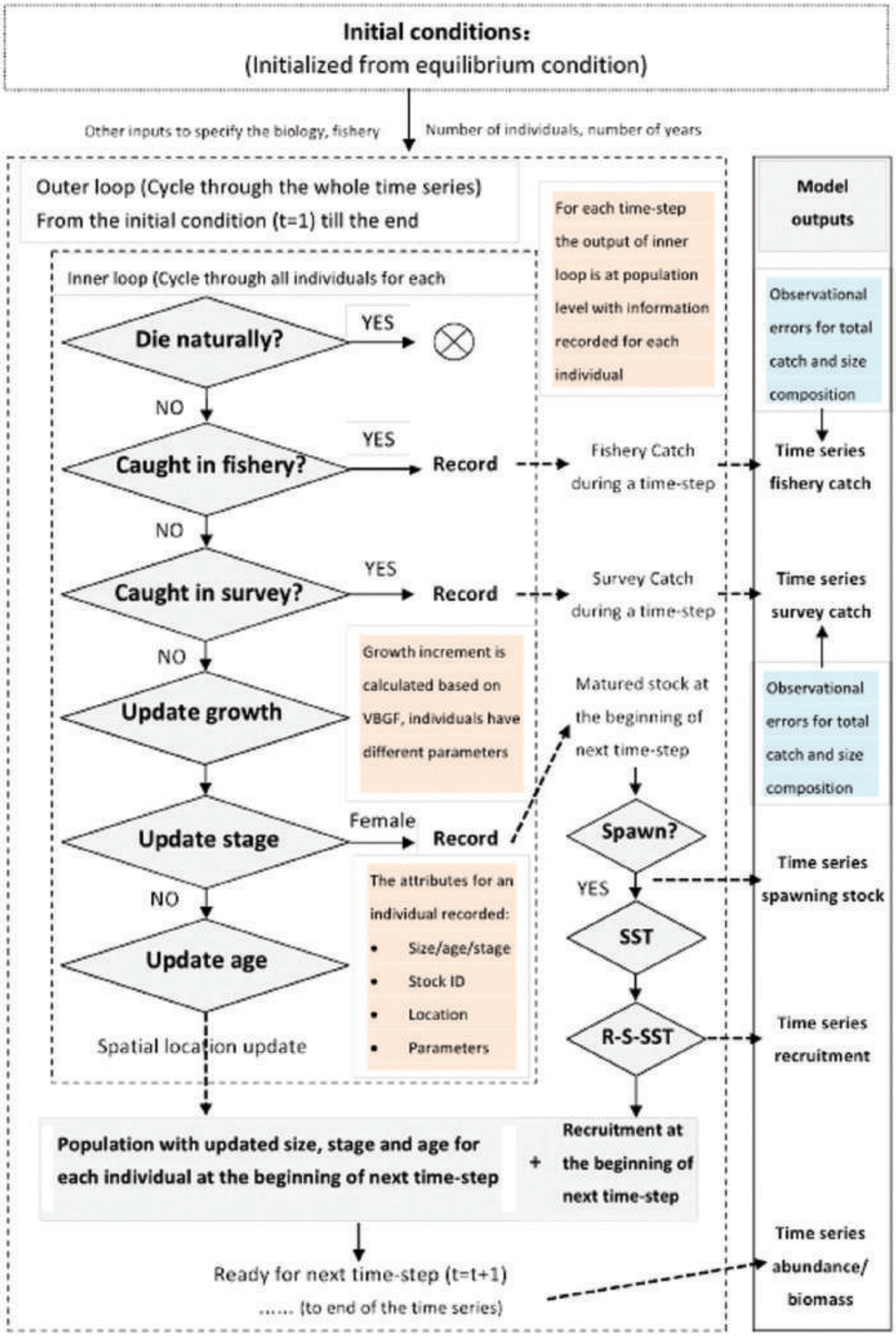
Modern fisheries stock assessment models are evolving towards increasing complexity (Maunder & Punt, 2013), with capabilities to assimilate a diverse suite of data and incorporate spatial structure (Cadrin & Secor, 2009) and the influence of environmental factors. As the number of such efforts increase, the behavior and performance of these complex models need to be tested to assure a scientific basis for fishery management. These efforts to test the plethora of models have resulted in extensive simulation studies have been conducted to examine the robustness of the models and incorporate various process and measurement errors, including data quality and quantity (Chen et al., 2003), mis-specifications of life history parameters (Deroba & Schueller, 2013; Punt, 2003), fishery characteristics (Cope & Punt, 2011), and violations of model assumptions (Guan, Cao, Chen, & Cieri, 2013).

Amongst these approaches one stream was oriented towards focussing on the habitat and ecosystem wherein the entire blend of biological dynamics are seen in action and models were built to suit them, leading to the ecosystem based models. Several approaches have been developed at the ecosystem level, motivated by the observation of some recurrent patterns of marine ecosystems, suggesting that interactions within the ecosystem are important structuring factors (Dickie and Kerr, 1982). For example, a widespread observation is the stability of the production of many marine ecosystems com- pared to that of individual species (e.g. Sutcliffe et al., 1977; May et al., 1979; Murawski et al., 1991). The maximum sustainable yield (*MSY*) is extended to a set of exploited species that are considered to form a single stock (Brown et al., 1976; FAO, 1978): the equilibrium production of the multispecies assemblage would then be a parabolic function of fishing effort and the *MSY* would correspond to the exploitation of half the virgin biomass of the whole assemblage. More recently, Polovina (1984) and Christensen and Pauly (1992) developed the ecosystem model ECOPATH, which is widely used among fisheries scientists. In this model, species are aggregated into functional groups, which are related by fluxes of matter. Forming the basis of the model are two equations of mass conservation, describing the production and the consumption at equilibrium for each group of species.

This leads to the most important aspect of modelling, testing the sensitivity of assessment models for mis-specifications requires an operating model to predict population dynamics with known or assumed population parameters. However, most operating models are formulated identically to the population dynamic component built into the assessment model (Cope & Punt, 2011; Deroba & Schueller, 2013; Guan et al., 2013; Punt, 2003), which implicitly assumes that the dynamic processes of the population are fully understood. To avoid this problem and test the assessment rigorously, an alternatively structured operating model is necessary to simulate the population dynamics.

Individual-based models (IBM), which consider each individual of a population as an independent entity, have been widely used in ecology (Grimm & Railsback, 2005). The events (e.g., birth, death and predation) that occur within the simulation are at an individual rather than population level and the overall population dynamics that emerged is the sum of the individual interactions and behaviours.

The majority of individual-based models in fisheries science are developed to investigating fish behavior and fleet dynamics. They have been used to simulate the behavior of individual fish or fishermen with rules that determine their movement (Tyler & Rose, 1994; Wilson & Yan, 2009). Spatial heterogeneities in individuals and/or their environment have been added to develop spatially explicit individual-based models (Werner, Quinlan, Lough, & Lynch, 2001). However, only a few of these models have been developed for simulating fishery population dynamics. Kanaiwa, Chen, and Wilson (2008) developed an individual-based lobster simulator to simulate seasonal, sex-specific population dynamics for the American lobsters to evaluate the assessment model for that species. Further, the models that have been developed are either species-specific or focused on one particular aspect of fish life history (Kanaiwa et al., 2008).


Initial conditions:
(Initialized from equilibrium condition)
Other inputs to specify the biology, fishery
Number of individuals, number of years
Outer loop (Cycle through the whole time series)
From the initial condition (t=1) till the end
For each time-step the output of inner loop is at population level with information recorded for each individual
Model outputs
Inner loop (Cycle through all individuals for each
Die naturally?
YES
NO
Caught in fishery?
YES
Record
Fishery Catch during a time-step
Observational errors for total catch and size composition
Time series fishery catch
NO
Caught in survey?
YES
Record
Survey Catch during a time-step
Time series survey catch
NO
Update growth
Growth increment is calculated based on VBGF, individuals have different parameters
Matured stock at the beginning of next time-step
Observational errors for total catch and size composition
Update stage
Female
Record
Spawn?
YES
Time series spawning stock
NO
Update age
The attributes for an individual recorded:
Size/age/stage
Stock ID
Location
Parameters
SST
R-S-SST
Time series recruitment
Spatial location update
Population with updated size, stage and age for each individual at the beginning of next time-step
+
Recruitment at the beginning of next time-step
Ready for next time-step (t=t+1)
...... (to end of the time series)
Time series abundance/ biomass

A typical IBM framework

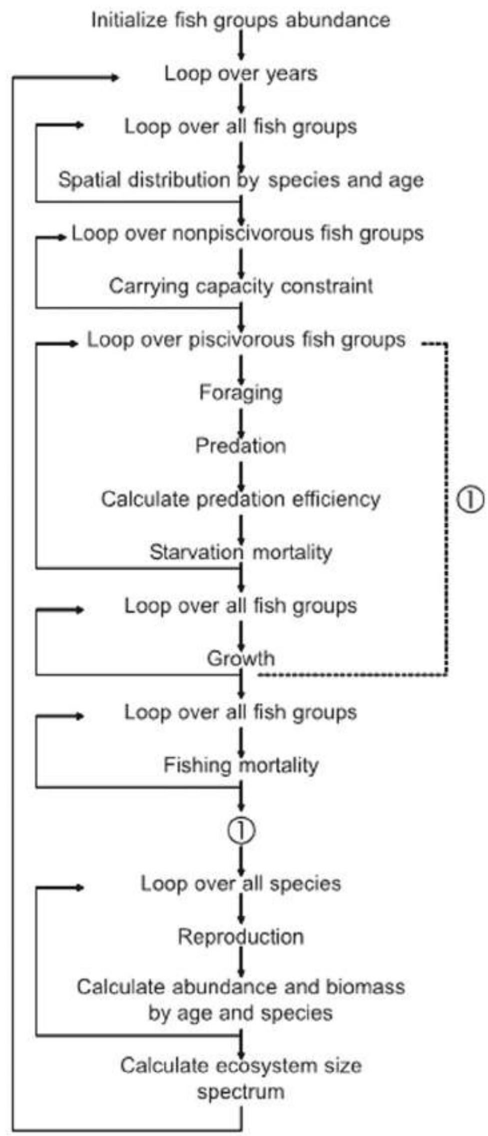
Although many leads can be followed to formulate a framework under which IBMs could be modelled, the ringside view of the process can best be obtained from a simple depiction of an algorithm, one such being given below (Cao et al, 2016).

The above figure depicts the steps and sequences alongside the checks and balances which create the sequences in a cogent way. Now the different life stages like, natural death, fishery mortality, growth , enhancement of age and stage, spawning and recruitment could have there own sub-conceptualisations of being either deterministic or probabilistic and under either whichever established process presumed., thereby leading to a combination of options in the programming and software sense. A typical look at the possibilities could result in the following steps;

Stage	Model definition
Initial condition	Equilibrium; with an assumed period to attain that
Stock spatial structure	Multiple stocks each with unique biological identities
Stock recruitment relationship	Specified functional relationship between spawning stock and its recruitment rate; Beverton- Holt, Ricker etc. or even incorporation of environmental parameters like SST
Recruitment	Can be directly put or could be derived from the S/R relationship with random fluctuation added; must be adjusted as per the intra annual pattern expressed by the resource(s) modelled
Natural mortality	Could be randomness added to the base value defined based on length or age
Fishing mortality	Classic method of merging catchability, effort and selectivity; random threshold could be used to simulate fishing mortality
Growth	VBGF based depiction
Life stage	Number of stages and the mean size at each stage could be the core with random normal deviations completing simulated values
Survey	Modelled similar to Fishing mortality
Observational error	A lognormal based error term added to the catch figure aggregated over time, length and area
Multi-species	Parallel replication of these steps for as many resources as planned to be simulated/ studied

A broad-based IBM

Another more holistic variant of this type of IBM could be one including much more broader habitat based components like availability of lower trophic level (LTL) biomass and the higher level foragers and their predators. The availability of food and the growth stage combination clearly heralding the status of larval mortality and the resultant niche based competitions between resources could also be included through IBM thereby scaling up to simulate regional ecosystems. One such comprehensive model is "Object oriented Simulator of Marine ecosystem Exploitation (OSMOSE)" (Shin and Cury, 2001, 2004). Herein the criterion for the selection of prey by a predator was considered to be firmly based on body sizes with opportunism applied at individual level with a localization principle based on the vicinity coming into picture. A cohort or super individual was made as pivot and the bio-phological dynamics applied on that and replicated to the tune existing in the area and focus. Four model classes, which represent particular ecological entities, are used: the class "system", the class "species", the class "age class", and the class "fish group" (Shin and Cury 2001). From each class, which is characterized by attributes and functions (e.g., growth, predation), a number of objects are created that are part of the simulated system. The architecture of OSMOSE is hierarchical, because a fish group be- longs to an age class, which in turn belongs to a species. This structure enables the investigation of some key variables at different levels of aggregation, in particular the size spectrum of fish assemblages.



The process of implementation of OSMOSE can best explained using the flow-chart given below:

As can be seen from the above figure, the dynamics associated with growth, mortality, reproduction (spawning) etc. could be modelled using the conceptualisation described in the previous case. But the new broad-based habitat and trophism based components need some elaboration. The parameterization of the components is presented in the following table;

Stage/ Component	Model Definition
Foraging	This is to be planned in such a way that the movement probabilities to the nearest spatial cell is highest and the availability of suitable prey/ LTL leading to feeding / starvation otherwise; It is a function of biomass and vicinity
Predation	This is functioned based on the spatio temporal co-occurrence of prey- predator and the size of both; The prey- predator size ratio was subjected to a literature (Fishbase) based threshold and the subsequent dynamics planned thereafter.
Starvation mortality	This is depicted as a function of density dependent issue dependent on intra specific competition and is built upon predation efficiency as defined by Beverton and Holt (1957)

With these cardinal principles in place OSMOSE is rolled out to simulate regions under study but with two very important safeguards, first being the localised calibration and the second the sensitivity analysis. These are computationally intensive procedures leading to thousands of trial runs with various combinations of input parameters including crucial ones like larval mortality and plankton availability, whose sensitivity have been historically be recorded as delicate and hence crucial. Once validated with a decent strip of time step these calibrated tweaked models can be put to great use in estimating, simulating and forecasting marine fishery resources.

Conclusion

Though IBMs offer a very robust modelling crucible for complex marine ecosystems, their success rate is severely dependent on the local tuning and sensitivity testing. Further as these are trophic level flow based, proper input on the LTL front using feeder models like Nutrient Phytoplankton Zooplankton Detritus(NPZD)- Regional Ocean Modeling systems(ROMs) may have to be coupled with the OSMOSE runs for more efficient forecast/ simulation. As such for systems where good coverage on the crucial biogeochemical and productivity parameters coupled with regular sample surveys on resource biology is undertaken these type of IBMs could turn out to be real boon.

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TROPHIC MODELLING OF MARINE ECOSYSTEMS AND ECOSYSTEM BASED FISHERIES MANAGEMENT

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Introduction

Fish populations are an integral part of marine ecosystems. Historically, fish population dynamics have been studied as single species, for example as mackerel, shrimp or sardine, and almost always in isolation from the system in which they exist. In recent years, however, there has been growing awareness that traditional approaches to managing fisheries are incomplete and partially unsuccessful. Sustainable use of living marine resources must consider both the impacts of the ecosystem on the living marine resources, and the impacts of fishery on the ecosystem. This holistic approach to fisheries management has been termed as '*ecosystem based fisheries management*'. The Principles of Ecosystem-Based Fisheries Management are: 1. Maintaining the natural structure and function of ecosystems, including the biodiversity and productivity of natural systems and identified important species, is the focus for management. 2. Human use and values of ecosystems are central to establishing objectives for use and management of natural resources. 3. Ecosystems are dynamic; their attributes and boundaries are constantly changing and consequently, interactions with human uses also are dynamic. 4. Natural resources are best managed within a management system that is based on a shared vision and a set of objectives developed amongst stakeholders. 5. Successful management is adaptive and based on scientific knowledge, continual learning and embedded monitoring processes.

A lot of attention has recently been directed at assessing the impacts of fisheries on whole marine ecosystems (ICES, 1998, 2000; Frid *et al*., 1999b; Hall, 1999a, b). This has in part been driven by the need to ensure conservation of biological diversity and sustainable use of the biosphere, key provisions of the convention agreed at the UN Rio summit (Tasker *et al*., 2000). The utilization of sound ecological models as a tool in the exploration and evaluation of ecosystem health and state has been encouraged and endorsed by the leading bodies in ecosystem-based fisheries research and management (NRC, 1999; ICES, 2000). The potential of the available dynamic ecosystem models to make measurable and meaningful predictions about the effects of fishing on ecosystems has not however been fully assessed.

Reprinted from the CMFRI, FRAD. 2014. Training Manual on Fish Stock Assessment and Management, p.150.

Ecological Factors

Harvesting alters ecosystem structure in ways that are only beginning to be understood. It is argued that long-term heavy commercial harvesting is likely to shift the ecosystem to high-turnover species with low trophic levels (Pitcher and Pauly, 1998). The biological mechanism underlying species shifts is that the relatively large, long-lived fishes which have low mortality rates are more strongly affected by a given fishing mortality rate than are smaller fishes which are part of the same community. A second shift-inducing biological mechanism is habitat degradation caused by various fishing gears especially bottom trawls. Here, the effect is through destruction of bottom structure, depriving benthic fishes of habitats and prey.

Thirdly, the above and the fishery-induced reduction of predatory pressure by benthic fish, may then lead to an increase of small pelagic fish and squids, which becomes available for exploitation. This may mask the decline in catches of the demersal groups. In the Gulf of Thailand, in Hong Kong Bay and other areas of the South China Sea, extremely heavy trawl pressure has resulted in a shift from valuable demersal table fish such as croakers, groupers and snappers to a fishery dominated by small pelagics used for animal feed and invertebrates such as jellyfish and squids.

These mechanisms almost often lead, through a positive feedback loop, to a fourth biological mechanism: harvesting small pelagic fish species at lower trophic levels reduces the availability of food for higher trophic levels, which then decline further, releasing more prey for capture by a fishery that finds its targets even lower down the food web, a process now occurring throughout the world (Pitcher and Pauly, 1998). Some examples of such documented species shifts in exploited multispecies fish communities are shown in table.

Table 1. Examples of documented shifts towards smaller, high-turnover species in exploited multispecies communities (modified from Pitcher and Pauly, 1998)

Fishing grounds/ Stocks (period)	Documented species shift
Gulf of Thailand Demersal stocks (1960-1980)	Overall biomass reduced by 90%; residual biomass dominated by trash fish
Philippine shelf Small pelagics (1950-1980)	Gradual replacement of sardine-like fishes by anchovies
Carigara Bay, Philippines All fish (1970-1990)	Fish replaced by jellyfish, now an export item
North Sea	Halibut and small sharks extinct; cod and haddock threatened; demersal omnivores and small pelagics favoured
Humboldt Current, Chile North Pacific	Large hake depleted, small pelagics favoured First marine mammal depletions, followed by huge trawl fisheries: Pollock favoured
South China Sea, Hong Kong	Croakers and groupers almost extinct; small pelagics bulk of fishery

It has also been observed that fishes evolve or change their life histories in response to selective fishing mortality, for e.g., halving of the size of mature Chinook salmon. In this semelparous species early maturity means less time at risk of being caught and therefore, higher fitness. This species has been intensively managed for over 80 years using the best that single species quantitative science can offer, and yet Chinook salmon are on decline.

Socio-Economic Factors

One of the main socio-economic mechanisms, which contribute to species shift, is increasing prices, both for traditional high-value species and for trash species. Such price increases are effective in masking the economic consequences of fishing at lower trophic levels.

Single Species Assessments

The tools developed for single species population dynamics are an essential part of any new methodology. Detailed information on growth, mortality and recruitment schedules and their associated errors and uncertainties are essential for the implementation of the ecosystem approach advocated in the Rio summit. When considering the management of single components of the ecosystem, such as the target fish stocks, it is possible to set target and limit reference points for particular measurable properties of the species. For example, the implementation of precautionary fisheries management in the North Atlantic has progressed through the setting of reference points for various measures of the status of the exploited species, e.g. the spawning stock biomass (SSB). two types of reference point are considered - a limit reference point and a target reference point (Fig.1).

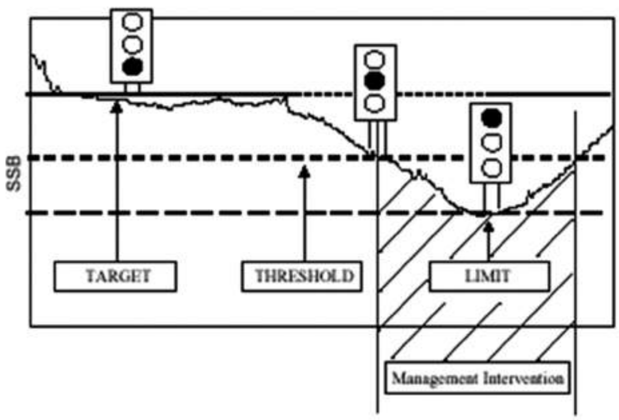

Fig. 1. Illustration of target, threshold and limit reference points with regard to spawning stock biomass (from Hall and Mainprize, 2004)

Management measures are aimed at achieving the target reference point in the medium term and ensuring that the limit reference point is never exceeded. In theory, it should be possible to apply reference points to any or all taxa in the ecosystem. ICES (2000) have contended that even if this was practical for a significant number of taxa, it may not ensure adequate protection of all the ecosystem components at risk. There is a need, therefore, to develop reference points for system level emergent properties as a measure of ecosystem health (Hall, 1999a; Gislason et al., 2000).

Ecosystem Modelling

There are many recent developments in building of trophic models of aquatic ecosystems. Such modelling can now be performed more rapidly and rigorously than ever before, providing a basis for viable and practical simulation models that have real predictive power (Christensen and Pauly, 1993; Walters et al., 1997). This was made possible by the development of ECOPATH (Polovina, 1984; Christensen and Pauly, 1992), for construction of mass-balance models of ecosystems, based mainly on diet composition, food consumption rates, biomass and mortality estimates. Such ecosystem models can describe the biomass flows between the different elements of the exploited ecosystems, and can provide answers to 'what if' questions regarding the likely outcome of alternate fishing policies. The ECOPATH suite of software has now been modified (Walters et al., 1997, 2000) to include ECOSIM (simulation module) and ECOSPACE (spatial module). These new routine have not only increased the quantitative power of the approach, but have also allowed qualitatively new questions to be asked. Ecopath applications to ecosystems, ranging from low latitude areas to the tropics, and from ponds, rivers, and lakes to estuaries, coral reefs, shelves, and the open sea, but all using the same metrics, allowed identification of several general features of aquatic ecosystems.

Multivariate comparisons demonstrated the basic soundness of E. P. Odum's (1969) theory of eco-system maturation (Christensen, 1995b), including a confirmation of his detailed predictions regarding ecosystems near carrying capacity (Christensen and Pauly, 1998). Conversely, this theory can now be used to predict the effect of fisheries on ecosystems, which tend to reduce their maturity, as illustrated by the comparison of Ecopath models for the Eastern Bering Sea in the 1950s and early 1990s (Trites *et al*., 1999a, b), and to guide ecosystem rebuilding strategies implied in "Back to the Future" approaches (Pitcher, 1998; Pitcher *et al.,* 2000).

The importance (relative to fishing) of predation by fish and marine mammals within marine ecosystems as suggested by complex models in a few areas (North Sea – Andersen and Ursin, 1977; North Pacific – Laevastu and Favorite, 1977) was confirmed globally by Ecopath models (Christensen, 1996; Trites *et al.,* 1997).

Identification of trophic levels as functional entities rather than as concepts for sorting species (Lindeman, 1942; Rigler, 1975) implied the use of non-integer values (computed as 1+ the mean trophic level of the preys, as proposed by Odum and Heald, (1975) that express degree of omnivory (Christensen and Pauly, 1992a), i.e., the extent to which feeding occurs at different trophic levels (Pimm, 1982). Also, trophic level estimated from analyses of stable isotopes of nitrogen has been shown to correlate well with estimates from Ecopath models (Kline and Pauly, 1998). Estimates of transfer efficiencies between trophic levels (Christensen and Pauly, 1993b; Pauly and Christensen, 1995), previously a matter of conjecture usually pertaining to single-species populations or even to studies of a few individual animals (Slobodkin, 1972), differed radically from earlier guesses by ecosystem types (Ryther, 1969) used for inferences on the potential yields of fisheries (Pauly, 1996), even though the mean was unsurprising (about 10%; Morowitz, 1991).

Performance Measures

It is generally agreed that reductions in single species fishing mortality levels is perhaps the most significant step one could take towards ensuring the persistence of marine ecosystems (Hall and Mainprize, 2004). It is also clear that ecosystem based fisheries management is still in its formative years, although substantial developments have been seen in some countries and regions. Among these, North America, Antarctica, Europe, Australia and New Zealand are the most notable.

Table 2. The six principles for an ecosystem based fisheries management approach (adapted from Inter-agency Marine Fisheries Working Group, 2002)

Principle	Description
Ecosystem identification	The ecosystem that fisheries will be managed within need to be defined on the basis of the main physical, biological and human dependency relationships
Clear objectives	Objectives for fisheries management shall have regard to local and national needs, and management should be decentralized to the maximum extent possible
Long term benefits	Ecosystem based management should aim for long term benefits – management should look to restore stocks to levels that are capable of delivering optimal yields over the long term; and achieving such yields should not compromise other marine species and habitats. Management should also aim to support biological biodiversity
Incentives aligned with and ecosystem based approach	Incentives should be realigned to support aims of the ecosystem based approach – incentives and financial support needs to be redirected from fisheries that aim at increasing fishing efficiency to those that make concerted efforts to those that promote the restoration of fish stocks to optimal yield levels and which support responsible fishing practices in sensitive marine areas.
Easily assessed information and alternate management options	Information necessary to implement the ecosystem based approach should be made available to all. Where information is insufficient, adaptive management and the precautionary approach should be followed. If the outcome falls short of what was intended the management decisions should be suitably altered – proactive management

Unfortunately, despite the legislative imperative and clearly articulated principles (Table 2), arriving at an operational framework for an ecosystem-based approach to fisheries management is fraught with difficulties. This difficulty is due, not only to the inherent challenge in establishing and quantifying the effects of fishing at an ecosystem level, but also due to the social and political dimensions associated with harvesting fisheries at an environmentally sustainable level.

An Overview of Ecopath & Ecosim

The Ecopath software is a simple approach for analyzing trophic interactions in fisheries resources systems (Christensen and Pauly 1992a,b, 1995). Ecopath is based on the earlier work of Polovina (1984), and is being widely applied to aquatic systems (Christensen and Pauly 1993, Pauly and Christensen 1995). It is a mass-balance approach that describes an ecosystem at steady-state for a given period. Further development of this steady-state model has resulted in a dynamic ecosystem model called Ecosim that is capable of simulating ecosystem changes over time (Walters et al., 1997). Ecopath and Ecosim represent all of the major components of the ecosystem, and their feeding interactions, but are relatively simple. These kinds of models readily lend themselves to answering simple, ecosystem wide questions about the dynamics and the response of the ecosystem to anthropogenic changes. Thus, they can help design policies aimed at implementing ecosystem management principles, and can provide insights into the changes that have occurred in ecosystems over time. Ecopath models rely on the truism that:

This applies for any producer (e.g., a given fish population) and time (e.g., a year or season). Groups are linked through predators consuming prey, where:

The implication of these two relationships is that the system or model is mass balanced (i.e., biomass is 'conserved', or accounted for in the ecosystem). This principle of mass conservation provides a rigorous framework – formalized through a system of linear equations – through which the biomass and trophic fluxes among different consumer groups within an ecosystem can be estimated (Christensen and Pauly 1995). Constructing an Ecopath model emphasizes ecological relationships rather than mathematical equations. All that is required are the types of data that are routinely collected by fisheries scientists and marine biologists. The model can incorporate and standardize large amounts of scattered information – information that might have otherwise languished in scattered journals, reports and filing cabinets (Christensen and Pauly 1995).

biomass accumulation + fisheries catch + mortality due to predation + other mortality + loss to adjacent systems = Production

Ecopath is essentially a large spreadsheet that is simultaneously keeping track of all the species and all the feeding interactions occurring within the ecosystem. It describes the ecosystem at one point in time. Ecosim, which is based on the Ecopath equation, simulates

production + non-assimilated food + respiration = Consumption

how a change in one or more components might affect the ecosystem over time.

Ecopath and Ecosim have been widely applied in recent years. More than 80 Ecopath systems have so far been published world-wide. They span a diversity of systems including upwelling, shelves, lakes and ponds, rivers, open oceans and even terrestrial farming systems (see Christensen and Pauly 1992a,b, 1995; Walters et al. 1997; and the Ecopath home page at http://www.ecopath.org)

Principles of the Ecopath Model

The core routine of Ecopath is derived from the Ecopath program of Polovina (1984), and since modified to make superfluous its original assumption of steady state. Ecopath no longer assumes steady state but instead bases the parameterization on an assumption of mass balance over an arbitrary period, usually a year. In its present implementation Ecopath parameterizes models based on two master equations, one to describe the production term and one for the energy balance for each group.

The first Ecopath equation describes how the production term for each group (i) can be split in components. This is implemented with the equation,

Production = catches + predation mortality + biomass accumulation + net migration + other mortality;

or, more formally,

$$P_i = Y_i + B_i \cdot M2_i + E_i + BA_i + P_i \cdot (1-EE_i) \qquad \text{Eq. 1}$$

where Pi is the total production rate of (i), Yi is the total fishery catch rate of (i), M2i is the total predation rate for group (i), Bi the biomass of the group, Ei the net migration rate (emigration - immigration), BA i is the biomass accumulation rate for (i), while M0i = Pi · (1-EEi) is the .other mortality. rate for (i).

This formulation incorporates most of the production (or mortality) components in common use, perhaps with the exception of gonadal products. Gonadal products however nearly always end up being eaten by other groups, and can be included in either predation or other mortality.

Eq. 1 can be re-expressed as

$$B_i \,.\, (P/B)_i \,.\, EE_i - \sum_{j=1}^{n} B_j \,.\, (Q/B)_j \,.\, DC_{ji} - Y_i - E_i - BA_i = 0 \qquad \text{Eq. 2}$$

where: P/Bi is the production/biomass ratio, Q/Bi is the consumption / biomass ratio, and DCj i , is the fraction of prey (i) in the average diet of predator (j).

Of the terms in Eq. 2 the production rate, Pi, is calculated as the product of Bi, the biomass of (i) and Pi/Bi, the production/biomass ratio for group (i). The Pi/Bi rate under most conditions corresponds to the total mortality rate, Z, see Allen (1971), commonly estimated as part of fishery stock assessments. The other mortality is a catch-all term including all mortality not elsewhere included, e.g., mortality due to diseases or old age, and is internally computed from,

$$M0_i = P_i \,.\, (1 - EE_i)$$

where EEi is called the ecotrophic efficiency of (i), and can be described as the proportion of the production that is utilized in the system. The production term describing predation mortality, M2, serves to link predators and prey as,

- catch rate
- net migration rate
- biomass accumulation rate
- assimilation rate and
- diet compositions

$$M2_i \,.\, = \sum_{j=1}^{n} Q_j \,.\, DC_{ji} \qquad \text{Eq. 3}$$

where the summation is over all (n) predator groups (j) feeding on group (i), Qj is the total consumption rate for group (j), and DCji is the fraction of predator (j) diet contributed by prey (i). Qj is calculated as the product of Bj, the biomass of group (j) and Qj/Bj, the consumption/biomass ratio for group (j).

An important implication of the equation above is that information about predator consumption rates and diets concerning a given prey can be used to estimate the predation mortality term for the group, or, alternatively, that if the predation mortality for a given prey is known the equation can be used to estimate the consumption rates for one or more predators instead.

For parameterization, Ecopath sets up a system with (at least in principle) as many linear equations as there are groups in a system, and it solves the set for one of the parameters for each group depicted in the infographic.

- biomass
- production/biomass ratio
- consumption/biomass ratio or
- ecotrophic efficiency

While the other three parameters along with parameters given in the infographic must be entered for all groups. It was indicated above that Ecopath does not rely on solving a full set of linear equations, i.e., there may be less equations than there are groups in the system. This is due to a number of algorithms included in the parameterization routine that will try to estimate iteratively as many missing parameters as possible before setting up the set of linear equations.

ECOSIM – Dynamic mass-balance approach for Ecosystem Simulation

By converting the linear equations of Ecopath models to differential equations, Ecosim provides a dynamic mass-balance approach, suitable for simulation (Walters et. al. 1997). Constructing a dynamic model from equation (1) there are three changes viz; (a) replace the left side with a rate of change of biomass; (b) for primary producers, provide a functional relationship to predict changes in (P/Bi) with biomass Bi (representing competition for light, nutrients and space); and (c) replace the static pool-pool consumption rates with functional relationships predicting how consumption will change with changes in biomass of Bi and Bj. The basics of ECOSIM consist of biomass dynamics expressed through a series of coupled differential equations. The equations are derived from the ECOPATH master equation (Eq.1), and take the form

$$dB_i / dt = gi \sum_j C_{ji} - \sum_j C_{ji} + I_i - (M_i + F_i + e_i)B_i \qquad \text{Eq. 4}$$

where dBi/dt represents the growth rate during the time interval dt of group (i) in terms of its biomass, Bi, gi is the net growth efficiency (production/consumption ratio), Mi the non-predation (other) natural mortality rate, Fi is fishing mortality rate, ei is emigration rate, Ii is immigration rate, (and ei·Bi-Ii is the net migration rate). The two summations estimates consumption rates, the first expressing the total consumption by group (i), and the second the predation by all predators on the same group (i). The consumption rates, Cji, are calculated based on the foraging arena concept, where Bi.s are divided into vulnerable and invulnerable components (Walters et al. 1997), and it is the transfer rate (vij) between these two components that determines if control is top-down (i.e., Lotka-Volterra), bottom-up (i.e., donor-driven), or of an intermediate type. The set of differential equations is solved in Ecosim using (by default) an Adams-Basforth integration routine or (if selected) a Runge-Kutta 4th order routine.

Using previously constructed Ecopath models, Ecosim calculates corresponding changes in biomass of each component when the fishing mortality of any particular group is altered. These dynamic simulations are plotted as coloured biomass curves. The scale differs for each curve. By altering the rate of flow between vulnerable and non-vulnerable prey different functional relationships for predators and prey can be considered. These can range from pure donor control, where the prey availability governs interactions, to top-down control where predation pressure dominates. Using equilibrium simulations, where equilibrium biomass is plotted over a range of F values, Ecosim provides the facility to predict the potential equilibrium yield for the fished group.

Trophic Modelling Studies in India

Trophic modelling studies in Indian aquatic ecosystems are few. The first preliminary attempt was made in small ecosystem in Veli Lake near Thiruvanathapuram. Subsequently another preliminary attempt was made to model the southwest coast ecosystem using already existing data and many assumptions (Vivekanadan et al. 2003). The first major targeted attempt to study was that of the model for the Arabian Sea off Karnataka (Mohamed et al. 2008; Mohamed and Zacharia, 2009). This Ecopath model had a pedigree index of 0.521 (scale from 0 for data that is not rooted in local data up to a value of 1 for data that are fully rooted in local data). The Karnataka model encompassed an area of 27,000 km^2 (from the shore to the edge of the continental shelf) and had 24 functional ecological groups (species assemblages) of which 23 were living groups and one dead group (detritus). Ecological groups ranged from apex predators like marine mammals, sharks and tunas to micro zooplankton and phytoplankton.

A comparison of ecosystem parameters from other parts of the world is given in table below (modified from Trites *et al.*, 1999) above. The total throughput for the Arabian Sea ecosystem of Karnataka ranks third after Peru and Monterey bay and is double that of Bering Sea and Venezuela upwelling ecosystem. The gross efficiency of the fishery (catch/PP) value obtained for Karnataka is close to that of the Peruvian ecosystem, which is also an upwelling ecosystem, harvesting fishes low in the food chain. The omnivory index is quite high comparatively for the Karnataka ecosystem indicating the complex feeding interactions in the ecosystem. The estimated ascendancy values for the Arabian Sea ecosystem of Karnataka indicate that it has not reached its full development capacity, unlike the Yacutan and Monterey bay ecosystems. The recycling capacity of the ecosystem throughput as indicated by the cycling index shows that recycling in Arabian Sea ecosystem of Karnataka is only moderate as compared to ecosystems like Brunei and Bering Sea.

Ecosystems	Through put	Catch /PP	PP/B	B/T	Net syst. prod.	Omnivory Index	Ascen-dency	Cycling Index	Path length
Yacutan	2362	0.0029	27.4	0.036	370	0.134	44.0	2.8	2.84
N. Gulf of Mexico	1790	0.0002	7.0	0.015	19	0.195	39.1	2.1	3.03
Venezuela (upwell.)	5309	0.0016	27.0	0.023	831	0.135	39.9	2.2	4.05
Brunei, SE Asia	1816	0.0008	28.6	0.018	300	0.201	29.4	16.3	2.80
Peru 70 (upwell.)	18800	0.0017	87.5	0.012	14709	0.169	38.1	8.7	3.63
Monterey	17513	0.0012	1.2	0.012	2208	0.324	66.2	4.4	3.63
Alaska Gyre	5946		38.1	0.015	407	0.103	42.3		2.03
British Columbia Shelf	1237		21.1	0.180	4106	0.140	40.1		2.03
Bering Sea 50's	6535	0.0002	5.9	0.050	-115	0.183	32.5	13.2	3.47
Bering Sea 80's	5692	0.0021	4.9	0.050	-356	0.157	30.9	11.1	3.51
Karnataka Arabian Sea	**11522**	**0.0016**	**29.9**	**0.012**	**904**	**0.299**	**33.0**	**6.03**	**2.81**

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Restrictions on size of fish that are caught are used as one of a number of measures considered for the sustainable management of fish stocks all over the world. The simple logic behind this conservation principle is to provide chance to the younger ones to grow, mature and reproduce at least once and contribute to the population before they are taken away in the catch. In many countries, there are legally implemented size (or length) limits for different species in the catch in the fishery including recreational fishing. Such size limits are arrived based on scientific research about the species especially its reproductive features. Though in most cases size restrictions are for the minimum size, there are restrictions on maximum size in some species were larger individuals contribute more to the population growth (example: Asian seabass younger ones are males and become females and spawn when they grow larger).

Advantages of implementing minimum legal size in a fishery

- Reduce juvenile fishing which results in economic loss
- Prevent growth over-fishing which is detrimental to the stock
- Maintain spawning stocks
- Ensures enough fish survive to grow and spawn
- Conservation of heavily exploited stocks
- Share catch more equally
- Reduce illegal marketing of fish
- Promote ethical and responsible fisheries
- Maximize marketing and economic benefits
- Promote aesthetic values of fish

In aquaculture the ultimate aim is to produce as many fish as possible in the shortest possible time which could be achieved *through* increased growth rate. an increased growth rate most probably will be accompanied by a subsequent decrease in age and size at sexual maturity. Since it is not economical to rear the species beyond sexual maturity, size at maturity is important for aquaculture also.

Information on size and reproductive behaviour of the species are necessary for a management regime to ensure that sufficient number of juveniles reach maturity and contribute to the growth of the population. An individual in a population is said to be fit when it survives to sexual maturity and contribute to the gene pool of the population and collectively, those surviving individuals determine the survival of the population. Thus it is very important to study about the reproductive biology of the fish for better understanding and management of an exploited ecosystem. As the reproductive behaviour vary highly from species to species

Some of the key measurements used for size regulation in fish include size at first maturity or size at which 50% of fish are mature (L50) and minimum size at maturity or size of the smallest mature fish. Proper estimation of these size measurements is very useful for fish stock management. Different methods have been proposed to estimate L50 and other measures of maturity size. According to a very useful study, each individual fish should be identified as reproductive or non reproductive. Although diverse methods are available for assessment of L50, most of the researchers apply some kind of logistic functions.

Thus restrictions on size of the animals that are caught is extensively used as one of the different means necessary for conservation of fish stocks. Accurate estimates of female age or length at maturity are thus critical for conservation of exploited fishery resources. Information on age and length at maturity based on histological evaluation of maturity status is therefore needed for different species. Fishery biologists prefer to conceive size at first maturity as the average size at which 50% of the individuals are mature. Size at 50% maturity (L50%) is commonly evaluated for wild populations as a biological reference point.

To estimate (L50%), a sample of organisms known to have just reached sexual maturity could be made available and their arithmetic mean size can be used as an estimator. One accepted method of estimating the size at first maturity is by sampling the mature animals from the population following a suitable sampling design. But the sample needed to obtain such a design based estimator (Sampling Design) for wild populations might be too expensive and would involve time-consuming histological procedures. With this conception, the estimator is usually not based on a sampling design but on a statistical model of the relation between body size and the number of individuals that are mature from a total number at each of many size intervals.

The most preferred model is the Logistic regression model to fit sigmoid curves to the proportion mature by length. The mathematical expression for a logistic regression model is

$$P(x) = \frac{e^{b_0 + b_1 x}}{1 + e^{b_0 + b_1 x}}$$

Here p(x) is the probability that a fish is mature in a given length *x*. The parameters in the model b0 and b1 determine the shape and location of the sigmoid curve. Once estimates of the parameters of the model are available we can workout the length corresponding to any required proportion (size of the animal for which a given percentage of the animals will be mature) using the expression (except for 0 and 100%)

$$x = \frac{ln\left(\frac{p}{1-p}\right) - \widehat{b_0}}{\widehat{b_1}}$$

where $\hat{b}_0$ and $\hat{b}_1$ are the estimates of the parameters in the logistic regression model.

Logistic regression model parameters can be estimated by adopting different statistical procedures. One method is through regression analysis after linearising the model by log transformation as shown below where *p* is the proportion mature having length *x* in the observed data.

$$x = \frac{ln\left(\frac{p}{1-p}\right) - \widehat{b_0}}{\widehat{b_1}}$$

The above method create estimation problems when the observed data have samples with proportions 0, 0.5 and 1.0 as the left hand side of the above equation become indeterminate or not defined for these cases. Some authors have suggested some adjustments in the observed data to handle this situation. A well accepted method is to use the statistically popular method of maximum likely hood which requires specific statistical softwares. Another alternative is to use Bayesian estimation for the logistic regression model which is explained here using the OpenBUGS computer software.

Bayesian methods are widely used in fisheries for stock assessment to obtain posterior probability densities of parameters of interest. Two important advantages of Bayesian inference are i) it provides estimates of posterior probability densities of unknown parameters of the model rather than the usual point estimates (ii) prior knowledge about the model parameters can be incorporated into the estimation process.

OpenBUGS is an open source version of WinBUGS, a statistical software for Bayesian analysis using Markov Chain Monte Carlo (MCMC), which is downloadable from www.openbugs.net. It is the windows version of the original DOS version BUGS (Bayesian inference Using Gibbs Sampling) software developed by MRC Biostatistics Unit, Cambridge, and Imperial College School of Medicine, London in 1989.

Practical Example

The source of data used for demonstration of Bayesian estimation using OpenBUGS is from the following publication accessed on line:

INFORMATION REPORTS NUMBER 2009-04, "Length and age at maturity of female yelloweye rockfish (*Sebastes rubberimus*) and cabezon (*Scorpaenichthys marmoratus*) from Oregon waters based on histological evaluation of maturity" by Robert W. Hannah, Matthew T. O. Blume and Josie E. Thompson, Oregon Department of Fish and Wildlife Marine Resources Program, 2040 Southeast Marine Science Drive, Newport, Oregon 97365, U.S.A

Number of female yelloweye rockfish sampled, number and proportion mature, by length (cm)

Length	Observed Number	Number Matured	Proportion	Length	Observed Number	Number Matured	Proportion
31	1	0	0.00	51	3	3	1.00
32	4	0	0.00	52	5	5	1.00
33	2	0	0.00	53	5	5	1.00
34	3	0	0.00	54	2	2	1.00
35	2	0	0.00	55	0	0	
36	4	2	0.50	56	1	1	1.00
37	5	2	0.40	57	4	4	1.00
38	4	1	0.25	58	2	2	1.00
39	4	2	0.50	59	0	0	
40	5	2	0.40	60	3	3	1.00
41	7	6	0.86	61	2	2	1.00
42	7	6	0.86	62	1	1	1.00
43	6	6	1.00	63	0	0	
44	8	7	0.88	64	1	1	1.00
45	5	5	1.00	65	2	2	1.00
46	19	19	1.00	66	0	0	
47	9	8	0.89	67	1	1	1.00
48	9	9	1.00	68	1	1	1.00
49	7	6	0.86	69	0	0	
50	3	3	1.00	70	1	1	1.00

OpenBUGS code for the logistic model

Download the OpenBUGS software (Version 3.0.3 or higher) from the website "http://www.mrc-bsu.cam.ac.uk/bugs" and install it on a computer system. Start the software and proceed with the following steps.

1. Open a new OpenBUGS page by choosing 'New' from the File Menu and copy the given code into the blank page (the portion from 'model' to the last line starting with 'list'.
2. Replace the input sample data portion (do not disturb the structure) with the original data where the x portion is for the lengths of samples, n portion is for the number of samples of each length observed and r is the numbers that are mature corresponding to each sample.
3. From the Model menu open the specification tool
4. Double click on the word "model" in the open page containing the code to select it and click on the check model button in the specification tool box. At the bottom left corner of the open page "model is syntactically correct" message should appear.
5. Double click on the word 'list' in the data portion of the open page to select it and click on the load data button in the specification tool box. At the bottom left corner of the open page "data loaded" message should appear.
6. Click on the compile button in the specification tool box. At the bottom left corner of the open page "model compiled" message should appear.

```
model
    {for ( i in 1 : N ) {
        r[i] ~ dbin(p[i],n[i])
    logit(p[i]) <- b0.star + b1 * (x[i] - mean(x[]))
        rhat[i] <- n[i] * p[i]
        culmative.r[i] <- culmative(r[i], r[i])}
       b0 <- b0.star - b1 * mean(x[])
       b1 ~ dnorm(0.0,0.001)
       b0.star ~ dnorm(0.0,0.001) }
#
# Input sample data
#
list ( x = c(31,32,33,34,35,36,37,38,39,40,41,42,43,44,45
    ,46,47,4
8,49,50,51,52,53,54,56,57,58,60,61,62,64,65,67,68,70),
n   =   c(1,4,2,3,2,4,5,4,4,5,7,7,6,8,5,19,9,9,7,3,3,5,5,2,
        1,4,2,3,2,1,1,2,1,1,1),
r   =   c(0,0,0,0,0,2,2,1,2,2,6,6,6,7,5,19,8,9,6,3,3,5,5,2,1,
        4,2,3,2,1,1,2,1,1,1), N = 35)
#
# Initial values for parameters
#
list(b0.star=0, b1=0)
```

7. Double click on the word 'list' in the initialization portion of the open page (last line) and click on the load inits button in the specification tool box. At the bottom left corner of the open page "model is initialized" message should appear.

8. Now close the specification tool box.

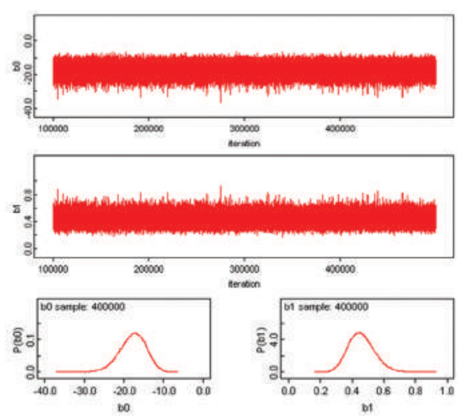
9. Open the sample monitor tool box from the inference menu. Type the parameter names (b0, b1,b0.star,rhat) one at a time in the box against node and press the set button. Repeat it with other parameter names and close the sample monitor tool box once finished.

10. Open the update tool box from model menu. Replace the number in the update box with your choice number of updates (say, 100000 or more for good results) and click on the update button. The MCMC algorithm starts and the number of updates completed will be displayed in the iteration box. Close the update tool box one the iteration/updating is complete.

11. Open the sample monitor tool box from the inference menu again. Select the parameter name by clicking on the down arrow against the node (* for all set parameters) and click on the respective buttons to get information about the MCMC results. The important items are

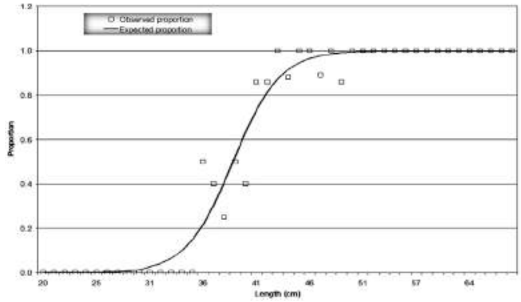
Name on the Button	Purpose
History	Graphical display of iteration history
Density	Graphical display of the probability density
Stat	Summary of statistics estimated

Here, for each parameter, the estimation history and posterior probability density plot should be examined before accepting the estimates displayed when 'stat' button is pressed. The history plot should be oscillating steadily in an acceptable range and the density plot should be smooth. For the sample data, the history plots, posterior probability density plots and summary statistics for the two parameters in the model obtained with 5,00,000 updations, omitting the initial 1,00,000 are given below.



	mean	sd	MC_error	val2.5pc	median	val97.5pc	start	sample
b0	-17.83	3.395	0.01676	-25.06	-17.61	-11.81	100001	400000
b1	0.4595	0.08398	4.226E-4	0.3111	0.454	0.6386	100001	400000

The Bayesian estimates of the parameters of the logistic regression model for the sample data are $\hat{b}_0 = -17.83$ and $\hat{b}_1 = 0.4595$ and the plot of the observed proportions and the fitted sigmoid curve are given below. From the fitted model, the estimates of L25, L50 and L75 (lengths corresponding to 25%, 50% and 75% are mature) for the species are 36.4cm, 38.8cm and 41.2cm respectively.



RESPONSIBLE FISHERIES - A PRELUDE TO THE CONCEPT, CONTEXT AND PRAXIS

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Introduction

The concept of Responsible Fisheries is synonymous with the FAO Code of Conduct for Responsible Fisheries (CCRF). CCRF is an international instrument for fisheries management which was developed and released by Food and Agriculture Organisation (FAO) functioning under the United Nations on 31 OCTOBER 1995 after a series of international deliberations that began in 1992. More than 160 countries, including India are signatories to this international instrument which is considered as a landmark document symbolizing the international consensus achieved on the necessity for providing guidelines to ensure sustainable utilization of fisheries resources of the world. The most salient feature of this global instrument is its voluntary nature. The Code is often referred to as the Bible of Fisheries Management.

Why the Code ?

The term "Responsible Fisheries' may evoke a doubt whether we have been irresponsible in the way we have been developing or managing our fisheries resources. In fact such a doubt is the stepping stone to understand the concept of Responsible Fisheries.

In common parlance the term "responsibility" is immediately read with the notions of rights or ownership. We tend to have a better sense of responsibility to things we own. Thus, we feel responsible in taking care of our properties or assets like land or house or vehicle. The lesser the sense of our ownership lesser will be our sense of responsibility. Thus we feel less responsible for the affairs of our ecosystem or political system because we deem them as owned by all. A property belonging to everyone tends to be no body's property though nobody is excluded from its utilization. This is an important point because in the case of fisheries what we are talking about is a Common Property. Or more correctly an Open access resource. An important question here is "Who actually owns the fish or who actually owns the sea? The *de jure* owner of the fisheries is the State or the government. But by all practical sense the fish, once caught by the fisher, becomes his or her property. If so, what about his or her sense of responsibility to ensure its conservation? It may sound a bit puzzling. That is why the Code makes it very clear in the very first article which is given under the general principles of the Code.

"States *and users of living aquatic resources should conserve aquatic eco systems. The right to fish carries with it the obligation to do so in a responsible manner so as to ensure effective conservation and management of the living aquatic resources.* "(Article 6.1).

What is in principle a property of every one, becomes the property of none in practice. This is the most fundamental challenge in scientific fisheries management. There is a notion that if a sense of ownership is assured, the likelihood of it being taken care of in a responsible manner is more. There are people who argue that it is a misplaced notion. The above-mentioned article of the Code, in fact, is a preemptive answer to this common misunderstanding.

It is for the same reason that, of the more than 230 clauses in the Code classified under 12 articles, a large number vest the responsibility with the State. This, in a way also, helps to clear the doubts regarding the real meaning of implementing the Code.

Another doubt could be on the real meaning of the voluntary nature of the Code. Being a voluntary instrument the question could be, "Is it something like a "barking dog that seldom bites"? The code answers this question in its fundamental philosophy called the Precautionary Approach, which is enshrined in Article 7.5.1.

"The *absence of adequate scientific information should not be used as a reason for postponing or failing to take conservation and management measures*."

In simple words what it means is "Better *safe than sorry*". It also has a deeper meaning which implies that when a person is given the license or permission or right to fish, what is being transferred is part of the stewardship obligation of the State. One needs to clearly understand this because, when individuals operate in a common property with the sole objective of making profitable livelihoods, the sustainable utilization of such a resource becomes an impossible task in the absence of mutually respected and endorsed regulations. The precautionary principle is further elaborated under the Foundations of the Code below.

Being a global guideline there is much practical sense for keeping it as a voluntary instrument too. Each nation can contextualize the code in sync with its own local realities and requirements at the same time respecting the globally agreed principles and norms. However there are scholars who argue for making the CCRF as a binding instrument given the sorry state of fisheries governance in most parts of the world.

Foundations of the Code

That the sustainability of marine capture fisheries at the current level of harvesting is at stake is no longer a moot point. It is being realized that fisheries anywhere in the world is more a socioeconomic process with biological constraints than anything else. The open access nature of the resource coupled with unregulated penetration of advanced, but not necessarily eco-friendly, harvesting technologies (a phenomenon called *technological creep*) has enacted a virtual "tragedy of the commons" in our seas. Making the issue still more complex, especially in the context of the Millennium Development Goals, is the rampant poverty existing among our fisher folk though the capture fisheries makes significant foreign exchange contribution in our country. The plateauing of the resource as revealed by recent trends in landings doesn't augur well for the ecologic and economic sustainability of the marine fisheries sector.

If there are no technological magical bullets for the current impasse what is the way out? This is precisely the question the FAO code is trying to answer. "*The right to fish carries along with it an obligation to do it responsibly*" is the cardinal principle of the code. This principle is built on the foundation of what is known as a Precautionary Approach. Precautionary approach, which originally was proposed as Principle 15 of Agenda 21 the Rio Earth Summit meeting in 1992, enunciates that

"*where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation*".

While in simple terms the precautionary approach means "better safe than sorry", it clearly recognizes that changes in fisheries systems are only slowly reversible, difficult to control, not well understood, and subject to changing environment and human values. As Restrepo *et al* define in fisheries, the precautionary approach is about applying judicious and responsible fisheries management practices, based on sound scientific research and analysis, proactively (to avoid or reverse overexploitation) rather than reactively (once all doubt has been removed and the resource is severely overexploited), to ensure the sustainability of fishery resources and associated ecosystems for the benefit of future as well as current generations".

It involves the application of prudent foresight. It is about applying judicious and responsible fisheries management practices, based on sound scientific research and analysis proactively rather than reactively to ensure the sustainability of fishery resources and associated ecosystems for the benefit of future as well as current generations.

Taking account of the uncertainties in fisheries systems and the need to take action on incomplete knowledge, it requires, *inter alia:*

a. consideration of the needs of future generations and avoidance of changes that are not potentially reversible;

b. prior identification of undesirable outcomes and of measures that will avoid them or correct them promptly;

c. that any necessary corrective measures are initiated without delay, and that they should achieve their purpose promptly, on a timescale not exceeding two or three decades;

d. that where the likely impact of resource use is uncertain, priority should be given to conserving the productive capacity of the resource;

e. that harvesting and processing capacity should be commensurate with estimated sustainable levels of resource, and that increases in capacity should be further contained when resource productivity is highly uncertain;

f. all fishing activities must have prior management authorization and be subject to periodic review;

g. an established legal and institutional framework for fishery management, within which management plans that implement the above points are instituted for each fishery, and

h. appropriate placement of the burden of proof by adhering to the requirements above.

The reversal of burden of proof means that those hoping to exploit our marine resources must demonstrate that no ecologically significant long-term damage will result due to their action. Or in other words human actions are assumed to be harmful unless proven otherwise.

Contents of the Code

The code provides a necessary framework for national and international efforts to ensure sustainable exploitation of aquatic living resources in harmony with the environment. It is achieved through 12 articles covering areas like

a) Nature and scope of the code (article 1)

b) Objectives of the code (article 2),

c) Relationship with other international instruments (article 3),

d) Implementation, monitoring and updating (article 4),

e) Special requirements of developing countries (article 5),

f) General principles (article 6),

g) Fisheries management (article 7),

h) Fishing operations (article 8),

i) Aquaculture development (article 9),

j) Integration of fisheries into coastal area management (article 10),

k) Post-harvest practices and trade (article 11), and

l) Fisheries research (article 12).

(The full text of the FAO CCRF (hereafter referred to as the Code) translated into Malayalam was published by CMFRI in 2002 under an agreement with the FAO (Ramachandran, 2002). Thus, Malayalam became the second language, after Tamil, to have a translated version of the most important international fisheries management instrument. You can access it at www.cmfri.org.in. The pdf of the English full text is supplied with the Winter school CD rom).

Characteristics of the Code

As we have seen, the most salient feature of the code is that it is *voluntary* in nature. Unlike other international agreements like UN Agreement to Promote Compliance with International Conservation and Management Measures by Fishing vessels on the High Seas or the Straddling Stock Agreement, 1995, it is not legally binding and violation of the code cannot be challenged in a court of law.

It would be tempting to castigate it as an Achilles' heel and thus the futility of the code. But it should be remembered, "open access imbroglios" cannot be resolved through attempts that fail to recognize altruistic spirit of the human actors. In a situation where "you and your enemy belong to the same eco-system", solutions must be found in managing relationships of the actors that make or move the ecosystem. It doesn't mean that the code is impractical or ineffective. What it demands is to construe responsible fisheries management as a *political process* rather than a *technical process*. This insight is a significant contribution of social scientists studying natural resource management. (Wilson et al 2006)

A fundamental objective of the Code is "to serve as an instrument of reference to help states to establish or to improve the legal and institutional framework required for the exercise of responsible fisheries and in the formulation and implementation of appropriate measures." The policies of the state for managing the fisheries resources should be based on the provisions of the code.

If world fisheries are to be sustainable in the long term, structural adjustment within the fisheries sector is required. Although policy decisions in this regard must be made by national governments, effective implementation of the code requires the participation and cooperation of a wide range of stakeholders, including fishers, processors, NGOs and consumers. Implementation of the code is primarily the responsibility of states. The code will require regional and sectoral implementation in order to address the particular needs of fisheries in different regions or sub-sectors.

Relevance of the Code in our context

Before analyzing the relevance of the code in our context it is necessary to have an inkling of the historical context in which the code was developed.

The code was unanimously adopted on 31 October 1995 after lengthy deliberations and negotiations spanning about four years. One of the major triggers for the idea behind the code is the international concern over the serious decline noted in the global catch of marine fish. The iconic cod fish of the Canadian waters collapsed in 1992. The famous Science magazine at that time wrote in its editorial that "Fisheries is five per cent protein and 95% politics". It was realized that the command and control regime of fisheries management banking mainly on scientific advice has come of age. Fisheries management was perceived more as fisher management or managing the behavior of human beings rather than that of the fish. No effective management was possible without the active participation of stakeholders. It was this realization that led to the concept of responsible fisheries. It is worth noting that the global production of marine fish after reaching a peak of 86.4 million tons in 1996 from a mere 20 million tons of the 1950s started stagnating or even plummeting down to 79.7 million ton in 2012.

The Lessons of the Code

In order to better understand the lessons we can garner from the code which is an international instrument a comparative key word analysis of the Code with the instrument we currently have namely the Marine Fisheries Regulation Acts of the maritime states in India. (Kerala MFRA is considered for the analysis here). Also given is the famous Magnuson –Stevenson Fisheries Conservation and Management Act 1976, 2007 of USA for a comparative understanding.

Table 1. A comparative Key word analysis of three instruments

Key word	FAO CCRF 1995	KMFRA 1980	MS Act 2007
Sustainability	5	0	8
Over fishing	0	0	45
Conservation	70	1	>200
Management	10	0	>200
Food security	4	0	0
Gender	0	0	0
Regulation	19	37	152
Research	46	0	64
Penalties	0	0	22
Mesh size	1	2	0
Over capacity	0	0	0
MSY	1	0	5
Fisherman	15	0	43
Justice	0	0	6
Discard	9	0	18
By catch	1	0	68
Participation	4	0	32
Fisheries development	0	0	1
Poverty	1	0	2
Conflicts	3	0	3
Rights	33	0	0
Safety	11	0	26
Ecosystem	27	0	13
Code of conduct	NA	0	0

The table reveals certain interesting things. The greater importance given to Resource Conservation both by the CCRF and the MS Act compared to KMFRA is indicative of the nature of exploitation in our waters. Remember that the KMFRA was developed in 1980. Today the situation has definitely changed given the declining trends we have witnessed in recent times. Another key word to take note of is MSY. Maximum Sustainable Yield is the most fundamental creed of fisheries stock assessment science. MS act of USA has given much more importance to MSY indicating the extent to which scientific stock assessment has influenced the fisheries management regime in that country. FAO CCRF has mentioned MSY only once (Article 7.2). It indicates the lesser global applicability of MSY as a management reference point. All the three instruments give importance to fisheries regulations. CCRF obviously does not deal with penalties. But what is relevant here for us is the fact that out of the 24 keywords used in this analysis only three keywords appear in KMFRA. They are conservation, regulation and mesh size. (What are your impressions over this finding?). The absence of these key words in our Act indicates that there is a need for reforming it taking into cognizance the new ecologic and economic realities emerging in our fisheries sector.

Another interesting thing is the fact that the MS Act of USA is silent about the FAO CCRF. But, in an international study published in Nature 2009, which assessed the extent to which the FAO CCRF is being complied by different nations USA got second rank. Out of the 53 countries where the assessment was made India got 27 th position. The lesson we have to draw from this study is the importance accorded by Nation States in adopting problem -based management measures in ensuring sustainable utilization of their marine fisheries resources and the kind of policy significance these countries bestow to the importance of sustainable fisheries in the economy of those nations. It is worth noting that all of the 10 highly ranked countries belong to temperate regions of the world. The issues like overfishing are more visible in these countries and hence there is no wonder that these countries are ahead of other nations in adopting conservation oriented- fisheries management and regulations in their waters. In this context a question may creep in our minds. Should we also follow these nations where overfishing has become a reality? Can we continue our business as usual attitude in the absence of fisheries collapses or severe decline in our resources? It indeed is a challenging poser.

It is here that the science of fisheries management and the knowledge base we have accumulated so far regarding the status of our marine resources become relevant.

There are only two fundamental questions in fisheries management anywhere in the world.

i) “How much fish we can safely catch?”

ii) “How much is the fish available?”

These questions are very simple. But answers are not so simple to come. That is precisely the reason why Precautionary approach has become the driving philosophy of the global thinking over sustainable or responsible fisheries. We should not fail to see the intellectual humility enshrined in this approach. It is the deep ecological insight that in the face of the excruciating uncertainty and ignorance attached to our fisheries management knowledge base we need to respect the self rejuvenating capacity of the ecosystem. This realization is the basic idea behind new approaches like Ecosystem based Fisheries Management. And of course this demands new approaches in fisheries research and governance.

What is the Problem?

The most important problem a fishery faces is what is known as Over Fishing. It takes place over time as the fishing is intensified. It is the stage where a stock of fish loses its capacity to keep on providing the Maximum Sustainable Yield. It is at this stage that the fishery is at the verge of an almost irredeemable loss, economically and biologically. MSY as a logic is easy to understand. But as a quantitative reference point, MSY is a methodological challenge especially in our multi- species tropical water scenario. This is still considered as the Holy Grail in fisheries stock assessment science. Remember, this should not be construed as a weakness of the scientist. It is the epistemological challenge the fisheries scientists all over the world share, lament and endeavour to overcome.

MSY is like a *Laxman Rekha*. The most frightening aspect about this *Laxman Rekha* is that we need to cross it to realize that we have trespassed it. Hence we can build our defense against the specter of overfishing only on the basis of a stronger understanding and contextual analysis of its symptoms.

Will our waters also witness collapses like that of the Canadian Cod? That such a tragedy has not happened so far is not a guarantee that it will not happen here. But we have a better sense of optimism thanks to the resilience of our marine ecosystem which is mainly due to the rich bio diversity. However, we need to be concerned if recent events like pelagic fatigue in Kerala are of any indication. The decline experienced by our fishers vouch for a serious rethinking on our laid back attitude. Our fishers also share the veracity of different ways in which symptoms of overfishing are being manifested. They are:

a) severe decline or total absence in those fish which used to be abundant,

b) decline in the size range of major species ,

c) excessive catch of juveniles,

d) increase in fishing time and distance,

e) frequent fluctuations in the total catch, and

f) changes in species composition.

Our Tool Box

There are five types of remedies for the disease called "over fishing".

1. Based on the total catch of the fish (yield or Output)
2. Based on fishing effort or input
3. Based on time or season (temporal)
4. Based on space or depth (spatial)
5. Based on technical things

A typical example of the first type of remedies is the Quota system of fisheries management which is common in countries like EU, USA. This demands the assistance from a very precise stock assessment science. These measures which are similar to rationing of the catch, can be considered as the last ditch effort feasible in areas of lower species diversity that makes determination of MSY much less cumbersome. The second type of measures aims rationalizing the fleet size. Licensing based on an optimum fleet size is an example here. The next type of measures based on time and space is well known to us through the Monsoon Trawl Ban. Other examples are Marine sanctuaries, and no- fishing zones. Technical measures include Mesh size regulations, and Minimum legal size.

For an overview of the status of the tool box (interpreted in a slightly different mode) in our context given in the form of a table , see the annexure. The table is taken from a forthcoming publication (Shinoj and Ramachandran 2017).

As long as a fishery remains a common property resource, a regulated fishery is more profitable than an unregulated fishery in the long run. Our fishers have started accepting this truism. But they are helpless to avoid competitive fishing due to two main reasons. One is the increase in fuel cost. And the other is the high demand for fish which has led to a situation where you are economically rewarded whatever be the catch. So fishers tend to do indiscriminate fishing. This has resulted in an illusion of super abundance which again drives more fishing effort. This is leading to a very dangerous situation. There are fishers (like Mr Jossy Palliparambil, Munambam Kerala) who characterize this ugly scenario as a phase of "Foolish Fishing". It is high time each fisher take more care in analyzing the fluctuations observed in the economics of their operations.

Challenges in the praxis

Sustainable Management of resources is no different from fisheries development. They are no longer considered as dichotomous. There will be no fisheries development if there is not enough fish in the sea. There won't be enough fish in the sea, if human beings, both as harvesters and consumers, do not act in a precautionary manner which is nothing but to nurture a feeling of "better safe today than sorry tomorrow". It means to understand clearly the limits to which nature can be tapped. The requirements of both the present generation and future generation are to be given equal importance. It is also about respecting the co-evolutionary culture of a fisheries-resource dependent community. Thus Responsible Fisheries management takes place at the dynamic interface between the behavior of man and that of fish. So the knowledge base for responsible fisheries ought to be a convergence of different disciplines like fisheries biology, socio-politics, ecology, economics, engineering, law and communication. The aim of fisheries management is to ensure optimum utilization of a common pool resource without jeopardising the inherent regenerative ability of the resource leading to livelihood security of the dependent community.

Much has been said about rights-based fisheries, fisheries co-management and ecosystem-based fisheries management with fisheries managers, policy-makers, scientist and researchers racking their brains about the meaning of each of these fisheries management approaches. In trying to find definitions and formulating "how-to" guidelines and handbooks on such fisheries management approaches, their essential ingredient often is overlooked, namely dialogue. Whether talking of co-management and partnerships between fisheries stakeholders or of the adaptive nature of ecosystem-based fisheries management the fundamental nature of any fisheries management effort is the communication process among its various protagonists. Neither a partnership between fishing communities, fisheries managers, researchers and other stakeholders, nor the merging of the development goals of human well-being with that of ecological well-being through an ecosystem-based fisheries management approach would be possible without free-flowing information among the various partners in the management process.

These communication processes can take many different forms and can be designed according to a diversity of purposes: (1) to meet specific fisheries management objectives, needs and aspirations for the fisheries sector; and 2) to generate new information about local fisheries systems through participatory (eg. catch-reporting) mechanisms. The experiences from these activities should encourage fisheries managers, scientists, and fishing communities to actively seek such dialogue and information exchange as a basis for improving fisheries management on an ecosystem approach.

The efforts to engender a scientifically- informed fisheries management or governance regime are always challenged by the inherent uncertainty that characterizes the epistemology of fisheries science. The complexity of an otherwise resilient tropical marine ecosystem adds fuel to the fire. And on the Human dimension we have a plethora of challenges despite promising perspectives from Hardin to Ostrom.

It is here that we need to fully appreciate the multitude of challenges we face in a precautionary and participatory framework. We have the instruments /tool box. But the credo of responsible fisheries is yet to become part of the community ethos. What could be the reasons and how we can overcome the barriers? As a concerned stakeholder each one of us has a responsibility to be part of a collective process to not only decipher the answers but also translate them into pragmatic ameliorative strategies.

The Code and CMFRI Initiatives

Our fisheries have undergone tremendous changes during the past six decades. Before the advent of modernization, (motorization, mechanization, refrigeration, export orientation and transportation) the access to sea was limited to a few skillful and adventurous people who were by birth fishers. The community could afford to have self regulations oriented towards resource conservation which were arrived through the ecological experience of the community over generations. These concerns were institutionalized too. An example of such an institution still, surprisingly, surviving in Kerala is the *Kadakkody* of the Malabar Coast (Ramachandran, 2006). The self regulations and community regulations which were rooted in the traditional wisdom have given way to technological skills. These skills, unleashed by what we generally refer to as an era modernization, most often take a dehumanized manifestation thus weakening the hold of the community. This is where the crucial role of the State comes into play in the management as well as development of the fishery. This is better known as fisheries governance.

Fisheries governance is dependent on the particular stage of economic development and local ecological status of the fishery resources. This varies with each country. It is because of this contextual nature that the Code has been made as a voluntary tool. Each government is free to make its own rules, regulations and strategies based on the guidelines and principles elaborated in the Code. Thus article 4.3 says "FAO through its competent bodies, may revise the code, taking into account developments in fisheries as well as reports to COFI on the implementation of the Code. (But in recent times an argument against this position has also emerged).

It is in this context that the actions and initiatives being taken by CMFRI, mainly through an NATP funded research project titled "Designing and validation of communication strategies for responsible fisheries –a co-learning approach" become relevant. A Responsible Fisheries Extension Module (RFEM), which consists of 13 tools including a Malayalam translation of the code, animation films in all maritime languages etc. developed have been widely used to create awareness among the fisherfolk. A state-wide campaign on Responsible Fisheries was launched and the RFEM was released for further scaling up by the respective State

Fisheries Departments. These mass communication tools have the potential to reach almost 85 % of the fisher folk and other stakeholders in the country. It is reasonable to conclude that CMFRI has made a pioneering initiative in the cause of popularization of the concept of Responsible Fisheries in India (Ramachandran, 2004)

Though the voluntary nature of the code has been necessary in garnering the all-nation agreement when it was drafted in the early 1990s, our attitudes to the oceans have changed since then (Pitcher *et al.,* 2009). There is now widespread scientific consensus on the ecological impacts of continued over-fishing and the threats to seafood security and broad agreement on policy issues such as curtailing illegal catches and minimizing the impacts of fishing on marine ecosystems. The basic requirement for adoption of Ecosystem Approach is a dynamic knowledge base on stock assessment. The stock assessment knowledge base generated and continuously maintained by CMFRI is a unique achievement among the developing tropical context countries. But the utility of this Knowledge base in translating into management praxis is less appreciated. There still exists a communication divide between the research system and the fisheries management system in the country.

Though the communication tools and strategies already developed by the institute have been useful in creating awareness on the need for sustainable /responsible fisheries there is a need to develop and scale up specific communication interventions to sensitize the stakeholders in making a transition towards ecosystem based approaches that ensure responsible management of our waters. Fisheries management is fisher management and participatory approaches informed/initiated by a proactive research system taking place in a democratic and decentralized civil society space is globally accepted as the key to Ecosystem Based Fisheries Management. The future is decided by the capacity we build today amongst the different stakeholders responsible for sustainably utilizing the marine fisheries resources of our country. It is with this objective that we are continuing the efforts in this line through innovative research projects in Capacity Development for compliance to Ecosystem Based Responsible Fisheries Management in India through Co-Learning and Multi-disciplinary action research under the leadership of Extension scientists in CMFRI.

Pathways before us

Taking into consideration the inherent epistemological limitations of the Fisheries science, it is essential to make a transition towards more participatory efforts fisheries governance and research. There cannot be any management without measurement. What our fishers lack is the big picture on the status of our fisheries resources. The science has the tools to draw this picture. But its precision depends on the accuracy of the data on landings. We badly need a National Marine Fisheries Data Acquisition Plan. The active and informed participation of fishers in providing the catch data needs to be encouraged through proper incentive mechanisms.

Engendering a scientifically informed fisheries management governance system is the need of the hour. As recent events like the Kochi Initiative (Ramachandran and Mohamed 2015) is of any indication, formation of multi stakeholder platforms of responsible fisheries co-governance is not an impossible task in our context. The response of the State in facilitating this transition is essential. With the landmark promulgation of insisting Minimum Legal Size for 55 species of fish by the Government of Kerala (GoK,2017) done based on the recommendation of CMFRI (Mohamed et al 2014), the State of Kerala has shown an instance of proactive engagement with responsible fisheries governance which is worthy of emulation by other maritime states. It is ,however, worth remembering that regulatory measures like MLS would become impotent in the absence of strong arm efforts to eliminate (or at least rationalize) external drivers like demand for the juveniles either for reduction or consumption. As scholars of regulatory politics argue, legislative coercion though necessary cannot be open to tendencies for inefficient rent seeking in a public good.

Annexure

Table 2. Capture fisheries regulatory framework in maritime states of India

Maritime State	**Access controls**	**Temporal controls**	**Spatial controls**	**Input/ effort-based**	**Output/ catch-based**	**Legislation/s in force**
Gujarat	Registration and licensing of fishing vessels.	Seasonal fishing ban (Jun 1 – July 31, 61 days)	Artisanal: up to 9 km; Mechanized: beyond 9 km.	Square mesh of minimum 40 mm size at cod end need to be used for trawl net; Gillnet with mesh size less than 150 mm cannot be operated.		The Gujarat Fisheries Act, 2003.
Maharashtra	Registration and licensing of fishing vessels.	Seasonal fishing (Jun 1 – July 31, 61 days); Mechanized vessels with trawl net prohibited between 6 pm and 6 am.	Mechanized (trawl net) : beyond 5-10 fathom depth in specified areas; Mechanized (any type with more than 6 cylinder engines): beyond 22 km.	Use of purse-seine gears by mechanized vessels at specified coastal zones prohibited within territorial waters.	-	Maharashtra Marine Fisheries Regulation Act, 1981 (Amended in 2015)

Maritime State	Access controls	Temporal controls	Spatial controls	Input/ effort-based	Output/ catch-based	Legislation/s in force
Goa, Daman & Diu	Registration and licensing of fishing vessels.	Seasonal fishing ban (Jun 1 – July 31, 61 days)	Artisanal: up to 5 km; Mechanized: beyond 5 km.	Mesh-size limits of 20 mm for prawn and 24 mm for fish.	-	The Goa, Daman and Diu Marine Fishing Regulation Act, 1982 (Amended in 1989)
Karnataka	Registration and licensing of fishing vessels.	Seasonal fishing ban (Jun 1 to July 31-61 days)	Artisanal: up to 6 km or up to 4 fathoms (whichever is farther); Deep sea vessels (up to 50 feet length): beyond 6 km Deep sea vessels (>50 feet length): beyond 22 km.	Ban of cuttle fish fishery using FADs.	-	The Karnataka Marine Fishing Regulation Act, 1986.
Kerala	Registration and licensing of fishing vessels.	Seasonal fishing ban (Jun 15- July 31, 47 days) [1]	Artisanal: 32-40 m depth in the first zone[2] and 16-20 m depth in the second zone; Mechanized vessels (< 25 GRT): 40-70 m depth in the first zone and 20-40 m depth in the second zone; Mechanized	Mesh-size regulations: code end minimum mesh size of bottom trawl net-35 mm; ring seine and driftnet minimum mesh size – 20mm.	Minimum legal size for 14 fish and shell-fish species notified to control juvenile fishing.	The Kerala Marine Fishing Regulation Act, 1980 (Amended in 2013).

Maritime State	Access controls	Temporal controls	Spatial controls	Input/ effort-based	Output/ catch-based	Legislation/s in force
			(> 25 GRT): beyond 70 m depth in first and beyond 40 m depth in second zone.			
Tamil Nadu	Registration and licensing of fishing vessels.	Seasonal fishing ban April 15 to June 14, 61 days)	Artisanal: up to 5 km. Mechanized: beyond 5 km; Fishing within 100 m below a river mouth is prohibited; The number of mechanized fishing vessels permitted in any specified area subject to restrictions.	No fishing gear of 100 mm mesh from knot to knot in respect of net other than trawl net to be used; Pair trawling and purse seining are prohibited.	-	Tamil Nadu Marine Fishing Regulation Act, 1983 (Amended in 1995; 2000; 2011; 2016).
Andhra Pradesh	Registration and licensing of fishing vessels.	Seasonal fishing ban (April 15 to June 14, 61 days)	Artisanal: up to 10 km; Mechanized (< 15 m OAL): 10-23 km; Mechanized (< 15 m OAL): beyond 23 km.	A minimum 15 mm limit for mesh-size for any gear; Shrimp trawlers not allowed without turtle-exclusion device (TED).	-	The Andhra Pradesh Marine Fishing (Regulation) Act, 1995 (Amended in 2005).
Odisha	Registration and licensing of fishing vessels.	Seasonal fishing ban (April 15 to June 14, 61 days)	Artisanal: up to 5 km; Mechanized (<15 OAL): 5-10; Mechanized (>15 OAL): beyond 10 km.			The Orissa Marine Fishing Regulation Act, 1981 (Amended in 2006).

Maritime State	Access controls	Temporal controls	Spatial controls	Input/ effort-based	Output/ catch-based	Legislation/s in force
West Bengal	Registration and licensing of fishing vessels.	Seasonal fishing ban (April 15 to June 14, 61 days)	Artisanal & mechanized crafts with < 30 HP engine: up to 18 km; Mechanized crafts with >30 HP engine: beyond 18 km.	Mesh size regulations for specific gears: minimum 25 mm for gillnet/shore seine/drag net; 37 mm for bag net/dol net; Trawl net of standard mesh-size fitted with TED to be used.	-	The West Bengal Marine Fisheries Regulation Act, 1993.
Andaman & Nicobar islands	Registration and licensing of fishing vessels.	Seasonal fishing ban (April 15 – June 14, 61 days)	Artisanal & mechanized crafts with <30 HP engine: up to 6 nm; Mechanized crafts with >30 HP engine: beyond 6 nm.	Trawl nets of standard mesh size fitted with TED alone are permitted; Gillnets, shore seines and dragnets with mesh sizes above 25 mm only are permitted.	-	The Andaman and Nicobar Islands Marine Fisheries Regulation Act, 2003 (Amended in 2011).
Lakshadweep	Registration and licensing of fishing vessels.	Seasonal fishing ban Seasonal fishing ban (Jun 1- July 31, 61 days)		Use of purse seine, ring seine, pelagic, mid water and bottom trawl of less than 20 mm mesh size, use of drift gill net of less than 50 mm mesh size and shore seine of less than 20 mm mesh size are prohibited in specified areas.	-	Lakshadweep Marine Fishing Regulation Act, 2000.

[1] While all other maritime states and UTs agreed to extending the ban to 61 days in conformity with the directive of the Union Government issued in May, 2015, Kerala continues to stick on to its earlier ban period for 47 days.

[2] The area from shore up to 32m depth in the sea along the coast from Kollencode in the south to Paravoor (Pozhikkara), a length of 78 km, is called the First Zone; The area up to 16 m depth in the sea along the coast line from Paravoor in the south to Manjeswar in the north for a length of 512 km is called the Second Zone.

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HARNESSING CO-MANAGEMENT FOR ADDRESSING SOCIOLOGICAL ISSUES AND REINVIGORATING FISHERY MANAGEMENT REGIME IN THE INDIAN CONTEXT

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Introduction

Does the fishery management regime in the Indian context require a reinvigoration? This is one of the queries which often becomes conspicuous, while speaking the present fishery management system prevailing in a developing country like India. Though the answer for the question is 'yes', it can also be a debatable issue highlighting both affirmative and negative sides of fishery management in the strict literal sense. Rather than exploring the intricacies of the meaning of 're-invigoration' with a surgical postmortem approach, this paper is a simple and subtle effort on addressing the sociological issues by harnessing the paradigm of co-management ultimately for augmenting the fishery management perspective in the Indian context. It is a truth that, in the scenario of Indian Fisheries Management regime, the 'questions' are very tough and timid, but answers are so simple and known to everyone, though the impediment is the practical implementation part. The open access regime prevailing in the harvesting of marine fishery resources in our country warrants stronger emphasis on invoking technological innovations as well as management paradigms that reconcile livelihood issues with concerns on resource conservation. It is a truth that, innovations do not emerge in a socio-political vacuum. Of course, it is the extent of partnership between the research and the client system that decides the fate of any technology in terms of its adoption or rejection. Quite rational utilization of common property resources for sustainable development without endangering the environment is possible through community participation. For more than 6 million fishers and fish farmers, fisheries are a source of livelihood in India. Fisheries sector has recorded faster growth as compared to the agricultural sector in all the decades and is contributing in a significant way to the economic growth of the nation. The vast Exclusive Economic Zone of 2.02 million sq. km of ocean under the possession of India is more than two third of its land area. Marine fishing has been considered a primary livelihood option since time immemorial, for the occupants of the coastal belts of the country. The marine fishery resources of India include a coastline of 8129 km with numerous creeks and saline water areas, an Exclusive Economic Zone (EEZ) of 2.02 million km^2 which are suitable for capture as well as culture fisheries.

The total marine fish landings from the mainland of India during the year 2015 were estimated as 3.40 million tonnes registering a 5.3% decline compared to 3.59 million tonnes in 2014 (CMFRI, 2016). About 3 million people are employed in the primary, secondary and tertiary sector of marine fisheries which provides livelihood security to about 18 to 20 million people (Sathiadhas, 2007). Fisheries development is a state subject in India, but, centre promotes fisheries development through state level programme planning and implementation units. The development plans for the fisheries sector have been aiming at fish production and promoting export. Though India is blessed with vast and varied fishery resources with great potential in both coastal and inland areas, fisheries production is showing a depleting trend which is adversely affecting the livelihood of fishers and making a large population vulnerable. Being the open access resource, stock assessment and irreplenishable nature of abundance in stock, conflicts of various types become the part and parcel of the fisheries system in the country. For addressing the livelihood issue, government introduced regulatory mechanisms such as gear selectivity, seasonal area closures and regulations that control the fishing effort and catching. This is the 'top down government driven management approach' through legislation. However, government managed models of management have proved to be unsuccessful as indicated by poor compliance of action and regulations resulting in crisis and adverse effects on the livelihood of fishers.

It is a truth that, the task of managing fisheries is very complex; however, new strategies like Community-Based Fisheries Management (CBFM) which take a more regional and integrated management approach, can be more productive than past centralized management methods. CBFM achieves such productivity by combining scientific research with community involvement and Local Ecological Knowledge (LEK) to create monitoring programs specific to local areas. What does CBFM do? Actually, CBFM moves the focus of ocean resource management to individual areas/fishing communities, rather than managing fisheries on a coast wide scale. Currently fisheries are managed in many areas by a centralized or blanket method administered by a top-down approach from external managers. This approach has little involvement of the local people that are mostly affected by the managed resource. By empowering local interests, as in CBFM, local relationships may be accentuated that, large scale management strategies might not include. These older management methods also predominantly focus on "single species modeling" while newer forms of management, such as CBFM, incorporate much more of an ecosystem based management approach. CBFM proposes that resource users (fisherman) and resource communities (coastal communities), should have the primary role in deciding how the resources of that community/area are managed. "Fishermen and coastal communities, being the most dependent on coastal and marine resources, should have a large role in deciding how these resources should be managed. This idea fits within an emerging understanding that management decisions of all sorts are often best made at the most local level possible." (Graham, et al, 2001)

While CBFM focuses on giving primary responsibility to the local community, it is important to note that CBFM cannot take place in every scenario. It takes willingness, cooperation, involvement, and flexibility from community members to work together for the collective good. It is important that all stakeholders consider their decisions as they apply to the whole community and the health of the coastal resources. This collective responsibility for the long term well-being of the natural resources depends on a type of responsible self-governance, dictated not by the achievement of maximum profits or harvest, but instead by promoting a stewardship and conservation ethic. CBFM seeks the conservation and preservation of ecosystem health, combined with the sustainable use of these local resources as seen fit by the community members.

Points of Focus for CBFM

CBFM is a uniquely applied and flexible management strategy specific for every situation. It depends on open, ongoing communication within the whole community. It utilizes the large knowledge base of fishermen who already have most of the tools for good local monitoring and research. It also requires patience, working toward long term rather than short term goals. It removes the competitive spirit out of the fisheries and focuses the community on working for sustainability.

In the meantime, there are a couple of Complications also in CBFM.There are many hurdles to address when implementing new management approaches such as community based fisheries management. Procedures that are necessary for legitimacy and credit among the scientific community and higher management, can pose a barrier for fisherman who lack the quantitative “hard data” about their observations. This has limited the amount of information that fisherman feel they can bring to the table, because fishermen’s knowledge is largely qualitative. Many factors dictate the feasibility and productivity involved in integrating CBFM into specific communities. Some factors include: size of the population in that community, societal values, socioeconomic relations, scale of the fishing being done (industrial vs. inshore or artisanal fisheries), large economic incentives, different management techniques required for highly mobile species, limited funding for CBFM organizations, and governmental willingness in allowing more control to come from communities. All of these factors and many more can affect whether an idea for CBFM even gets off the ground. These complications often can bring about competitions and even conflicts. Let’s have quick look into different types of fisheries conflicts.

Capture Fisheries Sector Conflicts: (Marine & Inland Fisheries)

With regard to conflicts in capture fisheries sector, there are marine and inland fisheries sectors to be considered. In marine sector, each country has their jurisdiction up to200Nm towards sea.In India concept of Exclusive Economic Zone (EEZ) enacted during 1997. In dealing with management, protection and proper utilisation of living marine resources several conflicts has been raised.

Conflicts between India and Neighbouring Countries: Certain examples

- Primarily arises from fishermen’s violations of national jurisdiction while in the pursuit of fish. Fishermen are lacking navigational devices which can forewarn fisherman from trespassing their jurisdiction.
- Political problem between India-Pakistan and Tamil problem causing tensions between India-Sri Lanka.
- Fishermen in Okha in Gujarat accidentally trespassing Indian jurisdiction being caught by Pak navy patrols.
- Fishermen in Rameshwaram in T.N. being caught by Sri Lankan navy.

❍ Conflicts over marine fisheries India and Bangladesh are rather rare.

Conflicts Between States: Some examples

Conflicts occur mainly between southwestern states and southeastern states. (Goa,Tamil Nadu,Karnataka,Kerala.) It essentially is because of differential fishing ban period during monsoon. There is no demarked boundary between states in the marine region. (Each state has their jurisdiction up to 12nm towards sea)

Conflicts Between Fishermen Using Two Levels of Technology

- Large scale industrial fishing vessel and small scale fishing vessel.
- Inshore and deep sea fishing vessel.
- Trawlers and Purse-seiners.

  Today there seems to be change in the direction of conflicts.

Regional Conflicts Between Fishermen

- Between fishermen from one state to the other.
- Between fishermen from one harbour to the other.

Conflicts Between Fishermen and Industries: Example: Mangalore coast is conspicuously noted for conflicts of fisherfolk with industries.

Inland Fisheries: accounted the conflicts in reservoir fisheries and riverine fisheries.

Culture Fisheries Sector (Aquaculture)

Social Conflicts and Aquaculture

- Growth of carp culture has led to the conversion of paddy fields to fish ponds.
- Affected poor people who depend on their staple food(cereal).
- Government of A.P. imposed a tax on water use for aquaculture.
- Shrimp farmer and village people.
- Effect of dykes.
- Effect of ponds around creeks.
- Salinisation problem

Conflicts Between the Shrimp Farmers and Fishermen

The shrimp farms do not provide access to the beach for traditional fishermen who have to reach the sea from the village.

A Typology of Fishery Conflicts

In most fisheries, there appears to be little space available to increase long-term sustainable fishery benefits simply by increasing production. The fishery policy tools are generally limited to

1) Increasing the efficiency of harvesting and of management
2) Making allocation (distributing) decisions, particularly determining who has the privilege of access to the fish available for capture.

Despite superficial appearances of chaos, the wide range of fishery conflicts (of both the efficiency and allocation varieties) can be organized into a relatively small number of categories, under for inter-related headings.

(1) Fishery Jurisdiction: Involving fundamental conflicts over the who 'owns' the fishery, who controls, access to it, has is the optimal form of fishery management, and what should be the role played by governments in the fishery system.

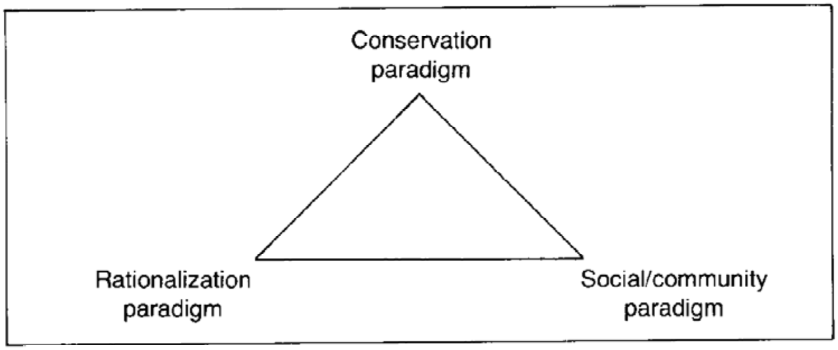
(2) Management mechanisms: concerning relatively short-term issues arising in the development and implementation of fishery management plans, typically involving fishers/ governments in the fishery system.

(3) Internal allocation: involving conflictsarising within the specific fishery system, between different user groups and rear types, as well as between fishers, processors and other players.

(4) External allocation: incorporating the wide range of conflicts arising between internal fishery players and outsiders, including foreign fleets, aquaculturists, non-fish industries (such as tourism and forestry) and indeed the public at large.

Conflicting Fishery Paradigms

While the above typology categorizes fishery conflicts, the real roots of the conflicts in the underlying systematic differences in priorities pursued by the various fisheries players are to be given prime consideration. For example, everyone wants their fishery to be efficient, but the real meaning of this pleasant-sounding goal depends entirely on the desired objectives which in turn vary widely with the philosophy and ideology of the fishery players.



The conflicts and wars related to the rights over the use ofland and water have been important sociological issuesthroughout recorded history. Although many of us areprobably more aware of wars fought over religiousfreedom, political ideologies and social issues, conflictsover fishing rights and resources are just as common, if lessreported. Since the Exclusive Economic Zones (EEZ) wereestablished in the 1970s, disputes have become morefrequent and more violent than ever before. Due to theestablishment of EEZs, access to the world's oceans hasbeen radically reorganized and the access rights of foreignfishing vessels have been curtailed. Negotiations, internationalfisheries agreements (such as those between Europeanand African countries), and recourse to an international tribunal have sometimes succeeded in resolving conflicts.

Similarly, the conflict between Philippines and China is essentially due to over-access to territorial waters.Thousands of Indonesian fishers have been incarcerated asa result of illegal fishing in Australian waters.While sovereignty issues are generally at the root of suchconflicts, they are also the manifestations of competition foraccess to fish stocks, in coastal waters as much as on thehigh seas. In addition, the use of flags of convenience servesto exacerbate the problem. The country where a boat isregistered does not necessarily identify its country oforigin, and this loophole enables fishing companies toflout international fishing and labor conventions with impunity.

Reinvigoration of Fishery Management Regime with a Paradigm shift in fisheries governance

In the Indian context, it would be vital for a reinvigoration of fishery management regime, with a paradigm shift in governance of fisheries which enables resource users (communities and fishers) and stakeholders' participation at all levels as effective partners in the management process. Management regimes as remedy cover Partnerships, Co-operation, Leasing (Aquaculture) and Co-management paradigms.

Partnership and Co-operations through Fisheries co-operatives and Self Help Groups mobilized in marine fisheries sector do play a vital role in sustainable fisheries management. (Vipinkumar, 2012). Leasing essentially occurs with regard to aquaculture sector. Let's have a look into the policy and programmes for aquaculture development in India.

The registration of open water body farms and government leasing determines the appropriate areas for Mariculture activity, allocating the rights to use the resource and evaluation of environmental impacts based on certain principles to be considered to frame the Mariculture policy. (Mohamed and Kripa, 2010)

1. Common Property use conflicts: Policy guided by: Use of open water bodies for navigation and fishing should not be hindered by Mariculture. Similarly, Mariculture activities in open water bodies should not cause disturbances to other users. Permitted Mariculture by the state should be afforded complete protection of structure and stock kept in the open water bodies.

2. Carrying capacity: Open water bodies have limits to biological productions and such limits should be defined by the state in consultation with research institutions.

3. Environmental Protection: The polluter pays principle enacted by the CAAI should be applicable to pen water bodies so as to minimise environmental impacts. Pre and Post EIA (Environmental Impact Assessment) is mandatory.

4. Conservation: Aquatic ecosystems are very sensitive to changes caused by human activities and hence all activities should take into consideration conservation of aquatic biodiversity.

5. Zonation: Since Mariculture in open water bodies is diverse and region specific, states have to draw-up zonation plans in GIS formats with the help of research institutions. Creation of Mariculture parks would be of amble scope and are to be encouraged.

Co-management and Partnership Paradigms

In Asia pacific region, there are adequate success stories where the alternative models have been able to take care of all the parameters of sustainability. One of such fisheries management approaches, as an alternative to the top down government management approach is 'co-management'. This is a partnership arrangement in which the community of local resource users (fishers), government and other stakeholders share the responsibility and authority for the management of fisheries through consultations and negotiations as regards to their roles, responsibilities and rights resulting in development of effective partnerships. This ensures sustainability of the resources as well as improving the livelihood of fishers.

Harnessing Co-management for Addressing Sociological Issues in Fisheries

In simpler terms, Fisheries co-management is defined as an arrangement where responsibility for resource management is shared between the government and user groups (Nielson et al, 2004). It is considered to be one solution to the growing problems of fishery resource over-exploitation. If the marine fishery management regime is both to be effective and legitimate, introducing a co-management arrangement, which can be defined as a dynamic partnership using the capacity and interest of user-groups complemented by the ability of the fisheries administration to provide enabling legislation? Co-management is also a mean to reorganizing the fisheries management system. Co-management is - from this perspective - an institutional process of integrating and reallocating management responsibilities and competence (legal power) among participants by sharing the costs deriving from fisheries management with the users. Fisheries co-management is based on the following hypothesis. The involvement and participation of user-groups create incentives for cooperation in order to formulate and implement more efficient, equal and sustainable management schemes which would benefit all parties.

Similarly, Co-management provides some sense of ownership to the fish resources, which makes the user groups far more responsible for obtaining long-term sustainability of the fish resources. It might also be more cost-efficient in terms of administration. Enforcement than centralized systems, but administration costs may increase in a co-management system, as the process may be rather time consuming, involving several interest groups.

Fisheries Co-management is often referred to as relations between fishermen and the national administration including fisheries research institutions, mainly concerning regulation methods, quota allocation and stock assessment. However, co-management can also be perceived in relation to market activities, whereby relations between fishermen and buyers come in focus. As market dynamics become more important to fishing activities, it can be expected that coordination of market performance and fisheries management measures will be increasingly important.

Co-management is a set of institutional and organizational arrangements (rights and rules), which determine how the fisheries administration and user-groups cooperate. A co-management arrangement is not a static legal structure of rights and rules, but a dynamic process of creating new institutional structures. A co-management institution can therefore be designed as an entirely new institution or can be based on already established institutional structures. The latter might often be the case in fisheries, where co-management institutions usually evolve as incremental user-group involvement in certain management tasks. The devolution of authority to manage the fisheries, away from the fisheries administration to user-groups, may be one of the most difficult tasks of co-management. On the one hand, the fisheries administration may be reluctant to relinquish their authority, or portions of it, and are often opposed to decentralization. On the other hand, user-groups may neither have the aspiration nor the capabilities to undertake enhanced fisheries management responsibilities.

The major advantages of approaching fisheries management as a bottom-up process versus the traditional centralized top-down system may be a high degree of acceptability and compliance with regulation measures, due to the participation of user-groups in the decision-making and implementation process. Once user groups are involved in the decision making and implementation of fisheries management, a spectrum of co-management arrangements can be identified. The figures illustrate the various types of institutional set-up for different co-management arrangements.

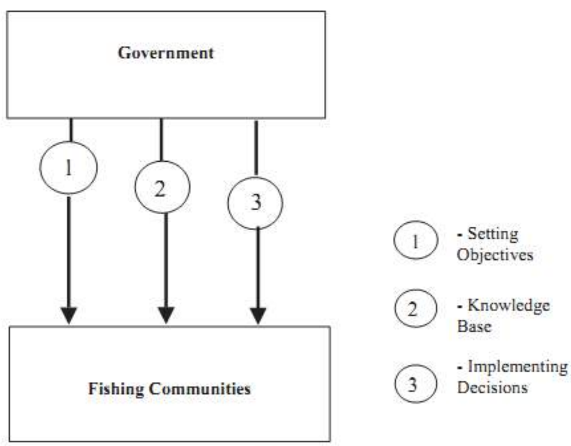


Fig. 1. Modern fisheries management.

It can be observed in the instructive type that, there is only minimal exchange of information between government and users. This type of co-management regime is only different from centralized management in the sense that the mechanisms exist for dialogue with users, but the process itself tends to be government informing users on the decisions they plan to make.

Co-management can be an innovative change to the modern fisheries management approach as it implies apower sharing arrangement between government and fishing communities to undertake fishery management. However, the practical adaptation by governments of the co-management approach has most often been limited to involving fishing communities in the implementation process—an 'instrumental co-management' approach.

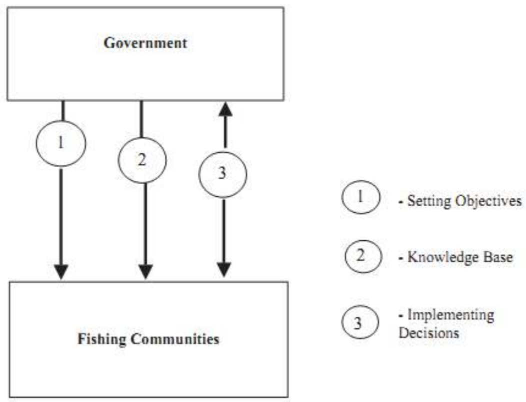


Fig. 2. Instrumental co-management.

Here, the Socio-economic considerations are likely to play a more prominent role within anempowering co-management arrangement.Empowerment of fishing communities is a mechanism to give the people within the fishing communities a chance to influence their own future in order to cope with the impact from globalization; competing use of freshwater and coastal environments; and other fisheries related issues.

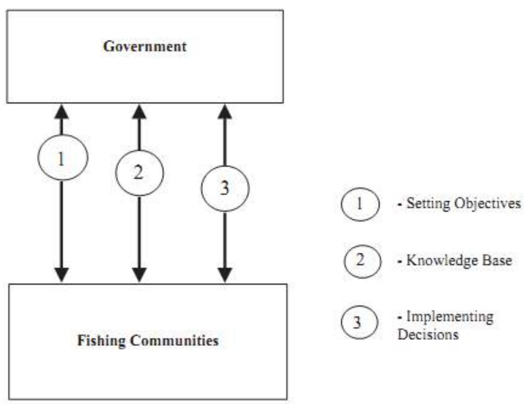


Fig. 3. Empowering fisheries co-management.

The empowering co-management approach is a demanding concept, as it requires:

- A rethink of the logic for management and subsequently a change in the knowledge base for management.
- A major restructuring of the institutional and organisational arrangements supporting management.
- A substantial change in attitudes from both governments and fishing communities towards their role insuch arrangements.
- Aspiration from fishing communities and government to proceed along this avenue.
- Capacity building at several levels both within government and fishing communities.

Co-management for Fisheries Conservation and Livelihood

- Competitive Fishing needs to be replaced by cooperative fishing to avoid depletion and ultimate extinction of several varieties of our marine flora and fauna.
- Fishery resources are renewable but not inexhaustible.
- Cooperative fishing minimizes capital investment vis-à-vis cost of production, sustainability of resources and maximizes the earnings and profit.
- Cooperative marketing enhances the efficiency of distribution channel and enhances the earningsof real producers.

Common property: Management Issues

- Common property means, no one is having ownership: hence no –management
- The literature on property rights identifies different ideal analytical typesof property rights regimes:
- State property: with sole government jurisdiction and centralized regulatory controls;
- Private property: with privatization of rights through the establishment of individual or Company-held ownership.

Fisheries Co- management: Theoretical Framework

- Co- management is a new alternative management approach with a human face.
- Co-management is an effective process for the collective governance of common property resources.
- Co-operative management or co-management of fisheries can be defined as a partnership arrangement in which the community of local resource users (fishers), government, other stakeholders (boat owners, fish traders, boat builders, business people, etc.) and external agents (non-governmental organizations (NGOs), academic and research institutions) share the responsibility and authority for the management of the fishery.
- The substance of sharing of responsibility and authority will be negotiated between community members and government and be within the boundaries of government policy.
- The term 'community' can have several meanings. Community can be defined geographically by political or resource boundaries or socially as a community of individuals with common interests.

A community is not necessarily a village, and a village is not necessarily a community. Care should also be taken not to assume that a community is a homogeneous unit, as there will often be different interests in a community, based on gender, class, ethnic and economic variations.

Co-management should be viewed not as a single strategy to solve all problems of fisheries management, but rather as a process of resource management, maturing, adjusting and adapting to changing conditions over time. A healthy co-management process will change over time in response to changes in the level of trust, credibility, legitimacy and success of the partners and the whole co-management arrangement.

- Co-management is also called participatory, joint, stakeholder, multi-party or collaborative management.
- Co-management sharing and decentralization. It attempts to overcome the distrust, corruption, involves aspects of democratization, social empowerment, power fragmentation and inefficiency of existing fisheries management arrangements through collaboration.

- Partnerships, roles and responsibilities are pursued, strengthened and redefined at different times in the co-management process, depending on the needs and opportunities.
- The process may include formal and or informal organizations of fishers and other stakeholders.
- Fisheries co-management can be classified into five broad types according to the roles government and fishers play (Sen and Nielsen, 1996).

(1) Instructive: There is only minimal exchange of information between government and fishers. This type of co-management regime is only different from centralized management in the sense that the mechanisms exist for dialogue with users, but the process itself tends to be government informing fishers on the decisions they plan to make.

(2) Consultative: Mechanisms exist for government to consult with fishers but all decisions are taken by government.

(3) Cooperative: This type of co-management is where government and fishers cooperate together as equal partners in decision-making.

(4) Advisory: Fishers advise government of decisions to be taken and government endorses these decisions.

(5) Informative: Government has delegated authority to make decisions to fisher groups who are responsible for informing government of these decisions.

The equity and social justice in fisheries management is sought through co-management. Equity and social justice are brought about through empowerment and active participation in the planning and implementation of fisheries co-management. The mutuality of interests and the sharing of responsibility among and between partners will help to narrow the distance between resource managers and fishers, bringing about closer compatibility of the objectives of management.

A Case Study of Co-management in Indian Context

There has been an interesting sharing of ideas in SAMUDRA Report on the experiences and principles of co-management. All over the world, fisher communities are trying desperately to safeguard their access to fish resources, while, at the same time, being driven to catch more in order to keep afloat. The fishers of the Saurashtra coast of Gujarat, one of the foremost fish-producing States of India, are no exception, as a result of the study undertaken on "The Impact of Development on Human Population Dynamics and the Ecosystem" in three locations of the west coast of India, with the help of a grant from the McArthur Foundation.

One of the study locations was the large fishing harbour town of Veraval in Gujarat. The findings of the study were rather revealing, not only regarding the nature of the decline of the overcapitalized trawl fishery, but also the poor environmental and social indicators in a place that had a booming fishery for over 25 years through the 1980s and 1990s. In the community feedback workshops held in 2005, people were also taken aback by the findings of the study for a while and they were aware that their fishery was on the downswing, they felt challenged to realize that a large number of the children of the community were not in school, that there was a fall in the female sex ratio, and that there was a rise in the levels of morbidity and demands for dowry at marriages. As a community that is basically business-oriented and with a desire to simultaneously claim progress, they found themselves in a prisoner's dilemma. A challenge of seeking a way out by the project authorities made them interact with them on a longer-term basis.

The fishery in the area is a trawl fishery along a 40-km coastline between the two fishing harbours of Veraval and Mangrol, which account for a third of the fish catches of Gujarat. There is also a vibrant hodi fishery of fiberglass-reinforced plastic (FRP) beach-landing craft, interspersed with the trawlers. Authorities got intensively involved in the fishing harbour/ community of Mangrol as the community has traditionally been well organized. They were also fortunate to get a local team that the local community agreed to host. In preparation for the work, an intensive training programme was organized for the team. There were also four representatives from Mangrol and Veraval, selected by the community, who participated in the programme. They actually represented the trawl fishery.

Initiating Change

Project people did not initially mind this fact as it was this sector that they thought had to be involved in initiating any change in resource management. The boatowners were intensely involved in the training programme and, during the subsequent period, they turned out to be the main agents of change in the community. Besides developing an analysis of the fisheries crisis, they were most intrigued by the connections made to the fall in the female sex ratio, the number of school-age dropouts, the high morbidity rates, and the extensive pollution of water bodies, all in a context where the communities were well organized but totally in the hands of men. The inputs on gender analysis and the patriarchal development paradigm helped them to see the negative side of male-dominated communities, where women have no voice, and, as a consequence, the issues of potable water, sanitation and health receive no priority. In fact, the community organizations had seen to it that entry into the trawl fishery was limited to members of the same caste. Yet just as these caste organizations camouflaged disparities in the community, they were unable to manage the manner in which investments were made in the fishery, which, in turn, aggravated the growing disparities.

The fishery in the area has been kept afloat by, on the one hand, State subsidies on diesel and, on the other, by the opening up of export markets and the development of surimi plants. It is otherwise an extremely inefficiently run trawl fishery, which has also contributed to the massive pollution in the harbours. But the government has gradually begun to be less lenient on the diesel subsidies, certain export consignments have been rejected by some importing countries, and the government has begun giving greater importance to developing coastal resources other than fisheries. The fishing communities, therefore, needed to get their act together and think differently about their fishery and its future if they did continue to consider the fishery as a means of livelihood.

Strategies to tackle this problem were developed at the training programme, and a plan was drawn up to set up a coastal area managing council in a year as well as push for co-management of the fisheries. The first step was to develop a general awareness in the community about the inter-relationships among the ocean, the land and the people so that people understand how these affect one another. This was done at several levels through all kinds of community programmes but the strategy in the first year was to:

- develop a forum for women where they could discuss and understand these issues and, at the same time, create a collective to gradually represent their cause and themselves in the community organization (samaj);
- create an awareness among the youth and children about the coast and oceans; and
- widen the understanding of the fishers themselves regarding coastal-area issues, and relate these to their fisheries-management possibilities. For this, efforts were made to also include the elected representatives of the municipality in discussions related to these issues so that they would be taken into consideration in town planning.

The most interesting results were from an active group of women fish vendors who pressured the municipality and the fisheries department for a better fish market, while another group made a detailed study of the community's problems relating to water, sanitation and attendant infrastructure, which was presented to the members of the samaj. In both these cases, the community's men were very responsive and open to the idea that women could also be part of the co-management process.

The discussions on co-management were done separately for the fishing sectors, the community organizations and the women so that all of them could understand the issues and felt free to raise doubts and make suggestions from the point of view of their own sectors. It was clear that there were several areas of conflict.

After the discussions, all the representatives got together to discuss the possibility of a larger plan and who would finally meet the government and scientists to make the proposed presentation on co-management. Importantly, it was the first time that women and men from various sectors, caste and religious groupings had got together to discuss coastal and fisheries issues.

An Expert Consultation on Fisheries and Area Co-management was held in Ahmedabad, the capital of Gujarat, supported by the Fish Code Programme of the Food and Agriculture Organization of the United Nations (FAO), where the State's entire fisheries department was present, together with scientists from the Central Marine Fisheries Institute (CMFRI), the Central Institute of Fisheries Technology (CIFT) and the Fisheries Survey of India (FSI), as well as trader, processor and non-governmental organizations (NGOs) and the Marine Products Export Development Authority (MPEDA).

The community leaders first presented their ideas on co-management, which included both the need for fisheries management and coastal-area management, and articulated why they thought that this was a viable option in their particular context. They requested the government to create a framework of legislation for co-management, where both their rights to the coastal resources and the responsibilities of the government and the various stakeholders would be clearly defined. Subsequently, the experts responded, and a group discussion followed on the action that could be taken.

An interesting and heated discussion between the trawl-boat owners, the scientists and the government officials had even the women chipping in, but unfortunately the hodi owners remained silent. The importance of this process has to do with the fact that co-management was proposed by the community representatives from a shore-based fisheries perspective and not a fishing perspective alone. This was possible because of the data available and the focus on the fishery as a means of livelihood that has to be sustained. But this is not an easy process and it still has to be operationalized. The bank on the tremendous amount of goodwill shown by all the stakeholders, indicates that the stakes in actually managing the fisheries are high.

Conflict Resolution Though Sui-generis Co-management:

A Case Study of Kadakkody in Kerala

Kadakkody: A linguistic aberration of the Malayalam word 'Kadal-kodathy' literally meaning 'Sea Court'. It has legislative, executive and judiciary roles to play in the Araya and Dheevara communities of Hindu fishermen belonging to Kasargod district of Kerala. Kadakkodies make their presence felt strongly in four regions like Kasargod, Kizhoor, Kottikkulam and Bakkalam. It plays as a community based fisheries management institution. Though functional only in a few pockets of north Malabar coast of Kerala, these age old institutions are similar to many ofthe Caste Panchayats prevalent in rural India. (Ramchandran, 2004).

Constitution of kadakkody: Each kadakkody is an adjunct to the temple of the fishermen community in each village. Ruling deity in all these temples is Kurumba Bhagavathy who is considered the most worshipped 'mother goddess' (Devi) among Hindu fisherfolk. Each kadakkody has three distinct bodies (1) Sthanikan(the permanently authorized), (2) kadavanmar/Sahayiees (temple messengers or assistant priest and they represent the police) and (3) Temple committee.

Sthanikans are composed for 4 separate constitutional groups namely Karnavanmar (4 members) Achanmar (6 members), Kodakaran (1 member) and Anthithiriyan (2 members). Karanavanmar are the high priests of the temple and they act as magistrates belonging to 4 illams such as chempillam, kachillam, karillam and ponnillam. Achanmar are six in number and are basically oracles (velichapadan) at the temple and are assistant magistrates. Kadavanmar are the messengers/ police. Temple committee is a democratically elected body. The factors determining the legitimacy of kadakkody are divine authority, social embeddedness, systematic procedures and behavioural norms, participatory and transparent process, quick and fair judgements, functional diversity, shared sense of pride etc.

Typological differentiation of 2 forms of co-management: (Ramchandran, 2004)

Characteristics	Sui-generis form of CBCRM	Stateinduced/supported CBCRM
Self-Governance	High	Low
Basis of legitimacy	Divine	Legislative
Group of homogeneity	High	Medium
Compliance	High	Low
Social embeddedness	High	Low
Adaptability	High	Low
Ethos	Cosmic	Livelihood
Norms	Uncodified	Codified
Management agenda	Inclusive	Exclusive
Epistemological base	Socially embedded	Mostly officiated version
Ownership over means of production	Exclusive	Inclusive

The best method of co-management is to follow the Code of conduct for responsible fisheries. Let's look into the issues pertaining to responsible fisheries management.

Govt. Regulations for Conservation

1. Regulation of fishing effort for exploiting the resources, particularly the shrimp resource which is a single critical resource and centre of most of the controversies and conflicts in the country
2. Restriction of number of fishing gears which exploit the juvenile phase in the backwaters, estuaries and shallow inshore were through licensing

3. Mesh size regulation
4. Minimum legal length for capture and
5. Closed seasons and areas

Fishing Methods & Resource Conservation

1. Introduction and popularization of synthetic fishing gear materials
2. Introduction of trawling in mid 1950s
3. Improvement in efficiency and diversification of trawls, purse seines, gillnets and lines, for mechanised sector,
4. Continuous improvement in size, endurance, installed engine power, winch capacities, fish-hold, freshwater and fuel capacities of mechanised vessels to enable multi-day fishing, since mid 1980s
5. Adoption of modern technologies such as eco sounder and GPS on a wider scale over the last decade, enabling precision fishing
6. Motorization of traditional fishing craft in 1980s and expansion of fishing grounds of traditional motorized fleet
7. Introduction of ring seine in commercial fishing in 1986
8. Introduction of mini trawling in mid-1987 and its subsequent proliferation
9. Introduction of ring seine with inboard engine and purse line haulers in 1999 and continuous increase in numbers

Mesh Size Regulations

- A common measure for reducingthe catch of juveniles and small sized non-target species in trawls and important step towards reducing the growth over fishing, rampant in Indian fisheries.
- Though 35 mm has been prescribed for trawl cod-end and incorporated in the MFR of Kerala, it has never been perfect.
- Mesh size for sardine/mackerel ring seines may be regulated at 22 mm or more in the

bunt and main body and maximum dimension of the gear may be limited to <600 m hung length and <60 m hung depth, for all replacement constructions; length overall and engine horse power for propulsion may be limited to 20m or less and 65 hp respectively, for replacement constructions. Anchovy ring seine may be regulated at 12 mm & Engine horse power for propulsion may be limited to 25hp.

Responsible Fishing Methods and Practices

- Guidelines associated with use and development of fishing gear and practices delineated in the Code focus on (i) selective fishing gear and practices (ii) environment friendly fishing gears (iii) energy conservation in harvesting and iv) enhancement of resource (FAO 1995) The CCRF is purely voluntary. The best way to follow these codes will be adoption of co-management.
- Specific pointers from CCRF, in responsible fishing and practices, adaptable to Kerala include the following:
- Evolve regionalized consensus Code of Conduct for Responsible Fishing, in close participation with all stake holders (traditional, motorized and mechanised fishermen organizations) fisheries research organizations and fisheries managers
- Take measures to control open access by strict enforcement of a system of licenses (authorization to fish) in traditional motorized and mechanised sectors
- Develop ecosystem based fishery management regime, in collaboration with the union Government and neighboring maritime states sharing the same fishery-related marine eco system services
- Identify and delimit protected areas in marine and inland water ecosystems
- Periodically revalidate maximum sustainable yield of resources in the existing fishing grounds and determine fishing units in each category for sustainable harvesting of resources
- Take steps to remove excess capacity over a time schedule, with active stakeholder participation.
- Explore possibilities for a rights based regulated access system based on a strong inclusive cooperative movement of stakeholders with built-in transferable quota system and buy-

back or rotational right of entry schemes for capacity management and optimization in the shelf fisheries, in collaboration with the Union Government and the neighboring states with confluent ecosystems and shared fishing grounds.

- Conduct periodic audit of fishing craft and gear combinations, their economics of operation and ecological impacts
- Standardize the capacities, dimensions and specifications of fishing units in each category, particularly in the mechanised and motorised sectors
- Evolve a system for marking fishing vessels and fishing gear (both traditional & mechanised)
- Maintain registry of all fishing vessels in waters under state jurisdiction with all essential details
- Evolve regulations and promote use of life saving, firefighting and communication equipment for safety of fishermen
- Evolve regulations for mandatory survey of mechanised fishing vessels
- Promote selective fishing gear and practices
- Optimum mesh size in trawl cod-ends
- Optimum hook size and shape for lines
- Square mesh windows in trawls
- Bycatch reduction devices in trawls
- Turtle excluder device in trawls
- Trawl designs with improved resource specificity
- Optimum mesh size for gill nets
- Optimum mesh size for purse seines
- Escape windows in fish and lobster traps
- Evolve an efficient Monitoring Control and Surveillance (MCS) system
- Promote effective use of Geographical Information System for fisheries management; monitoring and control of fishing effort and energy use

- Evolve an promote a package of practices for energy conservation in fish harvesting
- Evolve a mandatory programme of training and certification for non-motorized, motorized and mechanised fishermen in safe navigation responsible fishing, log keeping and reporting

Perspectives and Reinvigorating Challenges Ahead

Observations and experiences of various co-management implementations have revealed potentials and benefits of co-management, but also many unresolved sociological issues and problems that need to be addressed. There is still a long way to for harnessing the various co-management systems and examples of solutions to for addressing a varietal range of sociological issues and problems for reinvigorating the fishery management regime of a developing nation like India. Many of the problems and issues facing Fisheries can only be solved on a provincial, national or even international level. The resource systems on which fisheries rely are in most cases too large to be entirely within control of a few communities, and Fisheries management institutions must therefore be able to address problems of resource access and sharing on that level. The solution to this scale problem may be representation within nested systems, but this raises a new set of problems relating to mechanisms to ensure genuine representation and to avoid a new process of alienation between communities and management is initiated. Reconciling local and global agendas: International agreements on fisheries and environmental management are a special case of incongruence between scales. Means must be developed by which the governments can serve the double obligation of attending to international agreements while sharing power in setting objectives for fisheries management with the communities. Identifying a knowledge base for management, which is considered valid by stakeholders: The knowledge base for fisheries management should relate to the objectives of management and be considered valid by the stakeholders? A co-management system must develop mechanisms to reconcile formal scientific knowledge and fishers' knowledge about their resource system in a way that maintains scientific validity and wide acceptance. There are no shortcuts and easy solutions to this problem. One approach may be to identify indicators of the status of the resource system that are both supported by science and reflects fishers' observations. Developing approaches to manage conflicts between resource users who have acquired exclusion rights to a resource through the co-management process and those who are excluded: There is a need to understand the mechanisms and actual reasons behind the alienation process of the different user groups in order to manage these conflicts. Developing appropriate approaches for empowering local communities to participate in the setting of management objectives through institutional reform: This may require substantial change in the way that management authorities function to provide fisheries management services and changes in perceptions of stakeholders on the roles of fisheries management agencies. These issues must be addressed in practicein practical experiments with co-management. It is however important that, such experiments are documented and the experiences communicated to others who may be in the process of establishing or developing co-management arrangements. It is therefore imperative in the Indian context that, attempts to harness co-management are associated with independent research to document and disseminate the experiences for addressing sociological conflicts and emerging issues for an effective reinvigoration of the fishery management regime.

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