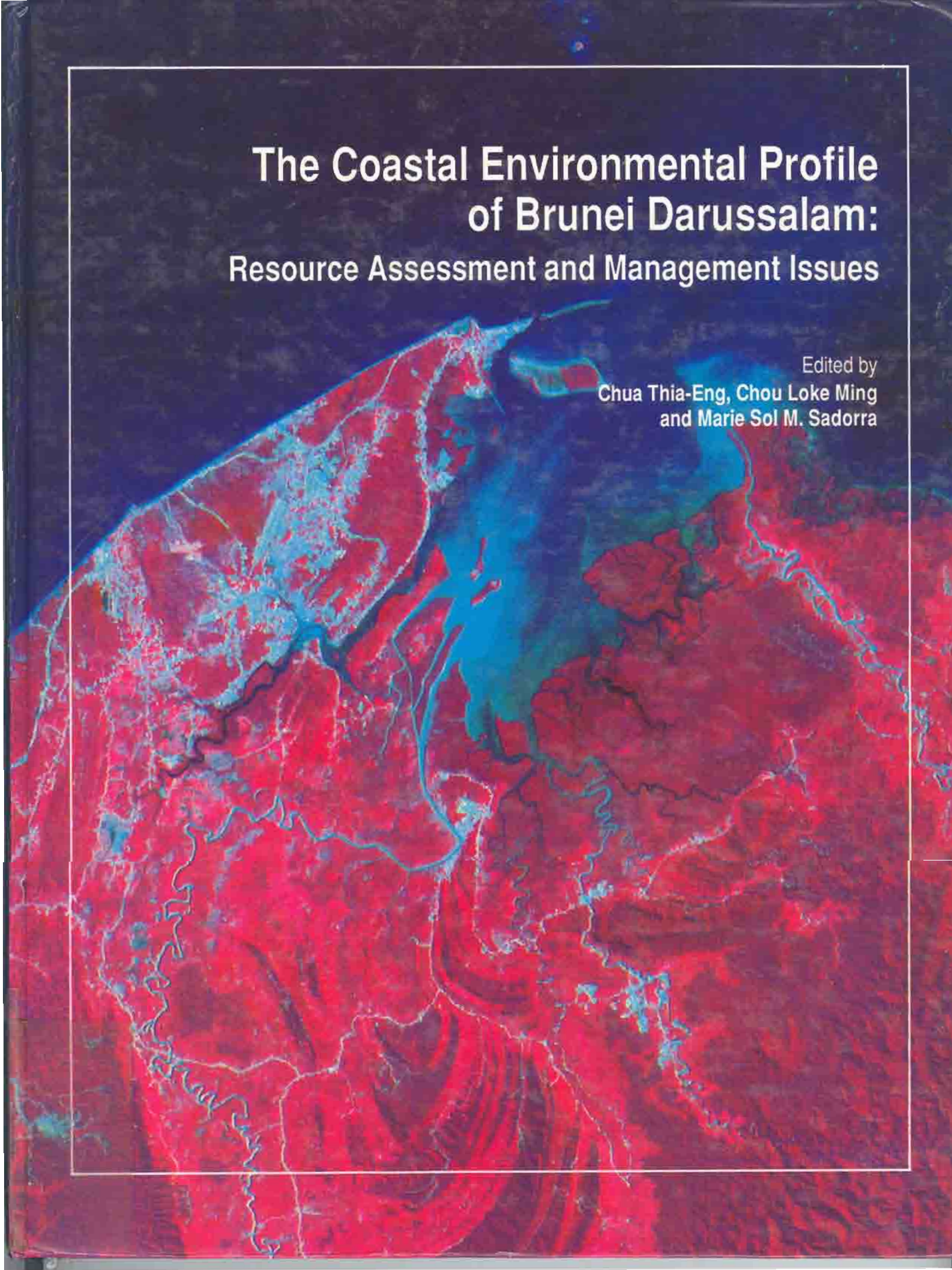
The Coastal Environmental Profile of Brunei Darussalam:

Resource Assessment and Management Issues

Edited by
Chua Thia-Eng, Chou Loke Ming
and Marie Sol M. Sadorra



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ICLARM Technical Reports 18

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Cover: Landsat 4 multispectral scanner image of the northeastern portion of Brunei Darussalam, showing the coastal features. Note the Brunei Estuaries discharging into the Brunei Bay on the north.

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AGR	Annual Growth Rate
AM	Arithmetic means
ASEAN	Association of Southeast Asian Nations
B/C ratio	Benefit/cost ratio
BLNG	Brunei Liquified Natural Gas
BSP	Brunei Shell Petroleum
CPUE	Catch per unit effort
CRMP	Coastal Resources Management Project
DO	Dissolved oxygen
DOA	Department of Agriculture
DOF	Department of Fisheries
DOFor	Department of Forestry
DOM	Department of Museums
DOTCP	Department of Town and Country Planning
DPW	Department of Public Works
EDB	Economic Development Board
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
FAD	Fish aggregating device
GDP	Gross Domestic Product
GM	Geometric mean
hp	Horsepower
IC	Industrial Committee
ICLARM	International Center for Living Aquatic Resources Management
IDU	Industrial Development Unit
IRR	Internal rate of return
ITB	Institute of Technology, Brunei Darussalam
ITCZ	Inter-Tropical Convergence Zone
Kg.	Kampong (meaning village)
LD	Land Department
LFR	Labu Forest Reserve
LOA	Length overall
MD	Marine Department
MOC	Ministry of Communications
MOCYS	Ministry of Culture, Youth and Sports
MOD	Ministry of Development
MOE	Ministry of Education
MOND	Ministry of National Development
MSY	Maximum sustainable yield
MuD	Museums Department
NGOs	Nongovernmental organizations

NMMP	National Mangrove Management Plan
NPV	Net present value
NSC	National Steering Committee
NUS	National University of Singapore
P.	Pulau (meaning island)
PL	Post-larvae
ppt	Parts per thousand
RIPAS	Raja Isteri Pengiran Anak Saleha Hospital
ROI	Return on investment
S.	Sungai (meaning river)
SD	Survey Department
SFR	Selirong Forest Reserve
Stn.	Station
Tg.	Tanjong (meaning cape)
TOL	Temporary Occupation License
UBD	University of Brunei Darussalam
UDPS	Urban Development Plan Scheme
UP	University of the Philippines
USAID	United States Agency for International Development

Foreword

Negara Brunei Darussalam is at present moving into a new era in its development history by embarking on a broad-based strategy to diversify its economy which for the past four or five decades has been primarily dependent on the exploitation of petroleum hydrocarbons.

More than 85% of Brunei Darussalam's population lives in the coastal area, and almost all of the major economic activities are confined to this zone. As such, the proper management of the coastal area is of prime importance. At present, the country's natural resources, except oil and gas, are not heavily exploited. The productive natural coastal ecosystems, such as the 18,400 ha of mangroves which represent 3.2% of the total land area, are considered to be well-preserved in a region noted for intense and often nonsustainable development pressures.

The high development potential of Brunei Darussalam's coastal resources and the declared interest of the government in economic diversification require the development of an integrated multisectoral strategy for the rational utilization of the coastal zone and its resources. The expansion of non-oil-based industries, agriculture and rapid urbanization, mooted under the Negara Brunei Darussalam's Fifth National Development Plan, are bound to place new pressures not only on the coastal resources but also on the quality of the environment, unless careful planning is carried out.

The development of a proper coastal zone management plan is not only crucial to avoid conflicts of interest among development projects, but also to prevent overexploitation of resources and degradation of the environment. It is becoming increasingly important to make an integrated plan for the management of the coastal zone and its resources in Brunei Darussalam, taking into account the socioeconomic and other factors in coastal resources management (CRM). One of the long-term objectives of the Fifth National Development Plan is to "have a clean and healthy environment," reflecting the environmental concerns of the government and its desire for rational development.

The marine environment and its productive ecosystems, such as mangroves and coral reefs, are important to the marine fisheries industry of Brunei Darussalam. This industry provides livelihood to 659 full-time and 1,566 part-time fishermen who make up 1% of the total population. With a per capita consumption of fish estimated at 40 kg/person/annum, fish form an important source of protein for the people of this country. Marine fisheries, which at present provide approximately 50% of the total fish and shrimp requirements of the country, have been estimated to have a development potential of 15 times the present exploitation, and have been targeted for further development under the Fisheries Development Plan.

Negara Brunei Darussalam is fortunate to be able to participate in the Coastal Resources Management Project (CRMP) under the auspices of the Association of Southeast Asian Nations (ASEAN)-United States (US) Cooperative Program on Marine Science at a time when strategic CRM planning could still be integrated into the development plans for the coastal area.

The publication of *The coastal environmental profile of Brunei Darussalam: resource assessment and management issues*, which is the first step towards rationally managing the

country's coastal zone, is the result of close collaborative work of a team of natural resource scientists, economists, ecologists, aquaculturists and resource planners from ASEAN countries and the International Center for Living Aquatic Resources Management (ICLARM). The successful completion of the profile within a period of only three months is evidence not only of the hard work and dedication of the team, but also of the true spirit of ASEAN cooperation.

I would like to congratulate all the members of the team who were directly and indirectly responsible for the preparation of this profile for a job well done. I particularly would like to thank the following for their genuine interest, unswerving support and manifold assistance to the CRMP in Brunei Darussalam: the Minister of Development, The Honourable Pengiran Dato Dr. Haji Ismail Bin Pengiran Haji Damit; Dr. Chua Thia-Eng, Project Coordinator of the ASEAN-US CRMP; and the National Steering Committee. I would also like to thank Pengiran Sharifuddin Bin Pengiran Haji Yusof, Deputy Director of Fisheries; Dr. M.W.R.N. De Silva, National Project Coordinator; and Dayang Munah Haji Lampoh for organizing logistical and other support to the CRMP study team to carry out their work on schedule.

Matdanan Haji Jaafar
Chairman, Brunei Darussalam
National Steering Committee
ASEAN-US Coastal Resources
Management Project

Preface

The coastal waters of Southeast Asian countries have some of the world's richest ecosystems characterized by extensive coral reefs and dense mangrove forests. Blessed with warm tropical climate and high rainfall, these waters are further enriched with nutrients from land which enable them to support a wide diversity of marine life. Because economic benefits could be derived from them, the coastal zones in these countries teem with human settlements. Over 70% of the population in the region live in coastal areas which have been recently characterized by high-level resource exploitation. This situation became apparent during the last two decades when population pressure and associated economic activities have increased considerably. Large-scale destruction of the region's valuable resources has caused serious degradation of the environment, thus affecting the economic life of the coastal inhabitants. This lamentable situation is mainly the result of ineffective or poor management of the coastal resources.

It is essential to consider coastal resources as valuable assets that should be utilized on a sustainable basis. Unisectoral overuse of some resources has caused grave problems. Indiscriminate logging and mining in upland areas might have brought large economic benefits to companies undertaking these activities and, to a certain extent, increased government revenues, but could prove detrimental to lowland activities such as fisheries, aquaculture and coastal-tourism dependent industries. Similarly, unregulated fishing efforts and the use of destructive fishing methods, such as mechanized push-nets and dynamiting, have caused serious destruction of fish habitats and reduction of fish stocks. Indiscriminate cutting of mangroves for aquaculture, fuel wood, timber and the like have brought temporary gains in fish production, fuel wood and timber supply but losses in nursery areas of commercially important fish and shrimp, coastal erosion and land accretion.

The coastal zones of most nations in ASEAN are subjected to increasing population and economic pressures manifested by a variety of coastal activities, notably, fishing, coastal aquaculture, waste disposal, salt-making, tin mining, oil drilling, tanker traffic, rural construction and industrialization. This situation is aggravated by the expanding economic activities attempting to uplift the standard of living of coastal people, the majority of which live below the official poverty line.

Some ASEAN nations have formulated regulatory measures for their CRM such as the issuance of permits to fishing, logging, mangrove harvesting, etc. However, most of these measures have not proven effective due partly to enforcement failure and largely to lack of support for the communities concerned.

Experiences in CRM in developed nations suggest the need for an integrated, interdisciplinary and multisectoral approach in developing management plans providing a course of action usable for daily management of the coastal areas.

The ASEAN-US CRMP arose from the existing CRM problems. Its goal is to increase existing capabilities within ASEAN nations for developing and implementing CRM strategies. The project, which is funded by the United States Agency for International Development (USAID) and executed by ICLARM, attempts to attain its goals through these activities:

- analyzing, documenting and disseminating information on trends in coastal resources development;
- increasing awareness of the importance of CRM policies and identifying, and where possible, strengthening existing management capabilities;
- providing technical solutions to coastal resources use conflicts; and
- promoting institutional arrangements that bring multisectoral planning to coastal resources development.

In addition to implementing training and information dissemination programs, CRMP also attempts to develop site-specific CRM plans to formulate integrated strategies that could be implemented in the prevailing conditions in each nation.

Brunei Darussalam has taken a major step in the conservation and protection of its valuable coastal resources by participating in the development of its CRM plan.

A reliable data base from secondary sources, crucial to the formulation of a viable management plan, was made available to the project. This data base was greatly strengthened through a number of collective field surveys by an interdisciplinary team of scientists from the National University of Singapore (NUS) and the University of the Philippines (UP) in Diliman; professional staff of ICLARM; and scientific officers of the Department of Fisheries (DOF) of Brunei Darussalam. The team's efforts were highly reflective of the spirit of cooperation and collaboration in ASEAN.

Chua Thia-Eng
Project Coordinator
ASEAN-US Coastal Resources
Management Project

Acknowledgements

The team is greatly indebted to the Government of Negara Brunei Darussalam for providing the necessary assistance through the following ministries and departments:

Ministry of Development (MOD):
- Department of Town and Country Planning (DOTCP)
- Department of Fisheries (DOF)
- Department of Forestry (DOFor)
- Department of Public Works (DPW)
- Land Department (LD)
- Survey Department (SD)

Ministry of Communications (MOC)
- Marine Department (MD)

Ministry of Culture, Youth and Sports (MOCYS)
- Department of Museums (DOM)

The directors, commissioners and executive officers of the above departments cooperated fully in making available all required information and in spending their valuable time in consultation with the team.

The CRMP's National Steering Committee under the chairmanship of Awang Matdanan bin Haji Jaafar (DOF) provided valuable support and encouragement during the survey. The committee's members are: Pg. Sharifuddin bin Pg. Haji Yusof (DOF); Pg. Haji Abu Bakar PSI Pg. Haji Ismail (Ports Department); Awang Rosli bin Omar (MOD); Haji Hafneh bin Mohd. Salleh (DOFor); Awang bin Haji Mat Daud (MD); Awang Haji Samat bin Haji Abas (DPW); Dayang Soraya binti Dato Hamid (DOTCP); and Awang Mohd. Jaya bin Sahat (DOM).

Thanks are also due to Unit Petroleum and Shell Brunei Petroleum Co. Sdn. Bhd. for permitting some of the team members to dive at one of its oil jackets at Champion Field.

DOF provided support to the team in terms of logistics, facilities and manpower in the course of the field investigations. This support created an opportunity for the team to interact with the department's scientific, administrative and support staff specifically, Dayang Munah Haji Lampoh and Awang Sirat Haji Besi.

Thanks are expressed to the following DOF personnel:

From the Aquaculture Section: Awang Abdul Rajid Haji Metali; Awang Hariel Haji Simpol; Awang Amzah Haji Edin; Awang Asli Haji Raub; Awang Teo Khai Pen; Awang Othman Haji Abdullah; Awang Zaini bd. Ibrahim; and Awang Muhammad bin Sulaiman.

From the Marine Fisheries Section: Awang Abdul Hamid bin Awang Haji Abas; Haji Marzuki Haji Mohd. Salleh; Awang Mat Salleh bin Haji Tahir; Awang Chuchu bin Haji Kassim; Awang Mohammad Nassar bin Mail; Awang Abdul Hamid bin Haji Zainin; Awang Bidin bin Suru; Awang Talip bin Omar; Awang Mazlan bin Hidup; and Awang Harun bin Haji Puteh.

From the Post-harvest Section: Dayang Ranimah Haji Abdul Wahab.

From the Transport and Maintenance Section: Awang Ramli bin Haji Hassan; Awang Bakri bin Haji Mansor; Awang Suhaili bin Haji Bolhaji; Awang Amir bin Amdan; and Awang Sea Kam Beng.

DOTCP facilitated access to the Negara Brunei Darussalam Master Plan Background Papers.

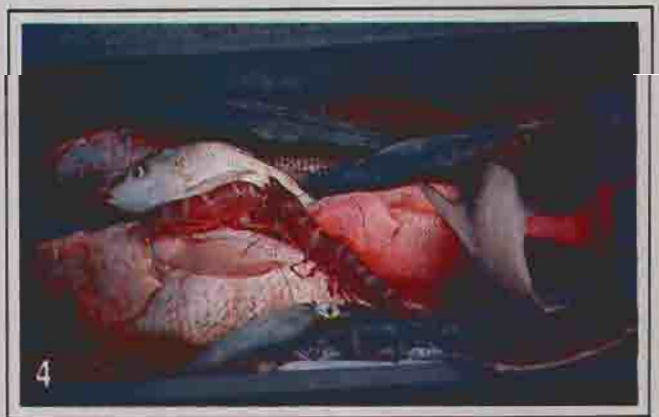
For approving the participation of Singaporean and Filipino scientists, gratitude is expressed to the Vice Chancellor of NUS and to the President of UP.

Thanks are due to the Director General of ICLARM, Dr. Ian R. Smith, for offering the center's facilities and secretarial support during the finalization phase of the team's report. Socorro Guerrero, Angelina Agulto and Rachel Josue, all of ICLARM, assisted in typing the manuscript. The drafting group of Mr. Ricardo Biña of the National Mapping and Resource Information Authority (NAMRIA) and Rachel Atanacio of ICLARM prepared the figures and maps. Acknowledgement is also given to those who reviewed the manuscript: Dr. Mark Valencia and Dr. Kenneth Ruddle, and Dr. Daniel Pauly and Mr. Jay Maclean, both of ICLARM.

The funds for this project were made available by USAID and the government of Negara Brunei Darussalam, to which the team is highly appreciative for the excellent opportunity provided for interaction and for a great, enriching experience.

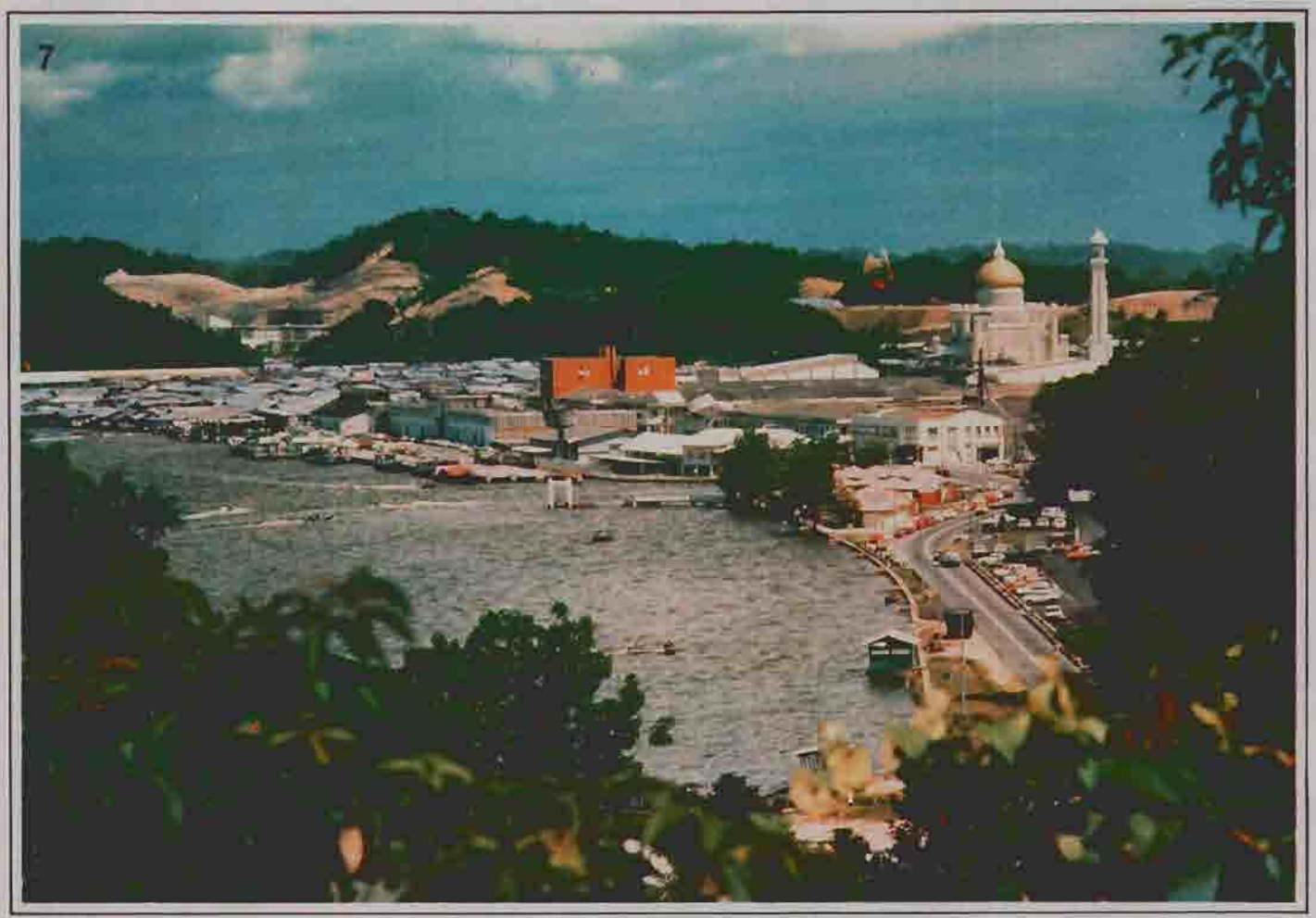
Color Plates

(1) A fisherman using a cast net to harvest shrimp and fish in Brunei Estuary. (2) Fish catch in an experimental trawl survey in Brunei Darussalam coastal waters. (3) Fishing in Brunei Estuary. (4) A catch of fish and shrimp.

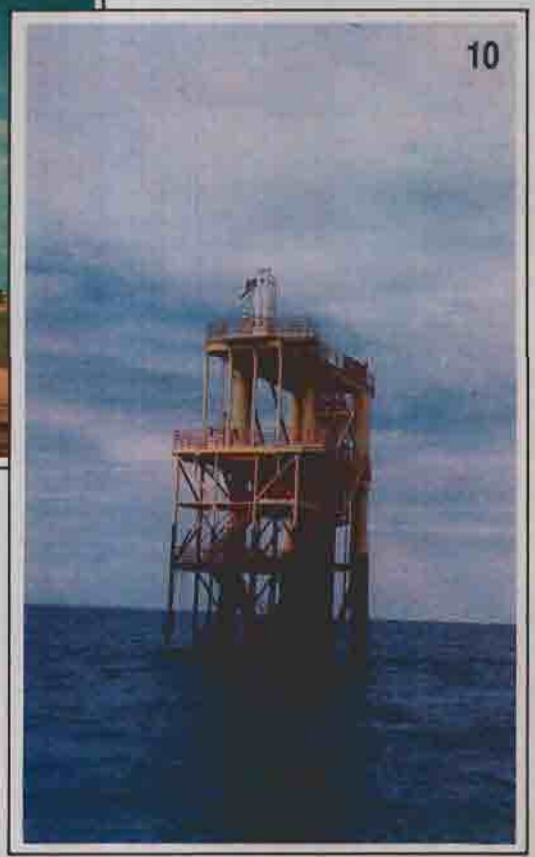


(5) Timber harvesting on the riverbank of Sarawak. Note the extensive clearance of mangrove swamp at the waterfront. On the Brunei Darussalam side of the river, mangroves are relatively undisturbed. (6) A common sight in Brunei Darussalam: the mangrove swamp often cleared for human settlement.

(7) An overview of Kampong Air, the "Water Village" and the adjacent town of Bandar Seri Begawan.

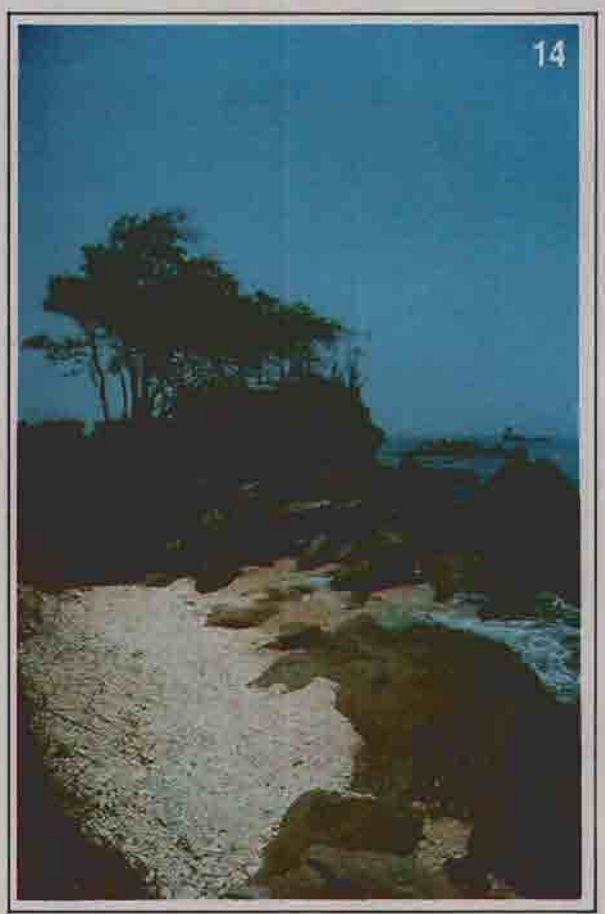


(8) Kampong Air, where about 30,000 people live. Solid waste and sewage disposal have become a major environmental concern here.



(9) Referred to as "Nodding Donkeys," these pumps extract oil from deep wells in the oil-rich coastal area at Seria, Belait District. (10) The Champion Well Jacket 30: its underwater pipelines form an excellent Fish Aggregating Device.

(11) Typical fish life in the artificial tire reefs built by the Department of Fisheries at Two Fathom Rock. (12) A sandy beach at Lumut, a popular recreational spot. (13) Sand mining is ongoing in the outer portion of Brunei Bay near the east end of the large sand spit. (14) The small Pelong Rocks Island was the site of extensive coral reef surveys during the coastal resources assessment of Brunei Darussalam in April-June 1987.



Chapter 1
Introduction

CHOU LOKE MING AND
ABDUL HALIDI MOHD. SALLEH

Background

Negara Brunei Darussalam has a land area of 5,765 km^2 with a coastline of 130 km (Fig. 1.1). Unlike other ASEAN countries, Brunei Darussalam is fortunate that most of its living coastal resources remain underexploited. This is unusual with regard to the country's relatively large mangrove areas (estimated to be 18,400 ha) in a region noted for intense and often nonsustainable development pressures on the living resources.

The social and economic importance of the coastal resources, in general, and the mangroves, in particular, is increasingly understood and documented in Southeast Asia. As an example, mangroves are now known to play a critical role as nursery grounds for commercially valuable species such as shrimp while serving to mitigate the effects of flood hazard and soil erosion. Mangroves are also a common source of wood, tannin and other products. The adjoining coastal environment is also subjected to external pressures such as pollution attributed to agricultural and domestic wastes; alteration of the upstream hydrological regime; and modifications to the sediment budget.

Brunei Darussalam is increasingly interested in developing its underexploited coastal resources, including the mangroves. The high development potential of these fragile resources, together with the growing interest by the government in economic diversification, requires a comprehensive and multisectoral natural resources management strategy which aims to promote sustainable utilization.

The participation of Brunei Darussalam in the ASEAN-US CRMP was initially confined to a training component. But aware of the greater importance of *full* participation, DOF (which is the national focal point of the project) requested and received permission from His Majesty The Sultan and Yang Di Pertuan Negara Brunei Darussalam. The project began in 1987 with the holding of the first National Steering Committee (NSC) meeting in March where representatives from various government departments attended. The meeting, chaired by the DOF Director, tackled matters on project rationale and preparation. The next step was to complete a profile that would describe the present status and importance of the coastal resources. The profile would serve as a key document in providing direction in refining subsequent project-related field investigations which would ultimately lead to an integrated coastal area management plan.

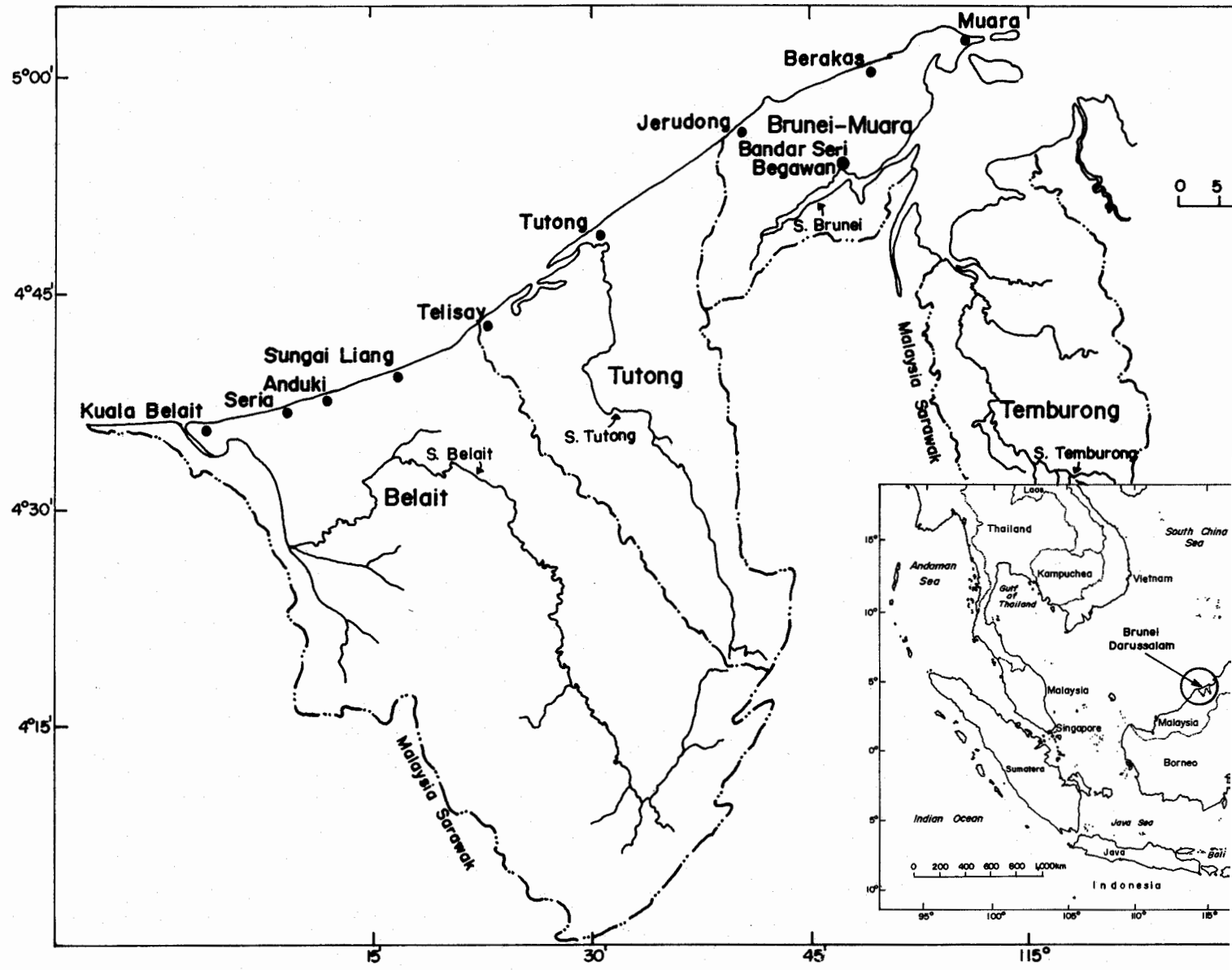


Fig. 1.1. Negara Brunei Darussalam and its districts (adapted from MOD-DOTCP No. 13, 1986i).

Purpose and Scope

The purpose of this profile is to present, analyze and synthesize all information from secondary sources on the nature, significance, utilization and management of Brunei Darussalam 's coastal resources. More facts were learned from meetings and interviews with the executive personnel of both governmental and nongovernmental agencies; the coastal residents; and the various economic sectors concerned with the coastal zone. In cases of limited information, the team surveyed and mapped the coastal area, with particular emphasis on the nearshore habitats, the living resources and their uses. Questionnaires were also used. Thus, existing or potential management issues and information gaps were identified.

The definition agreed on by the team of the coastal zone is "1 km landward from shore extending out seawards to the 60 m (20 fathom) isobath." The inland distance was extended to cover the estuaries of the more important rivers which have significant influences on the coastal zone. The scope of work was expanded to cover potential sites for aquaculture. Some inland areas have also been included in the field surveys.

Approach and Methods

An interdisciplinary approach to examine the multisectoral use, resources and current status of the coastal area was adopted in this profile.

In view of the country's manpower constraints, ICLARM organized a multidisciplinary team of natural resource scientists from Singapore and the Philippines to work closely with their Brunei Darussalam counterparts between April and June 1987. The profile was finalized at ICLARM in mid-June. The team consisted of:

Leader: Dr. Chou Loke Ming - Senior Lecturer, Department of Zoology, NUS.
Co-leader: Dr. Khoo Hong Woo - Associate Professor, Department of Zoology, NUS.
Members: Awang Matdanan Haji Jaafar - Director, DOF, MOD, Brunei Darussalam; Pengiran Sharifuddin bin Pengiran Haji Yusof - Deputy Director, DOF, MOD, Brunei Darussalam; Dr. M.W.R.N. De Silva - National Project Coordinator, DOF, MOD, Brunei Darussalam; Dr. Chua Thia-Eng - Coordinator, ASEAN-US CRMP, ICLARM; Dr. Alan White - Technical Advisor, ASEAN-US CRMP, ICLARM; Dr. Prescillano M. Zamora - Professor, Institute of Biology, UP; Dr. Catalino dela Cruz - Senior Scientist and Leader, Rice-Fish Integrated Farming Systems Project, ICLARM; Mr. Beato Pudadera Jr. - Site Officer, DOF, MOD, Brunei Darussalam; Mr. Kusumo Djoko Kuntjoro - Site Officer, DOF, MOD, Brunei Darussalam; Mr. Victor Wong - Fisheries Officer, DOF, MOD, Brunei Darussalam; Mr. S. Selvanathan - Fisheries Officer, DOF, MOD, Brunei Darussalam; Mr. Abdul Halidi Mohd. Salleh - Fisheries Officer, DOF, MOD, Brunei Darussalam; Mr. James Paw - Project Specialist, ASEAN-US CRMP, ICLARM; Ms. Lilian Hsu - Research Assistant, Department of Zoology, NUS; and Ms. Maylene Loo - Research Assistant, Department of Zoology, NUS.

Secondary data were obtained from published and unpublished sources from government and nongovernment organizations (NGOs). These sources especially included the Negara Brunei Darussalam Master Plan Background Papers. Meetings and interviews with executive personnel of the government and NGOs were conducted on resource use conflicts.

Extensive field visits to various coastal habitats were made to come up with qualitative and quantitative analyses on resource utilization.

The data obtained were synthesized and presented in this profile's nine chapters, covering comprehensive analyses of Brunei Darussalam's physical environment; types and levels of resource utilization; demographic characteristics; land use development; economic activities in the coastal zone; and environmental threats. Resource assessment methodologies used are described in each chapter. The identification of resource management issues and the formulation of preliminary management strategies are emphasized.

Chapter 2
Physical Environment

MAYLENE LOO, LILIAN HSU
AND JAMES PAW

Geography

Brunei Darussalam is situated on the northwestern coast of the island of Borneo, between east longitudes 114°23' and 115°23' and between north latitudes 4° and 5°5'. It shares a common border with the eastern Malaysian state of Sarawak, which also divides the country into two (Fig 2.1) (Garrett 1981).

In the eastern part is Temburong District with a land area of 1,288 km^2. Mountainous terrain dominates here, rising to 1,839 m at Bukit Pagon. Three districts make up the western part. Belait District is the largest with a land area of 2,696 km^2; then Tutong, 1,152 km^2; and Brunei/Muara, 563 km^2, within which is the capital city, Bandar Seri Begawan. These three districts are dominated by hilly lowlands below 91 m elevations. Exceptions are areas close to the coast which are marked mainly by swampy plains with narrow alluvial valleys that stretch out to the main rivers.

Offshore, the area of the continental shelf is 9,400 km^2. Beyond the shelf is the Brunei Fishery Limits (BFL) which comprises 38,600 km^2.

Geology

The geology of Brunei Darussalam (Fig. 2.2) is complex due to rapid lateral and vertical changes in rock type and to the fairly complicated geological structure in some fold areas (Wilford 1961).

The country lies within one of the most intricate areas of plate activity in the world (MOD-DOTCP No. 9, 1986f), resulting in Tertiary sedimentary rocks of great thickness. Due to reworking and leaching, the largely fine-grained composition of sandstone and mudstone is devoid of weatherable minerals. Brunei Darussalam also has ill-defined boundaries and rapid variation of rock types, laterally and vertically.

A youthful, heavily dissected landscape in Brunei Darussalam is preserved despite vigorous weathering and erosion. This is due to successive phases of uplift, denudation and tilting during Pleistocene and recent times.

Generally, the older, harder, more intensely folded Tertiary sediments occupy the mountainous east and southeast, that is, Temburong District. The most strongly folded

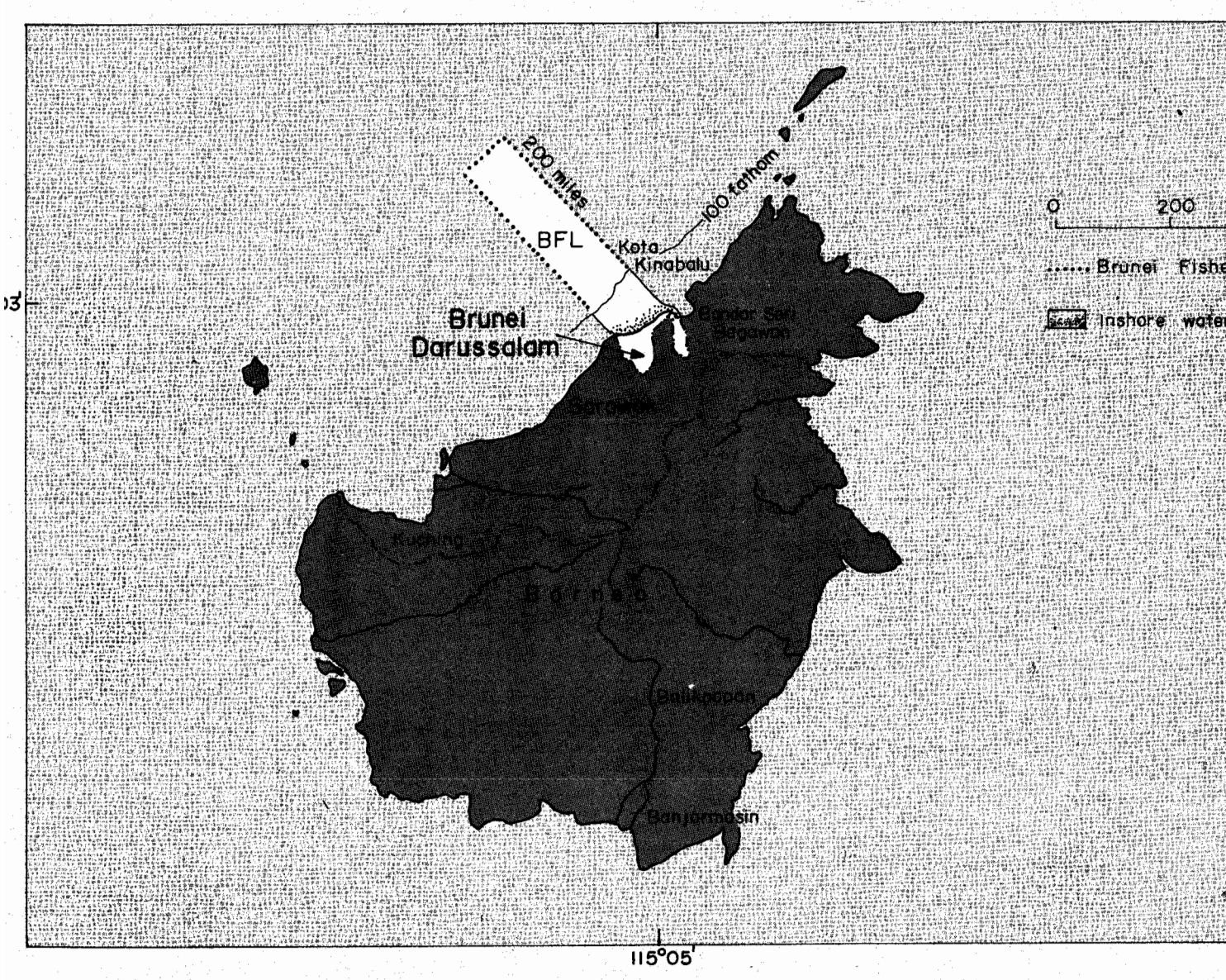


Fig. 2.1. Negara Brunei Darussalam and its boundaries, indicating the Brunei Fishery Limits (BFL).

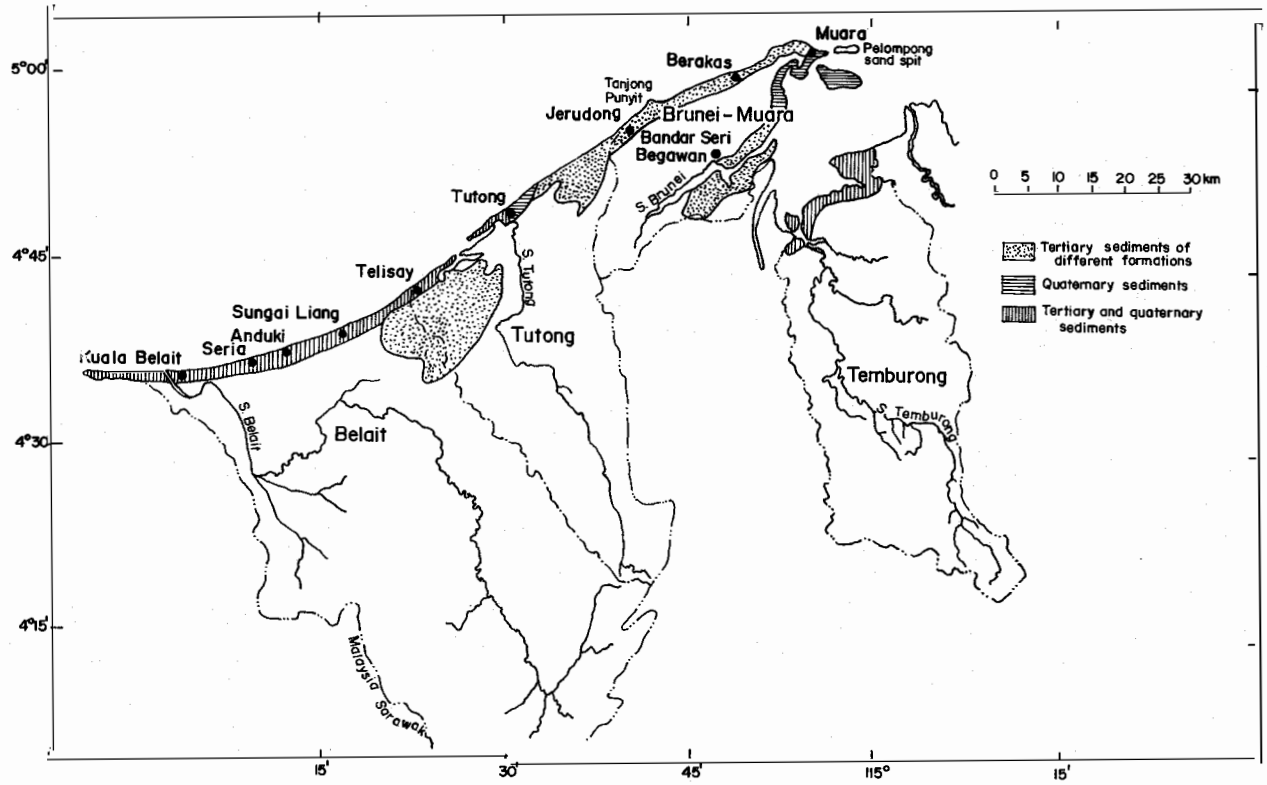


Fig. 2.2. Coastal geology (adapted from MOD-DOTCP No. 9, 1986f).

sediments have given rise to strike ridges of sandstone, alternating with deep valleys cut along the less resistant interbedded shale.

The basin-shaped lowlands of the west and northwest are covered by younger, moderately folded sediments of Tertiary origin. These Upper Tertiary synclinal basins underlying the coastal lowlands are expressed topographically by lines of long ridges. The coastal lowlands encompass most of Brunei-Muara District. The interior of Belait and Tutong Districts is also underlaid by such basins. The rims of the synclinal basins gradually rise from groups of low hills, surrounded by swamp, to distinctive hill ridges of considerable heights.

Most of the coastal areas, particularly in Temburong, are occupied by flat, swampy alluvium. This alluvium also extends as broad belts up the valleys of Belait and Tutong Rivers. The accumulation of the alluvium in the lower parts of these valleys occurred since the post-Glacial rise of the sea level about 5,400 years ago. Almost all the alluvial plains are covered by peat except near the riverbanks and in the vicinity of hills. Thin clay or sandy alluvium is usually located in these areas. Terraces formed by older Quaternary sediments, usually of unconsolidated sand and gravel, are found in the main river valleys and also along the coastal land between Tutong and Muara.

Coastal geomorphology

The spit at Pelompong in Muara; the Baram-Belait Delta; and the headland of Tanjong (Tg., from here, and which means cape) Punyit are distinct coastal features of Brunei Darussalam (Grant 1984b).

The Pelompong Sand Spit extends 7.5 km from the mainland of Tg. Batu east, then east-northeastwards to Tg. Pelompong (Fig. 2.3). To allow access to the port of Muara, a

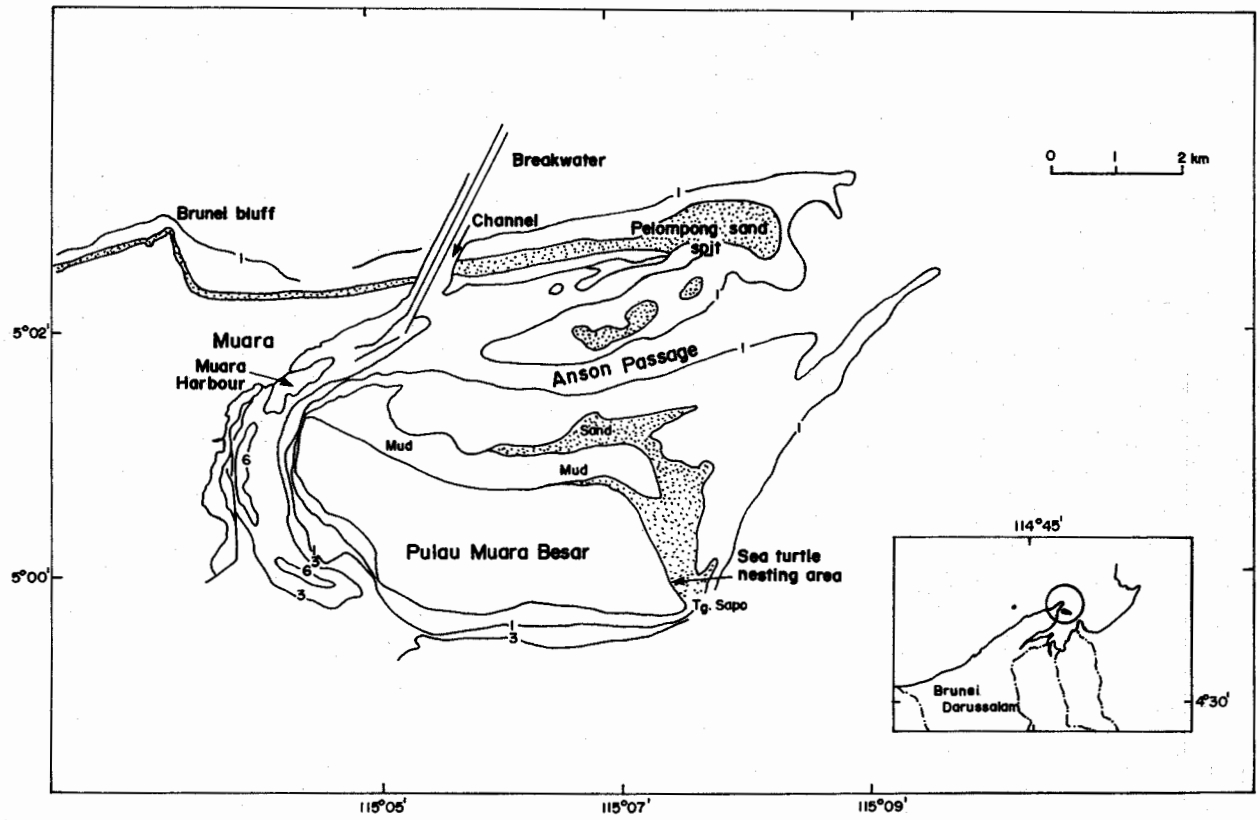


Fig. 2.3. Pelompong Sand Spit.

channel was cut halfway along the spit. This channel is protected at each side by breakwaters which extend seawards towards the northeast. A series of closely spaced stranded beach ridges separated by narrow swales make up both the spit and the island. On the northern shore of the island, over a hundred of these ridges are sharply truncated. Generally, the ridges mark the former position of the coastline which has been extending towards the east. Some erosion has also occurred on the southern tip of the island. The spit does not form a smooth continuation of the shoreline at Tg. Batu; instead it turns sharply southwards for a distance before continuing eastwards under the action of longshore drift. On this point of Brunei Darussalam Coast, the longshore drift is easterly or northeasterly, which is contrary to the direction on the western part of the coast where the drift is westerly or southwesterly.

The east of the headland at Tg. Punyit appears to be the dividing line between the two zones of longshore drifts. Sand is apparently accumulating on the eastward side of the many promontories to the west of the headland. The growth of a small spit has apparently diverted the mouth of Sungai (S., from here, and which means river) Punyit towards the west.

Sand bars along the mouths of Belait River and Tutong River are also notable coastal features. Longshore drift is the source of the sand forming these bars with little contribution made by the rivers. The bar across Belait River is a hazard to shipping. It has greatly reduced the depth of the channel and, also in some places, sand banks reach the water surface. This is also an area of intense turbulence with standing surface waves. Belait Estuary forms part of the delta front of Baram-Belait Delta as a whole.

Baram-Belait Delta has a mainly alluvial sediment which consists of sand, clay, peat and gravel. There are great depths of sediments, especially near the river mouth. Wave processes rather than tidal or fluvial processes influence the shape of the delta. There is a seasonal conflict in longshore drift resulting in the symmetrical shape of the delta around its major tributaries. Immediately beyond the mouth of the tributary, fine and very fine sands occur with

rapid transition at the base of the relatively steep delta front slope into silts. These silts form part of the modern shelf mud blanket of silts and clays which extends outwards towards the shelf edge. Being fine fluvial sediments, the silts can bypass the nearshore zone and become deposited on the outer shelf margins.

Drainage

Basin areas

There are four main river systems in Brunei Darussalam: Belait, Tutong, Brunei and Temburong (Fig. 2.4). These are tidal for long distances inland, especially during low flow and drought periods, where salinity is high, up to 90 km inland.

Temburong Basin, which drains nearly the whole of Temburong District, is the smallest of the four river systems, with an area of some 1,100 km^2. S. Temburong has two tributaries flowing into its estuary, S. Batu Apoi, which has a mountainous catchment, and S. Labu, which is a coastal swamp river. Both divide the basin into two with S. Temburong flowing into the head of Brunei Bay. The coastal area of Temburong is all swamp which is subject to tidal influence.

Belait Basin is the largest, having an area of some 2,700 km^2. The lower catchment comprises an extensive area of peat swamp forest. A low ridge, 10 m in height, separates the coastal belt. The river becomes narrower at Kuala Belait and has a sand bar; hence, restricting the discharge of water to the South China Sea. The upper catchment is mostly jungle and

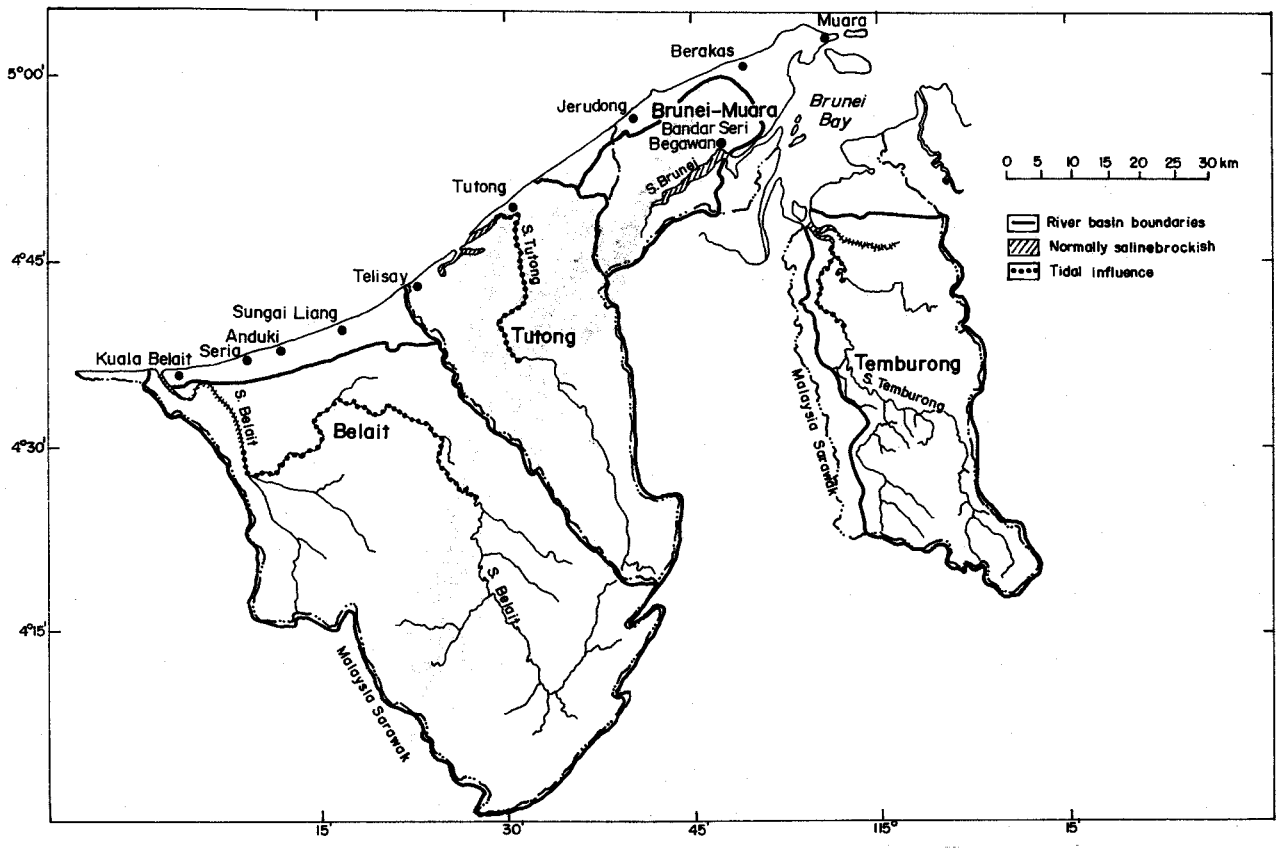


Fig. 2.4. River basins (adapted from Grant 1984b).

sparsely populated. Only small areas along the river and its tributaries have been cleared for agriculture.

Tutong Basin covers around 1,300 km^2, and the river is contiguous with that of S. Belait on the west. S. Tutong discharges to the sea between two sand spits which form an elaborate estuarine system. Two branches extend parallel to the coast and cover a distance of about 15 km. The western end of the basin is drained by S. Telisai. From the head of the estuary and over its full length, the river channel is extremely sinuous, and like S. Belait, is tidal a distance upstream. The lower catchment is a broad flood plain, while the upper catchment is mostly jungle with some clearing for agriculture along the river.

The watershed of S. Brunei is low-lying and swampy. The catchment is characterized by broken high ground with deeply incised valleys forming the three major subcatchments, S. Kedayan, S. Damuan and S. Imang. Each of the subcatchment rivers enters S. Brunei at different points. S. Kedayan includes a high proportion of urban development and enters S. Brunei at Bandar Seri Begawan. S. Damuan enters about 3 km upstream from that of S. Kedayan. The headwaters of S. Brunei are S. Imang and its tributaries. The main catchment adjoins that of S. Tutong on the western side, and to the north, is defined by an irregular ridge parallel to the coast. The watershed boundary then moves southeastwards and continues along the ridge parallel to S. Brunei Estuary back to Bandar Seri Begawan.

The remainder of Brunei Darussalam's total land is located in two areas near the coast. The first comprises a narrow belt between Kuala Belait and Lumut where the Lumut River and Streams drain directly into the sea. Brunei-Muara District constitutes most of the second, where streams drain into Brunei River and in turn to Brunei Bay.

Drainage patterns

Drainage patterns of Brunei Darussalam are largely determined by geological structure (Grant 1984b). A trellis pattern has developed on most of the land surface. Generally, the larger rivers flow north-northwest across the regional strike of the rocks. The main rivers follow beds of readily eroded shales and clays, while the relatively short tributaries flow on the harder sandstone bands.

Most of the rivers meander through alluvial plains covered extensively by peat. Only a small part of the alluvial plain is occupied by the meandering channel at any one time, that is, the rivers lie within a meander belt which is a complex of active and abandoned channels. The abandoned channels are gradually infilled with sediment, forming oxbow lakes. This drainage pattern is seen in Belait and Tutong as the relatively low slopes favor the generation of meanders with the meander belt shifting its position on the alluvial plain through time.

A radial drainage pattern has developed on the Labi Hills. The geological sediments of Lumut Hills have produced a radial, dendritic pattern, with streams rising there flowing to Belait, Lumut and Tutong Rivers.

Flooding

There are three main classifications of flooding observed in Brunei Darussalam: river flood plain, tidal and local (Fig. 2.5) (MOD-DOTCP No. 13, 1986i).

River flood plain flooding occurs when flood flows exceed the capacity of the river channels which naturally adjust to accommodate a dominant river flow. This occurs several times annually to a small extent in a few places but infrequently causes severe flooding. However, large areas can be affected for considerable periods of time.

Significant tidal flooding occurs during November to January when extreme high tides

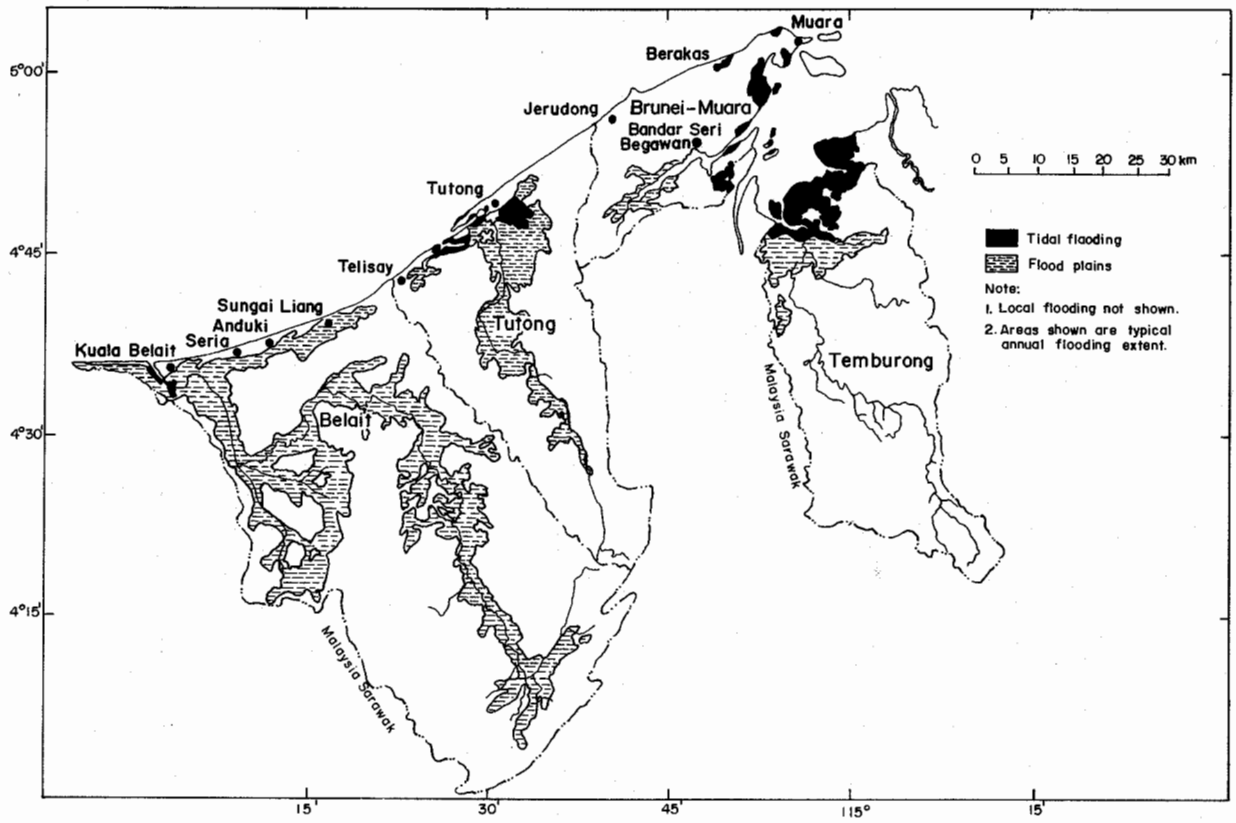


Fig. 2.5. Areas of flooding (adapted from MOD-DOTCP No. 13, 1986i).

occur. This exacerbates if the high tides coincide with surges due to storm or wind conditions. Areas affected by tidal flooding are confined to the lower-lying coastal areas, generally along the estuaries of the main rivers. Local flooding occurs frequently due to obstruction of channels and inadequate culverts or bridges.

In S. Belait Basin, the lower catchment is an extensive flood plain, mostly of peat swamp forest. This flood plain is bounded on the north by a low ridge of peat; hence, the floodwater can only discharge to the sea through the mouth of S. Belait which is relatively narrow with a shallow bar. This causes a severe backwater effect in the upper catchment when a big flood needs to disperse. More local flooding also occurs on the basin probably due to the obstruction of the channel.

There is only little flooding in the villages along the spits in S. Tutong Basin and this tends to be of a local nature. However, in the lower S. Tutong, floods are regular.

In S. Brunei Basin, tidal flooding occurs in low-lying land during spring tides. This is, however, not eminent in all areas for local flooding occurs at S. Damuan and its tributaries. Local flooding results from inadequate culverts or bridges. Also, the tributaries converge onto Mulaut Plain from which the only drainage outfall to S. Brunei is the main S. Damuan channel. Hence, relatively shallow but widespread flooding occurs frequently on Mulaut Plain which is compounded by inadequate waterways.

Under normal conditions, flooding in S. Temburong Basin is confined to the lower reaches for short duration (usually less than a day). If flooding occurs, it is mostly linked with tidal movements. Local flooding in Muara Peninsula and south of Brunei River is of moderate depth and for short duration. Along Belait Coast, flooding is probably influenced by high tides. However, the depth of flooding reported is greater than would be expected from tides alone, so there may be other causes. The Temburong coastal area is a low-lying tidal swampland with many creeks. So, flooding is purely tidal in nature.

Soils

The most fertile soils overlie imperfectly to poorly drained nonpeaty river alluvium and the more clayey younger Tertiary formations found in the lowlands. The less fertile soils are developed on sand and sandstone and on older Tertiary formations which underlie steep hilly areas.

The soils found along the northern coastal belt stretching from Kuala Belait to Muara Harbor are grey-white podzolics, podzols, regosols or sandy soils. Though of different types, they are all characterized by a sandy texture and by low iron, aluminum and clay content. Beach sands contain unusually large amounts of organic material.

In some low-lying coastal areas formerly occupied by brackish, organic-rich mangrove swamps, potential acid sulfate soils are present. Oxidation by aeration or leaching with oxygen-charged water of these soils converts iron sulfides into sulfates and sulfuric acid. The soils will, thus, have very low pH, releasing large amounts of aluminum which are toxic to plants.

In most of the estuarine areas of the major rivers, alluvio-marine soils predominate. These soils are gleysols which are usually poorly drained and which have potential acid sulfate layers beneath.

Offshore on the continental shelf, deposits are generally predominated by sand, silt or mud. However, patches of sand, coral and rock may be found nearer to shore. Beyond the continental shelf, the predominant sediments are fine-grained clays and oozes.

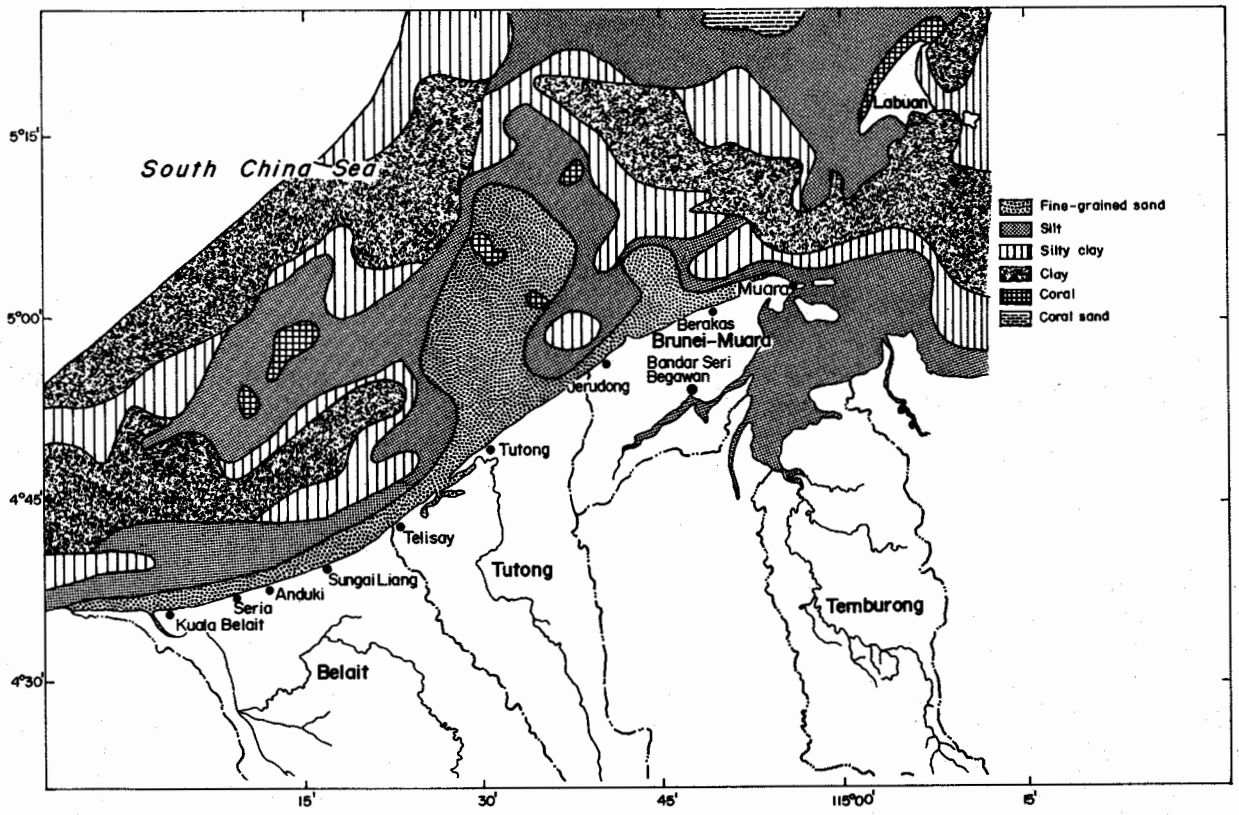


Fig. 2.6. Generalized distribution of bottom substrates (adapted from DOTCP 1987c).

Seabed Configuration

The Brunei Darussalam seabed has a large proportion of silt (Fig. 2.6). The entire Brunei Bay mainly consists of silt brought by rivers that open into the bay. Along the coast all the way from Muara to Kuala Belait is a 1 km belt of sand bordering the coastline. At Tutong, there appears a buildup of sand, that 30 km offshore, the main bottom deposit is still sand. One reason for this is the longshore drifts. During the northeast monsoon, the longshore drift results in the net movement of sediments towards the south and southwest. However, the southwest monsoon causes the sediments to move in the opposite direction. The combined efforts of the two longshore drifts result in the huge accumulation of sand at Tutong, Pelompong Sand Spit and Kuala Belait. Farther offshore, the seabed consists mainly of clay, silt or a mixture of the two. There are also corals around some of the islands and shallow shoals.

The coast of Brunei Darussalam has a narrow area of shallow water. The belt with a depth of 2 to 4 m is 2 km wide. The next section with depths of 6 to 20 m extends approximately 8 km offshore. Between Jerudong and Tutong, about 20 to 24 km offshore, the water is still shallow. This protrusion of shallow water coincides with the sand accumulation deposited by the longshore drifts. Beyond this, the water depth increases steadily towards the South China Sea and interrupted occasionally by raised seafloor like Ampa Patches (off Lumut) and Champion Field (off Jerudong). The depths of the shelf off Brunei Darussalam is shown in Fig. 2.7. In Brunei Bay where a number of rivers empty into, the depth scarcely exceeds 2 m, though in a few areas, the depth can reach 10 m.

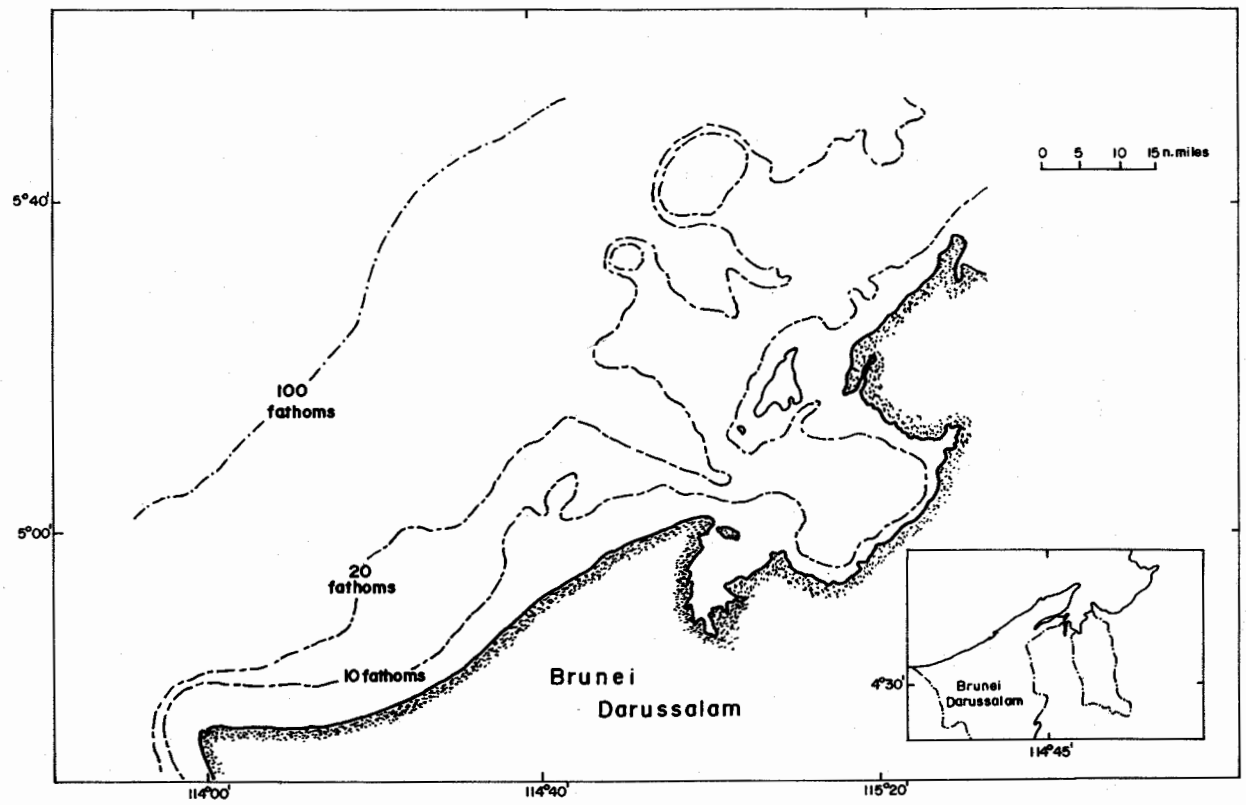


Fig. 2.7. Depth of shelf off Brunei Darussalam.

Climate

Brunei Darussalam has an equatorial climate characterized by uniformly high temperature and rainfall throughout the year. There is no distinct seasonality, but the climate is governed by two monsoon winds generated by the low pressure trough called Inter-Tropical Convergence Zone (ITCZ) and the trade winds. The northeast monsoon blows from November to March, and the southwest monsoon, from April to October. The two stations with the longest weather records are the Agricultural Research Station at Kilanas and the Brunei Shell Petroleum (BSP) Head Office at Seria.

Rainfall

The annual rainfall is generally high, with an average of over 2,800 mm. It exceeds 2,300 mm throughout Brunei Darussalam and can be as high as over 4,000 mm further inland and in many parts of Temburong (Fig. 2.8). The higher rainfall towards the interior is due to the geographic effect of an increased amount of precipitation with altitude.

Records from Kilanas and Seria stations show that the rainfall pattern is a reflection of the two monsoons and the oscillation of the ITCZ across the equator. However, seasonality is not well-defined as seen in the wide variation of monthly and annual means. There are two maxima recognized: the first is from September to January, with December being the wettest month, and the second is from May to July. The former is higher. February to April is virtually the drought period (Fig. 2.9).

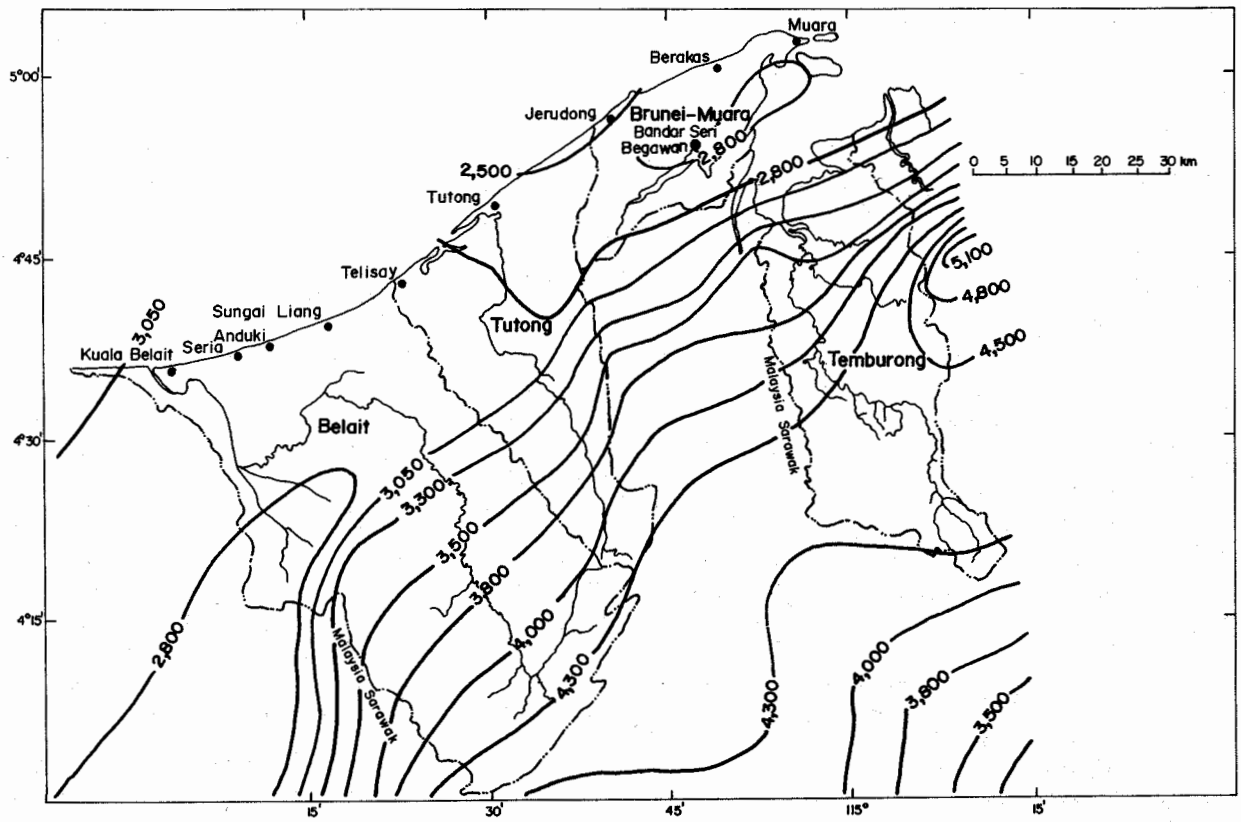


Fig. 2.8. Annual rainfall (in mm) distribution (adapted from DOTCP 1987c).

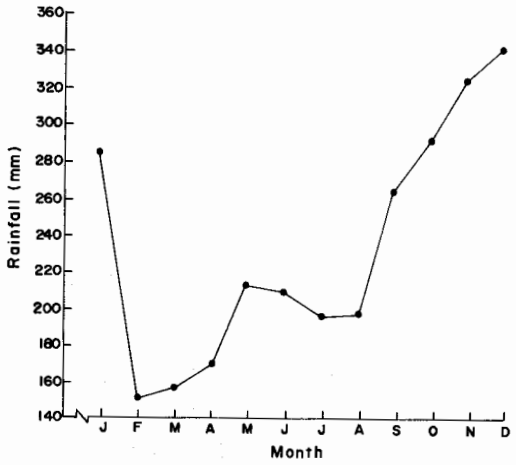


Fig. 2.9. Monthly mean rainfall based on data from Kilanas over a period of 48 years.

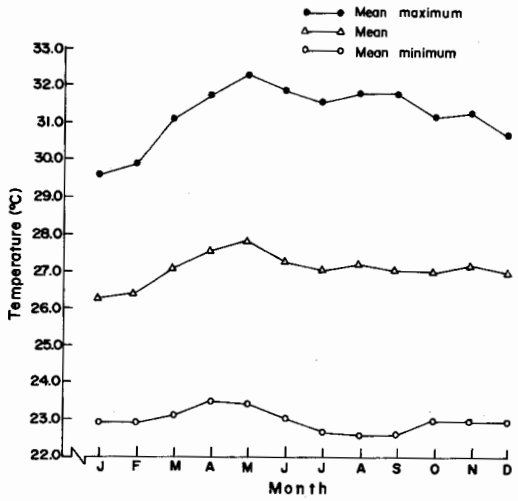


Fig. 2.10. Monthly mean temperature based on data from Kilanas, 1976-1982.

The rain is commonly in the form of thunderstorms with rather high intensity and very localized distribution, occurring in regions in the ITCZ and originating from vigorous small-scale convectional cells (Grant 1984b). The majority of such thunderstorms occur from late April to early June, mostly during the late afternoon and early evening. Thunderstorms with the highest intensity, however, occur in December.

Air temperature

The air temperature is uniform throughout the year, with little variation in seasonality and in different parts of Brunei Darussalam (Fig. 2.10). The annual mean temperature is 27.5°C, but inland temperature can range from 35 to 38°C and fall to 20°C occasionally. The offshore air temperatures are generally more stable, with an annual range of 26.9 to 29.7°C. During December and January, increased cloudiness results in slightly reduced daily temperature range. The drought months of March and April are the warmest. The temperature in the elevated interior is slightly lower than that at the coast (MOD-DOTCP No. 5, 1986c).

Relative humidity and evaporation

Relative humidity is high throughout the year because of high temperatures and rainfall. The annual mean is 92.6%, with a range of 89.3 to 95.6% (Fig. 2.11).

The rate of evaporation depends on the air temperature, relative humidity and wind velocity. Evaporation is higher during the hot, dry months, March-May (Fig. 2.12).

Winds

The prevailing winds are north to northeasterly from December to April (northeast monsoon) and south to southwesterly from May to November. Wind speeds are generally low,

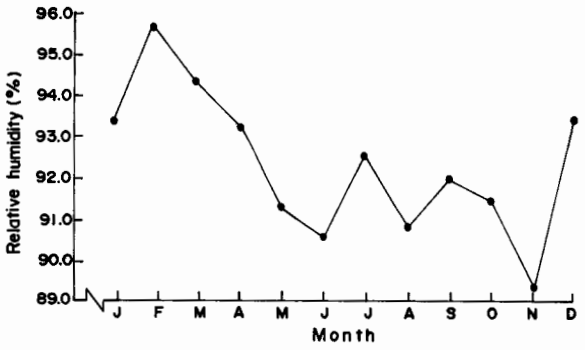


Fig. 2.11. Relative humidity from data recorded at Kilanas.

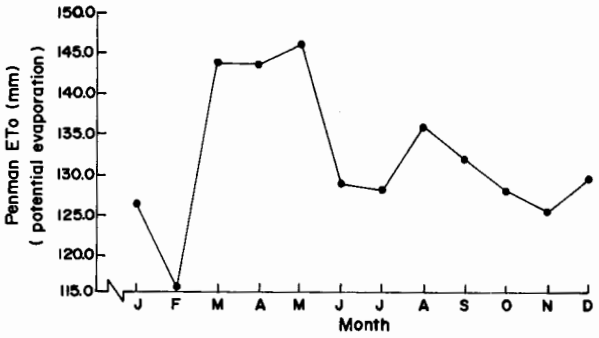


Fig. 2.12. Potential evaporation from data recorded at Kilanas.

with 30% of the annual records calm (less than 0.2 m/second), and rarely rising above 12 to 16 m/second (43.2 to 57.6 km/hour). The most common wind velocity is in the range of 4 to 8 m/second (14.4 to 28.8 km/hour). The most frequent wind direction is from the south. There is, however, a marked variation in the wind direction of land and sea breezes which form the nearshore circulation.

Strong winds with speed of 25 to 30 m/second (90 to 108 km/hour) occur during squalls associated with thunderstorms. Such winds are of short duration and do not exceed two hours. Tropical storms and cyclones that pass the South China Sea do not affect Brunei Darussalam directly but rather the water circulation of the sea and the local sea swell conditions (DOTCP 1987c).

Hydrological Characteristics of Coastal Waters

Tides and currents

The tides affecting Brunei Darussalam are generated in the South China Sea. The tides are mixed with a large diurnal component and, a few days in a month, with a semidiurnal one.

There are few measurements of current in Brunei Darussalam. The only available sources are Admiralty China Sea Pilot (or ACSP 1982) and Brunei Shell Petroleum Co. Sdn. Bhd. The latter has been monitoring currents along the Brunei Darussalam Continental Shelf since 1984. The pattern of the surface and deepwater currents is very complex in Brunei Darussalam waters due to the interaction of the four main types of currents.

First, there are the oceanic or semi-permanent currents generated in the South China Sea. These are concentrated at the eastern part and are much more variable in direction and speed as they are controlled mainly by the positions of gyres common in central South China Sea all year round. The second type, caused by the differences in seawater density, are known as density currents. These are indirectly dependent on seawater temperature, salinity and concentration of suspended sediments, properties which affect the density of seawater.

The third type is the tidal current or tidal stream generated by the rise and fall of water levels during the daily tidal cycles. This type probably accounts for a relatively large portion of the deepwater currents towards the shore during rising tide and away from the shore during ebbing tide. The fourth type, referred to as meteorological currents, is probably the most significant. These currents are generated by the winds, particularly, the northeast and southwest monsoons. The prevailing winds generate surface water movements or waves which direction determines the pattern of the surface currents. During the northeast monsoon from October to

March, the main flow of the current is in the southwest, parallel to the coastline of Brunei Darussalam. During the southwest monsoon, however, the direction is towards the northeast. During either monsoons, irregularities do occur; there appear to be reversals in the direction of the currents probably due to the interaction of the other types of currents.

Farther offshore, in deeper unsheltered waters, the southwest monsoon appears to be stronger. Hence, the strongest and most frequent current is in the northeast direction. The nearshore currents, observed 2 km from the coast, seem to be dominated by the northeast monsoon; are in the west and southwest direction; and have a net transport of sediments towards the south and southwest parallel to the shore (Grant 1984b). However, studies of the longshore drift in Muara Port showed that the northeastern component is stronger than the southwestern one (MOD-DOTCP No. 5, 1986c).

Other water movements

Waves along the coast are usually less than 1 m high. However, waves of over 3 m occur during the northeast monsoon due to swells generated in the South China Sea combined with the waves generated by local winds. Squalls can produce waves of over a meter very rapidly, but they do not last long (DOTCP 1987c).

Physicochemical parameters

There are only small variations in the monthly mean seawater temperature. The highest temperature during the drought period is about 30°C, while the lowest, in December, is about 27°C. The temperature of the water farther offshore and of greater depths tends to be lower.

The salinity of the seawater also varies only slightly. The mean salinity at the water surface is approximately 31.5 $\pm$ 1.0 parts per thousand (ppt). The highest salinity recorded is 34.6 ppt. Salinity increases with increasing distance from the coast, away from the freshwater influences of river discharges.

Studies carried out in S. Brunei (Currie 1979a) showed that, unlike water from the open sea, there is great variation in the salinity of the river estuarine water horizontally and vertically. The range in salinity depends on the degree of water exchange and the mixing of both freshwater and seawater. During the study, the salinity of S. Brunei Estuary at high tide ranged from 10.5 to 31.8 ppt and 7.7 to 29.5 ppt at low tide. This showed that there was a fair amount of mixing in S. Brunei Estuary. S. Temburong Estuary, however, showed little mixing of water, and the salinity range was 2.6 to 32.9 ppt at high tide and 4.0 to 30.6 ppt at low tide.

The pH of the seawater is generally about 7.5 to 8.5. In the estuarine regions like S. Brunei Estuary, the pH tends to be lower due to high acidic humus, low carbonate and bicarbonate contents carried into the estuary by river systems.

The dissolved oxygen (DO) content of the coastal waters is generally high as the water is continuously being mixed with the open sea to the north. This is not true for all the estuarine conditions. A survey in 1978 in Brunei Bay was made, the results of which were contained in the unpublished "Final report: Sungai Brunei water quality and pollution study" by Syed Muhammad and Jurutera Perunding Hooi. The survey showed that the oxygen saturation in S. Brunei Estuary is very low due to domestic sewage from Bandar Seri Begawan and Kg. Air. Also, the bay is semi-enclosed, and complete mixing with the open sea is prevented. The oxygen saturation in Temburong Estuary, however, is close to 100% but falls to approximately 70% farther upstream due to increased organic sediment load from runoffs from mangrove and peat swamps.

Turbidity studies in Brunei Darussalam waters using a Secchi disc revealed that water clarity is greatest during the drought season from March to May. Low river discharge is associated with low rainfall, hence, there is low sedimentation load. Also, during this period, intermediate between the two monsoons, the sea is relatively calm. Thus, the seabed sediments are not churned up. The sedimentation from coastal upland deforestation and the erosion that results from it account for a major part of the water turbidity, especially during the rainy season.

Estuarine Environment

There are three major estuarine areas in Brunei Darussalam, namely, Belait Estuary, Tutong Estuary and Brunei Estuary or Inner Bay which is part of Brunei Bay that extends toward Sabah and Sarawak, including Labuan Island (Fig. 2.4).

S. Belait is located at the western part of Brunei Darussalam and drains from the southern hilly portion of the border to the sea at Kuala Belait. S. Belait is Brunei Darussalam's largest river with a total catchment area of 2,130 km^2 (Watson 1977). It has a relatively long, deep and narrow coastal plain estuary with tidal effects 90 km upstream below Kampong (Kg., from here and which means village) Apak Apak. The upper reaches of the river are a major freshwater source for the western part of the country. There are two tributaries, S. Mendaram and S. Damit, which join S. Belait some 29 km from the river mouth. *Nipah* covers the sides of the channel up to 22 km inland with a sand spit at the river mouth that restricts the discharge of high flows to the South China Sea.

The second estuary is situated between Belait and Brunei Bay and flows in the northwesterly direction. S. Tutong discharges into the sea between two sand spits which form an elaborate estuarine system. It runs parallel to the coast for about 10 km, passing from Tutong town and entering the sea at Kuala Tutong. The estuary is relatively short, and tidal limit is 46 km upstream from the river mouth. As with S. Belait, S.Tutong banks are covered with *nipah* up to 12 km upstream. A large tidal swamp which is blackened by peat is located upstream from Tutong town. Tidal cycle is mixed with two strong diurnal and two much weaker semidiurnal components.

Brunei Estuary covers an area of 1,380 km^2 of Brunei Bay (MOD-DOTCP No. 5, 1986c). A trench with a maximum depth of 110 m lies amid a chain of islands and submerged rocks; its axis, northwest by southeast. The Inner Bay is fed by several large rivers within Brunei Darussalam (S. Brunei and S. Temburong) and Sarawak (S. Limbang and S. Trusan). The estuary, divided longitudinally into Brunei Channel and Temburong Channel (Currie 1979b), is fringed with mangrove at the northeastern end of the coastline especially towards Temburong District.

Hydrological characteristics

Most of the hydrological studies on the major river systems were related to freshwater resource exploitation. The major concern of the government is towards establishing adequate freshwater sources for domestic, agricultural and industrial uses. Among such hydrological studies are the salt intrusion upstream and tidal effects particularly during low fluvial flow in S. Belait and S. Tutong (Watson 1977).

In Brunei Bay area, the major concern is towards pollution control, especially from domestic effluent load. Most of the studies conducted along S. Brunei were related to effluent discharges of Bandar Seri Begawan and Kg. Air. These studies pertain to physicochemical and

biological analyses of the waters within S. Brunei. Currie (1979b, 1982), on the other hand, studied some hydrological aspects of Brunei Bay in relation to effluent discharges and also on the biology of important penaeid and metapenaeid species. The study, which also included S. Temburong, is related to the flushing time along the various outlets of the bay into the South China Sea during low and high tides and some physicochemical parameters around the bay and along major domestic effluent outfalls.

Salinity. Brunei Estuary appears to be vertically and horizontally partially stratified. Based on Currie (1979b), surface salinity is generally lower than bottom water. Salinity range along Brunei Channel is 10.5 to 31.8 ppt at high tide and 7.7 to 29.5 ppt at low tide. In Temburong Channel, salinity is 2.6 to 32.9 ppt at high tide and 4.0 to 30.6 ppt at low tide. Such salinity variation is attributed to the presence of extensive shallow areas in the estuary as well as to the freshwater inflows from rivers around the bay. Water sampling done on 13 April 1987 within the lower reaches of S.Temburong showed a salinity range of 18 to 22 ppt and which is vertically mixed. Within the mouth of S. Brunei, the water appears to approach full vertical mixing, but generally with slight reduced salinity at the top layers due to freshwater influx (Table 2.1).

Salinity recordings from Belait and Tutong Estuaries are mostly concentrated upstream to monitor tidal effect and salt intrusion since the two rivers are a major freshwater source of the country's western part (Watson 1977). Records on salinity studies in the estuaries are not available at present. However in a monitoring done on 18 April 1987, salinity ranged from 25 to 35 ppt and appeared to be vertically mixed. Table 2.2 shows the physicochemical characteristics of Tutong Estuary taken on 18 April 1987.

Dissolved Oxygen. DO records for Belait and Tutong Estuaries are not available, but in a survey conducted on 18 April 1987, the value ranged from 4 to 6 ppm (Table 2.2). The low levels observed, due to high organic content, are similar to other estuaries which are caused by high organic content (Boaden and Seed 1985). The major source of the organic load could be the mangroves which fringe the banks of the estuary.

For Brunei Estuary, the DO profile tends to have a lower saturation percentage (25 to 35%) where S. Kedayan confluenced with S. Kianggeh around Kg. Air. This is possibly due to the organic load from urban centers and some contributions from mangrove areas upstream.

In Temburong Estuary, DO values taken on 13 April 1987 were low (<4 mg/L). In Fig. 2.13, the vertical DO profile showed various degrees of mixing in the seven sampling stations. Stations 3 and 5 appeared to have some degree of stratification. The water was almost anoxic, especially at the bottom particularly at Station 5. This may be due to the decomposition of plant remains as evidenced by rotting leaves taken from the bottom. However, such occurrence cannot be correlated with low DO values taken from other stations. Water transparency, taken using a Secchi disc, ranged from 0.87 to 2.7 m.

Other Physicochemical Parameters. There is paucity of data for Belait and Tutong Estuaries. In the 18 April 1987 survey, the pH ranged from 7.7 to 8.4 at water temperatures of 29.0 to 29.5°C, and water transparency was up to 1.75 m. Limited studies done in Brunei Estuary indicated that the water pH is influenced by the presence of mangroves that fringe the bay. The pH is generally reduced because of the presence of humic acids from mangrove areas aside from the low input of carbonates and bicarbonates into the bay. Average upstream pH of S. Brunei is 6.9 while downstream is 7.5. Lower reaches of S. Temburong (7.2 to 7.5) showed higher pH values than S. Brunei. Flushing time of effluents from the river to South China Sea is about 2 to 4 days (Currie 1979b).

Nutrients like various nitrogen and phosphorus compounds have not been extensively monitored except within S. Brunei in relation to the domestic sewage problems of Kg. Air. The turbidity of Inner Bay appears to be influenced by freshwater discharge from rivers especially during monsoon seasons.

Table 2.1. Summary of water quality, substrate and common faunal characteristics for Temburong Estuary based on the field survey on 13 April 1987 (1020-1600 hr). (Refer to sites.) S: Surface; B: Bottom.

Station	Water quality and parameters							Soil parameters		
	Depth (m)	Transparency (m)	Direction of flow (N°)	Speed (cm/s)	Temperature (°C)	Salinity (ppt)	pH	Soil pH	Texture	Flora
1	6.5	1.03	112.5	22-27	29.1 (S/B)	22.0 (S/B)	7.5 (S) 7.2 (B)	6.9	Clayey	Mixed vegetation
2	3.0					20.0	7.3			Pure *nipah*
3	9.0	2.0	187.5	12	30.0 (S/B)	21.0 (S/B)		7.3	Sandy/peaty	Mangrove
4	3.0				30.0 (S/B)	18.0 (S)	7.2 (S)	6.6	Clayey	Mixed vegetation
5	9.0	2.7			30.0 (S/B)	18.0 (S/B)	7.2 (S/B)			
6	5.0	0.87			29.0 (S/B)	18.0 (S) 21.0 (B)	7.5 (S/B)	6.7	Clayey	Pure *nipah*
7	6.0 sandy mud bottom	0.87	277.5	34	29.0 (S/B)	18.0 (S) 21.0 (B)	7.5 (S/B)	6.7	Clayey	More *nipah*
8								6.7	Peaty	*Rhizophora*
9									Silty/clayey	*Rhizophora*
9a	11.0 silty bottom		187.5	23	29.0 (S/B)	22.0 (S/B)	7.4 (S/B)	7.3	Clayey	Mixed vegetation
10									Clayey	
11	5.0	1.43	172.5	23	29.0 (S/B)	20.0 (S/B)	7.3 (S/B)			

Table 2.2. Physicochemical characteristics at Tutong Estuary based on a field survey on 18 April 1987 (1130-1320 hr). (Refer to Fig. 2.14 for the sampling sites.) S: Surface; B: Bottom.

Station	Depth (m)	Transparency (m)	Temperature (°C)	Salinity (ppt)	Oxygen (mg/L)	pH
1	2.0	1.0	29.5 (S) 29.0 (B)	25 (S) 28 (B)	5.0 (S) 4.2 (B)	7.7 (S) 8.0 (B)
2	4.0	1.0	29.0 (S/B)	25 (S/B)	4.0 (S) 3.5 (B)	7.8 (S/B)
3	4.0	1.0	29.2 (S/B)	35 (S) 34 (B)	6.0 (S/B)	8.4 (S/B)
4	4.0	1.75	29.2 (S/B)	35 (S) 34 (B)	5.9 (S) 5.1 (B)	8.4 (S) 8.5 (B)
5	4.5	1.5	29.5 (S/B)	34 (S/B)	5.9 (S) 5.7 (B)	8.4 (S/B)

Biological characteristics

Estuaries are highly variable environments with wide fluctuations of physicochemical parameters, especially salinity, due to freshwater influx from rivers within a tidal cycle. So, relatively few species could adapt to live here (Boaden and Seed 1985). Among the three major estuaries, Brunei Estuary is the most studied. However, biological data are limited. Data on the fish species found in Belait and Tutong Estuaries are not available, but small-scale fishing operations are conducted especially at the river mouth. A benthic survey done in Tutong Estuary on 6 June 1987 showed the occurrence of five species of bivalves, four of crustaceans and one of echinoderms (Table 2.3). The survey was limited to four sites, including the river mouth (Fig.2.14). Towing time was 5 min per tow. Many of the species collected were those that were observed to be more adapted to higher salinities. Higher salinity values obtained indicated low river flow possibly due to prolonged drought since February 1987.

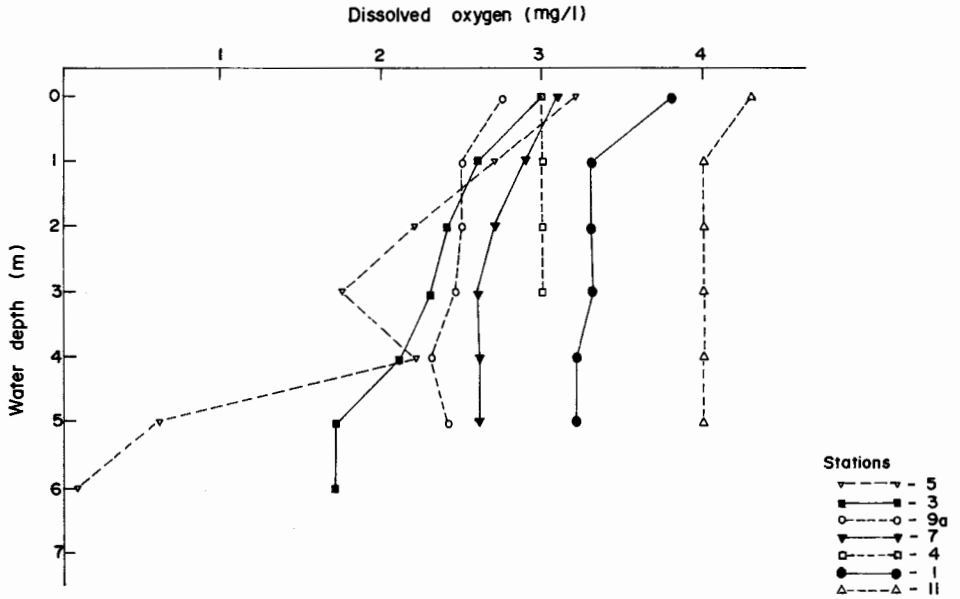


Fig. 2.13. Vertical dissolved oxygen profile of the lower reaches of S. Temburong. Sampling date was 13 Apr 1987. Refer to Fig. 2.14 for the location of the sampling stations.

Table 2.3. Invertebrates collected during the Tutong benthic survey (6 June 1987). (Refer to Fig. 2.14 for the sampling sites.)

Class	Family/Order	Species
Bivalvia	Corbiculidae	*Geloina* sp.
	Anomiidae	*Enignomia aenigmatica*
	Tellinidae	*Tellina* sp.
	Veneridae	Unidentified sp.
	Ostreidae	Unidentified sp.
Crustacea	Paguridae	Unidentified sp. (hermit crab)
	Penaeidae	*Metapenaeus ensis*
Cirripedia	Balanidae	*Balanus amphitrite*
Malacostraca	Amphipoda	Unidentified sp.
Echinoidea	Temnopleuridae	*Temnotrema* sp.

In Inner Bay, a significant trawl fishery for prawns exists (Currie 1982). Dominant species found are penaeids and metapenaeids. The distribution of these species appears to be affected by salinity where seaward occurrences are more abundant during the rainy season in November. *Metapenaeus afffinis* adults, for example, are not found in the inner waters of the bay during increased rain in November.

There are limited studies done on plankton, including Foraminifera, from the bay. Red tides caused by *Pyrodinium bahamense* var. *compressa* have been observed in the north of Brunei Bay on two occasions (1976 and 1980) (MOD-DOTCP No. 5, 1986c). Some of the species observed, particularly fish, are discussed in Chapter 6. Species diversity is depauperate due to the turbid condition in the bay.

In Temburong Estuary, a 10-minute dredging for benthic organisms was done on 11 May 1987. Trammel netting was also done to collect nektonic species during the study (Table 2.4), many of which are typically mangrove-associated although some, such as portunids and penaeids are nonresident mangrove types (Gomez 1980). The bivalve, *Corbula* spp., has been collected in four dredging sites within Temburong. The species are of low salinity types of mollusks (Plaziat 1984). As Currie (1979a) pointed out, S. Temburong has a lower salinity than S. Brunei which possibly favors the presence of *Corbula* spp.

Serasa Bay

Serasa Bay is situated in the north of Brunei Estuary towards Muara Port. It is enclosed by a 1.6-km long Serasa Sand Spit (Fig. 2.15) which is an artificial sand bar created by dumping dredged sands from Muara Port area complex, including Pelompong Sand Spit. There are two rivers that drain directly into the bay, S. Mangsalut and S. Mengkabau. In addition, the Muara Sewage Treatment Complex is near the bay but as yet is nonoperational. An experimental netcage fishfarm of DOF is close to the sand spit. Among the species being reared are snappers, jacks, seabass and groupers. A channel running parallel to the sand spit has been dredged to facilitate water circulation especially towards the area not readily accessible by direct tidal exchange.

The whole length of the sand spit has been planted with *Casuarina equisetifolia*. A windsurfing establishment is located at the entrance to the spit. The spit is used as a recreational ground mostly for picnics, part-time angling and net fishing.

Hydrological monitoring of Serasa Bay is limited but the net cage farm of DOF monitors water quality within the farm area. The bay is generally shallow especially towards the western

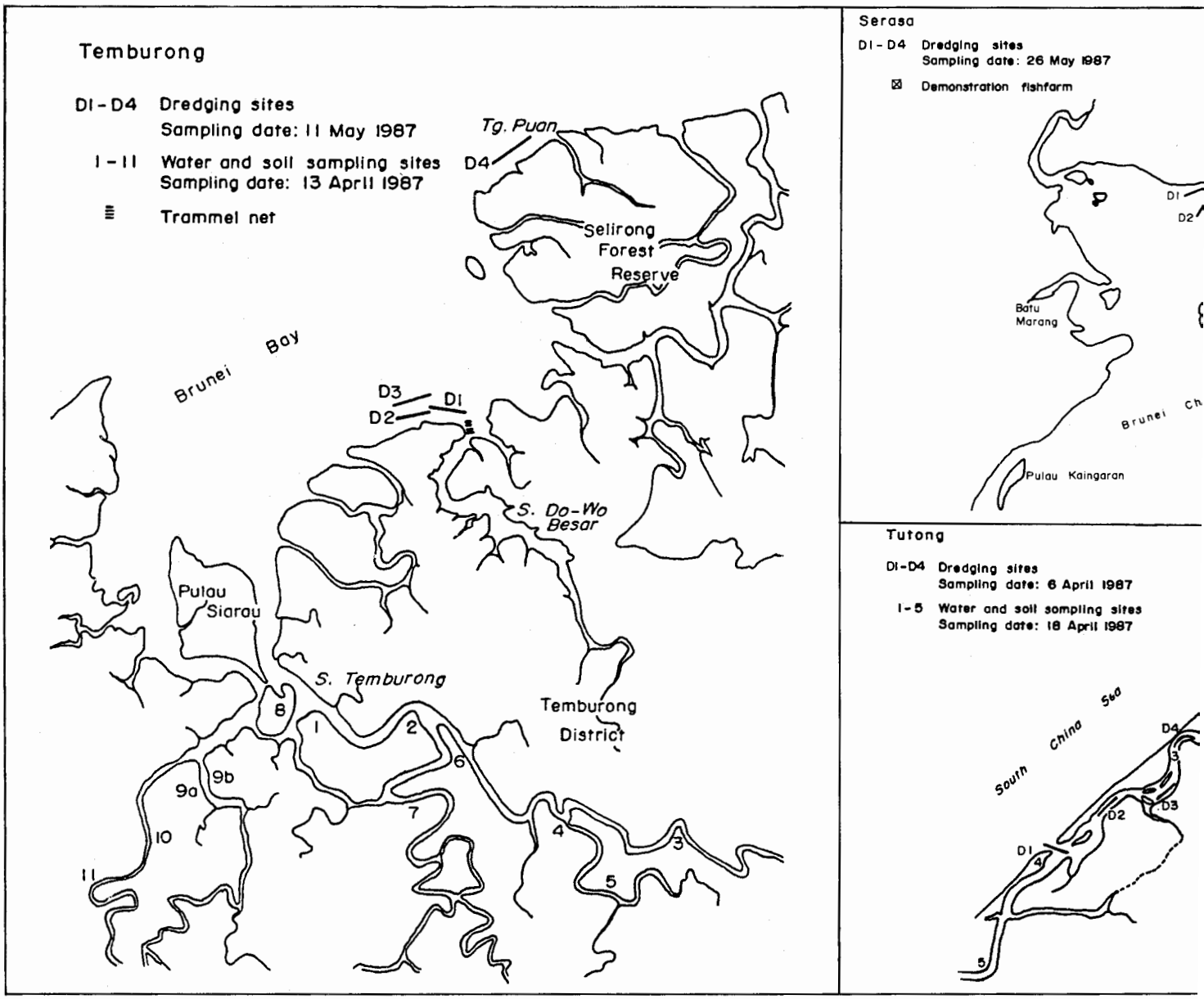


Fig. 2.14. Sampling sites for water, soil and biological parameters at Temburong, Tutong and Serasa.

Table 2.4. Specimens collected during benthic sampling along the lower reaches of S. Temburong, 11 May 1987. (See Fig. 2.14 for the sampling sites.)

Location	Class	Family	Species
D1	Bivalvia	Anomiidae	*Placuna placenta*
Dowo Besar, Temburong		Corbulidae	*Corbula* sp.
		Veneridae	*Circomphalus calophylla*
	Gastropoda	Naticidae	*Natica tigrina*
	Crustacea	Penaeidae	Unidentified sp.
		Paguridae	Unidentified sp.
		Portunidae	*Portunus* sp.
D2	Bivalvia	Corbulidae	*Corbula* sp.
Entrance, Dowo River		Veneridae	*Callista* sp.
	Gastropoda	Maticidae	*Natica tigrina*
	Scaphopoda		*Dentalium* sp.
	Osteichthyes	Platycephalidae	*Platycephalus* sp.
		Gobiidae	Goby sp.
	Crustacea	Psammobiidae	*Gari* sp.
	Polychaeta		
D3	Bivalvia	Corbulidae	*Corbula* sp.
Entrance, Dowo Besar		Psammobiidae	*Gari* sp.
	Gastropoda	Buccinidae	*Burnupena* sp.
	Scaphopoda		*Dentalium* sp.
	Crustacea	Portinudae	*Portunus* sp.
		Leucosiidae	Unidentified sp.
D4	Osteichthyes	Cynoglossidae	*Cynoglossus* sp.
Tg. Selirong	Bivalvia	Corbulidae	*Corbula* sp.
		Mactridae	*Mactra* sp.
	Gastropoda	Nassariidae	*Plicarcularia thersites*
		Naticidae	*Natica tigrina*
		Olividae	*Oliva oliva*
		Solenidae	*Solen* sp.
	Crustacea	Portunidae	*Portunus* sp.
	Polychaeta		
Piasau 2	Crustacea	Penaeidae	Unidentified sp.

part close to the shore and also between Pulau (P. from here, and which means island) Badukang. Depths of less than 1 m at low tide have been observed.

Serasa Bay has been earmarked by the government as a potential site for an aquaculture complex. However, industrial and port development at Muara might be a potential threat which requires immediate attention. So, the CRMP team carried out field surveys to obtain more information on the physicochemical and biological characteristics of the bay. The surveys included a general one on the environmental parameters of the bay; a 24-hour one on the seven stations in Serasa Bay; and a benthic faunal survey.

Variation in Hydrological Parameters. During the general survey on 6 June 1987, 10 stations were designated with 3 sites outside the bay area towards Muara Port. Salinity outside the bay ranged from 20 to 30 ppt, which was more saline than the bay area (16 to 26 ppt). Higher salinity generally coincided with high tide which was more pronounced in the site outside Serasa Bay. The bottom salinity was higher than that at the surface, indicating partial stratification with bottom current speeds ranging from 12 cm/second to 36 cm/second and direction indicating outward movement towards the sea.

During the 24-hour sampling, it was observed that Stations 3 (at 1:10 a.m.), 4, 5 and 6 (the three at around 4 p.m.) were quite shallow at low tide. Hence, values for surface and bottom were the same. Surface salinity values were generally lower than the bottom and ranged from 10 to 19 ppt. Higher salinities were observed at the bottom and which ranged 14 to 30 ppt. There was distinct stratification in the three stations (Fig. 2.16). This stratification was more

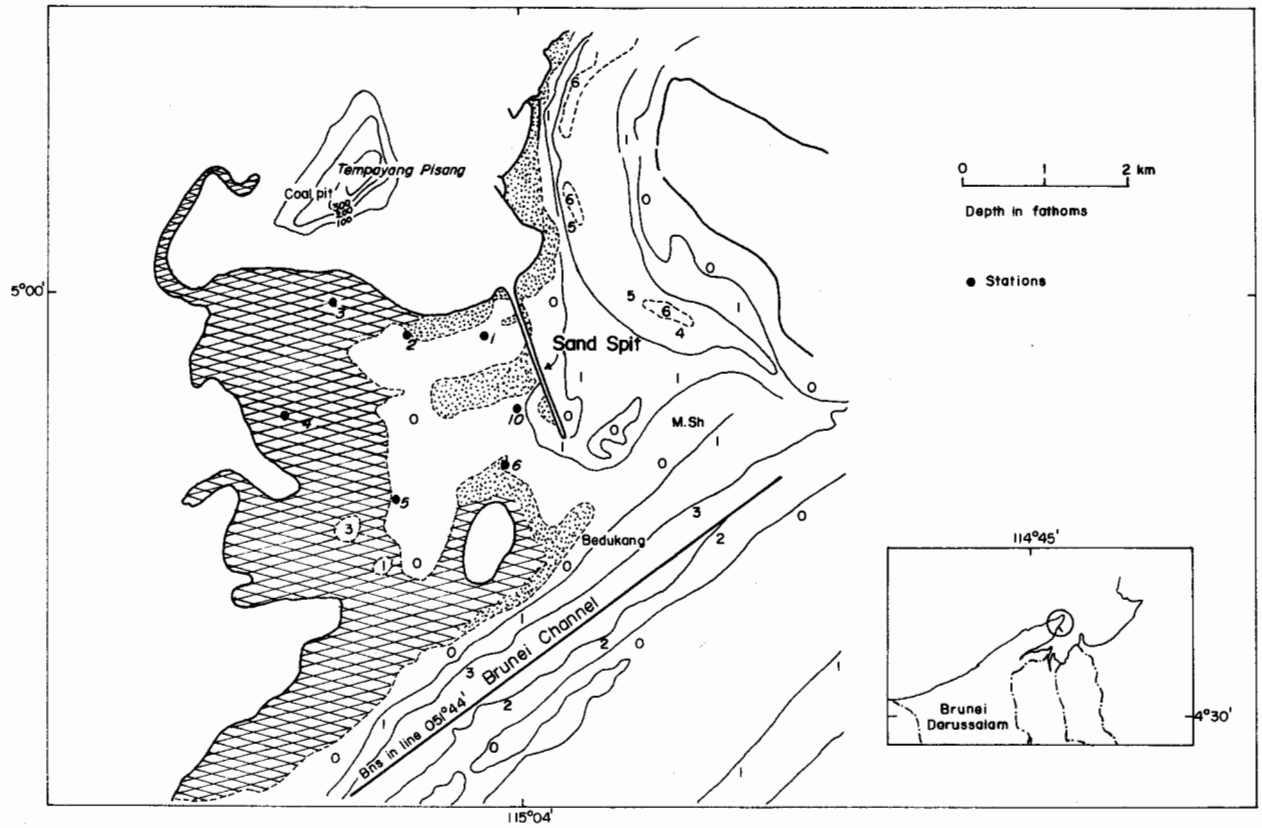


Fig. 2.15. Serasa Sand Spit area and water sampling stations.

pronounced at Station 10 probably because it is located close to the end of the sand spit where tidal influence is distinct. The rest of the stations showed various degrees of vertical mixing over 24 hours. There was a decreasing salinity pattern from Stations 2 to 10, the lowest being at Stations 4 and 5 possibly due to freshwater influx (especially in Station 5). Station 4 was sited between the two rivers which perhaps accounts for the lower salinity values.

The DO values in all stations appeared to be uniform, ranging from 4.9 to 6.5 mg/L at the surface to 4.4 to 8.4 mg/L at the bottom. The oxygen level in the early morning was lower than that in the afternoon and early evening. However, the difference was not high. The values were typical of estuarine DO profiles which tend to be low due to high organic material load (Boaden and Seed 1985). There was no significant DO difference between the surface and the bottom (Fig. 2.16) except in Station 2, where bottom water showed higher DO. Why such high variation existed was not certain. In general, the fairly uniform DO profile was probably due to the shallow nature of the bay where light penetration may be fairly uniform during daytime. The weather throughout the sampling period was fair with clear to partly cloudy skies during daytime. However, the bay was turbid and dull greenish which is typical of mangrove-associated estuaries.

Water temperatures were high, ranging from 27 to 32.8°C. No distinct temperature differences were observed between the surface and the bottom waters of the bay (Fig. 2.16), due to the shallow nature of the bay including the low fluvial influx at the time of sampling.

The pH values during daylight hours were generally above 7.0. There is no distinct vertical difference in pH between the surface and the bottom waters (Fig. 2.16). Values taken beginning at midnight were below 7.0 but these were most likely due to system error. The pH values ranged from 4.7 to 8.30 at the surface and 4.9 to 8.30 at the bottom.

Current speed values ranged from 5 to 29 cm/second at the surface to 4 to 39 cm/second at the bottom. Bottom current appeared to be faster than the surface especially at

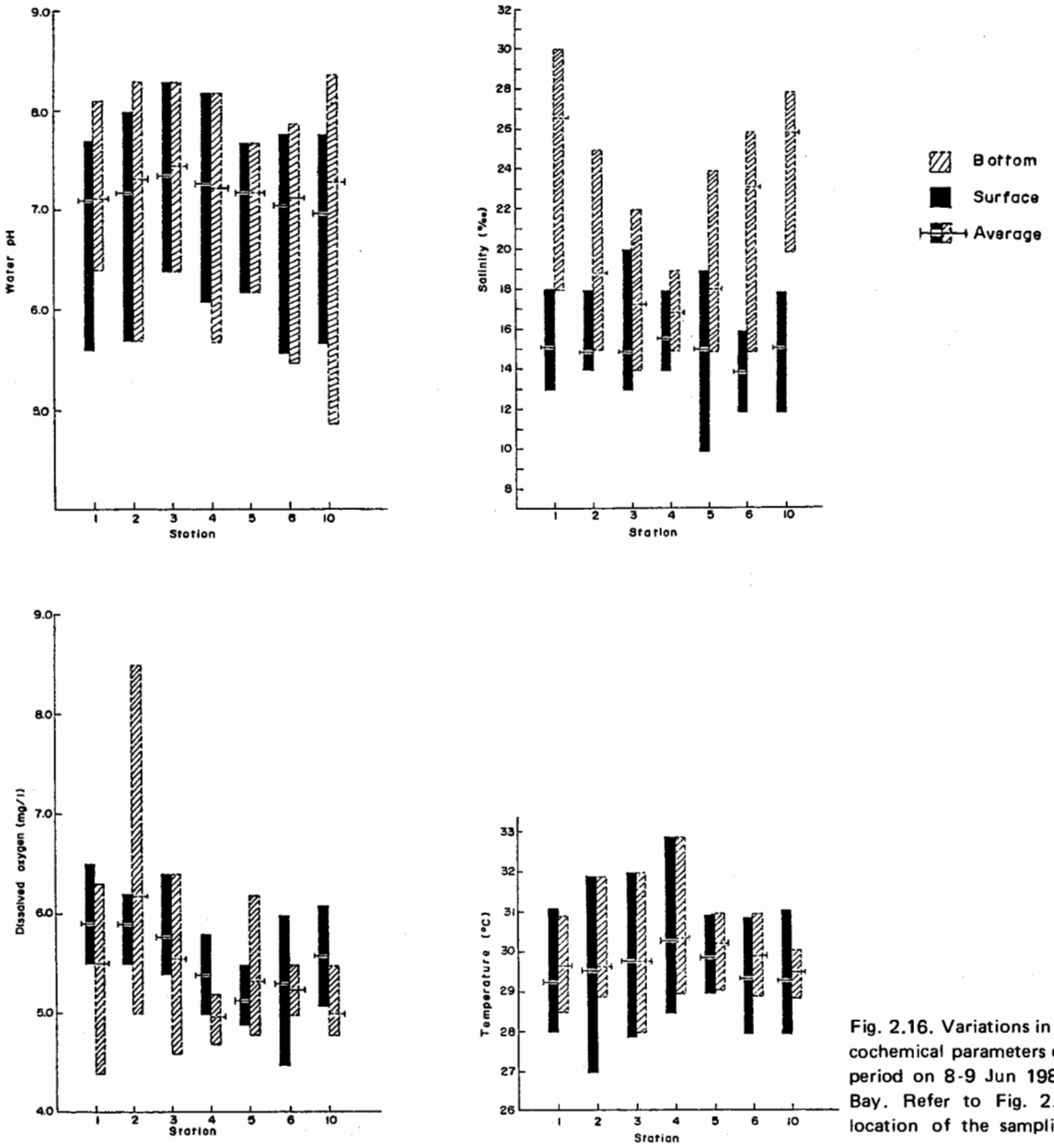


Fig. 2.16. Variations in some physicochemical parameters over a 24-hr period on 8-9 Jun 1987 at Serasa Bay. Refer to Fig. 2.15 for the location of the sampling stations.

Station 6. Current directions showed a circular motion around the bay for both the surface and the bottom currents. There were instances when bottom currents ran nearly opposite that of surface currents. Along Serasa Sand Spit, currents showed variable directions throughout the sampling period, indicating that water was not stagnant particularly towards the entrance to the spit (as also shown by salinity and DO values). This was probably due to the channel that was dredged parallel to the spit intended to facilitate water exchange.

Based on these results, Serasa Bay appears to be partially stratified. However, further studies need to be undertaken to determine the actual hydrological profile of the bay over a long period, including seasonal variation.

Benthic Community. Based on the results of the benthic tows, there were three species of bivalves, seven of gastropods, six of crustaceans, a holothurian, two of polychaetes, a sea pen and a goby (Table 2.5). Many of these were obtained from tows at Stations 3 and 4 which were situated between P. Badukang and the sand spit. Stations 1 and 2 were poor in benthic biota.

Table 2.5. Organisms collected during the benthic survey at Serasa Bay.

Class	Family	Species
Bivalvia	Tellinidae	*Tellina* sp.
	Veneridae	Unidentified sp.
	Scrobiculariidae	*Scrobicularia* sp.
Gastropoda	Nassariidae	*Plicarcularia thersites*
		Nassarius spp.
	Mitridae	*Mitar* sp.
	Terebridae	*Terebra* sp.
	Cymatiidae	Unidentified sp.
	Turridae	Unidentified sp.
	Cerithiidae	Unidentified sp.
Crustacea	Paguridea	Unidentified spp. (hermit crabs)
	Penaeidae	Unidentified sp.
	Portunidae	*Portunus* sp.
	Leucosiidae	*Leucosia* spp.
	Dorippidae	*Neodorippe callida*
		Polyonyx obesulus
Holothuroidea		Unidentified sp.
Polychaeta	Glyceridae	Unidentified sp.
	Aphroditidae	Unidentified sp.
Pennatulacea		Unidentified sp. (sea pen)
Osteichthyes	Gobiidae	Unidentified sp.

The species composition was varied and richer compared to samples taken from Tutong. Many of the species were those adapted to higher salinities, which may be attributed to the higher salinity levels of the bottom water and the enclosed nature of the bay. More saline water flows through the channel along the Muara Port Complex area with low freshwater discharges from the rivers in the bay area compared to greater Brunei Estuary (Currie 1979b). It is not certain whether these species are abundant all year round. It would be important to determine seasonal composition of species of the bay to assess the biological productivity of the area. Many of the species collected are typical mangrove-associated type such as cerithiid, terebrid, nassariid, portunids and penaeids (Gomez 1980; Plaziat 1984). Some of these, particularly crustaceans, are nonresident mangrove fauna but spend part of their life cycle in mangrove areas.

Fish species composition was not assessed but some of those observed around the cage farms were scat, rabbitfish, jacks and half-beaks. There were other fish unidentified. Other species observed but not collected in the benthic tows include oysters, barnacles, sponges, crabs and red seaweed.

Chapter 3
Coastal Resources

Mangroves

PRESCILLANO ZAMORA

Made prosperous by its oil fields at Seria (Belait District), Brunei Darussalam has not found it necessary at present to develop other natural resources such as the forests (including the mangrove ones) as a major source of revenue. Insofar as forest resources are concerned, Brunei Darussalam continues to adhere to its forest policy (formulated and published in 1951): "to protect by reservation and to develop forests where their retention is essential for the conservation of soil and water resources necessary for agriculture and to ensure that every district (Brunei-Muara, Temburong, Tutong and Belait) is as far as possible permanently self-supporting in respect of timber and other forest produce" (Anon. 1957). Thus, relative to other land uses, the proportion of forest area of the country remains very high (Table 3.1).

The forests of Brunei Darussalam are entirely evergreen, generally referred to as tropical rain forest. But within their broad classification, the forest types are remarkably diverse, depending on the soil conditions (Fig. 3.1 and Table 3.2).

The term *mangrove* is used in this book to denote a complex of plant communities found as a belt of varying width along the tropical shores of sheltered creeks, lagoons, deltas and islands below the high tide mark. The meanings of such other terms as *mangrove area*,

Table 3.1. Summary of present land use in Brunei Darussalam.

Land use category	Approximate area (ha)	Percentage
Agricultural purposes	13,200	2.3
Gazetted forest reserves	226,287	28.8
Proposed new forest reserves and extensions	93,660	16.0
Conservation areas outside forest reserves	8,930	1.5
Urban and residential areas	12,400	2.1
Resettlement areas	2,600	0.4
Gravel and white sand deposits	3,550	0.6
Subtotal	360,627	61.8
Uncommitted state land	223,323	38.2
Total	583,950	100.0

Source: MOD-DOTCP No. 1 (1986a).

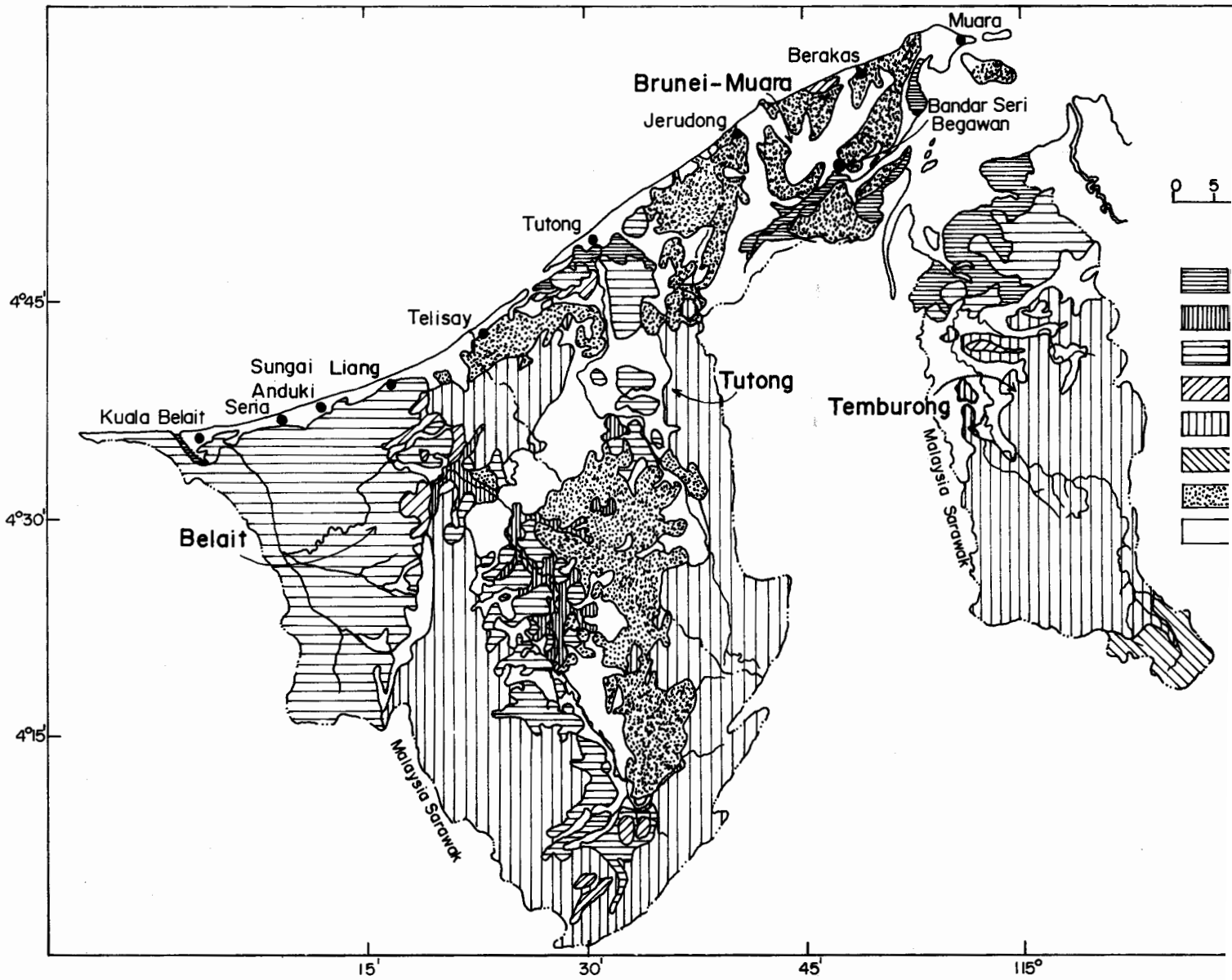


Fig. 3.1. Distribution of basic forest types (adapted from MOD-DOTCP No. 8, 1986e).

Table 3.2. Area of forest cover by forest types in Brunei Darussalam.

Forest type	Area (ha)	As a percentage of national land area[a]
Mangrove	18,418	3.2
Freshwater swamp	12,668	2.2
Peat swamp	90,884	15.6
Heath	3,455	0.6
Mixed dipterocarp	192,575	33.1
Montane	7,196	1.2
Mixtures of above types	15,988	2.7
Primary, undisturbed	341,184	58.6
Secondary, disturbed, plantation	127,862	22.0
Total forest cover	469,046	80.6

[a]All land area estimates in the forestry sector report exclude estuarine and riverine surface water that exceeds 50 m in width, and all landlocked, permanent surface water area. Comparisons between these estimates and the official figures for district and national areas are not valid as the latter will surely include at least some of the surface water area excluded from the figures shown here.

Source: MOD-DOTCP No. 8 (1986e).

mangrove plants, *mangrove resources* and *mangrove-associated biota* are given in Appendix 1. Plant density was based on data obtained using the transect line plot method following the Manual of Survey Methods of the Australian Institute of Marine Science (Anon. 1986).

The mangrove forests occur in saline soils subject to tidal inundation in Temburong, along the upper Belait River, Tutong River, Brunei River and around Muara. The total mangrove forest area is 18,418 ha representing 3.2% of the national land area (MOD-DOTCP No. 8, 1986e) and Table 3.2). The extent of the forest is much smaller compared to that of its Malaysian neighbors, thus:

	Area (ha)	Source
Brunei Darussalam	18,418	MOD-DOTCP No. 8 (1986e)
Sabah	350,342	Anon. (1979)
Sarawak	172,792	Chai (1982)
Peninsular Malaysia	105,537	Chan (1987)

According to Malley et al. (1978), Brunei Bay has large areas of coastal swampland with 31,160 ha of mangroves and 13,128 ha of *nipah* or a total of 44,290 ha. The shoreline of Brunei Bay is 194.73 km long, and has 366 ha of swampland for every 1.6 km of coastline. The *nipah* swamps are found near *bakau* swamps and in riverine areas.

The areal (ha) extent of the mangroves in the four districts are estimated as follows:

Districts	Total land area	Mangrove area
Temburong	116,600	12,167
Brunei-Muara	57,000	3,934
Tutong	130,300	1,784
Belait	272,500	533
Totals	576,500	18,418

Mangrove habitat type

Subtypes. Four major subtypes have been recognized in Brunei Darussalam (Fig. 3.1 and Table 3.3): (1) undifferentiated, (2) *Rhizophora*, (3) *Xylocarpus* and (4) *Bruguiera*. Other minor subtypes recognized are *Sonneratia* and *Oncosperma* formation.

Undifferentiated mangrove consists of a mixture of species (depending on the soil composition and degrees of inundation experienced by the area).

Rhizophora mangrove is almost completely dominated by *R.apiculata (bakau minyak)* of the family *Rhizophoraceae*. A second species, *R. mucronata (bakau kurap)* is only of occasional occurrence, most especially as a riverine species along deltaic channels and creeks.

Xylocarpus mangrove is characterized by pure stands of *X.granatum (nyireh bunga)* of the family Meliaceae. Lobster mounds, usually covered by *Acrostichum aureum* (*piai* fern) abound in the areas occupied by this subtype. *X. granatum* is also found more usually with *R. apiculata*.

Table 3.3. Occurrence of the subtypes of mangrove forest in the four districts of Brunei Darussalam (+ denotes presence; - denotes absence).

District	Subtypes	Occurrence	Area (ha)
Temburong	Undifferentiated	-	
	Rhizophora apiculata	+	5,572
	Xylocarpus granatum	+	172
	Bruguiera gymnorrhiza	+	71
	Nypa fruticans formation	+	1,885
	N. fruticans-Heritiera globosa	+	2,257
	Subtype mixtures	+	2,008
			(12,167)
Brunei-Muara	Undifferentiated	+	2,848
	R. apiculata	+	59
	X. granatum	-	
	B. gymnorrhiza	-	
	N. fruticans formation	+	303
	N. fruticans-Heritiera globosa	+	726
	Subtype mixtures	-	
			(3,934)
Tutong	Undifferentiated	+	1,052
	R. apiculata	+	74
	X. granatum	-	
	B. gymnorrhiza	-	
	N. fruticans	+	301
	N. fruticans-Heritiera globosa	+	357
	Subtype mixtures	-	
			(1,784)
Belait	Undifferentiated	+	153
	R. apiculata	-	
	X. granatum	-	
	B. gymnorrhiza	-	
	N. fruticans formation	+	273
	N. fruticans-Heritiera globosa	+	107
	Subtype mixtures	-	
			(533)
Total			18,418

Sources: Anon. (1984a); Anon. (1984b); MOD-DOTCP No. 5 (1986c); MOD-DOTCP No. 8 (1986e); and field survey results in the districts of Temburong, Brunei-Muara, Tutong and Belait on 9 April-7 May and 4-14 June 1987.

Bruguiera mangrove is characterized by pure stands of *B.gymnorrhiza (linggadai)* of the family Rhizophoraceae. The three other species, *B. cylindrica (berus ngayong), B. parviflora (berus linggadai)* and *B. sexangula (berus pulut)* that are locally abundant and sometimes form pure stands in Sarawak mangrove (Chai 1975; Chan 1987), are of very rare occurrence. *B. gymnorrhiza* also occurs in association with *Nypa fruticans (nipah)* and as a constituent of the mixed overstory above *Nypa*.

Sonneratia mangrove is dominated by *S. caseolaris (pedada)* of the family Sonneratiaceae, small gregarious stands of which occur on recently deposited silt along Temburong and Labu Rivers.

Oncosperma palm subtype is characterized by *O. tigillarium* which is a marginal mangrove species. A tall spiny species called *nibong* occurs locally towards the upriver limits of *nipah* swamps and is sometimes found in almost pure clumps.

Occurrences. In Temburong, the undifferentiated mangrove subtype is probably absent. *Rhizophora* is one of the dominant components, aside from *Nypa* and *Nypa-Heritiera*. *Rhizophora* comprises about 5,570 ha. *R. apiculata* covers virtually the whole of Selirong Forest Reserve and extends from the seaward fringe to the margins of the peat swamp inland where it borders onto the transition zone.

Xylocarpus and *Bruguiera* subtypes form only a minor component. The former comprises only about 172 ha concentrated in the middle of the mangrove area of Labu Reserve, while the latter is concentrated in the middle of P. Siarau.

In Brunei-Muara, *Xylocarpus* is virtually absent, while the undifferentiated subtype dominates the fringes of Brunei River and its tributaries along the northwest side of Brunei Bay. The rest of the subtypes occur in various but small proportions.

In Tutong, the undifferentiated and *Rhizophora* subtypes (along with *Nypa* and *Nypa-Heritiera*) dominate. These are concentrated on the southwestern (Telisay) side; while *Xylocarpus* is toward the northeastern (Pekan Tutong) side of the district. *Bruguiera* is virtually absent.

The undifferentiated subtype (along with *Nypa*) dominates the mangrove areas of Belait, while *Rhizophora, Xylocarpus* and *Bruguiera* (also *Nypa-Heritiera*) are virtually absent. The undifferentiated subtype is concentrated on the upper east and upper west banks of Belait River.

Flora

Based on library research and a study of the combined results of field surveys (9 April-7 May, 4-14 June 1987) in the mangrove areas of Brunei Darussalam, there are 49 species of flowering plants in the mangrove swamps. Of these, 24 fall under the exclusive species category (i.e., those that are restricted to the mangrove habitat), while the rest fall under the nonexclusive species category (i.e., those that may be important in the mangrove but which are not restricted to it).

Most of the exclusive species found in Malaysia (Peninsular Malaysia, Sarawak and Sabah) are also found in Brunei Darussalam (Table 3.4). Several species of the exclusive category are considered rare such as *Kandelia candel (aleh-aleh), B. cylindrica (berus ngayong), B. parviflora (berus linggadai)* and *B. sexangula (berus pulut)*. Also, of the exclusive species, *R. apiculata (bakau minyak)* and *N. fruticans (nipah)* are the most dominant.

Researchers of Brunei Darussalam Museum have found about 30 species of ferns in their study sites in the mangrove forests (Table 3.5). The occurrence of most species was further confirmed in the CRMP survey. Two species, *Psilotum nudum* and *Lycopodium carinatum*, were added.

Table 3.4. Vascular mangrove flora of Peninsular Malaysia (PM), Sarawak (SR), Sabah (SB) and Brunei Darussalam (BR). Life forms (LF): fern (F); palm (P); shrub (S); tree (T); climber (C).

Species	LF	PM	SR	SB	BR
Acanthus ebracteatus[a]	S		x		x
Acanthus ilicifolius	S				x
Acrostichum aureum	F		x		x
Acrostichum speciosum	F				x
Aegiceras corniculatum[a]	S	x	x	x	x
Allophyllus cobbe	S		x		x
Amoora cucullata	T		x		
Ardisia elliptica	S		x		x
Avicennia alba[a]	T	x	x	x	x
Avicennia lanata[a]	T	x			
Avicennia marina[a]	T	x	x	x	x
Avicennia officinalis[a]	T	x	x	x	x
Barringtonia conoidea	T		x		
Barringtonia racemosa	T		x		x
Brownlowia argentata	T		x	x	x
Brownlowia tersa	T		x		x
Bruguiera cylindrica[a]	T	x	x	x	x
Bruguiera gymnorrhiza[a]	T	x	x	x	x
Bruguiera hainesii[a]	T	x			
Bruguiera parviflora[a]	T	x	x	x	x
Bruguiera sexangula[a]	T	x	x	x	x
Caesalpinia crista	C		x		
Calamus aquatilis	P		x		
Calamus erinaceus	P		x		
Cassine viburnifolia	T		x	x	
Cerbera manghas	T	x	x	x	x
Cerbera odollam	T	x	x		x
Ceriops decandra[a]	T	x	x		
Ceriops tagal[a]	T	x	x	x	x
Cynometra ramiflora	T		x		
Derris trifoliata	C		x		x
Dolichandrone spathacea	T		x		x
Excoecaria agallocha[a]	T	x	x	x	x
Flagellaria indica	C				x
Glochidion littorale	T		x	x	x
Heritiera globosa[a]	T		x	x	x
Heritiera littoralis[a]	T	x	x	x	x
Hibiscus tiliaceus	T	x	x	x	x
Ilex cymosa	T				x
Inocarpus edulis	T		x		
Intsia bijuga	T		x	x	x
Intsia retusa (rare)	T		x		x
Kandelia candel[a]	T	x	x	x	x
Lumnitzera littorea[a]	S,T	x	x	x	x
Lumnitzera racemosa[a]	S,T	x		x	x
Lygodium microphyllum	F				x
Merope angulata	S				x
Myrsine umbellulata	T		x		x
Nypa fruticans[a]	P		x		x
Ochthocharis borneensis	S		x		
Oncosperma tigillarium	P		x		x
Osbornia octodonta[a]	S				
Pandanus affinis	S		x		x
Paramignya longispina	S		x		
Podocarpus polystachyus	T				x
Pongamia pinnata	T				x
Ponteria obovata	T		x		
Rhizophora apiculata[a]	T	x	x	x	x
Rhizophora mucronata[a]	T	x	x	x	x
Sapium indicum	T		x		
Scolopia macrophylla	T		x		
Scyphiphora hydrophyllacea[a]	S	x	x	x	x
Sonneratia alba[a]	T	x	x	x	x
Sonneratia caseolaris[a]	T	x	x	x	x
Sonneratia ovata[a]	T	x	x		x
Thespesia populnea	T	x		x	x
Vitex peralata	T				x
Xylocarpus granatum[a]	T	x	x	x	x
Xylocarpus moluccensis[a]	T	x		x	

[a]Exclusive species: those that are restricted to the mangrove habitat.

Table 3.7. Fauna collected from selected mangrove sites in Brunei Darussalam.[a]

Bivalves	
	Enignomia aenigmatica
	Geloina sp.
Gastropods	
	Calliostoma spp.
	Cassidula sp.
	Cassidula vespertilionis
	Cerithidea sp.
	Chicoreus sp.
	Ellobium aurisjudae
	E. aurismidae
	Littorina sp.
	Nerita lineata
	Nerita planospira
	Neritina spp.
	Neritodryas spp.
	Onchidium sp.
	Pythia sp.
	Terebralia palustris
Crustaceans	
	Balanus amphitrite
	Sesarma sp.
	Unidentified sp.

[a]Collections made by Dr. Chou Loke Ming from these mangrove areas in April 1987: Temburong District (Selirong Forest Reserve, S. Temburong, S. Pandu-ruan, Tg. Lumut, S. Labu); Brunei-Muara District (S. Brunei near the Sultan's Palace); and Tutong District (S. Tutong, edge of *nipah* swamps).

Table 3.8. Marine organisms from mudflats associated with mangrove areas in Brunei Darussalam[a].

Bivalves	Crustaceans
Callista sp.	*Portunus* (?) sp.
Circomphalus calophylla	Others[b]
Corbula sp.	
Gari sp.	Scapods
Mactra sp.	*Dentalium* sp.
Placuna spp. (?)	
	Osteichthyes
Gastropods	Unidentified sp. (goby)
Bumupena (?) sp.	*Platycephalus* sp.
Natica sp. (?)	
Olivia sp. (?)	Polychaetes[c]
Plicarcularia thersites	
Solen sp.	

[a]Dredged from mudflats near or at the mouth of Dowo Besar, Temburong, mouth of Dowo River, Tg. Selirong and Piasau.

[b]Unidentified species of this class belonging to the families penaeidae, paguridae, portunidae and leucosiidae.

[c]Several unidentified specimens.

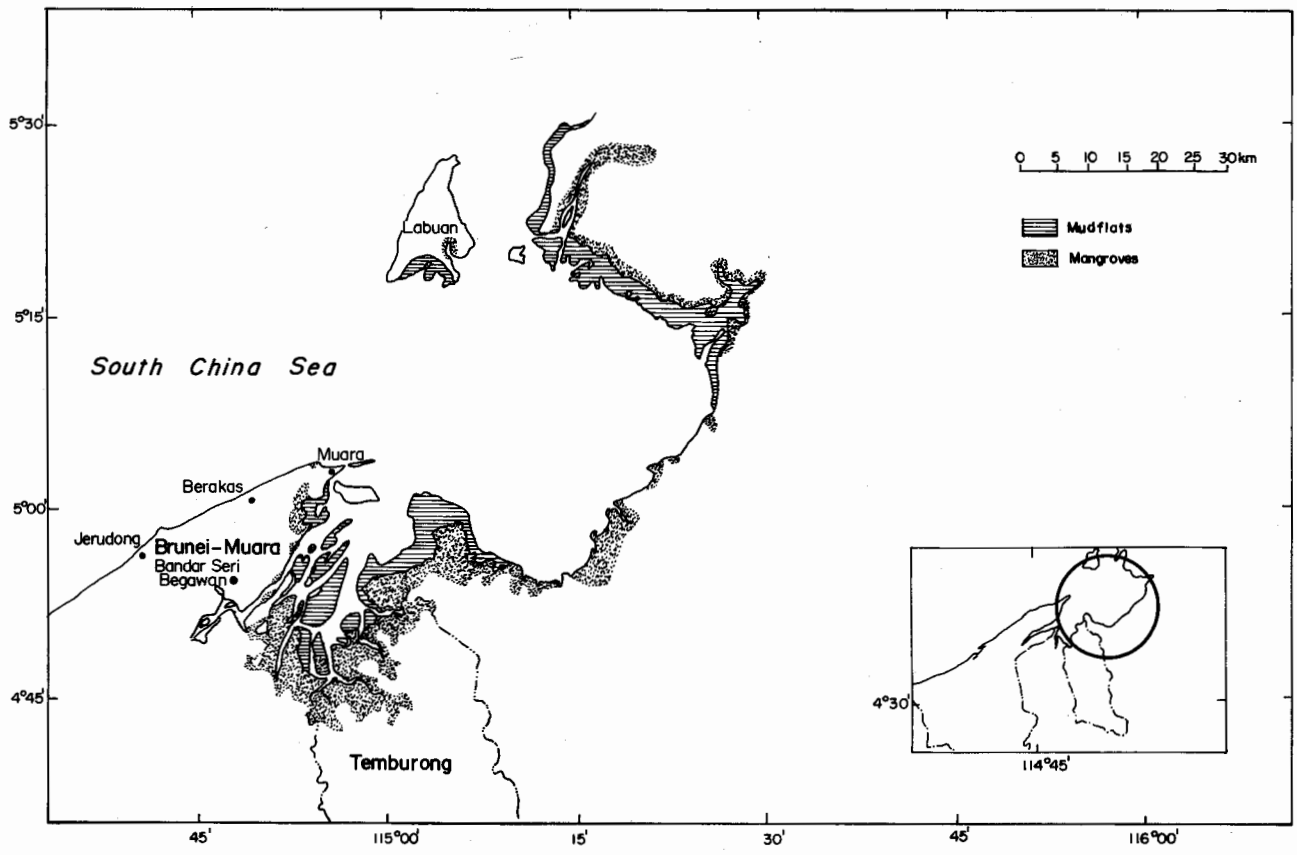


Fig. 3.2. Distribution of mudflats and mangroves in Brunei Bay.

loss of soil and other resources due to the battering effects of wave action. The strips of mangroves around small islands in Brunei Bay and along riverbanks and estuaries are a line of defense against erosion due to strong water movements caused by watercraft traffic.

During the course of surveying the mangrove swamps of Belait, Tutong, Brunei-Muara and Temburong Districts, the team saw shrimp and fish fry in great quantities among the tangled roots of *bakau* (*Rhizophora*) plants, presumably using the mangroves as nursery habitat. Based on his studies in Papua New Guinea, Frusher (1986) stated that juvenile penaeid shrimp use the mangrove ecosystem as a nursery habitat. Quite a few have obtained evidence to support this view (Lewis et al., 1985). Also, species of fish have been seen throughout the estuarine mangrove system.

In recent years, not a few (Macnae 1974; Martosubroto and Naamin 1977; Turner 1977; Chong 1980; Christensen 1982; Macintosh 1982; Lewis et al. 1985; Frusher 1986; Umali et al. 1987) have stated that mangroves are essential links in the: (1) food chain; (2) life history; and (3) shelter and physical protection of shrimp (Frusher 1986) which are represented in Brunei Darussalam by the marine forms *Penaeus merguiensis*, *P. indicus*, *P. monodon* and *Metapenaeus brevicornis* (Currie 1982)

The mangroves in the country are known to provide habitat for many animal species, some of which are very unique. The *nipah*-mangrove islands in the immediate vicinity of Bandar Seri Begawan harbor substantial populations of proboscis monkeys (*Nasalis larvatus*), which is a protected wildlife; crab-eating macaques (*Macaca fascicularis*); silver-leaf monkey (*Presbytis cristata*); a variety of birds such as stork-billed kingfisher *(Pelargopsis capensis*), white-collared kingfisher *(Halcon chloris*) and forest kingfisher (*Ceyx erithacus*).

P. Siarau, a *nipah*-mangrove island in Brunei Bay, southeast of Bandar Seri Begawan, is the roosting site for an enormous population of the flying fox *(Pteropus vampyrus)* (Mittermeier 1980).

The mangroves on P. Berambang have been proposed for designation as a conservation area for the proboscis monkey, and the whole of P. Siarau for the flying foxes (MOD-DOTCP No. 5, 1986c).

Mangrove harvest

In the past, the mangrove resources of Brunei Darussalam had been a major source of: (1) bark for the manufacture of cutch, a dye extract used in tanning industry from 1901 to 1952; in 1911, cutch accounted for 90% of the export (Stewart 1986) and (2) wood for the charcoal industry (Lim and Shariffudin 1975) and for firewood for local use as well as for export mainly to Hong Kong (1942 to 1960). Kg. Berbunut in Brunei Bay is the main center of charcoal production (Lim and Shariffudin 1975). According to MOD-DOTCP No. 8 (1986e), charcoal is produced by four kilns, i.e., three on P. Berbunut and one on P. Baru-Baru.

Mangrove firewood is still used for daily cooking and ironing where electricity and gas are not available. Mangrove charcoal is still used for cooking special dishes, e.g., *satay* (cooked only over a charcoal fire); baking traditional cakes such as *kueh sapit, kueh baulu, kueh bingka, kueh rangin*; and boiling water by coffee shops (because charcoal is efficient and cheap and because coffee shop owners are very slow in changing to gas and electricity) (Lim and Shariffudin 1975).

Mangrove charcoal is traditionally used by Brunei Darussalam women as a sort of postnatal treatment: "The local women believe that after giving birth a mother should stay near charcoal fire to warm herself and they also believe that the heat helps to contract the muscles of the womb" (Lim and Shariffudin 1975).

At present, mangrove resources continue to be exploited for charcoal and firewood on a small scale and for poles for piling in construction work. Charcoal production, however, is declining because of competition from "bottled gas" (Stewart 1986). On the other hand, the demand for mangrove poles has increased markedly in recent years as a result of the substantial development of the building industry. More than 90% of the poles are obtained from Selirong and Labu Forest Reserves in Temburong District.

Only *R. apiculata (bakau minyak)* forest is exploited for firewood, charcoal and pole production. *X. granatum (nyireh bunga)* and *B. gymnorrhiza (linggadai)* forests are not exploited; thus, trees of said forests attain moderately large dimensions (up to 50 cm diameter for *X. granatum* and up to 40 cm for *B. gymnorrhiza).*

Mangroves for shrimp culture

Assuming that there are suitable mangrove areas for conversion into shrimp ponds, the next question is: how much of the mangrove area should be allocated for pond aquaculture and for conservation? Probably, there may be an optimum ratio of pond area to mangrove area that can be maintained so that sufficient litter is produced to sustain the detritus/detritivore link necessary for the maintenance of adjacent natural shrimp fisheries. Hamilton and Snedaker (1984) suggested that the quantity of mangrove forest to be converted into fishponds should not exceed 1 ha of pond for 4 ha of natural mangrove kept untouched. However, they also stated that this ratio: (1) is only an approximation expected to vary from one country to another or from one mangrove type to another; and (2) can be determined only after appropriate research has been carried out.

There is very little known information about the impact of clearing local mangrove habitats on fish resources but work in some countries, e.g., the US and Indonesia, has indicated that significant reductions in shrimp production occur when mangrove vegetation is removed.

In the US, Mock (1966) demonstrated what can happen to a shrimp nursery area when it is altered. The altered area harbored 2.5 times less brown shrimp (*P. aztecus*) and 14 times less white shrimp (*P. setiferus*) than the natural habitat. This was attributed to the reduced organic content and changes from the normal soft, muddy substrates.

In Indonesia, Martosubroto and Naamin (1977) attempted to relate surface areas of mangrove forest to commercial shrimp catches in those areas and adjacent waters. They obtained a linear relationship between these two variables, which indicates that shrimp production increases with the size of the mangrove forest area; implying that any reduction of the mangrove forest is likely to reduce shrimp production. Whether this relationship is one of cause-and-effect is not known; evidence is needed to show whether the destruction of mangroves has reduced shrimp production in these areas. Turner (1977) came up with a similar correlation over a wider geographical area between intertidal vegetation and commercial yields of penaeid shrimp. Gedney et al. (1982) also showed a statistical correlation between mangrove area and shrimp landings in Peninsular Malaysia.

In a report on "Shrimp pond siting and management alternatives in mangrove systems in Ecuador," Snedaker et al. (1986) stated the following:

> A most pressing issue in CAMP programs worldwide is the effect of converting vast areas of mangrove to aquaculture, particularly shrimp ponds. If too many ponds are created and mangrove converted, the supply of larvae stock for the ponds is depleted and other coastal fisheries degraded. Ecuador provides an example of massive conversion and subsequent depletion. The shrimp mariculture industry in Ecuador is the largest and most advanced in Latin America and is a major source of foreign currency

earnings. In recent years, the industry began facing a number of economic and technical problems; namely, the uncertainty and scarcity of shrimp postlarvae (PL) supply and the increased operating costs. In 1984/1985, a research project was undertaken to assess the relationship among shrimp pond siting and management practices, and the acknowledged reductions in mangrove forests and PL stocks.

Among the conclusions distilled is that "conversion of mangrove forests for the construction of shrimp ponds is an ecologic and economic mistake."

Nipah swamp habitat

Nipah is the second most dominant species in the mangrove ecosystem of Brunei Darussalam in terms of areal coverage (Appendix 2).

Subtypes. Two of the seven recognized subtypes which are common are *Nypa* and *Nypa-Heritiera*.

Nypa is characterized by pure stands of *N. fructicans (nipah)* and is usually associated with *Heritiera globosa (dungun)* in the *Nypa-Heritiera* subtype. Both subtypes tend to merge with *Nypa-Heritiera*, and there is rarely a precise boundary between them. The former is also of widespread occurrence in the other mangrove habitat type.

Nypa-Heritiera is characterized by dense stands of *N. fructicans (nipah)* with *H. globosa (dungun)* of the family Sterculiaceae emerging above the canopy of *Nypa* and attaining massive dimensions. At the downriver limits of this subtype, *Excoecaria agallocha (buta-buta)* and *B. gymnorrhiza (linggadai)* occur, whereas towards the upriver limit (where the influence of freshwater is greatest), *Brownlowia argentata (melapeh), Aegiceras corniculatum (sekang mata)* and *Glochidion littorale (buah kenanang)* are common.

The approximate area occupied by the *Nypa* and *Nypa-Heritiera* subtypes is 2,725 ha, broken down as follows (Table 3):

District	*Nypa*	*Nypa-Heritiera*	Total
Temburong	534	124	658
Brunei-Muara	303	726	1,029
Tutong	301	357	658
Belait	273	107	380
Total	1,411	1,314	2,725

Compared to those of its Malaysian neighbors, the total mangrove area of Brunei Darussalam is indeed small. Peninsular Malaysia has 13,542 ha (Heath 1949), and Sarawak and Sabah have 121,500 ha (Dennett 1925). In Malaysia, the *nipah* is exploited for alcohol, sugar and shingle production (Hamilton and Snedaker 1984).

Occurrences. In Temburong, *Nypa, Nypa-Heritiera* and *Rhizophora* dominate, mainly upstream of Temburong, Pandaruan and Duwan Rivers and their tributaries. Both *Nypa* and *Nypa-Heritiera* occur in various but small proportions in Brunei-Muara. In Tutong, both occur, along with the undifferentiated and *Rhizophora* subtypes. In Belait, *Nypa* and the undifferentiated subtype dominate. The former is concentrated on the lower west bank of Belait River. *Nypa-Heritiera* is virtually absent.

Plant Density. The *nipah* swamp in Belait, Tutong, Brunei-Muara and Temburong Districts has a very dense canopy with luxuriant growth. To obtain a rough estimate of the density of *nipah* plants in a given area of swampland, the number of plants and leaves per plant

was determined by actual count, and the length of the leaves, by visual estimate in nine 10-m x 10-m quadrats laid out in selected *nipah* swamp areas; one in each of the four districts. The results are: (1) the average number of *nipah* plants per hectare of *nipah* swamp is 2,240; (2) the average number of leaves per plant is 5.5; and (3) the average length of leaves is 8.5 m.

The *nipah* swamp habitat is also characterized by the large amount of litter in the form of fallen leaves cluttered over the forest floor filling up much of the spaces between clumps. The leaves, which in other countries are harvested for thatch, are not now utilized in Brunei Darussalam as they were before the advent of the oil economy.

Fauna. Insects (particularly mosquitoes), snails, birds and monkeys have been observed in the *nipah* swamp habitat in the four districts during field surveys.

Products. Nowadays, *nipah* is seldom used. The leaves are used as roofing material, and sugar extracted from inflorescence stalks is used as an ingredient for a kind of cake in a very limited scale. The most abundant species caught by fishermen in Brunei Darussalam from waterways around *nipah* swamps are the mangrove crabs, shrimp and some species of fish.

Dense strips of *nipah* line the embankments of portions of tidal rivers, estuaries and other habitats flooded by brackishwater. Here, *nipah* palms act as sediment traps and minimize substrate erosion and evaporation loss. The detritus derived from decomposing *nipah* material through bacterial, protozoan and fungal action is utilized by a group of consumer organisms in the *nipah* palm habitat. So, these palms contribute significantly to energy flow within the swamp ecosystem. The detrital mud is inhabited by numerous crabs, snails and bivalves; while the creek and water channels, by various estuarine fish.

Mangrove forest reserves

A forest reserve is a tract of forest land set aside by government for protection and production purposes. There are two such reserves in Brunei Darussalam that have mangrove lands: (1) Selirong Forest Reserve (SFR) and (2) Labu Forest Reserve (LFR). Both are administered directly from the District Forest Office in Bandar Seri Begawan.

SFR comprises the large tidal island of Selirong on the east of Brunei Bay. This reserve is bounded to the north and west by Brunei Bay; to the south, by S. Aloh Besar; and to the east, by S. Bangau (which also marks the national boundary).

LFR is bounded to the north by S. Aloh Besar; by S. Aru to the east; by the state boundary to the south; by the north bank of S. Labu from a point about 2.4 km downstream from Labu Estate, hence a series of four cuts to the state boundary; and to the west, by S. Labu and Brunei Bay.

The areal extent (surface area) in hectares of the two reserves and their forest types are:

Type	SFR	LFR	Total
Mangrove	2,409	5,124	7,533
Peat swamp	-	8,756	8,756
Total land area	2,409	13,880	16,289
Total water area	157	468	625
Grand total	2,566	14,348	16,914

Ninety-four percent of SFR's surface area is occupied by mangrove forest, while 36% of that of LFR, by mangrove forest. Of the two types in LFR, the mangrove forest (5,124 ha) covers the northern and western portions, while the peat swamp forest (8,756 ha, mainly of poor quality) covers the central, eastern and southeastern parts of the reserve.

Based on the study made by ULG Consultants Ltd. and Anderson and Marsden (Forestry Consultants) Ltd. (1984), the mangrove forest subtypes found in the two reserves and their respective areal extents (in hectares) are:

Subtype	SFR	LFR	Total
Bakau	2,338	3,234	5,572
Bakau-Nyireh bunga	-	273	273
Bakau-Nipah	-	787	787
Nyireh bunga	71	101	172
Linggadai	-	71	71
Nipah	-	534	534
Nipah-Dungun	-	124	124
Total	2,409	5,124	7,533

As may be gleaned from above, SFR is virtually (97%) composed of *bakau* subtype; and LFR, of five mangrove forest subtypes of which *bakau* predominates (63%), which in some localities occurs in mixture with *nyireh bunga* and *nipah*.

Analyses of production figures from the two reserves from 1977 to 1984 show these: (1) Firewood production remained relatively constant in the last eight years. (2) With the exception of 1980, when production was substantially greater, annual charcoal production is 264 t. (3) Pole production increased since 1979, and with the heavy demand from the expansion of the building industry, the quantity of poles extracted from these reserves is likely to increase in the near future.

Firewood production is very largely comprised of *bakau* species (*R. apiculata*), while charcoal production, only of *bakau* species.

Permits are issued for the extraction of wood for firewood, charcoal and poles. However, "there is not any significant silvicultural management" being applied. As stated in the MOD-DOTCP No. 8 (1986e), "Active control or management is not undertaken because the royalty offtake for the whole country is very low (about B$11,000*) and thus, not regarded as cost effective by the Department of Forestry, Ministry of Development."

Economic aspects

The major uses of mangrove resources included in the past cutch manufacture (1901 to 1952), firewood and charcoal for local use and for export (1943 to 1960). Now, mangrove resources continue to be exploited for firewood and charcoal on small scale and for poles (for piling in construction work) on commercial scale. The demand for mangrove poles increased markedly from 1983 to the present as a result of the substantial development of the building industry. Most of the poles are obtained from SFR and LFR in Temburong District. Details of present permits issued for mangrove use and locations are in Fig. 3.3 and Tables 3.9 and 3.10.

As mentioned above, the total revenue derived from mangrove forests did not exceed B$11,000 in 1983 and the 1984 total was similar. However, according to MOD-DOTCP No. 8

*B$2.09 = US$1, as of mid-October 1987.

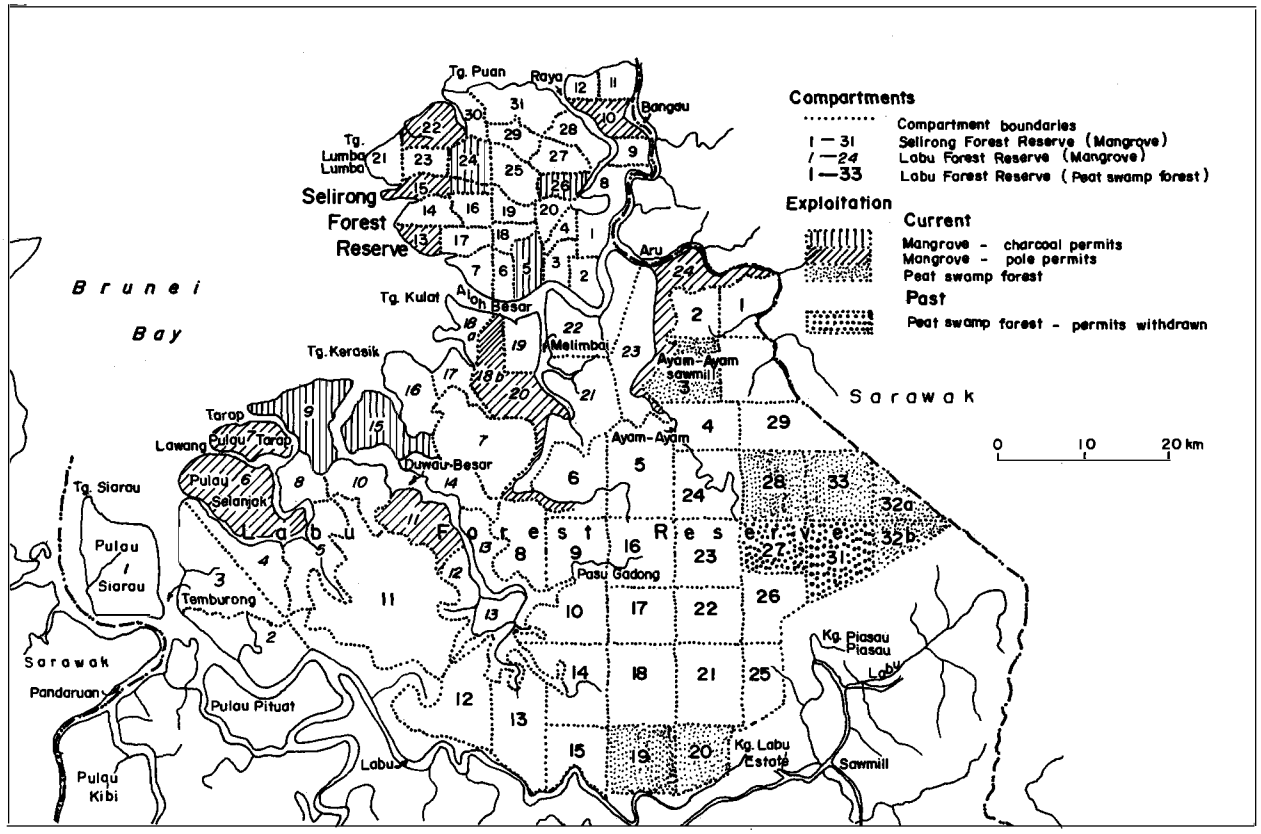


Fig. 3.3. Compartments and exploitation of Selirong and Labu Forest Reserves. Source: DOFor records.

Table 3.9. Details of current mangrove charcoal permit areas in the Selirong Forest Reserve (SFR) and the Labu Forest Reserve (LFR) in Temburong District.

Permit no.	Forest reserve	Permit holder	Compartment no.	Area (ha)	Entry date
04/79	LFR	Ho Chuan Ooi	15	184	1-03-79
06/79	LFR	Ang Chui Thian	9	255	1-01-79
10/65	SFR	Lee Chai Hin	26	68	1-10-65
11/62	SFR	Lee Lim Ghee	24	89	11-10-62
05/79	SFR	Haji Hamid bin Matrais	5	87	1-01-79
Total		5		683	

Source: Unpublished DOFor records.

(1986e), the resource "generated a known market value of over B$1 million in 1984 and demand for its products".

Management Issues

The mangrove forests in Brunei Darussalam are not intensively exploited, and there are no known serious conflicts among users. However, there is increasing interest to convert mangrove swamps into brackishwater shrimp ponds. And this may become a future issue of resource use conflict. Due to limited natural resources, the existing mangroves are, therefore, valuable and should be managed on a sustainable basis.

Table 3.10. Details of current mangrove pole permit areas in the Selirong Forest Reserve (SFR) and the Labu Forest Reserve (LFR) in Temburong District.

Permit no.	Forest reserve	Permit holder	Compartment no.	Area (ha)	Entry date
04/62	LFR	Haji Rahman bin Kilali	11	200	16-07-62
11/62	LFR	Haji Besar bin Haji Sahat	18(b)	198	18-10-62
12/62	LFR	Haji Naim bin Duraman	20	95	1-12-62
03/79	LFR	Haji Naim bin Duraman	6	342	1-3-79
01/79	LFR	Haji Mastan	7	136	1-1-79
02/79	LFR	P.O.K.K. Haji Ali bin Ismael	24	227	1-1-79
07/62	SFR	Haji Laidin bin Maserudin	13	52	1-10-62
01/66	SFR	Haji Rahman bin Kilali	10	95	29-1-66
12/63	SFR	Haji Rahman bin Kilali	15	62	15-8-63
11/81	SFR	Mohamad Noor bin Othman	22	134	15-10-81
Total		10		1,541	

Source: Unpublished DOFor records.

Coral Reefs, Algae and Seagrasses

CHOU LOKE MING, M.W.R.N. DE SILVA
AND ALAN T. WHITE

Coral Reefs

Brunei Darussalam is not well-endowed with coral reefs and coral formations because of its somewhat turbid offshore waters. Areas (Fig. 3.4) known to have coral growth include P. Punyit, Pelong Rocks, Two Fathom Rock, Brunei Patches and Louisa Reef (about 230 km off the Brunei Darussalam coast). There are other small coralline patch reefs which remain unexplored. No reef formations were observed within Brunei Bay. The total areal extent of coralline areas is estimated to be approximately 4,500 ha within the territorial waters of Brunei Darussalam.

Little research has been done on coralline-related resources of Brunei Darussalam. This section relied heavily on first-hand field observation. A few existing references used include: DOTCP, Vols. 1-4 (1987c); Mittermeier 1980; and Birkenmeier 1970.

Field Surveys. Field observations were made at Pelong Rocks, Two Fathom Rock and P. Punyit. These are all easily accessible by local boat from Muara Port area within 1 to 1.5 hours. Although these sites are probably not representative of the richest coral areas farther offshore, they give good indication of the general quality, diversity and extent of coral resources in Brunei Darussalam. Pelong Rocks is the most thoroughly documented area in this investigation.

The coral reef sites were observed by wide area snorkel surveys and line transects on scuba. A general collection of hard coral samples was made at each reef site for laboratory

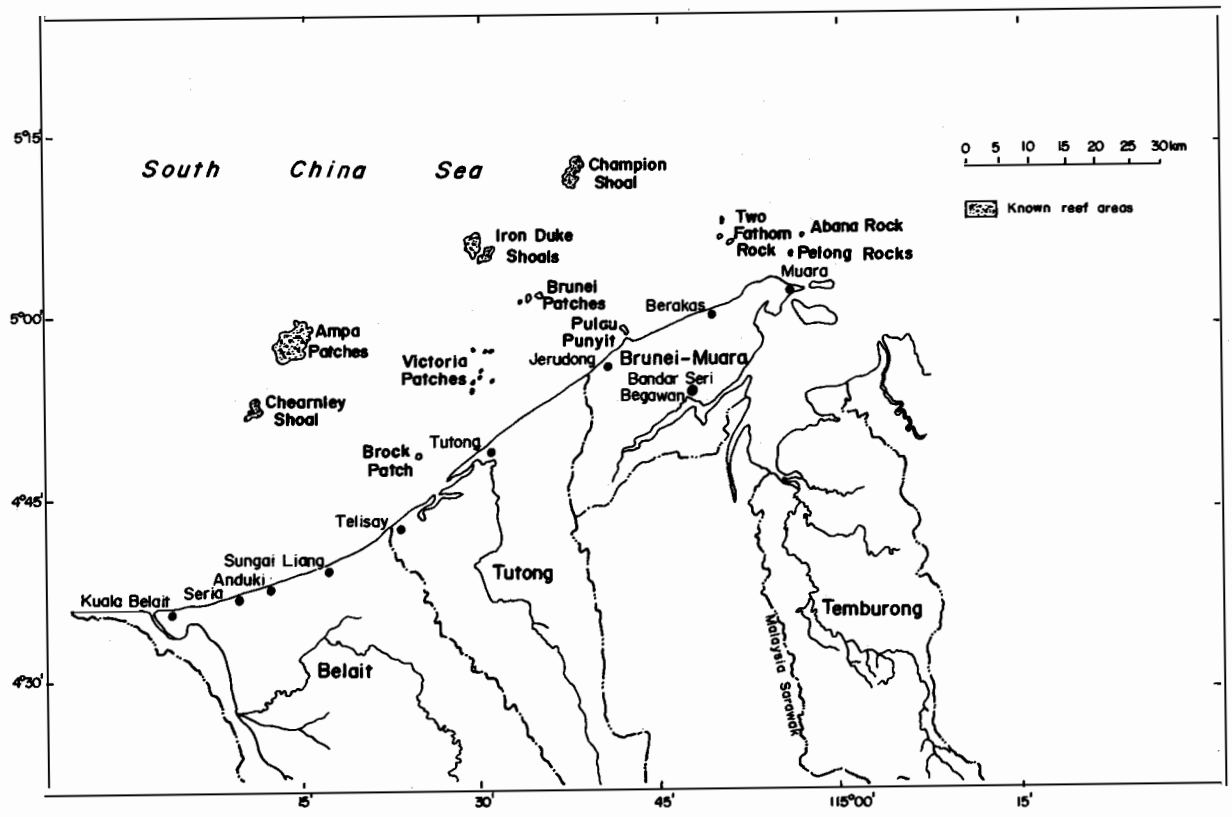


Fig. 3.4. Location of known reef areas.

identification aimed at expressing the coral diversity at each of the three selected reefs. The community structure of the reefs was determined along depth-specific, 100-m parallel-to-shore line transects.

These transects were established at Pelong Rocks and Two Fathom Rock. Fish species diversity and abundance per unit area was observed along 60-m line transects (Russ 1984). This method selects 18 families of common reef fish and counts the number of species and total individuals for each family within 750 m^2. The 18 families were selected based on their importance to fishermen as "target species"; how "visible" they were on the coral reef; and their being easy to count. Most common reef fish were covered in the sample.

Description of Sites. Pelong Rocks is a small islet of uplifted, scattered rock formations and a small rocky land surface of about 100 m in diameter. A lighthouse sits on the highest point 13 m above sea level. The entire length of rock formations on the north-south line is about 900 m. The higher parts of the land surface are vegetated with several trees and small scrub forest. Several seabirds nest there. The islet and associated rocky outcrops occupy an area of 2 ha (Fig. 3.5).

The islet and rocks are surrounded by a gradually sloping fringing coral reef. The width to the 10-m isobath varies from about 50 m around the northern rocks to 200 m on the southwest side and 300 to 400 m on the east side.

The fringing reef is generally flat without much topographical variation except in the east side where some large, 2 to 3 m-high coral outcrops occur. There are no steep drop offs from the reef flat. On the southwest side, the reef slopes down on about a 20° decline, the steepest drop off observed. The reef has three not well-defined zones: (1) the inshore reef flat dominated by sand, rubble, rock and scattered small hard coral colonies; (2) the reef crest area which is

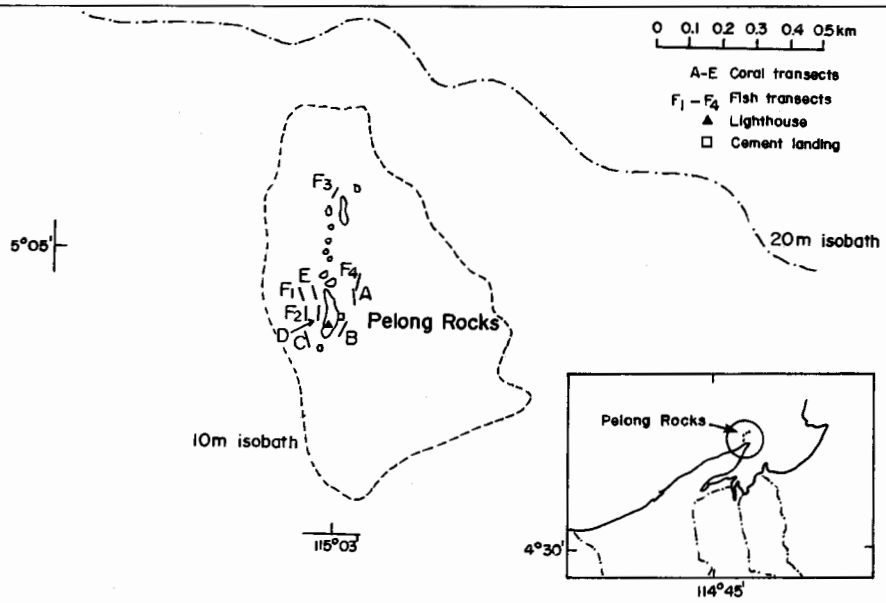


Fig. 3.5. Pelong Rocks with location of transect sites.

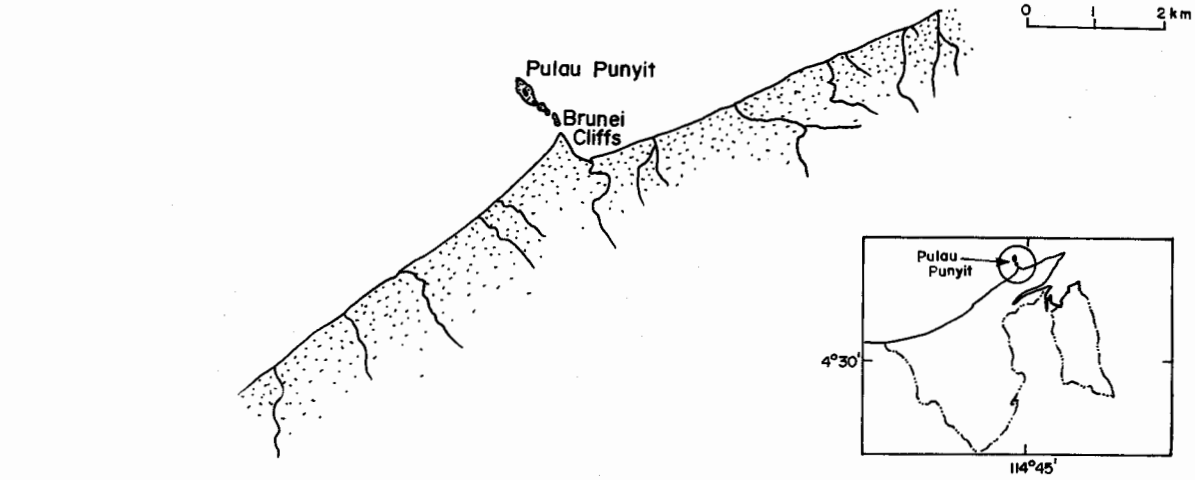


Fig. 3.6. Location of P. Punyit.

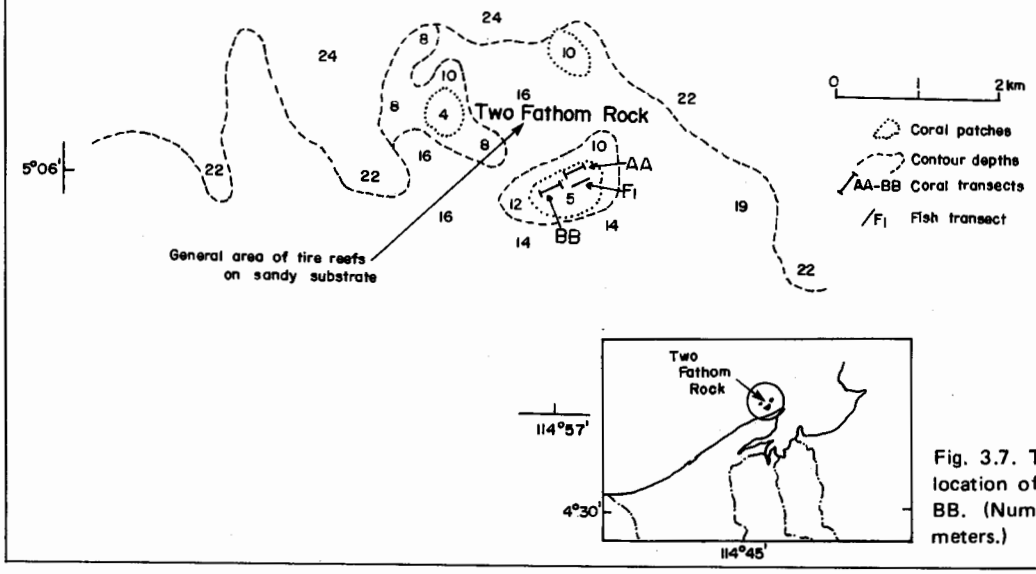


Fig. 3.7. Two Fathom Rock with location of Transect Sites AA and BB. (Numbers indicate depth in meters.)

wide and not distinct where most coral formations occur between 2 and 8 m depth; and (3) the reef slope below 8 m composed of a few scattered corals and mostly sand and rubble.

Impressions of the coral reef environment include a generally low coral cover and a high cover of sand, rubble and rock. There is a low diversity of fish species although fish tend to be large in size. The water visibility varied from 3 to 7 m during observations. There were some recent (5 to 10 years ago) disturbances on the reef which resulted in broken corals, dead standing corals and rubble. These were attributed to blast fishing at various times.

P. Punyit consists of a main rocky island 200 m long and 50 m wide covered with vegetation located 0.6 km off the coastline. Its associated rocky outcrops are strung out between the island and Brunei Cliffs on the mainland with a few scattered to its north (Fig. 3.6). The island and the associated rocky outcrops occupy an area of 8 ha and are surrounded by gradually sloping fringing reefs with low coral cover. Large rocks occur abundantly in the shallower waters around the island and the rocky outcrops and offer an excellent habitat to the gastropod mollusks found abundantly on these rocks. Macroalgae are also abundant and diverse, spreading down to lower depths.

Poor visibility, which did not exceed 3 m, made the observation of fish difficult, but serranid groupers of 30 cm length were commonly seen. Nudibranchs were represented by the various species of *Casella*, *Chromodoris* and *Phyllidia*. Low visibility could possibly be due to sedimentation caused by soil mining activities along the beaches of the coast nearby and to the closeness of this reef to the mainland.

Two Fathom Rock is approximately 8 km from the northern coastline and consists of three raised seafloor areas surrounding a 16 m deep basin (Fig. 3.7). To the north, east and west, the seafloor dips to 22 m while beyond the south, to 12 to 16 m. Of the three raised areas, only the western and southeastern ones are the most shallow at 4 m and support coral reefs with a rich and varied fauna.

The shallower raised reef was surveyed for substrate cover and fish diversity and abundance at about 10 m depth. Visibility approached 10 m. Coral cover was healthy and diverse with some large outcrops of *Porites* with numerous coral fish hovering over. Fish diversity was somewhat higher than Pelong Rocks; and abundance, notably more. Large schools of caesionids and small serranids were seen. Hard coral cover was estimated at 30%. Other invertebrate life was rich and diverse. Abundant were the colorful ascidian, *Polycarpa aurata*; several species of soft corals; holothurians; crinoids; anemones; and the blue starfish, *Linckia laevigata*. Large coral outcrops mainly of *Porites lutea* supported the differently colored fanworm, *Spirobranchus giganteus*.

Hard Coral Diversity. The distribution of hard corals, including octo- and hydrocorals among the 3 sites, is listed in Table 3.11. Pelong Rocks supported the highest diversity of scleractinian corals with 60 species belonging to 43 genera. The lowest diversity, 19 species from 12 genera, was recorded from P. Punyit. At Two Fathom Rock, the diversity was approximately 25% less than that at Pelong Rocks, which may reflect fewer observations made at the former. The octocoral, *Tubipora musica* (organ-pipe coral), was common to all 3 sites while various species of hydrocorals (*Millepora*, *Distichopora*, *Stylaster*) were found only at Pelong Rocks and Two Fathom Rock.

The total of 88 species in 52 genera of hard corals from the 3 sites combined represents a diversity which is less than that found in Singapore waters carrying a high sediment load (Chuang 1977). Higher generic diversities were recorded for Peninsular Malaysia with 58 genera (Betterton 1981); west coast of Sabah, 56 genera (Wood 1979); and Philippines, 69 genera (Pichon 1977). However, it cannot be suggested that the coral diversity in Brunei Darussalam is low as the collections were restricted to only 3 sites and sampling was limited. Actually, diversity is high for the limited sampling sizes. Further sampling from the same and other reef sites will result in a more comprehensive list of the actual diversity. The offshore

Table 3.11. Corals collected from Pelong Rocks (Site 1), P. Punyit (Site 2) and the Two Fathom Rock (Site 3).

	Site 1	Site 2	Site 3
Class: Anthozoa			
Subclass: Zoantharia			
Order: Scleractinia			
Suborder: Astrocoeniina			
Family: Thamnasteriidae			
Psammocora contigua	+		
Psammocora sp.		+	+
Family: Siderastreidae			
Pseudosiderastrea tayamai		+	
Family: Pocilloporidae			
Madracis kirbyi			+
Seriatopora[a] *hystrix*	+		+
Stylophora[b] *pistillata*	+		+
Pocillopora[b] *damicornis*	+		+
P. eydouxi	+		+
P. verrucosa	+		+
Family: Acroporidae			
Acropora[b] *florida*	+		
A. formosa	+		
A. hyacinthus	+		+
A. Palifera	+		
A. robusta	+		
Acropora sp. 1	+		
Acropora sp. 2			+
Acropora sp. 3			+
Acropora sp. 4			+
Montipora verrucosa	+		
Montipora sp. 1	+		
Montipora sp. 2		+	
Montipora sp. 3		+	+
Montipora sp. 4		+	
Suborder: Fungiina			
Family: Agariciidae			
Leptoseris sp.	+		
Pavona[b] *frondifera*	+		
P. varians	+		
Pavona sp.	+		+
Gardineroseris ponderosa	+		+
Coeloseris mayeri	+		+
Pachyseria speciosa	+		
Family: Fungiidae			
Fungia[b] *echinata*	+		
F. fungites	+		
Fungia sp.	+		
Halomitra[b] *pileus*	+		
Heliofungia actiniformis	+		
Herpolitha limax	+		
Polyphyllia[b] *talpina*	+		+
Sandalolitha robusta	+		+
Family: Poritidae			
Alveopora sp.			+

Continued

Table 3.11 (continued)

Goniopora stokesi	+	+	+
Porites lutea	+	+	+
Suborder: Faviina			
Family: Faviidae			
Caulastrea tumida	+		
Cyphastrea chalcidicum	+	+	+
Cyphastrea microphthalma		+	+
Diploastrea heliopora	+		+
Echinopora lamellosa	+		+
Favia[b] *amicorum*			+
Favia favus	+	+	
Favia sp.		+	+
Favites abdita			+
Favites sp. 1	+	+	
Favites sp. 2		+	+
Favites sp. 3		+	+
Favites sp. 4			+
Goniastrea retiformis			+
Goniastrea sp.	+	+	+
Hydnopora exesa	+		+
Leptastrea sp.	+		+
Leptoria phrygia			+
Montastrea magnistellata	+		
M. valenciennesi	+	+	+
Oulastrea crispata	+		
Plesiastrea versipora	+		
Platygyra[b] *daedalea*		+	
Platygyra lamellina	+		
Platygyra sinensis		+	+
Platygyra sp.	+		
Family: Merulinidae			
Merulina[b] *ampliata*	+		+
Family: Oculinidae			
Galaxea fascicularis	+		+
Family: Mussidae			
Lobophyllia[b] *costata*	+		
Lobophllia sp.	+		
Symphyllia recta	+		+
Symphyllia sp.	+		
Family: Pectiniidae			
Mycedium elephantotus	+		+
Oxypora lacera	+		+
Suborder: Caryophylliina			
Family: Caryophylliidae			
Catalaphyllia jardinei			+
Euphyllia[b] *ancora*	+		+
E. divisa	+		
Physogyra lichtensteini	+		
Plerogyra sinuosa	+		
Family: Dendrophylliidae			
Heteropsammia michelni			+
Turbinaria frondens		+	
Turbinaria sp.	+		+

Continued

Table 3.11 (continued)

Subclass: Octocorallia			
Order: Stolonifera			
Family: Tubiporidae			
Tubipora[b] *musica*	+	+	+
Class: Hydrozoa			
Order: Milleporina			
Family: Milleporidae			
Millepora[b] *exesa*	+		+
M. platyphylla	+		+
Order: Stylasterina			
Family: Stylasteridae			
Distichopora violacea	+		
Stylaster spp.			+

[a]The corals were recorded during four 45-minute dives in Pelong Rocks, and one 45-minute dive each in P. Punyit and Two Fathom Rock.
[b]Genera previously recorded for Brunei Darussalam.

Louisa Reef should have a distinct reef life that will be of much biological interest.

Community Structure. This was studied over five 100-m line transects (A to E) at Pelong Rocks (Fig. 3.5) and two 100-m line transects (AA to BB) at Two Fathom Rock. No line transects were established at P. Punyit because of generally low coral cover and poor visibility. The percentage substrate cover of the different transects on the reefs of Pelong Rocks and Two Fathom Rock is shown in Table 3.12.

The live coral cover at Pelong Rocks was best (40%) at the southwest drop-off and generally higher at the western side. The eastern side had low live coral covers of less than 10%. The abiotic component of mainly sand and rubble was high at all transects, and algae were more prominent at the eastern transects. Soft corals, sponges and holothurians made up most of the reef-associated organisms. The community structure along each of the 5 transects at Pelong Rocks is listed in Tables 3.13-3.17.

Acropora was the dominant genus at the eastern transects while *Montipora* of the encrusting growth form dominated the southwestern transects. The generic diversity of 5 to 17 per 100 m over the 5 transects was low compared to similar studies on Singapore reefs which registered generic densities of 15 to 28 per 100 m (Chou and Koh 1986). *Acropora, Montipora* and *Favia* were the most widely distributed genera in all 5 transects. All three were also found at the 2 transects at Two Fathom Rock. In terms of colony number, either *Acropora* or *Montipora* dominated the transects studied. Colonies on the eastern side were less abundant than on the western and southwestern sides.

Coral colonies were generally smaller on the eastern side than on the western and southwestern slopes. The maximum colony size of 95 cm diameter was recorded for *Acropora* on the eastern side while many genera on the western and southwestern sectors exceeded 100 cm diameter with a colony of *Favites* reaching 440 cm diameter at Transect C. This indicated

Table 3.12. Reef component characteristics of Pelong Rocks and Two Fathom Rock.

	Pelong Rocks					Two Fathom Rock	
Transect	A	B	C	D	E (Mean)	AA	BB (Mean)
Depth (m)	4	3	10	3	3	8	11
Rubble, sand (%)	50.07	70.23	41.65	57.05	54.00	38.22	53.80
Algae (%)	37.06	26.42	17.55	1.95	14.20	22.20	22.82
Reef-associated organisms (%)	3.86	0.32	0.65	6.20	6.60	12.68	2.09
Dead coral (%)	-	-	-	2.85	-	-	0.24
Live coral (%)	9.01	3.03	40.15	31.95	22.40	26.90	16.20

Table 3.13. Reef community structure of Pelong Rocks (east), transect A, 4 m depth. The CRMP survey was done on 20 April 1987.

	Percentage cover		No. of individuals per colony	Size range (cm)
Abiota	50.07			
Rubble		30.28		
Sand		19.79		
Algae	37.06			
Algal assemblages		5.56		
Turf algae		31.50		
Reef-associated organisms	3.86			
Soft corals		3.41	22	5 - 32
Holothurians		0.45	3	
Hard Corals	9.01			
Pocilloporidae				
Pocillopora		0.18	2	8 - 10
Seriatopora		0.15	1	15
Acroporidae				
Acropora		3.96	9	2 - 95
Montipora		0.62	6	4 - 15
Poritidae				
Porites		0.50	3	7 - 23
Faviidae				
Cyphastrea		0.60	2	24 - 36
Favia		0.75	7	5 - 16
Favites		0.30	2	10 - 20
Hynophora		0.20	1	20
Leptastrea		0.20	1	20
Montastrea		0.38	4	8 - 10
Oulastrea		0.20	1	20
Oculinidae				
Galaxea		0.97	4	11 - 53

Table 3.14. Reef community structure of Pelong Rocks (east), Transect B, 3 m depth. The CRMP survey was done on 20 April 1987.

	Percentage cover		No. of individuals per colony	Size range (cm)
Abiota	70.23			
Rubble		66.09		
Sand		4.14		
Algae	26.42			
Algal assemblages		2.87		
Macroalgae		13.40		
Turf algae		10.15		
Reef-associated organisms	0.32			
Soft corals		0.32	2	10 - 22
Hard Corals	3.03			
Acroporidae				
Acropora		0.98	4	13 - 40
Montipora		0.15	1	15
Agariciidae				
Coeloseris		0.10	1	10
Poritidae				
Porites		0.40	3	10 - 20
Faviidae				
Cyphastrea		0.58	2	20 - 38
Favia		0.06	1	6
Favites		0.18	1	18
Hynophora		0.10	1	10
Montastrea		0.18	1	18
Oculinidae				
Galaxea		0.30	1	30

Table 3.15. Reef community structure of Pelong Rocks (west), Transect C, 10 m depth. The CRMP survey was done on 14 April 1987.

	Percentage cover		No. of individuals per colony	Size range (cm)
Abiota	41.65			
Rubble		40.65		
Sand		1.00		
Algae	17.55			
Turf algae		17.55		
Reef-associated organisms	0.65			
Sponges		0.60	2	10 - 50
Holothurians		0.05	1	
Hard Corals	40.15			
Pocilloporidae				
Pocillopora		0.70	4	10 - 20
Seriatopora		0.80	4	10 - 30
Acroporidae				
Acropora		3.50	15	10 - 80
Montipora		9.60	20	5 - 160
Agariciidae				
Pachyseris		5.85	17	10 - 160
Pavona		0.50	3	10 - 30
Fungiidae				
Fungia		2.50	13	5 - 80
Herpolitha		2.20	9	10 - 60
Parahalomitra		0.60	1	60
Poritidae				
Porites		3.00	11	10 - 90
Faviidae				
Cyphastrea		0.55	2	25 - 30
Favia		2.75	11	5 - 50
Favites		4.60	2	20 - 440
Montastrea		0.10	1	10
Mussidae				
Symphyllia		0.30	1	30
Pectiniidae				
Pectinia		2.40	5	10 - 150
Caryophylliidae				
Euphyllia		0.20	1	20

Table 3.16. Reef community structure of Pelong Rocks (west), Transect D, 3 m depth. The CRMP survey was done on 14 April 1987.

	Percentage cover		No. of individuals per colony	Size range (cm)
Abiota	57.05			
Rubble		52.45		
Sand		4.60		
Algae	1.95			
Turf algae		1.95		
Reef-associated organisms	6.20			
Sponges		4.95	13	10 - 110
Soft corals		1.25	7	5 - 50
Dead corals	2.85		8	10 - 130
Hard Corals	31.95			
Pocilloporidae				
Pocillopora		1.65	8	10 - 50
Stylophora		0.60	3	10 - 30
Acroporidae				
Acropora		4.35	13	10 - 170
Montipora		25.25	43	5 - 215
Faviidae				
Favia		0.10	1	10

Table 3.17. Reef community structure of Pelong Rocks (west), Transect E, 3 m depth. The CRMP survey was done on 16 April 1987.

	Percentage cover		No. of individuals per colony	Size range (cm)
Abiota	51.20			
Rubble		43.10		
Sand		8.10		
Algae	14.20			
Algal assemblages		0.90		
Turf algae		13.30		
Reef-associated organisms	6.60			
Sponges		0.50	2	20 - 30
Soft corals		5.30	12	10 - 80
Bryozoa		0.80	1	80
Hard corals and octocorals	28.00			
Pocilloporidae				
Pocillopora		4.90	6	20 - 230
Acroporidae				
Acropora		5.90	7	30 - 200
Montipora		11.00	19	30 - 170
Agariciidae				
Pachyseris		0.80	2	30 - 50
Pavona		0.50	2	20 - 30
Fungiidae				
Polyphyllia		0.10	1	10
Poritidae				
Porites		0.20	1	20
Faviidae				
Cyphastrea		0.30	1	30
Favia		1.60	3	10 - 80
Favites		1.00	4	20 - 40
Montastrea		0.30	2	10 - 20
Platygyra		0.30	2	10 - 20
Oculinidae				
Galaxea		0.30	2	10 - 20
Dendrophylliidae				
Turbinaria		0.40	1	40
Milleporidae				
Millepora		0.40	1	40

the higher degree of establishment of the hard corals on the western and southwestern parts of the reef. Algal cover was higher at the east transects, while reef-associated organisms, at the west.

The reef community structure along the two transects at Two Fathom Rock suggested a reef of comparable quality to Pelong Rocks. Despite the low live coral cover of 5.42%, Transect BB had a generic diversity of 13 per 100 m which was almost similar to the generic diversity of 16 per 100 m at Transect AA (Tables 3.18 and 3.19). *Porites* was dominant at both transects, especially the shallower one, in terms of percentage cover, colony number and size. Reef-associated organisms were more prominent and varied at Transect AA while algae occupied a similar percentage cover at both transects. A greater proportion of sand and rubble was at the deeper transect.

No community structure analysis was made for P. Punyit reefs due to poor coral cover and poor visibility. The coral cover at all transects studied was generally low compared to the reefs of Singapore (Chou and Koh 1986). This may be attributed to the:

1. Turbid conditions and low visibility particularly of P. Punyit;
2. Exposure to heavy surf/wave conditions during times of the year on the eastern side of Pelong Rocks;
3. Probable destruction by fishermen using dynamite; and
4. General lack of coral reef formations along this part of the west coast of Borneo Island.

Table 3.18. Reef community structure of Two Fathom Rock (Transect AA), 8 m depth. The CRMP survey was done on 19 May 1987.

	Percentage cover		No. of individuals per colony	Size range (cm)
Abiota	38.22			
Rubble		21.80		
Sand		16.42		
Algae	22.20			
Algal assemblages		19.78		
Macroalgae		2.42		
Reef-associated organisms	12.68			
Sponges		0.96	3	10 - 20
Anemones		0.04	2	2
Gorgonians		0.24	2	
Soft corals		9.28	36	4 - 180
Zooanthids		1.20		
Starfish (Linckia)		0.58	2	
Holothurians		0.30	4	
Crinoids		0.08	6	
Hard corals and octocorals	26.90			
Pocilloporidae				
Pocillopora		1.40	8	10 - 22
Acroporidae				
Acropora		0.68	4	9 - 25
Montipora		2.26	14	5 - 30
Agariciidae				
Pavona		0.60	4	10 - 20
Poritidae				
Alveopora		0.20	2	10 - 12
Goniopora		0.40	2	40 - 45
Porites		14.74	34	2 - 250
Faviidae				
Cyphastrea		0.20	2	5 - 10
Favia		1.46	12	5 - 20
Hydnophora		0.60	2	25 - 30
Leptastrea		0.46	4	8 - 15
Platygyra		0.24	2	8 - 12
Merulinidae				
Merulina		0.30	2	10 - 15
Oculinidae				
Galaxea		1.06	8	10 - 18
Dendrophylliidae				
Turbinaria		0.40	2	10 - 20
Milleporidae				
Millepora		1.90	6	15 - 40

Reef Fish. Four transects were made to measure fish species diversity and abundances per 750 m^2 of the reef area at Pelong Rocks. The transects were done on the southwest, northwest and east reef flats (Table 3.20).

Since there were no similar observations of reef fish in Brunei Darussalam, the species diversities and abundances (Table 3.20) may serve as a baseline for the area. When compared to other coral reef areas, such as in southern Philippines, the figures are relatively low with several exceptions. It was not expected that the diversity and abundance of reef fish would be high on a reef with relatively low and disturbed coral cover. Also, fishing pressure affects the fish population in general and especially certain "target" species. On the rich and diverse coral reefs, those numbers in Table 3.20 would all be somewhat higher. But if heavy fishing occurred, certain families of fish would be lower. Families either indicating a rich coral area or a heavily fished area are called "indicator" species. These families may help in the evaluation of Pelong Rocks.

Butterflyfish (chaetodontids), for example, are low in diversity and abundance at Pelong Rocks, indicating a relatively poor quality of coral environment. In contrast, groupers (serranids) are high here as contrasted to heavily fished but richer coral reefs in the Philippines. Thus,

Table 3.19. Reef community structure of Two Fathom Rock (Transect BB), 11 m depth. The CRMP survey was done on 18 April 1987.

	Percentage cover		No. of individuals per colony	Size range (cm)
Abiota	69.43			
Rubble		69.41		
Sand		0.02		
Algae	22.82			
Macroalgae		9.65		
Turf algae		12.92		
Coralline algae		0.25		
Reef-associated organisms	2.09			
Sponges		0.70	3	
Anemones		0.20	2	
Soft corals		0.73	7	4 - 27
Crinoids		0.42	4	
Sea urchins		0.04	1	
Dead corals	0.24		1	20
Hard Corals	5.42			
Pocilloporidae				
Stylophora		0.38	2	15 - 23
Acroporidae				
Acropora		0.05	1	5
Montipora		0.44	1	44
Poritidae				
Goniopora		0.04	1	4
Porites		1.59	7	2 - 104
Faviidae				
Cyphastrea		0.20	1	20
Diploastrea		0.10	1	10
Favia		0.69	7	6 - 15
Favites		0.10	1	10
Merulinidae				
Merulina		0.58	2	20 - 38
Oculinidae				
Galaxea		0.24	3	3 - 13
Mussidae				
Symphyllia		0.96	1	96
Caryophyliidae				
Euphyllia		0.05	1	5

Table 3.20. Mean fish species diversity and abundance per 750 m, Pelong Rocks[a] and Two Fathom Rock[b].

	Pelong Rocks		Two Fathom Rock	
	Species	No.	Species	No.
Acanthurids	0.25	8.25	2.00	11.00
Siganids	0.00	0.00	2.00	134.00
Chaetodontids	3.75	21.25	3.00	12.00
Labrids	4.50	134.75	7.00	77.00
Caesionids	1.00	81.00	3.00	171.00
Serranids	3.50	10.25	5.00	19.00
Balistids	0.25	0.25	2.00	2.00
Pomacentrids	8.00	362.00	7.00	1,113.00
Lutjanids	2.00	5.25	1.00	9.00
Pomacanthids	0.50	0.75	0.00	0.00
Carangids	0.50	0.50	1.00	3.00
Nemipterids	1.25	21.25	1.00	33.00
Kyphosids	0.50	0.50	0.00	0.00
Lethrinids[c]	0.00	0.00	1.00	9.00
Mullids[c]	1.00	2.25	1.00	33.00
Pomadasyidae[c]	0.75	1.25	1.00	6.00
Scarids[c]	1.00	51.00	1.00	33.00
Zanclids	0.25	0.75	1.00	1.00
Total	29.00	701.25	39.00	1,636.00

[a]Four 60-m transects at 60 m depth (parallel to shore).
[b]One 60-m transect at 10 m depth.
[c]Species, not differentiated.

fishing must not be intense at Pelong Rocks, as verified by the relatively large size of snappers, groupers and breams seen on the shallow reef flat. These fish are also quite tame, an unusual characteristic in heavily fished areas.

A list of fish species seen at Pelong Rocks during five scuba dives and three snorkel surveys is given in Table 3.21. Although the total number of reef species at Pelong Rocks is much higher, the list at least provides an idea of the most common species found in the area. Cuttlefish were regularly observed in the reef where they spawn. Also, a single black-tip shark was seen over the reef flat at three different times.

One similar transect was made at Two Fathom Rock (Table 3.20). Although the coral habitats were similar at Pelong Rocks and Two Fathom Rock, the total fish diversity of 39 species and 1,636 individuals was somewhat higher than that observed at Pelong Rocks. Several notable differences were the higher abundance of siganids, caesionids, serranids, pomacentrids, lutjanids and mullids at Two Fathom Rock. All these families, except for pomacentrids, are "target" fish. This implied that fishing pressure may be somewhat higher at Pelong Rocks than at Two Fathom Rock, and general impressions indicated a more favorable habitat. But, since only one transect was made, references should be made with extreme care when comparing the two sites.

Reef Management. Although coral reefs are of moderate to low natural quality, they are a scarce resource in Brunei Darussalam waters and have several redeeming features. The reefs warrant protection and management to maintain and improve their quality and usefulness to ensure their existence.

The reef areas are apparently not heavily fished or used for recreation or tourism. Nevertheless, they show signs of disturbance. It is rumored that blast-fishermen from Sabah and/or the Philippines are to be blamed. But this may or may not be so since some local fishermen also frequent the reefs. Yet, the fish population, although not very abundant, is obviously not intensively fished because of the large size and tameness of the fish. It is also important to note that turbid waters do not support luxuriant reef growth and that the deterioration of the reef may be related to increased siltation in recent years.

The ecological and human-related values of the reef areas are that they are:

- Useful for feeding of large pelagic migratory or offshore benthic species;
- Spawning and breeding grounds for cuttlefish, other invertebrates, many fish and other offshore species;
- Used for education and research;
- Potential for tourism; and
- Useful as marine park sites.

Issues generated in relation to the reef areas include:

1. How to prevent destructive fishing or other nonecological uses of the reefs and fisheries;
2. How to encourage restoration of the reefs so that coral cover improves; and
3. How to promote those uses consistent with the ecology of the areas and their limitations.

The general management options possible which would be consistent with the above issues and values are:

1. Total protection of the coral reef to a distance 500 m offshore without provision for any fishing/collecting activities or any other uses damaging to the coral reef area; or
2. Total protection of the coral reef area with allowance for traditional and ecologically sound fishing methods in parts of the reef area.

Table 3.21. Fish at Pelong Rocks (as noted by A. White in five scuba dives in April 1987).

Family	Species
Carcharhinidae (sharks)	*Carcharhinus* sp.
Dasyatididae (stingrays)	*Taeniura* sp.
Synodontidae (lizardfish)	*Saurida gracilis*
	Synodus variegatus
Holocentridae (soldier fish and squirrel fish)	*Apogon* spp.
Apogonidae (cardinalfish)	*Pempheris* sp.
Oplegnathidae	*Oplegnathus fasciatus*
Mullidae (goatfish)	*Parupeneus pleurostigma*
	P. bifasciatus
Serranidae (groupers)	*Cephalopholis boenack*
	C. argus
	C. miniatus
	Epinephelus fasciatus
	E. tauvina
	E. microdon
	Epinephelus sp.
	Anyperodon leucogrammicus
	Plectropomus truncatus
Kyphosidae (rudderfish)	*Kyphosus* sp.
Nemipteridae (threadfin and monocle breams)	*Scolopsis bilineatus*
	S. ciliatus
	Scolopsis sp.
Lethrinidae (emperor breams)	*Lethrinus harak*
	L. lentjan
Lutjanidae (snappers)	*Lutjanus vitta*
	L. fulvilamma
	L. johnii
	L. gibbus
	L. decussatus
Caesionidae (fusiliers)	*Caesio cuning*
	Pterocaesio diagramma
	P. tile
Pomadasyidae (grunts and sweetlips)	*Plectorhynchus lineatus*
Carangidae	*Caranx fulvoguttatus*
	Caranx sp.
Pomacentridae	*Abudefduf sexfasciatus*
	A. sordidus
	A. saxatilis (vaigiensis)
	Chromis caeruleus
	C. margaritifer
	C. ternatensis
	C. retrofasciatus
	Pomacentrus melanopterus
	P. amboinensis
	P. philippinus
	P. coelestis
	Chrysiptera cyanea
	Paraglyphidodon behni
	Plectroglyphidodon dickii
	Plectroglyphidodon lacrymatus
	Dascyllus reticulatus
	D. trimaculatus
	Amphiprion spp.
Labridae (wrasses)	*Bodianus mesothorax*
	Anampses sp.
	Cheilio sp.
	Gomphosus varius
	Thalassoma hardwickii
	T. lunare
	T. trilobatum
	Hemigymnus fasciatus
	H. melapterus
	Labroides dimidiatus

Continued

Table 3.21 (continued)

	Halichoeres centriquadratus (hortulanus)
	Halichoeres spp.
	Coris gaimard
	Cirrhilabrus sp.
	Cheilinus fasciatus
	Cheilinus undulatus
	Cheilinus trilobatus
Scaridae (parrotfish)	*Scarus* spp. (5)
Monodactylidae	*Monodactylus argenteus*
Pomacanthidae (angelfish)	*Pomacanthus annularis*
	P. sextriatus
Chaetodontidae (butterflyfish)	*Chaetodon auriga*
	C. adiergastos
	C. baronessa
	C. lunula
	C. melannotus
	C. octofasciatus
	C. vagabundus
	C. trifasciatus
	Chelmon rostratus
Zanclidae	*Zanclus cornutus*
Echeneididae (remoras)	*Echeneis naucrates*
Acanthuridae (surgeonfish)	*Acanthurus dussumieri*
	A. lineatus
	Ctenochaetus striatus
	Naso lituratus
Siganidae (rabbitfish)	*Siganus virgatus*
	S. lineatus
Bothidae (flounders)	*Bothus* sp.
Balistidae	*Balistoides viridescens*
Ostraciidae	*Ostracion* sp.

Algae

No extensive algal beds were found by diving or benthic dredging in the areas investigated. In the rocky mid- and lower shore areas west of Tungku Beach were seen marine macroalgae. Many of the boulders in the lower middle shore were dominated by the brown algae, *Sargassum*. The other algae recorded from the area were the brown algae, *Padina* and *Turbinaria*; red algae, *Laurencia*; *Gracilaria; Porphyra*; and an unidentified calcified form and encrustations of *Lithothamnion*. The dominant green algae were *Acetabularia* and *Caulerpa*.

At P. Punyit, the dominant algae were the brown algae of the genus *Dictyota*; two unidentified forms; and *Sargassum*. Of the red algae, *Halymenia* was dominant although others such as *Laurencia*, *Porphyra* and small calcified genera were also present. The green algae recorded were *Caulerpa, Udotea, Bryopsis* and *Halymenia*, but not in abundance.

Seagrasses

In view of the significant shrimp industry within Brunei Bay and the shallow waters over the extensive mudflats, benthic dredging was conducted within Serasa Bay and on the muddy substrates close to the mangrove swamps of Temburong District to determine the existence of seagrass beds. None of the benthic dredging revealed the presence of seagrass beds. Repetitive field visits to the beaches along the northern coast at low tides did not find any evidence of their existence offshore such as washed up blades. Benthic dredging in the subtidal areas off Jerudong and the mouth of Tutong River did not also reveal the existence of seagrass beds. The exposed nature of the northern coast, together with the sandy substrate, is not

conducive to seagrass growth. The seasonal (December/January) occurrence of large numbers of shrimp off Jerudong Beach remains an interesting phenomena for investigation.

The only reference on seagrass existence was the presence of *Halophila* sp. on the sandy shorelines in the lower reaches of S. Brunei. This species, however, is not as productive as the other species with taller leaf blades. More benthic surveys should be undertaken to cover a more extensive region of Brunei Darussalam's territorial waters within the bay to determine the existence and extent of seagrass beds.

Beaches

ALAN T. WHITE
AND M.W.R.N. DE SILVA

Sandy beaches are an important coastal resource of Brunei Darussalam. They occur from Muara Jetty in the north to Kuala Beliat in the south, interrupted only by a few rocky headlands in Muara and Jerudong areas. The coastline of Brunei Bay to the east of Muara is dominated by mangroves and is devoid of beaches, which are generally narrow, (between 50 and 150 m wide) and composed of fine-grained sand. The total length of the beaches, including the sandy islands of P. Muara Besar and the Pelompong Sand Spit is approximately 194 km.

Beaches serve as a natural barrier for the shoreline from coastal erosion and flooding from South China Sea. Sandy beaches are gradual transition zones and buffers which dissipate wave energy of the ocean and provide sand for movement by natural longshore currents. When a sandy beach disappears or is weakened, these dynamic processes of interaction between the water movement and the land tend to seriously affect inland areas from the beach. Such interaction can normally lead to erosion and flooding. Beaches also provide for gradual access to water, facilitating boating, fishing, bathing, swimming and other water-based activities.

Status

Pelompong Islet (sand spit) Beach is a natural sand spit islet, now cut off from Muara Beach to the east by the shipping channel and has a sandy beach facing South China Sea. The sand spit to the east of the shipping channel is made up of two islets both of which showed evidence of erosion at the time of the study. The small easternmost islet showed signs of rapid erosion, while the larger western islet showed signs of erosion, particularly on the northern side. The obstruction caused to longshore currents by the deepwater shipping channel and the associated protective barriers could be a cause of the observed sand spit erosion. The wildlife observed included birds, monitor lizards, crabs and mollusks. According to local fishermen, sea turtles nest on this beach during November and December.

P. Muara Besar Beach is protected from South China Sea by Pelompong Sand Spit. This white sand beach extends along the northeast side of the island and is heavily littered with driftwood and garbage washed up from Brunei Bay. It is reported that sea turtles also nest on this beach in December and that the eggs are collected by the local people. The species and frequency of nesting are yet unknown but worthy of investigation.

Serasa Beach is a man-made sand spit serving recreational needs such as swimming, fishing, windsurfing, boating and picnicking.

Muara Beach is a clean 300-m wide beach extending from the channel jetty in the north to the first rocky headland. It has healthy beach vegetation and is a popular recreational area.

Crocodile Beach is a fine sand beach popular for recreational use, although no facilities are available yet, picnicking, bathing, swimming and fishing with rod and line are already popular activities here. The presence of a shallow freshwater stream makes the area particularly attractive to children. However, due to the absence of facilities for disposing of rubbish, there is an accumulation of unsightly garbage.

Sand mining has reduced the size of Berakas Beach. Some sand mining and extraction activities are still carried out particularly to the west of the Berakas Military Base.

Tungku Beach, with some picnic facilities and a shaded area of large casuarina trees, is a pleasant recreational site. The beach is wide and has clean sand. Facilities for collection and disposal appear to be poor as there is an accumulation of garbage here, too.

Several leisure/picnic areas have been developed in the relatively wide Tutong Beaches. They have the potential for more recreational uses and tourism development. Mangroves border the large lagoon inland running parallel to the coast.

Seria Beach is wide and has the potential to be developed into a recreational area. Although local residents reported the presence of oil films on the water from time to time, none were observed during the survey. Even the beach behind Sea View Hotel in this area is wide and is bordered by natural vegetation; however, it is utilized only by a few people.

Fine sand Belait Beach has a coastline protected from erosion by an extensive seawall.

In general the majority of the beach areas, particularly those used for recreation, are strewn with rubbish (such as empty bottles, cans and plastic bags) and driftwood. Very few beaches have basic facilities such as shade, seats and tables.

The productivity of the beaches seems to be low as very little fauna are isolated from beach sand through a 2-mm sieve. The organisms isolated from the sand in the midshore region included a few shells identified as *Donax* sp. and *Umbonium* sp., crabs and isopods.

The beaches were scrutinized for possible presence of tar ball pollution. But no evidence was found at the time of the survey.

Benthic survey of Jerudong and Tungku Beach areas

Four 10-minute benthic tows, two carried out in front of Tungku Beach and the other two in front of Jerudong Polo Grounds at depths 4-5 m showed the abundance of the green alga, *Acetabularia*, in Jerudong. The presence in small numbers of the following organisms was also found:

Class	Family	Species
Bivalvia	Pholadidae	*Pholas* sp.
	Tellinidae	*Tellina* sp.
	Corubulidae	*Corubula* sp.
	Veneridae	Unidentified sp.
Gastropoda	Ficidae	*Ficus* sp.
	Cymatilidae	*Cymatium* sp.
	Nassariidae	*Nassarius* sp.
	Muricidae	*Murex* sp.

Class	Family	Species
	Trochidae	*Umbonium vestarum*
	Volutidae	*Amora* sp.
		Oliva sp.
Crustacea	Paguridae	Unidentified hermit crab
	Portunidae	*Portunus* sp.
	Penaeidae	*Metapenaeus ensis*
		Unidentified sp.
	Leucosiidae	*Leucosia* sp.
Osteichythes	Cynoglossidae	*Cynoglossus* sp.
	Platycephalidae	*Platycephalus* sp.
Asteroidea	Arachnoididae	*Arachnoides placenta*
	Astropectinidae	*Astropecten* sp.

Artificial Habitats

CHOU LOKE MING
AND ALAN T. WHITE

Artificial habitats within the territorial waters of Brunei Darussalam can be categorized into two: those intended and those not intended to serve as artificial reefs. The unintentional artificial habitats are those offered by the offshore petroleum-related drilling platforms and structures as well as the submarine pipelines connecting these structures to the mainland terminals. All these structures create a new habitat for the settlement of benthic organisms and provide shelter and attraction for fish. The intended artificial habitats consist solely of tire reefs in an artificial reef program established by DOF since 1985. These habitats were observed during scuba dives in April and June 1987.

Tire reefs

Over 5,000 tires were deposited since the program began. A unit comprised about 100 to 300 tires strung together by a rope running through them and weighed down at both ends by concrete blocks. The tires were not tightly bound, and the units were scattered at random on the 16 to 17-m deep sandy bottom of the basin within Two Fathom Rock (Fig. 3.7). The visibility below 13 m decreased considerably to 2 m and a distinct thermocline of up to 5°C was present. The sandy seafloor supports the growth of the solitary dendrophyllid coral, *Heteropsammia michelni*.

Also present were scattered elongated hydroid stalks swaying with the currents to which large numbers of crinoids were seen clinging and colonies of the soft coral, *Dendronephthya* spp. Siphonaceous, calcareous green algae occurred quite commonly on the seafloor. The tires were covered by a thin layer of filamentous algae and supported very few encrusting or sessile invertebrates. Algal growth was not extensive as light was limited. Fish density was low, but the abundance of a few species of caesionids and labrids was high. Since the tires were not stacked or well-anchored, their habitat value was limited. They seemed to move slightly in the swell surge even though they were deep and the swell was very small. These tires probably

moved vigorously when the swell was large. Also, since there was no systematic pattern for the tire reef placement or map of the area, surveys were difficult and by chance only. Table 3.22 lists the fish species observed around a tire reef unit.

Table 3.22. Fish observed on artificial tire reef at Two Fathom Rock (in one 40-min scuba dive by A. White on 18 April 1987).

Family	Species
Apogonidae	*Apogon* spp.[a]
	Cheilodipterus spp.[a]
Mullidae	*Parupeneus* sp.
Serranidae	*Epinephelus* sp.
Nemipteridae	*Scolopsis bilineatus*
	S. ciliatus
	Scolopsis sp.
Lutjanidae	*Lutjanus johnii*
	L. fulviflamma
	L. sebae
Caesionidae	*Caesio cuning*[a]
	Pterocaesio digramma[a]
Pomadasyidae	*Plectorhyuchus lineatus*
	(diagrammus?)
Pomacentridae	*Chromis margaritifer*
	Chromis sp.[a]
	Pomacentrus coelestis[a]
	Pomacentrus spp.[a]
	Chrysiptera cyanea
Labridae	*Cheilio* sp.
Ephippididae	*Platax* sp.
Acanthuridae	*Acanthurus thompsoni*
Siganidae	*Siganus lineatus*[a]

[a]Most abundant fish.

Note: Low visibility limited a complete census of the one 150-tire reef surveyed. This reef had a low diversity of fish but had a fairly good abundance of those marked above.

Oil-related offshore structure

A scuba dive was made on 11 June 1987 at Well Jacket No. 30 in Champion Fields (Fig. 3.8), 24.3 km offshore. This well jacket consists of a rectangular tower of tubes with various crossbraces. The tubes are 0.5 m in diameter with the main shaft more than 1 m in diameter. The entire structure extends from the surface to the seafloor at 27 m depth.

During the survey, it was seen that the pipes and supports were heavily encrusted with invertebrate organisms, tunicates and algae, which formed a layer of at least 10 cm thickness in most areas from the surface to the bottom. The barnacle, *Balanus* sp., was abundant on the pipes and dominated the small rocks covering the seafloor. Hard corals were absent except for a 15-cm wide colony of *Pocillopora damicornis* which settled on a rope tied around one pipe at 8 m depth. Numerous colonies of the soft coral, *Dendronephthya* sp., covered the tubes particularly below the 4 m depth. Hydroids of *Lytocarpus* sp. were more abundant in the upper levels while gorgonian fans occurred more in the lower depths. The sea urchin, *Echinometra calamaris*, was present at the lower levels. Oysters were also abundant but not immediately apparent because of the heavy encrusting material over their top valves. Other invertebrates found on the tubes without indications of depth zonation were zoanthids, small crabs, crinoids, tube worms and sponges. Tunicates included *Polycarpa* spp. and large colonies of *Didemnum molle*. Coralline algae and filamentous algae were also abundant. The diversity of these organisms on the structure was high.

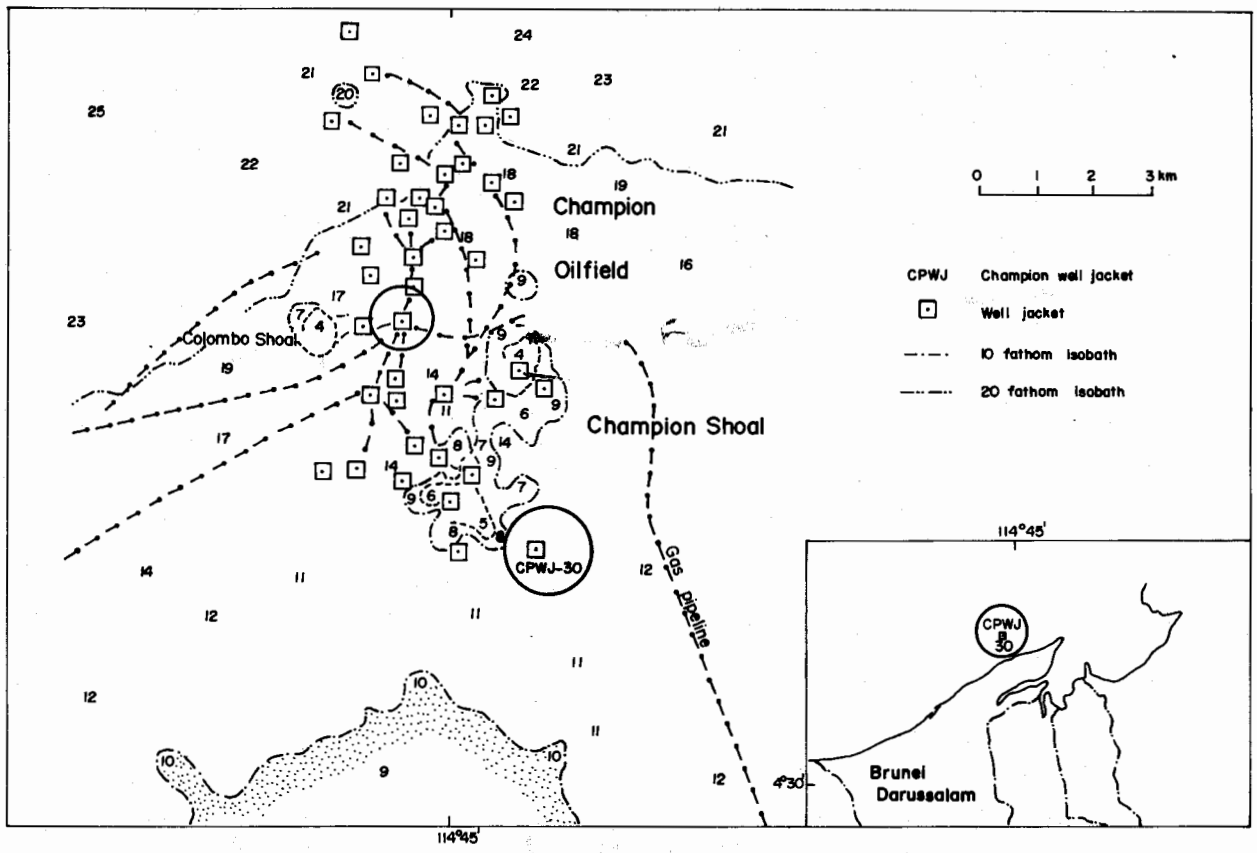


Fig. 3.8. Location of Well Jacket CPWJ-30 at Champion Oil Field.

The fish community primarily consisted of planktivores, herbivores or species which feed on small invertebrates. There were also a few carnivores. Schooling fish were large and abundant, but the few fish high on the food web like groupers, sweetlips and carangids were of particularly large size. It was apparent that the fish stock was not exploited, and that although not very diverse, had a relatively high biomass for the small area occupied.

Table 3.23 shows the common and dominant fish seen during the survey and their estimated numbers for the entire tower/structure area from 0 to 28 m. Most of the species seen schooling were noted, while some of the small, sedentary species were ignored.

Habitat enhancement

In view of the limited coral reef resources, artificial habitats serve an important role in enhancing the diversity of marine life. It was observed that both tire reefs and offshore oil rigs served to aggregate fish. The fish community at the latter was more diverse and abundant as the structure occupied the entire water column. The location of the tire reefs, although at a shallower depth, had high sediment load and low temperature due to a thermocline. Both factors were not present at the oil rig structure. The fish community and the encrusting organisms that tire reefs attract was less diverse and abundant.

Two options are present for the tire reefs. The first is the selection of shallower depths such as at the raised areas of Two Fathom Rock itself or at other reefs such as the eastern gently sloping reef flat of Pelong Rocks. Should alternative sites be unavailable, then the next option would be to design the tire modules such that they stack up to reach a shallower depth. Fishing pressure and the relatively young age of the present tire reefs may account for the low

Table 3.23. Fish and their abundance estimates observed on offshore rig at Champion Field (in one 60-min scuba dive by A. White on 11 June 1987).

Species	Abundance
Apogon spp.	5,000+
Cephalopholis argus	10+
Epinephelus sp.	1
Caesio cuning	250+
Caesio sp.	100+
Pterocaesio tile	500+
Pterocaesio diagramma	1,000+
Plectorynchus sp.	2+
Carangoides sp.	100+
Caranx sp.	500+
Selar sp.	500+
Abudefduf sexfasciatus	50+
A. saxatilis	50+
Pomacenthrid spp.	5,000+
Thalassoma lunare	1,000+
Thalassoma trilobatom	100+
Cirrhilabrus	500+
Pomacanthus annularis	1
Heniochus acuminatus	20+
Acanthurus dussumieri	20+
Acanthurus mata	10+
Acanthurus spp.	20+
Ostraciid	10+
Siganus virgatus	30+
Siganus lineatus	10+
Platax spp.	3+
Dasyatidae	1

fish diversity and abundance but evidence seems to point more to environmental differences, especially when the depth at which these structures occur is considered. It was seen that the oil rig structure extended a further 10 m down, and fish and other encrusting communities within this zone were comparatively rich. Other types of materials such as hollow concrete modules may be suitable for the shallower reef flats in terms of stability.

Mineral Resources

ALAN T. WHITE

This section identifies mineral resources, oil and non-oil, which occur in the coastal zone of Brunei Darussalam. Several locations of the known mineral deposits and current and potential exploitation in relation to the coastal-marine environment are discussed.

Field observations were supported with two references on the geology and mineral resources of Brunei Darussalam (MOD-DOTCP No. 9, 1986f; James 1984).

Minerals

The variety of mineral resources is limited. The presence in quantity of oil and natural gas dominates mineral use and extraction.

There are other extractive industries based on deposits of gravel and sand, which are used for construction (mostly as concrete aggregates) and brick-earth clays for brick-making. Sand is also mined for use as landfill in Belait District (MOD-DOTCP No. 9, 1986f).

Minerals not currently exploited in the coastal areas include silica sand for glass-making; Kaolinitic clays for ceramics; coal; and quarry stone.

The locations of the current oil and gas fields are shown in Fig. 9.1; of fine aggregate and sandfill (on land), coal, possible brick-making clays and ceramic clay deposits, in Fig. 3.9.

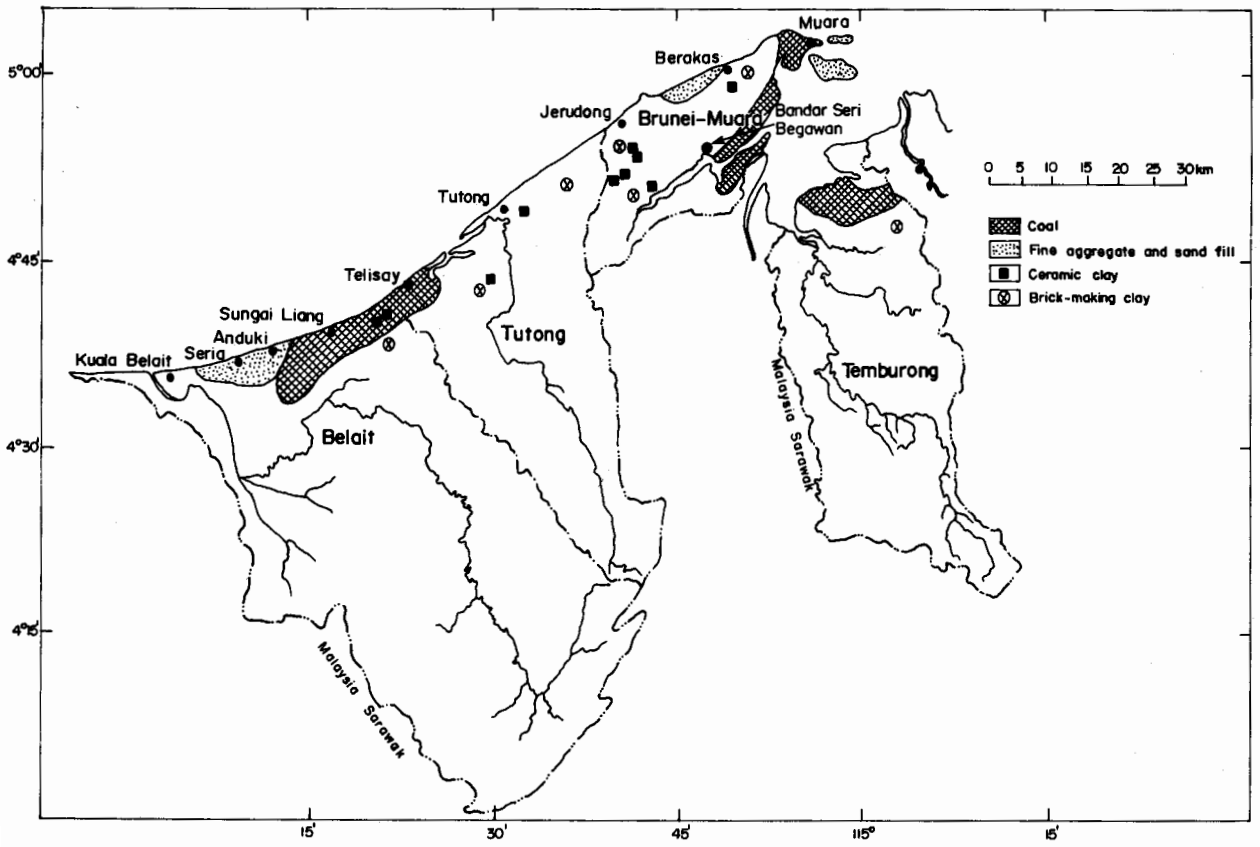


Fig. 3.9. Non-oil mineral resources (adapted from MOD-DOTCP No. 9, 1986f).

Coarse aggregates

Most coarse aggregates used now are from the alluvial gravel deposits in the valley of S. Temburong and not in the immediate coastal zone. Nevertheless, extraction affects river water quality, and in turn, coastal waters. As stated in the MOD-DOTCP No. 9 (1986f), the main problems are:

- Siltation and pollution of parts of the river due to the discharge of washing plant "fines" back into Temburong River and its tributary, S. Selunyang;
- Lack of control and absence of systematic land restoration of the washed-out areas;
- Loss of agricultural land and pollution of the rivers; and
- Possible changes in the river course.

It is said that these effects have increased in recent years.

Former gravel pits in swamps and terrace gravels near Butir in Brunei-Muara District and a quarry at Berakas are not in operation now. If they would reopen, similar environmental problems would affect coastal waters and land.

Fine aggregates

In the past, much of the fill material for construction was extracted directly from beaches. In the late 1940s in Seria, considerable amounts of sand were extracted for construction activities in the oil field. More than 2.7 million m^3 of sand were removed which resulted in the steady lowering of the level of the beach. One effect of this removal was it made Seria liable to flooding. An 11-km long dike (seawall) had to be constructed between 1954 and 1957 to alleviate this problem. Further extraction of sand not only continued to lower the beach but also caused deficiency in the supply of sand available for longshore drift. This accelerated beach erosion in general along the coast (James 1984) and increased sediment load of the coastal water. It might have also affected current patterns.

Beach sand had previously been extracted from Belait, Muara and Jerudong areas with similar consequences of increased erosion. Although beach sand extraction in many areas was, it is still permitted in Berakas/ Jerudong which show clear signs of beach erosions. LD, until very recently, was responsible for giving permission for sand extraction. However the department does not specify the quantity of sand that could be extracted. Sand mining contractors are each given a fixed plot along the coast. Any person requiring sand comes to an agreement with the contractor and is requested to seek prior approval from LD for the quantity of sand to be extracted per operation. Very recently, MD was given overall control to restrict the removal of sand, soil, gravel, shingle and others from the beach.

Clay

Clay soil was traditionally extracted for brick- and ceramic-making. As with other mining, the most significant environmental consideration is the change in land use to a nonvegetated open area vulnerable to erosion and gullies. If located near a river or sea, the runoff affects water quality and bottom sediment composition during and after heavy rainfalls. Such effects are concentrated in Jerudong and Tutong Beach areas.

Silica sands

White quartz sands of glass-making quality form a resource in Tutong District (Fig. 3.10). A conservative estimate of the resource is 20 million t. Several companies submitted proposals in the early 1970s for the use of this sand for a glass manufacturing plant, but none have been implemented. The environmental implications for such a development need to be studied and included in an Environmental Impact Assessment (EIA).

Coal

Coal deposits within the coastal zone occupy an area around Lumut and also the mangrove forests within Brunei Bay. Thick coal seams exist in a band along the coast between Bandar Seri Begawan and Muara. An estimated 650,000 t (Wilford 1961) of coal were mined from this area between 1888 and 1924, and this figure represents only about 10% of the total production potential. Future mining prospects remain dim due to the relative inaccessibility of much of these coal-bearing areas.

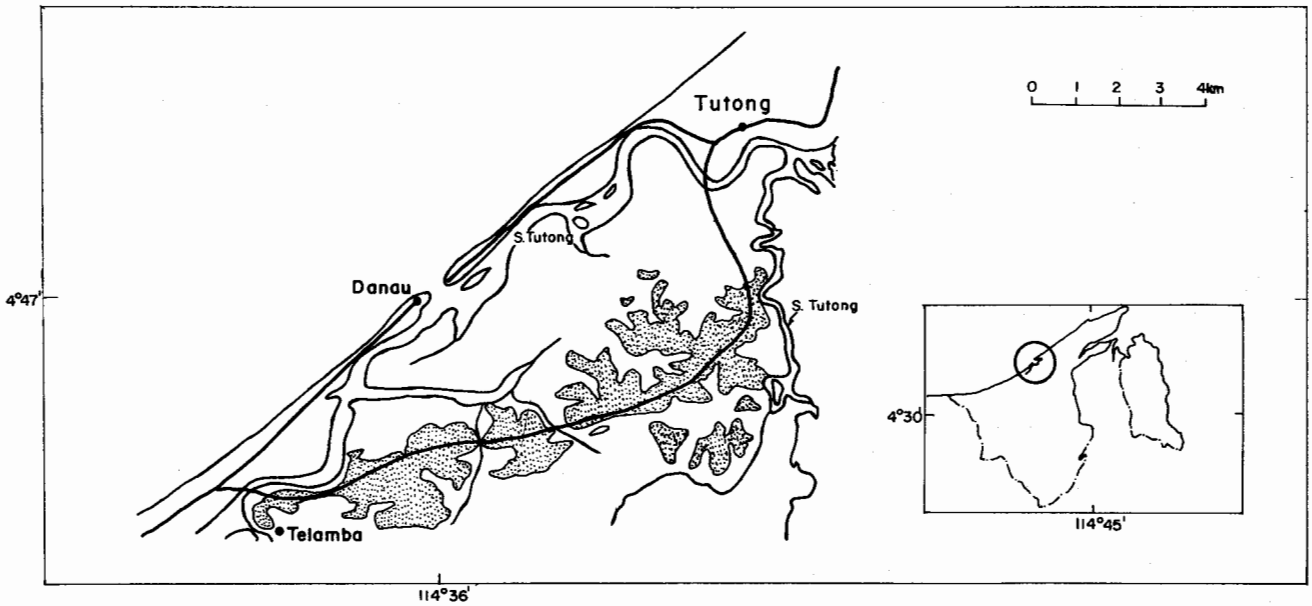


Fig. 3.10. Silica sand in Tutong District (adapted from Wilford 1961).

Hard rock

Most hard rock and sandstone deposits occur inland except for those at Tg. Punyit and P. Punjit in Brunei-Muara District near Jerudong. Extraction would of course deface scarce coastal resources.

Oil and gas

Oil has been flowing from Brunei Darussalam fields since 1929. There have been many discoveries and much development of various sites since. The principal oil and gas fields are in Fig. 9.1. The main discovery sites are: Seria (1929); Southwest Ampa (1963), situated some 25 km west-northwest of Seria in water depths of 10-40 m; Fairley (1971), 45 km northwest of Seria in about 60 m depth; Champion Field (1970), 60 km north of Bandar Seri Begawan in 10-45 m water; Maypie (1975), 50 km northeast of Seria in water 30-50 m; Egret (1971, 1979), 45 km northwest of Seria in water 60 m deep (Chapter 9).

Important environmental considerations to oil installations and transport are:

- Dumping of drilling muds and other by-products during drilling and initial extraction of oil;
- Construction of oil platforms and land-based facilities near or on the beach for transport;
- Pipeline construction;
- Pipeline leakage or breakage;
- Production leaks or blowouts; and
- Transport leaks into marine waters.

Although the possibilities for oil-related pollution are high in Brunei Darussalam, a few major incidents have occurred in recent years. Some oil pollution is reported in Seria's inshore and freshwater areas during rainy periods, which could be prevented by improved maintenance and surveillance.

Guidelines for prevention of oil pollution and environmental impact analysis are yet to be formulated. Such guidelines could help establish better preventive measures.

Chapter 4
Population Profile

KUSUMO DJOKO KUNTJORO

Demography

The 1981 Census shows the population of Brunei Darussalam to be 192,832 (EPU 1983). By mid-1985, the population was estimated to have reached 221,900. Table 4.1 shows the distribution of the 1981 and mid-1985 population by administrative districts. The latter did no change much compared to the former.

Brunei-Muara is the most populous coastal district, comprising about one-third of the country's population. It is close-linked to Bandar Seri Begawan Municipality, particularly in serving residential area for the main urban area. This district and this municipality have 60% of the total population. In contrast, Tutong and Temburong, the more rural coastal districts, comprise under 15 %.

Majority of the population is concentrated in the urban areas and around Bandar Seri Begawan which lie along the coasts (Fig. 4.1). The two population poles in which over 80% of the population is concentrated are Brunei-Muara, including Bandar Seri Begawan, and Kuala Belait/Seria.

The population density variations throughout the country (Fig. 4.2) reflect these observations. Density throughout most of the inland rural areas is below 10 persons/km^2. This is found in Temburong District and along the coast between Seria and S. Liang of Belait District. Outside Brunei-Muara District, density exceeds 50 persons/km^2 in the coastal towns.

Table 4.1. Population by district in 1981 and mid-1981.

District	1981[a]		Mid-1981[b]	
	No.	Percentage	No.	Percentage
Bandar Seri Begawan	49,902	25.9%	133,600	60.2%
Brunei-Muara	64,329	33.4%		
Belait	50,768	26.3%	58,400	26.3%
Tutong	21,615	11.2%	22,900	10.3%
Temburong	6,218	3.2%	7,000	3.2%
Brunei Darussalam	192,832	100.0%	221,900	100.0%

[a]Source: unpublished 1981 Census.
[b]Estimated by the Economic Planning Unit.

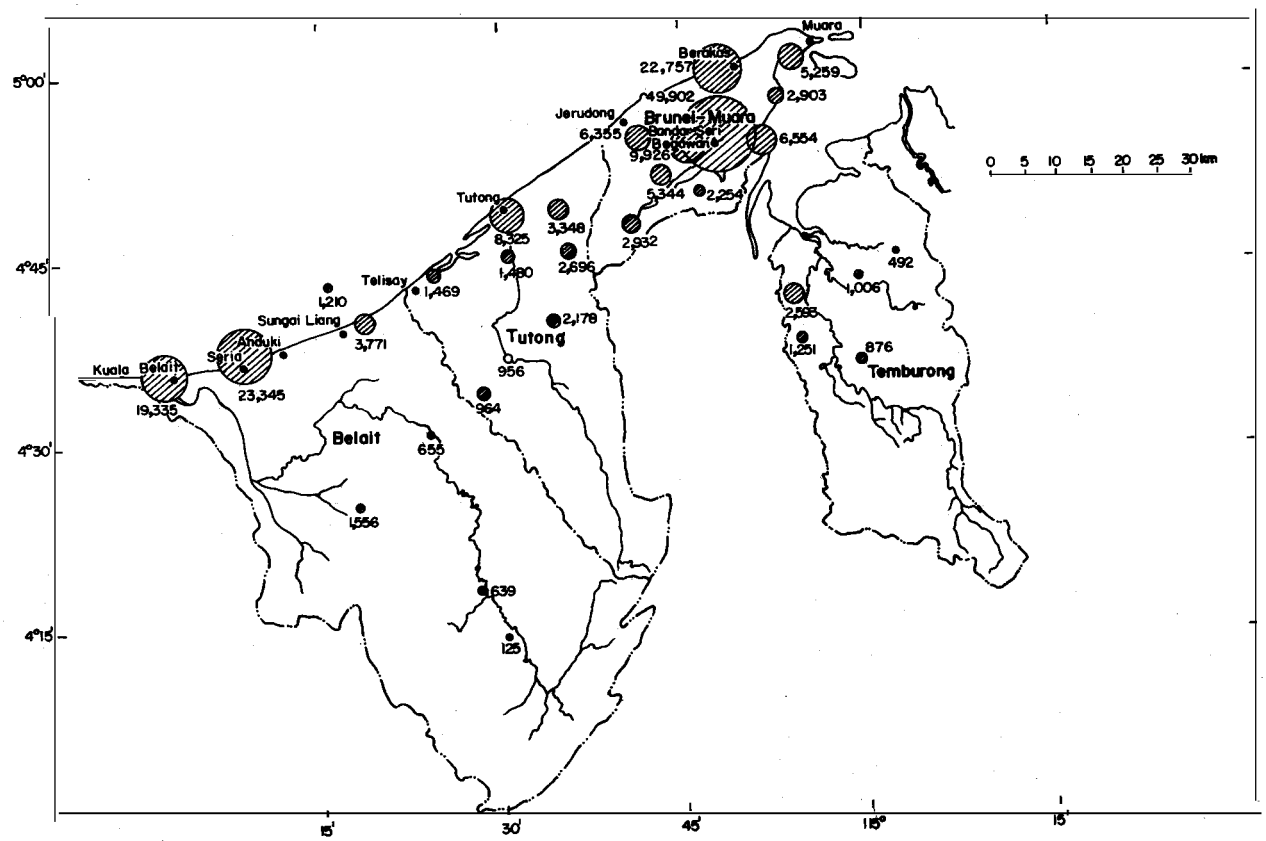


Fig. 4.1. Population distribution by *mukims* (adapted from MOD-DOTCP No. 2, 1986b).

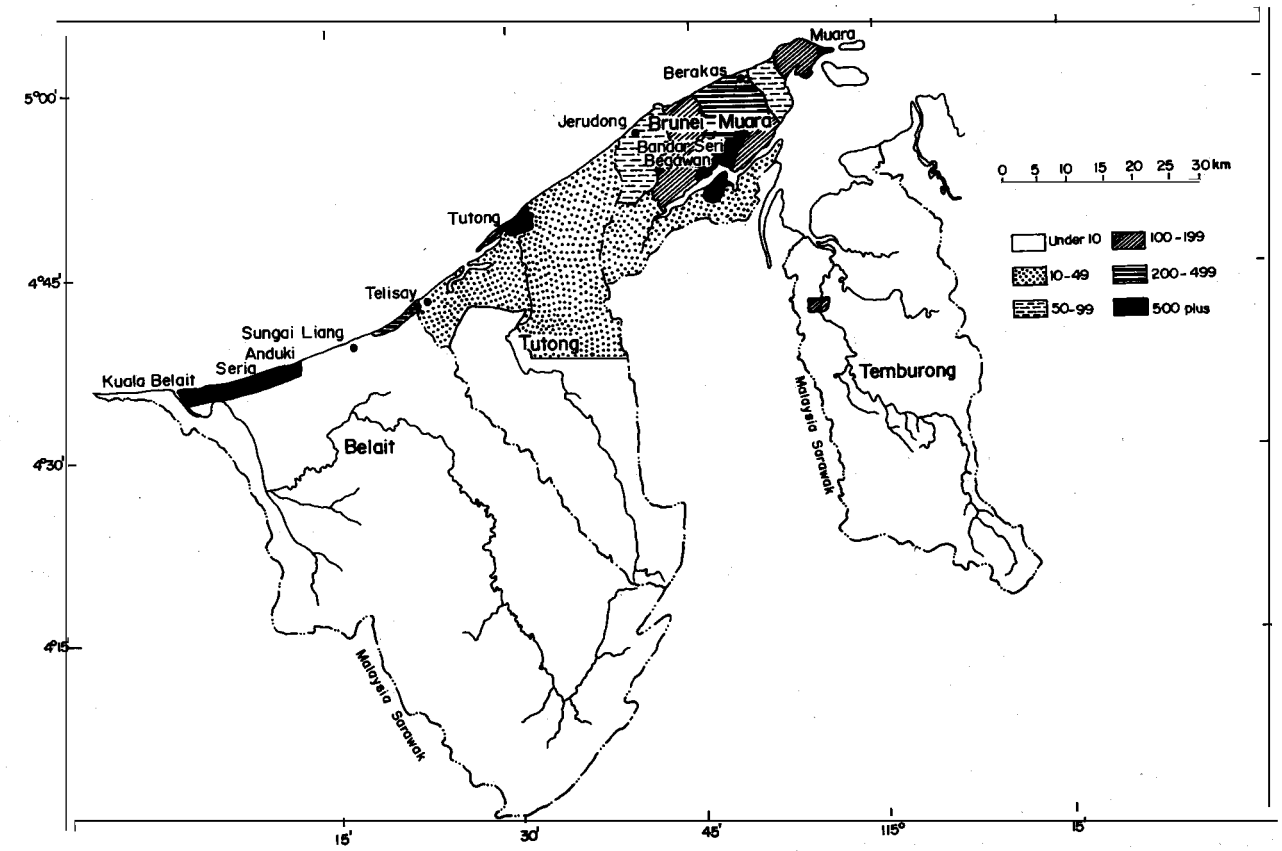


Fig. 4.2. Population density, 1981 (adapted from MOD-DOTCP No. 2, 1986b).

In 1981, persons of Malay origin comprised two-thirds; Chinese, 21%; other indigenes, 14% (Table 4.2). In general, there has been little change since 1971, although the indigenes increased by a third. Typically, Belait has 40% Malays and above average population of all the other groups due to the oil and gas industry which employs a large number of both resident and immigrant Chinese, Europeans and others. In all districts, except Belait, the proportion of Malays does not fall below two-thirds.

The total population of Brunei Darussalam increased 42% (about 57,000) from 1971 (136,256) to 1981 (192,832), implying an annual growth rate (AGR) of 3.5%. From 1981 to mid-1985, the population increased by 28,068 to about 221,900 based on the natural increase and immigration trends.

The natural increase of 2.9%, being lower than the overall increase rate from 1971-1981 indicates a net immigration to Brunei Darussalam. Two factors of external immigration which contribute to population growth are a high turnover of short-term immigrants and emigration of the permanent population.

Permanent population increased at a rate of 2.7% which is slightly lower than the rate of natural increase due to migration. On the other hand, there is a high rate of increase (6.8%) of temporary population. In absolute terms, this group almost doubled in size, from 23,360 to nearly 45,000. The decline in the number of permanent residents could be due to emigration and the classification of newborn children as Brunei Darussalam citizens.

Table 4.2. Distribution of ethnic groups by district, 1981.

Districts	Ethnic group %				
	Malay	Other indigenes	Chinese	Others	Total
Bandar Seri Begawan	67	4	22	7	100
Brunei-Muara	78	4	13	5	100
Belait	40	15	34	11	100
Tutong	82	8	9	1	100
Temburong	66	25	7	2	100
Brunei Darussalam	65	8	20	7	100
Brunei (1971)	66	6	21	7	100

Source: unpublished 1981 Census.

Internal migration does not affect the total population, but changes the geographic distribution of the population.

Table 4.3 and Fig. 4.3 give the 1971 and 1981 growth rates for census districts and *mukims* of coastal and inland areas. The former is defined by a *mukim* which is connected geographically to the shore. The coastal areas have an above average growth rate. The average growth rate itself is above the natural increase rate. Thus, the coastal areas have received population from inland.

In the coastal area, Brunei-Muara and Tutong Districts have above average growth rates. Bandar Seri Begawan has above the natural increase rate. Kuala Belait and Tutong have implied net emigration. The 1981 Census showed that the sex ratio is 114.5 men:100 women. The imbalance is due to the immigration by single men which is supported by the ratio for the permanent population of 102:100.

Table 4.3. Coastal and inland population change by *mukim*, 1971-1981 (based on 1971 and 1981 censuses).

Mukim/district	Population 1971	Population 1981	Annual growth rate (%)
Coastal area			
Bandar Seri Begawan	17,410	22,777	2.7
Kg. Air	19,577	27,125	3.3
Bandar Seri Begawan	36,987	49,902	3.0
Berakas	12,321	22,757	6.3
Gadong	4,480	9,926	8.3
Kota Batu	4,587	6,554	3.6
Sengkurong	3,596	6,365	5.9
Mentiri/Serasa	3,714	8,167	8.2
Brunei-Muara	28,698	53,769	6.7
Kuala Belait	14,329	19,335	3.1
Seria	20,824	23,415	1.2
S. Liang	3,965	3,771	-0.5
Kuala Belait	39,118	46,521	1.8
Pekan Tutong	4,373	8,525	6.9
Keriam	2,612	3,348	2.5
Telisay	1,134	1,469	2.6
Tutong	8,119	13,342	5.2
Labu	582	492	-1.7
Bangar	2,458	2,593	0.5
Temburong	3,030	3,085	0.1
Total (coastal area)	115,962	166,619	3.7
Inland area			
Lumapas	1,800	2,284	6.3
Kilanas	3,623	5,344	4.0
P. Batu	1,683	2,932	5.7
Brunei-Muara	7,106	10,560	4.1
Kuala Balai	206	62	-11.3
Labi	1,558	1,556	0.0
Bukit Sawat	847	655	-2.5
Sukang Menilas	744	764	0.3
Kuala Belait	3,355	3,037	-1.0
Tg. Maya	1,443	1,480	0.3
Kiudang	2,204	2,678	2.0
Lamunin	1,632	2,195	3.0
Ukong	1,214	964	-2.3
Rambai	1,246	956	-2.6
Tutong	7,739	8,273	0.7
Batu Apoi	706	1,006	3.6
Amo	583	876	4.2
Bokok	895	1,251	3.4
Temburong	2,184	3,133	3.7
Total (inland area)	20,384	25,003	2.1
Brunei Darussalam	136,256	192,832	3.5

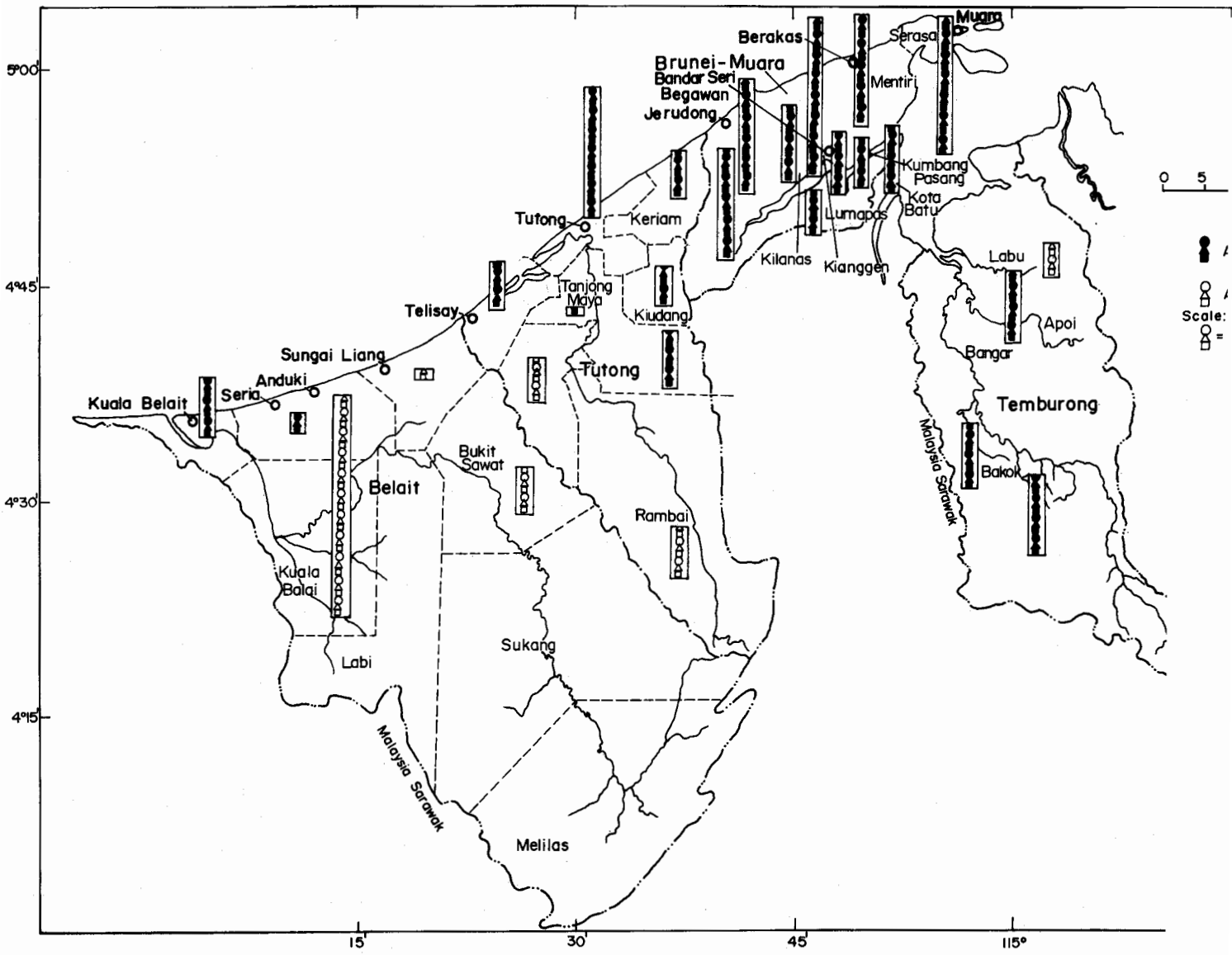


Fig. 4.3. *Mukim* population growth rates, 1971-1981 (adapted from MOD-DOTCP No. 2, 1986b).

Tradition and Culture

Brunei Darussalam is an Islamic country, where religious traditions and customs are widely observed. The country is also a Sultanate with the Sultan as the highest chief executive representing the people (Zain et al. 1971).

As one of the oldest kingdoms in Southeast Asia, Negara Brunei Darussalam has a long heritage of traditions. Here are some.

Traditions related to coastal area

Building Lighters and Sampans. If the boat is to be ocean-going or for carrying cargo for international trade, the forest timber meant for its construction should be collected in the morning of Mondays, Wednesdays and Fridays. Should the collectors chance upon animal carcass or any wild animal during the journey, then the work is not going to be worth it as the carcass or wild animal is a sign of decline in good fortune or potential profit. In contrast, meeting snakes or wild boars is considered good omen, for these animals are always on the quest for food.

The preferred woods are *kapur*, *madang sisek*, *madang lama-lama*, *siak*, and *garang buaya meralia batu*. The wood has to be selected from trees along foothills where the soil is fertile, and the timber is large. Hence, the fortune will be as large. Trees with termites but not eaten by them are selected. Termites signify diligence. The wood chips of the first blow are buried at the base of the tree while making a wish that the boat do not sink or come to any mishap. The tree is made to fall in the direction of the rising sun in the belief that the boat would always stay calm in a mishap so that the cargo remains safe. It is also believed that quarelling or telling bad stories while cutting down the trees will bring bad luck.

After the planks and other paraphernalia are readied, the length and width of the frame are measured with a stick. When construction is completed, the measurements are taken to determine the boat's fate. If the new measurement is longer by half of the measuring stick, the condition is known as *puteri meninjau* which means that the boat contains the spirit of the sea princess. This is considered good as the princess is known for looking far ahead and for protecting the boat from impending danger. If the new measurement is longer but by less than half, the condition is known as *puteri terkurong* which is not beneficial. If the measurement remained the same, the work is considered half successful only. Should the new measurement be shorter, the boat is labelled *bantal mayat* (which literally means carcass pillow) and is considered very dangerous and accident-prone (Ibrahim 1969). However, there is no confirmation as to whether these traditional beliefs still proliferate as they are contrary to Islamic teaching where it is forbidden to believe in powers other than God.

Charcoal Production. Charcoal is produced on Berbunut Island only. The first kiln was built in 1930. Charcoal was widely used for cooking when electricity and gas were available only in the urban areas. The 1974 production was about 460 t, and according to the producer, it was not sufficient to meet with the local and overseas demand (Lim and Sharifuddin 1975).

Charcoal is still preferred for certain types of traditional cooking. Women, after giving birth, warm themselves near a charcoal fire in the belief that this practice helps contract the womb's muscles.

The charcoal industry is closely linked to coastal resources as mangrove wood is primarily used as raw material. Other charcoals are used as firewood in heating mangrove logs.

Some traditions of Kg. Air

Kg. Air was, for a long time in the past, the urban center of Borneo and the hub of Brunei Darussalam kingdom. A new mainland town was built in 1908 to replace Kg. Air. But it still remains as a large residential area where houses are built on stilts and connected to each other by wooden bridges.

Boat-building Industry. As a river-oriented settlement, boats are important for transportation. In the past, boats were propelled by oars. Now, most are engine-driven. Rafts were used before dugout canoes. Now, plank-built boats are popular as their sailing efficiency, loading capacity and navigational security are far superior. Boat builders in Kg. Air lay claim to having initiated the development of the keel which changed the boat's structure, shape and performance (Hashim 1984). The several types of boats built in Kg. Air are the:

1. School boat - for carrying school children between the *kampong* and the mainland;
2. Taxi boat - for transporting people across the river;
3. Bus boat - for commuting between Bandar Seri Begawan and Limbang, Temburong and other towns across the border;
4. Barges *(tongkang)* - for carrying sand, gravel and wood;
5. Racing boats - for racing during festive and other occasions;
6. Pleasure boats - usually ordered by locals and expatriates; and
7. Padian boats - small canoe-like boats for river hawking.

The types of wood used are *meranti (Shorea)* and *selangan (Bruguiera)* for the hull sections; and *kapur (Dryobalanops)* for the keel and stern sections. More resilient grades of wood are used for the ribs which reinforce hull unity.

Metalwork. Traditional metalwork, which is a cultural heritage, is still done in Kg. Air. This includes gold-, silver- and brassworks. The blacksmiths are known for crafting the Malay *keris*, spears, knives, swords, choppers *(parangs)* and other cutting implements. The blacksmiths, however, have reduced their activities due to competition from cheaper factory productions and decline in the demand for agricultural implements.

Handicraft. The people of Kg. Air practice handicraft using local plants and other natural resources. Traditional designs, patterns and operational processes are retained in spite of modern influences. Materials used include *nipah*, bamboo, rattan and *pandan*. The leaves of *nipah* palm (*Nypa fruticans*) are used for making *attap* roofing, hand fans, rice-cake envelopes *(ketupat)*, artificial fish house *(lawa-lawa)*, mats and other utensils. Trays and baskets are made from bamboo. *Kain songket*, a woven cloth of intricate patterns of gold or silver threads based on local plants and flowers or geometrical forms, is traditionally popular in ceremonial and other important functions. Yarn materials used are cotton, silk, linen, wool and nylon.

Floating Market (Padian). For centuries, the *padian*, a floating market activity, is part of Kg. Air culture. The *padian* is done by womenfolk who, in the past, rowed around the *kampong* selling commodities such as fish, vegetables, *sago*, fruit and rice. At present, *padian* vendors sell mostly fish; and only a few are operating near Bandar Seri Begawan wharf. These vendors are recognized by their very large hats.

Some traditions of the Kedayans

The Kedayans are one of the indigenous groups of Brunei Darussalam. They have a common dialect and are distributed over limited areas along the coastal plains. Their traditions are based on the concept of community sharing. An annual festival known as *makan tahun* is held after harvests when the Kedayans gather, bringing with them their farm produce. Food and drinks are shared in a feast after prayers by a religious elder; and often, everything that is left

unconsumed is distributed equally among those present. In deer hunting, the Kedayans have special traps which are laid in areas where hoof prints are conspicuous. The meat is divided equally among the villagers by the headman. Expectant mothers are given two shares (Sharifuddin 1963).

Apart from using the common cast net *(rambat)*, line *(panching)* and traps *(bubu)* for fishing, the Kedayans have developed the *menimba babang* technique which involves the construction of temporary dams (made of earth, stones, wood and leaves) a few meters apart across rivers to block water flow. Water above the dams is then bucketed out to enable easier collection of trapped fish.

Employment

People aged 15 years and over and who are working or seeking employment are considered as the economically active population or labor force. This category excludes students, housewives and retired persons. People actually working comprised the working population. The difference between the labor force and the working population composed the unemployed. There were only 2.6% and 3.6% of the labor force who are unemployed in 1971 and 1981, respectively.

Most (88%) of the labor force were employees, including 9% of the immigrants. Men composed 76%; women 24%. Male immigrants made up 35% of the male labor force while female immigrants formed 21% of the female labor force.

The 1970 working population tended to shift from blue-collar to white-collar jobs. Immigrant workers were scattered in every occupational grouping, but most were found in production/transport where they exceeded the permanent workers. However, there were less among clerical and agricultural jobs.

The Brunei Darussalam working population in the 1970s changed structurally from agriculture, forestry and fisheries into community and personal services. The proportion of the workforce directly involved in production (agriculture, forestry, fisheries, mining, quarrying, and manufacturing) fell significantly from 23% in 1971 to 15% in 1981. The mining sector also decreased; although in absolute terms, there was an increase by 2.9% per annum. The construction sector remained a big employer at 19% of all production sectors.

Observations of the workforce in the four districts (Fig. 4.4 and Table 4.4) showed that:

1. Belait's oil and gas economy employed 84% of the labor force in the mining and manufacturing industries.
2. Almost all (92%) of the Brunei-Muara workforce is in the service economy.
3. Tutong and Temburong are more agricultural. However, the impact of armed forces on the workforce exceeded that in agriculture.
4. The construction sector is a dominant employer throughout Brunei Darussalam, especially in Brunei-Muara and Belait.
5. Government administration, education, health and security services employed nearly one-half of the regional workforces in Tutong and Temburong and two-fifths in Brunei-Muara.
6. Fisheries industries employed 0.6% of the total workforce in the state. Most (79%) of the workforce was in Brunei-Muara.

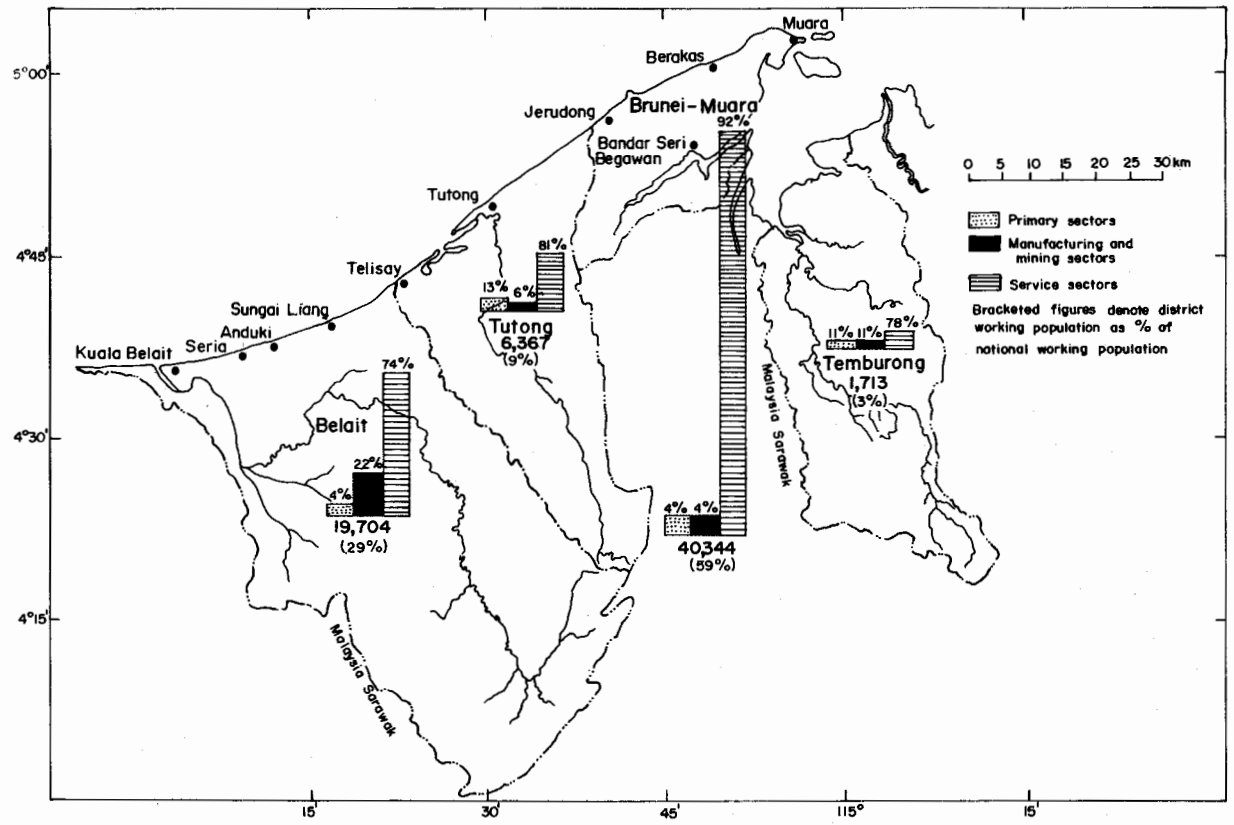


Fig. 4.4. Working population by district and by economic sector, 1981 (adapted from MOD-DOTCP No. 6, 1986b).

Health

The National Health Policy of Brunei Darussalam emphasizes health-oriented, preventive and promotive care for the whole community rather than disease-oriented, curative services for the sick. The target is the avoidance of disease and disability and health for all by the year 2000. The policy gives more emphasis to primary health care. Identified requirements include a sound, physical infrastructure, basic utilities, health information, logistic support, adequate supplies to remote areas, better communication facilities and training of community nursing staff. Improvement of sanitation and epidemiological surveillance to eliminate major health hazards are also important. This plan of action involves the community and is intersectoral.

The system practiced in government hospitals is based on western medical systems. The two larger hospitals at Bandar Seri Begawan and Kuala Belait provide specialist services. Brunei Shell provides its own health services for employees in Seria and Kuala Belait. The Royal Brunei Darussalam Armed Forces runs its own medical unit. There are also registered private practitioners in the main towns. In the remote areas, traditional medicines remain popular, and their practitioners are also registered. The mobile dispensary service provides limited primary health care to the rural areas on a routine basis. A flying medical team services 3 to 4% of the population residing in parts inaccessible by land or water. Dental health care and pharmaceutical services are available throughout the country. Dental services are provided in schools in their and mobile dental clinics.

Table 4.4. Working population by district and industry, 1981.

Industry	Brunei Muara	Belait	Tutong	Temburong	Total
Agriculture	1,253	619	738	164	2,774
Forestry	52	69	68	19	208
Fisheries	316	98	37	2	453
Subtotal	1,621	786	843	185	3,435
Oil and gas	93	3,470	36	2	3,601
Quarrying	144	-	2	116	262
Sawmilling	98	205	252	59	614
Other manufacturing	1,408	689	69	3	2,169
Subtotal	1,743	4,364	359	180	6,646
Electricity and water	1,074	567	233	87	1,961
Construction	7,532	3,918	1,010	184	12,644
Distribution	3,804	1,171	236	61	5,272
Hotels	1,293	721	52	25	2,091
Transport and communications	2,804	1,416	258	51	4,529
Finance and business services	1,450	469	80	11	2,010
Public administration	3,408	498	504	231	4,641
Security	6,247	1,622	1,314	315	9,498
Education and health	5,847	2,255	1,138	313	9,553
Other services	3,521	1,917	340	70	5,848
Subtotal	36,980	14,554	5,165	1,348	58,047
Total (1981)	40,344	19,704	6,367	1,713	68,128
Total (1971)	19,811	14,755	4,062	1,384	40,012
Average growth 1971-1981 (% p.a.)	+7.4	+2.9	+4.6	+2.2	+5.5

Source: unpublished 1981 Census.

During the 1975 to 1984 period, there was some progress towards better health status as seen by the following indicators:

- Life expectancy increased from 65 years to 70.1 for men and 72.7 for women.
- Birth rate declined from 32-90/1,000 to 29-33/1,000.
- Infant mortality rate decreased from 27.23/1,000 to 12.72/1,000 births.
- Neonatal death declined from 14.15/1,000 in 1976 to 8.3/1,000 births.
- Perinatal death rate per 1,000 has decreased from 22.12 to 12.23.
- Maternal death rate per 1,000 reduced from 0.94 to 0.46.

Water- and seafood-related communicable diseases such as salmonella, shigella and gastroenteritis were reported mostly in Kuala Belait but these were not serious. The general health condition of the coastal population is very good. There is no report of malnutrition among the coastal communities.

Education

Historical background

In 1934, 20 years after the first formal school was established, there were only 15 schools throughout the country with a total of 866 pupils. In 1949, a State Education Officer was

appointed to oversee education. There were 37 schools then with a total enrolment of 2,267 of which 1,892 were boys. Enrolment doubled to 4,661 by 1951 when the first government English-medium school was opened. Another was established the next year in Seria. Primary schoolers who completed 4 years of Malay- or Chinese-medium education were selected and placed in English-medium for a 2-year course meant to prepare them for secondary education which began in 1953. After internal self-government was achieved in 1959, education grew rapidly.

Schools and colleges are either government or nongovernment, the latter consisting of mission, Chinese-medium and private. The government schools were, before the introduction of bilingual policy, divided into Malay-, English- and Arabic-medium schools. Education is free in government schools, inclusive of tuition, textbooks, transport, board and lodging, refreshments and lunch.

The bilingual system was launched as a means to ensure the sovereignty of the Malay language and to maintain a high degree of proficiency in both Malay and English languages.

There are two higher educational institutions, the Institute of Technology, Brunei Darussalam (ITB) and the University of Brunei Darussalam (UBD). ITB, geared mainly to produce senior level technicians, began admitting students in January 1986. Graduates are considered for entry to second year, university level. Offered initially are Higher National Diploma programs in business studies, computer studies and electrical and electronic engineering.

UBD became fully operational in October 1985. Degree courses for all undergraduates are four-year leading to a Bachelor of Arts (Honors) or Bachelor of Science (Honors). At present, there are two faculties, the Faculty of Arts and Science and the Faculty of Education. Courses offered are:

1. BA (Malay medium) - Malay Language, Malay Literature, Economics, Geography and History;
2. BA Education (Malay medium) - Malay Language, Malay Literature and Islamic Studies;
3. BA Primary Education (English medium);
4. BSc Education (English medium) - Biology, Chemistry, Physics and Mathematics;
5. BA Management Studies (English medium); and
6. BA Social Policy and Public Administration (English medium).

Training centers and colleges

Some of these are the Sinaut Agricultural Training Centre; Brunei Arts and Handicraft Training Centre; Mechanical Training Centre; Sultan Saiful Rijal Technical College; and Jefri Bolkiah College of Engineering.

The Sinaut Agricultural Training Centre's main emphasis is to train young men to become commercial farmers. The first enrolment was in January 1976. In response to the country's need for intermediate level technicians/managers, a new course was designed in 1982 leading to Brunei National Diploma in Agriculture. The first intake graduated in December 1985.

The Brunei Arts and Handicraft Training Centre, set up in 1975, incorporates training, exhibition and marketing facilities. The center offers a wide range of silverware, brassware and bronzeware made by local craftsmen whose knowledge stretches back to many generations. The trainees produce articles such as jugs, trays, boxes, napkins, rings, spoons, threads, bracelets, traditional woven cloths and baskets and mats of bamboo and *pandan*.

The Sultan Saiful Rijal Technical College offers courses at the craft, technical and nontechnical levels. Courses at the craft level are basic furniture-making, motor mechanics, basic cookery and food services. Technical courses lead to a Technician Diploma in

Construction, National Certificate in Laboratory Service or National Certificate in Telecommunications. The nontechnical courses lead to a Basic Certificate in Computer Programming, BTEC First Certificate in Business and Finance or Business Studies.

The Jefri Bolkiah College of Engineering offers courses at the craft and technical levels. The latter leads to a BTEC National Certificate in the various courses. Also offered is Marine Engineering leading to Class 4 Engineering Officer level.

Adult education

Initially, the aim of adult education was to eradicate illiteracy. The emphasis, however, shifted towards the improvement of general education, aquisition of technical skills and programs for the enrichment of leisure activities. Most adult education centers offer academic subjects up to GCE 'A' level. Other popular courses include home science, typing, shorthand, stenography and bookkeeping. Adult religious education has also been actively organized in various venues to improve Islam knowledge.

While ecology is taught as part of the science subject, environmental sciences have yet to be incorporated in the school curriculum. However, due to the high general educational attainment of most of the population, there is public awareness on the serious impacts of environmental degradation.

Chapter 5
Land Use and Development

CATALINO DELA CRUZ, CHOU LOKE MING
AND M.W.R.N. DE SILVA

Land Use Capability

Elevation

Most of the entire northern coastal belt (1 km inland from the shoreline) consists of flat slopes of 0 to 2° or up to 3.5% elevation, or of gently rolling slopes of 2 to 12° (3.5 to 20%). Steep slopes having greater than 12° (20%) elevation are restricted to Brunei Cliffs or Tg. Punyit and to areas closer to the western end of the northern coast (Fig. 5.1). The irregular coastline of Brunei-Muara and Temburong Districts facing Brunei Bay consists of flat or gently rolling slopes not exceeding 12.

The slopes along the northern coastline are characterized mainly by raised beaches and sand deposits with occasional occurrences of mangrove and peat swamps. Within Brunei Bay, the flat coastal slopes are dominated by mangrove forests with raised beach and sand deposits

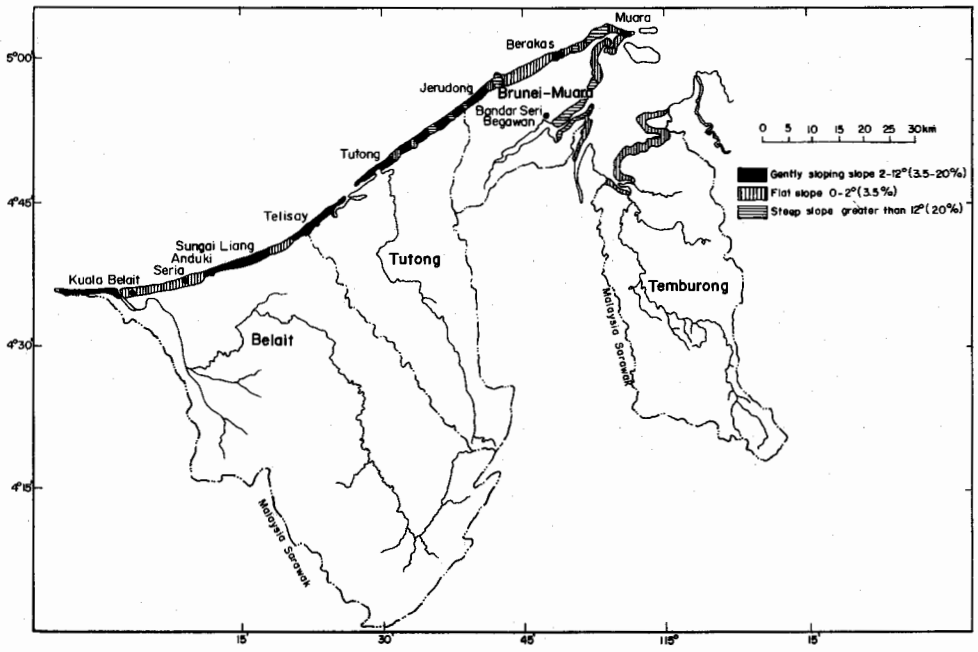


Fig. 5.1. Coastal topography and slopes (adapted from MOD-DOTCP No. 1, 1986a).

supporting development along the south of Muara promontory. The gently rolling slopes which feature the older alluvial deposits are found extensively throughout the northern coast. Steep slopes consist of a 2 to 3-m thick layer of residual and colluvial soils over weathered bedrock which is sensitive to erosion.

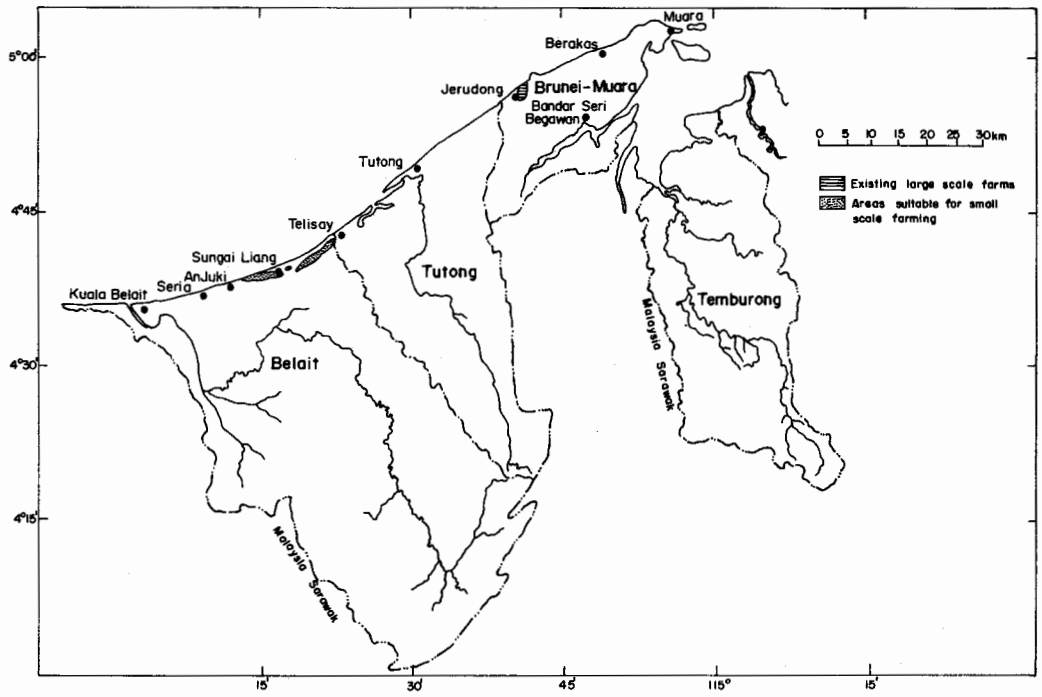


Fig. 5.2. Existing and potential agricultural areas (adapted from DOTCP 1987a).

Suitability for agriculture

Almost the whole of northern coastal belt between Kuala Belait and Muara Harbor consists of grey-white podzolics, podzols, regosols or sandy soils. These soils are characteristically sandy in texture with low iron, aluminum and clay contents, and are not suitable for any of the six agricultural uses identified by the report submitted to the government by ULG Consultants, Ltd. in 1982 and the Master Plan, as the likeliest forms of future agricultural development in Brunei Darussalam. These forms are: (1) mechanized wetland rice; (2) wetland smallholder rice; (3) mechanized dryland farming; (4) tree crops and forest plantations; (5) buffalo grazing; and (6) large-scale cattle farming.

The coastal beaches have no agricultural value but this does not exclude the smallholder cultivation of crops and fruit trees scattered irregularly throughout the coastal belt (e.g., the Telisay coast in Tutong supports limited growing of vegetables and watermelon).

Two areas along the northern coast having agricultural development potential are at Sengkurong in Brunei-Muara District and S. Liang in Belait District (Fig. 5.2). The Sengkurong area, with its coastal front of about 1 km and extending 2 km inland, occupies a space of 100 ha of flat land surrounded on the east, south and west boundaries by steeply sloping land. The soil here is alluvial and imperfectly drained, formed mainly as river levees free of marine influence, and therefore, possessing no acid sulfate hazard. Although suitable for all the six forms of agriculture, the soil is currently utilized mainly for cattle farming with the already established Jerudong Cattle Fattening Station and the Luahan Cattle Breeding Station.

In S. Liang area, 800 ha of land in two narrow strips hugging the coastal road are being developed for the growing of homeyard vegetables and the establishment of fruit tree gardens.

Poultry farming is carried out here. Although the soils are grey-white podzolics, podzols, regosols and are sandy in texture, they are slightly better and sufficient to support these forms of agriculture.

Suitability for urban development

Due to their inability to support large-scale agriculture, the coastal land's best use as identified in the Master Plan is for urban, residential and industrial development. Raised beach and sand deposit areas found extensively in Belait, Seria and Tutong can be economically developed into recreational playgrounds, roads, car parks and low-rise buildings not exceeding two storeys. A higher but still average cost would be incurred to support high-rise buildings of up to eight storeys because of the required foundational pilings. These developments have taken place along the coast stretching between Kuala Belait and S. Liang, and in some parts of the coast stretching between S. Liang and Muara.

The flat peat swamps such as those around S. Mangsalut on the eastern boundary of the Berakas Military Reserve are not appropriate for development because of the soft, unsettled soil conditions and possible flooding hazards. The flat alluvial flood plains more of which occur on the northern coast of Brunei-Muara District have generally firm soils which become soft in the deeper layers. They can be economically developed into recreational fields, road, car parks and single-storey buildings. Alluvio-marine mangrove and *nipah* swamps which dominate the coastal areas of Brunei Bay can also be economically converted to have recreational fields, roads and single-storey buildings.

Hills and remnant hillocks with steep slopes have limited occurrences along the northern coast and the northern flank at the entrance of S. Brunei. These can be economically developed to support fields, roads and high-rise buildings provided the necessary erosion protection measures are taken.

Land Development

Belait District

This coastal strip covers Kuala Belait and Seria, including S. Liang, which falls within the Urban Development Plan Scheme (UDPS) area. At the mouth of S. Belait estuary is the Belait Shipyard. About 1 km upstream of the river and farther are land development areas for human settlement, domestic sewage discharge and two sawmills. Along Kuala Belait-Seria coast, raised beach and sand deposit, oil and gas operations make the land unsuitable for agriculture. However, between Lumut and Tunggulian, some 470 ha, mostly north of the coastal highway, have been identified as having potential for smallholder farming. Much of the area within the strip is already under cultivation.

The entire Kuala Belait-Seria UDPS area includes a total of 3,995 and 4,680 ha, respectively. UDPS includes housing, industry, commercial expansion, government functions, educational facilities, recreation, transport and infrastructure.

Exploitation of the Seria oil field, and subsequently the offshore oil and gas fields, has shifted virtually all economic activities to the coastal strip. More than 100 ha between Lumut and S. Liang are occupied by Brunei Liquified Natural Gas (BLNG) terminal.

BLNG sites and cogeneration plants are protected from flood by S. Lumut through drainage systems. Flood drainage channels are currently constructed. Other major industrial

and residential developments also require similar works. Major flood protection works are also planned to prevent Belait River from overflowing its banks. S. Keduan and S. Belait/Penipir Reservoirs in headwaters of Belait River have been identified as potential sites for flood control reservoirs.

Both Kuala Belait and Seria have sewer systems, but neither have treatment plants. Kuala Belait sewers serve about 50% of the population and discharge into Belait River. Seria sewers serve all but the western part of the town and discharge into S. Bera. The 1982 Sewerage Master Plan proposes land reserves for treatment plants: 3 ha at Tg. Baram, near the mouth of Belait River and 15 ha at S. Bera. A new treatment plant with a capacity of serving about 40,000 people and a land reserve for a plant serving 150,000 are being built on Belait River, south of Kg. Pandan.

S. Liang is a proposed site of industrial development. Several timber processing operations will be integrated into a single management unit which includes two sawmills, a plymill and a medium-density fiberboard plant. Another government-sponsored wood treatment plant is proposed. The area is also preferred for other industries such as glass factory and petrochemicals processing. Other potentially polluting industries such as artificial coarse aggregate production, precast concrete manufacture and cement bagging are planned. These require direct drainage to the sea.

The beaches of S. Liang are now protected from sand excavation but are vulnerable to pollution from industries at Lumut and S. Liang, and from offshore oil fields.

The pit resulting from sand extraction in Anduki could be used for recreation and fish production. However, the danger of oil pollution in the water should be investigated. Pond fish may have satisfactory growth, but oil could concentrate in fish and other organisms. Thus, the development of Anduki Pit and of S. Liang Beach for recreation requires further study and should be made part of a proposed enviromental study of the entire Brunei Darussalam coast.

The major development areas in Belait are linked by the regional primary road. Traffic volumes on the section between Tutong District boundary and Seria are projected to increase to more than 15,000 vehicles per day by 1995. Therefore, dualing of the road by 1990-1995 is proposed in the Master Plan.

Tutong District

The coastal strip of Tutong District is composed of Telisay, Tutong Town and Penanjong/Binturan Military Reserve between Tutong Town and Brunei-Muara District boundary. The area between Telisay and Tutong Town is generally unsuitable for agriculture. Some areas are already occupied by the coastal villages of Telisay, Danau, and Kuala Tutong. Tutong Town proper is under UDPS which covers 2,485 ha.

Along the coast is a broad estuarine lagoon sheltered from the sea by two long sand spits. Tutong and Telamba River Systems drain into this lagoon. The estuaries extend inland to mangrove areas backed by waterlogged brackish swamps. The higher ground between the two major waterways is made up of infertile fine sands with extensive surface deposits of silica sand

The natural resources and land use potentials within the strip are:

1. Aquaculture. Some stretches in the protected estuarine waters of Tutong and Telamba River Systems are suited for small-scale cage culture of brackishwater fish species. The coastal sand spit between South China Sea and the estuarine waters is also suitable for a multispecies fish hatchery.
2. White sand nature reserve. This extends inland and is located between the coastal highway and Tutong Estuary. Most of the reserve area is already outside the defined limit of the coastal strip.

3. Beach sand. Longshore drift and sand movement are considerable in this area, thus, interfering with natural wave action that might erode the narrow spits between S. Tutong Estuary and the sea. It is essential for the survival of these pits that trees and ground cover are maintained--reinforced by planting and, if necessary, protected by seawalls and breakwaters. Proposed picnic areas, shaded car parks, and low-key recreational facilities along the sand spits would complement the suggested sport and hotel facilities in town.

The coastal strip within Tutong UDPS is around 127 ha, located between the coastal road and South China Sea. The Master Plan suggests using it for tourism and recreation. A Regional Sports Centre; a golf course with low-density housing around the inland perimeter; and possibly a small beach tourism hotel of 50 to 100 rooms are suggested. The new coastal highway will provide excellent access to these potential development areas.

The planned development would have a significant effect on the environment and would require an EIS. Two sewage treatment works are operating in the district. One in Tutong Town, within the UDPS area, is designed for a population of 46,900 to 59,800; the other one, in Penanjong, could serve up to 18,000 people. Both treatment facilities discharge effluent to the South China Sea. A third proposed facility will discharge in Tutong River.

The remaining coastal stretch from Penanjong to Brunei-Muara District boundary is mostly a military reserve. Military activity is largely confined to camps in Tutong and Penanjong and to Binturan Firing Ranges. However, in Kg. Penanjong, some residential coastal areas are identified for light-density housing of eight units per hectare.

Brunei-Muara District

As the commercial center of the country and seat of government, the land resources of Brunei-Muara District have been planned or committed for full-scale development by the year 2005. Development projects include public and residential projects; industrial areas; sites for government functions; transport; utilities; landscape and conservation.

The coastal strip runs from Jerudong to Berakas to Muara, and up to S. Brunei Estuary. Between Jerudong and Berakas, Jerudong and Tungku Beaches are used for recreation. A third, less developed beach located toward Berakas has some potential for recreation. Residential houses have been established near Berakas. Also, certain areas on the fringe or outside the coastal strip are identified for a university and an institute of technology. These sites along the coastal highway are adjacent to a botanical garden and an area slated for residential development. A military camp and a forest reserve are also located in Berakas Proper.

From Berakas to Muara Port, the coastal strip nearer Muara is a potential urban development area. Muara and Serasa Beaches are also located here. In Muara, some industrial development projects exist or are being developed. These are the Muara Industrial Estate (which includes the port extension and cement plant) with an area of about 85 ha, and the Takehira Shipyard with about 13 ha. Muara is also being considered as an aquaculture complex (9 ha) and a fish landing complex (2.3 ha).

Sewerage treatment works and waste discharge from a number of septic tanks drain directly to S. Brunei. These works are:

System	Location of discharge
1. Existing/committed systems	
Bandar Seri Begawan	S. Brunei Estuary
Muara	Brunei Bay
Lambak Kanan	South China Sea
Lambak Kiri and Berakas	South China Sea
Pengkalan Sibabau	Brunei Bay
2. New systems	
Jerudong	South China Sea
Lumapas	S. Brunei Estuary

The promotion of a high-quality physical environment is one of the prime objectives of the Structure Plan. This will involve the conservation of areas with significant ecological and/or scenic potential and the creation of landscape facilities. The Structure Plan categorized these conservation areas as environmental protection and major urban parks. Those within or touching the coastal strip are the following:

1. Subok Ridge, which is proposed as a national park linking the town center to the national museum, has forest and soil to be conserved while also providing a view of the estuary, the town center and Kg. Air.
2. The botanical garden at Rimba is adjacent to the new university and is considered for a long-term development project.
3. P. Ranggu mangrove conservation area, which constitutes the mangrove areas in Brunei Estuary, are aesthetically and ecologically important, providing valuable habitat for fish and shellfish. A mangrove conservation park is proposed under the Master Plan on the island opposite Damuan River Park. This highly visible scenic area of mangrove has potential as an educational park which could be combined with Damuan River Park to provide an amenity adjoining Istana Nural Iman.
4. Aside from several existing local neighborhood parks, the coastal beaches to be maintained and conserved are those in Jerudong, Tungku, Muara and Serasa.

Temburong District

Temburong District has four major river systems that meet in the estuary around P. Siarau. These are S. Labu, S. Batu Apoi, S. Temburong and S. Pandaruan. There are three totally protected areas recommended for long-term conservation in the Master Plan. These extend inland with Labu-Selirong Wildlife Sanctuary fronting the coastal fringes of Brunei Bay.

The proposed Labu-Selirong Wildlife Sanctuary combines the Selirong Forest Reserve (2,566 ha including integral areas of open water), the Labu Forest Reserve (14,348 ha) and the 375-ha P. Siarau which is already a designated conservation area. The sanctuary, which has an estimated total land area of 15,935 ha, is recommended for management to ensure that large commercial inshore fisheries of the bay are maintained and to control exploitation of the mangrove forest.

Although Labu and Selirong Forest Reserves are designated to become wildlife sanctuaries, it is envisaged that limited cutting of mangrove and other timber, particularly by those with customary rights, will be permitted. The extent of cutting will be within the proposed national conservation strategy and a detailed development and management plan which is to be prepared for the sanctuary.

Current exploitation in the mangrove forests of Labu and Selirong Forest Reserves is confined to permit holders that take timber for a small charcoal industry and poles for pilings.

The latter use has increased significantly in recent years as a result of the building industry.

More than 3,700 ha around the inner estuaries of the four rivers were identified as potentially suitable for mechanized rice cultivation. First, this area needs detailed soil and topographical investigations and carefully designed reclamation and flood protection measures. Sufficient irrigation water must also be provided. The potential threat of mangrove and fisheries pollution downstream from future rice farming operations should also be studied. Hence, pond aquaculture is probably a more suitable use of this area because with brackishwater pond fish culture, agricultural pollution is not a problem. Also, the need for freshwater supply is less than in rice farming. However, detailed soil, topographical, tidal fluctuation and salinity studies are necessary if the area is to be developed for aquaculture.

Land Tenure

The Land Code, introduced on 6 September 1909 and amended from time to time, forms the basis of legislation relating to land. Historically, all lands in Brunei Darussalam belongs to the State. At present, forest reserves and state land make up the bulk of land available. The rest is made up of Extract District Register land (alienated land); gazetted land reserved for government use; private land held in perpetuity or on lease, concessions or Temporary Occupation Licenses (TOL). Land can be alienated by His Majesty The Sultan in Council by way of leases on terms varying from perpetuity to a fixed number of years.

State land of less than 4 ha in extent can be approved for development purposes through TOL granted by LD after being cleared by the interested departments. The main departments involved are LD; the District Officer of the area in which the land is located; SD; and other departments that might have a claim of interest to the land. The duration of a TOL is one year, but is extendable through successful new applications made from year to year. A TOL is not transferable without a new successful application to even the next of kin.

Upon successful clearance by LD, a TOL of over 4 ha for a development purpose needs to be forwarded through the Industrial Development Unit and the Industrial Committee for final approval by the Minister of Development.

An application from a government department for state land would go through the same initial phases as for a TOL. But the former is gazetted by MOD on being successfully cleared by the Land Office after consulting the relevant departments.

Applications for concessions and leasing of state land, transfers, subdivision and the change of condition of all lands need the approval at the highest level from His Majesty The Sultan in Council. This involves the preparation of a council paper by the Land Commissioner after the application is processed by the Land Office and is recommended by the Minister of Development prior to presentation to His Majesty The Sultan in Council (Fig. 5.3).

The period taken for approval of an application for a land transaction will depend to a large extent on how fast responses are received from the interested departments and the frequency of the relevant committees and other meetings. This could vary from four to six months in case of land transfers and up to one year or more for leasing or concessions on state land.

To overcome some of the problems of the present procedures of land tenure such as long delays, the Brunei Darussalam Master Plan recommended a more sophisticated system of tackling land transaction which involves the formation of a formal Land and Planning Board.

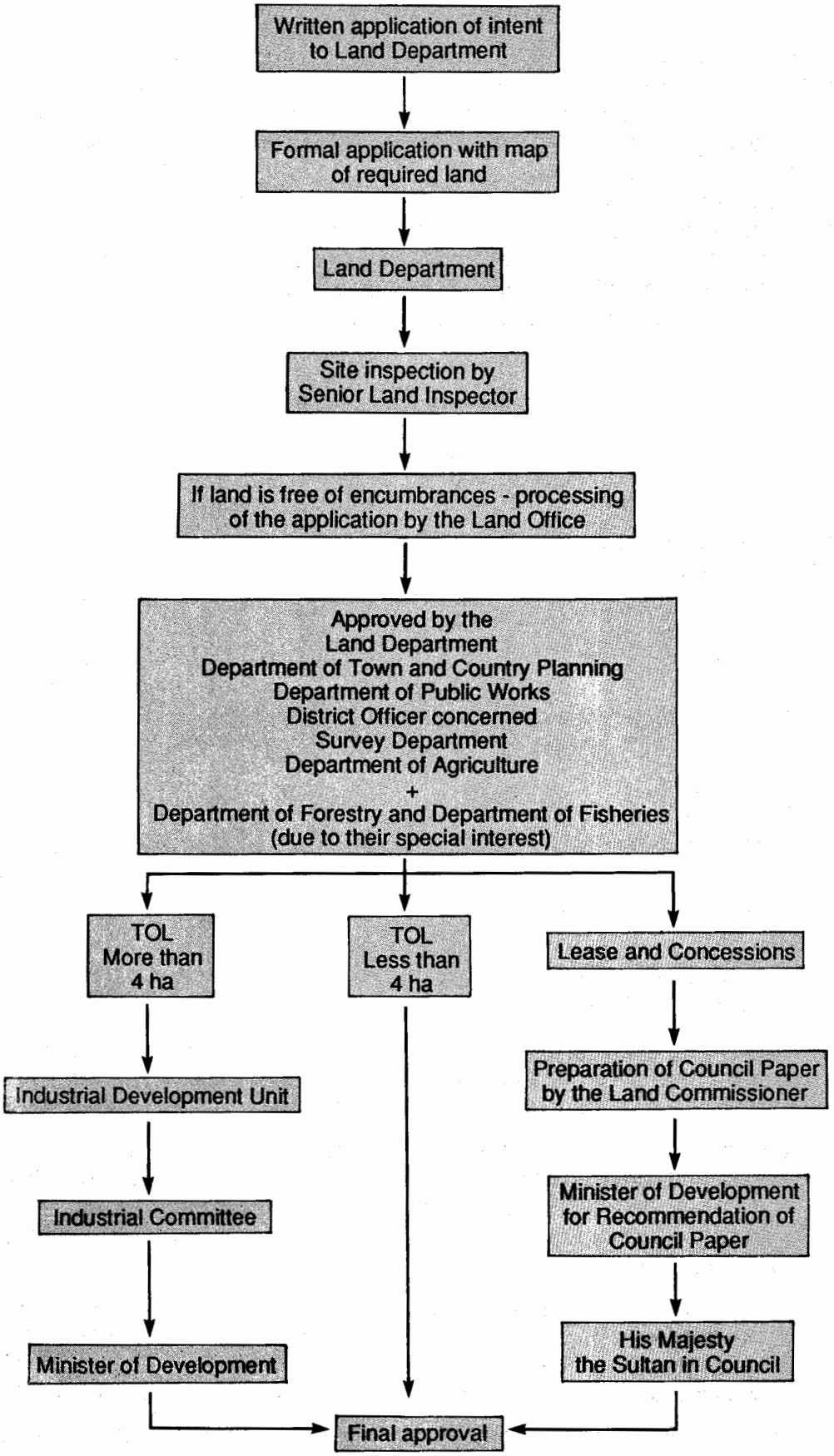


Fig. 5.3. Flow chart from application to approval of land concessions or lease, subdivision or utilization.

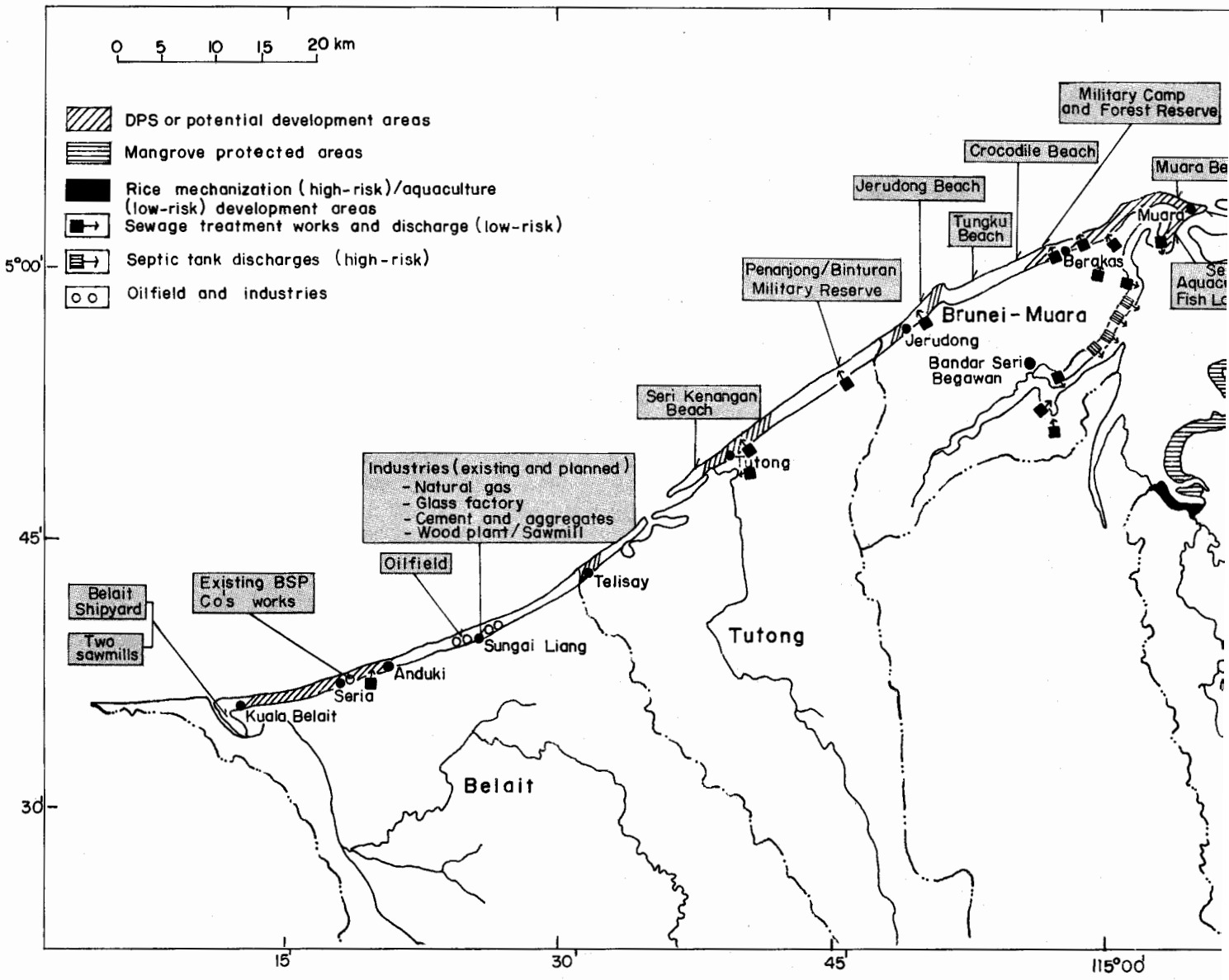


Fig. 5.4. Existing, ongoing and planned land development activities along the coast (adapted from MOD-DOTCP No. 1, 1986a).

Aside from TOL, the period of ownership of two other categories of land in the nonpermanent ownership of land granted by the state are as follows:

Lease - Given for a limited period which could extend up to 99 years or in very special cases, such as specific diplomatic missions, up to 999 years.

Concessions - Given for an indefinite period until the land is needed by the person/company or is required by the state.

Implications of Land Development

The activities enumerated on land development (Fig. 5.4) have wide-ranging implications on coastal management. The probable adverse effects of these activities to coastal ecology may be categorized as low- or high-risk over the long-term period.

Housing, beach, road, drainage works development and the like which involve earthworks are just temporarily affecting the coastal area, but the more continuing or long-term threats to the environment arising from these, particularly human settlements, are domestic sewage and garbage. If uncontrolled, these could be high-risk pollutants, depending on the quantity and the state at the time of disposal. Sewage from septic tanks that is directly discharged to the seashore is a high-risk pollutant. But sewage that is treated before being discharged to the sea can be considered as low-risk.

Oil fields, natural gas and factories/plants such as cement and sawmill/wood are high pollution-risk industries. Glass factories may fall in the low-risk category.

Improper agricultural cultivation may be classified as high-risk because of induced soil erosion and the excessive effects of pesticides.

Some mitigating measures need to be taken to minimize pollution threats arising from these activities. Along with the evaluation of environmental impacts on these activities, regular monitoring of high-risk pollutants from established stations has to be carried out. Treatment plants for industrial effluent need to be established for every potential polluting industry, before effluents are discharged to the sea. The effluents should be discharged far enough into the sea where quick dilution and currents could immediately carry them seaward.

Chapter 6
Economic Sector

The different components of the economic sector discussed in this chapter include capture fisheries, aquaculture, coastal agriculture, coastal forestry, tourism and recreation and industry.

Capture Fisheries

KHOO HONG WOO, S. SELVANATHAN AND
ABDUL HALIDI MOHD. SALLEH

The industry

The fisheries sector in Brunei Darussalam contributes about 0.2% to the country's Gross Domestic Product (GDP), comparatively small among Southeast Asian nations, and provides work to about 660 full-time and over 1,500 part-time fishermen. Based on the 1986 statistics provided by DOF, the sector produced 2,268 t of fresh fish in 1986, that is, 52% of the requirements. Imports of other fish products amounted to 2,587 t. A comprehensive review of fisheries development in the country was done by Birkenmeier (1969).

Crown Agents for Overseas Governments and Administrations, in (1976), conducted a detailed study of the fishing industry--its structure, marketing system, supply system, markets, socioeconomic factors, production, role of DOF and fisheries development policy. Recommendations were also made.

ULG Consultants Ltd., in 1983, made a renewable resource study on fisheries activities in Temburong. The present status of fisheries is comprehensively reviewed in MOD-DOTCP No. 5 (1986c).

Marine capture fisheries produce a consistent amount yearly, around 2,500 t, since 1983. A slight reduction to 2,100 t was recorded in 1986 (Table 6.1).

Freshwater finfish production remained below 8 t since 1983 (about 8 t in 1986). Imports were also at a low level of 4 t/year. There was, however, an increasing trend in local landings over the past four years probably due to a slight increase in freshwater aquaculture activities. The amount contributed by riverine fisheries was mainly from freshwater prawn with an annual yield of about 40 t in 1986. The production level was maintained between 40 to 50 t for the past four years. Imports of freshwater prawn, however, were about two to three times that of local production. In 1986, import was 63.6 t.

Marine finfish production in 1986 was 1,723 t; 1,333 t were imported. Shrimp production was 377 t; 440 t were imported. Mollusk production was 36 t and about four times that amount were imported (159 t).

Local catches are collected from fishermen by dealers or sold directly to fishmongers who retail at municipal markets in Gadong, Tutong, Seria, Kuala Belait and Bandar. The Gadong market began to be operational only in late 1986, replacing the old market at the heart of Bandar Seri Begawan.

Ice facilities are provided by the newly built landing complexes (at the moment, only for Kuala Belait areas until the new Fish Landing Complex at Muara is completed towards the second half of 1987) but most of the village fishermen land at their traditional landing points and often without icing facilities. There are 4 flake ice factories producing 240 rice sacks per day (36 kg/sack). The department is involved in educating the fishermen to use ice to preserve their catches at the correct proportion (1:1) to ensure that the best-quality fish reach consumers. There is a preference for some types of fish with the mucus still present, as this is taken to be an indication of freshness. It is believed that ice destroys this layer. So, DOF is trying to educate consumers to accept chilled fish as comparable in quality to those with bodies covered with slimy mucus.

Table 6.3. Fish marketed in Brunei Darussalam in 1986.

Grade	Value (B$)	Quantity		Average price (B$)		Range (B$)	
		Kati	kg	Per *kati*	Per kg	*Kati*	kg
1	9,675,219	2,454,558	1,485,008	3.94	6.51	2.15 - 5.75	3.55 - 9.50
2	2,095,197	832,594	503,719	2.52	4.16	1.69 - 3.79	2.79 - 6.21
3	585,456	367,358	222,252	1.59	2.63	1.36 - 2.90	2.25 - 4.78
4	3,217,202	1,268,047	767,168	2.54	4.19	0.70 - 4.27	1.16 - 7.06

Fish are graded for marketing purposes (Table 6.3), generally, according to market prices; the higher the price of the fish, the better their grade. Freshwater fish, crustaceans and mollusks are not graded but treated as separate categories.

There are nine small-scale, cottage-type processing plants for the manufacture of prawn crackers (*keropok*), fishballs and cakes.

Inshore fisheries

Inshore fisheries are the primary source of animal protein for a population which consumes about 40 kg per capita per annum, on the average much higher than any other Southeast Asian population.

Traditional or inshore fisheries have a long history in Brunei Darussalam (Hickling 1947; unpublished DOF reports on fisheries surveys in Brunei waters in 1950; Anderson et al. 1952; Birkenmeier 1969; and Currie 1982).

Distribution of Fishermen. It was only recently that DOF took over the licencing of fishing gears. Previously, this was done by MD. Licencing applies only when the fishermen market their catches.

The bulk of inshore fisheries activities are concentrated in Brunei-Muara District. In 1986, there were 659 licenced full-time and 1,566 part-time fishermen with 1,190 outboard fishing vessels listed. Of the full-time ones, 71.3% are in Brunei Muara; 17.3%, in Seria/Belait; and 11.4%, in Tutong (Table 6.4). In Temburong, there are 7.9% part-time and no full-time fishermen. Overall, there are two to three times more part-time than full-time fishermen. Catching by the former group has not been monitored while the latter has been monitored since

Table 6.4. Number of fishermen, fishing gears/vessels in Brunei Darussalam in 1986.

District	Fishermen			Fishing vessel - Inboard						Nets[a]
	Full-time	Part-time	Nonpowered	Outboard	Total	No. using *Tunda*	*Lingkung*	*Rawai*	*Bubu*	Others	
Brunei-Muara	470	1,267	12	933	12	4	7	1	-	-	986
Tutong	75	60	2	111	-	-	-	-	-	-	125
S/B	114	116	-	112	-	-	-	-	-	-	132
Temburong	-	123	-	34	-	-	-	-	-	-	57
Total	659	1,566	14	1,190	12	4	7	1	-	-	1,300

[a]Nets include the following: *anchau/lingkung* (ring net/purse seine); *selambau* (small hauling net); *pukat* (small hauling net); *rambat* (cast net); *peguyut* (seine net); *rantau* (drift (scoop net); *lingkung* (purse seine); *tugu* (tidal trap net); and *andang* (bottom set gill net).
[b]Hooks include: *pancing* (hook) and *rawai* (long line).
[c]Traps include: *bubu* (trap); *kilong* (deepwater fish trap); *kabat* (small fish trap); and *lintau* (shoal water fish trap).

Table 6.5. Predominant species caught in artisanal gears in 1986.

Gears	Dominant species	Yield (t)
Ancau (small purse seine)	*Sardinella* sp. (72%)	283.7
Andang (trammel net)	Large shrimp (95%)	392.4
Andang jarang (gill net)	*Elasmobranchs* (30%); *siluroids* (18%); *leiognathids* (17%)	66.2
Bubu (trap/pot)	*Caranx* sp. (37%); *Lutjanus malabaricus* (18%); *Pomadays maculatus* (16%)	35.1
Kabat (tidal weir)	*Scatophagus* spp. (30%); *Mugil* sp. (27%)	60.1
Kembura (cast net)	*Mugil* sp. (43%); *Anodontosoma chacunda* (31%)	128.8
Kilong (large corral)	*Sardinella fimbriata* (72%)	45.1
Lintau (small corral)	*Siganus* sp. (49%); *Sardinella* spp. (21%)	
Pancing (hand or long line)	*Selar* sp. (28%); *Lutjanus malabaricus* (27%); *Epinephelus* sp. (21%)	2.4
Panau (ring net for *Formio niger*)	*Formio niger* (59%); *Selar* sp. (36%)	154.0
Rambat (cast net)	*Selar* sp. (41%); *Sardinella* sp. (17%)	45.0
Rantau (drift gill net for night operations)	*Scomberoides* (39%); *S. commerson* (30%)	22.2
Tugu (intertidal funnel barrier net)	Shrimp (0%)	682.3
Total		1,917.21

1982. Part-time fishermen could account for a substantial proportion of the exploitation of inshore areas; hence, more accurate catch information is needed from this group. DOF estimated a subsistence consumption of 408 t of marine fish and 83 t of freshwater fish (Table 6.1).

Most fishermen fish in Brunei's estuarine system and in the northwest of Muara in South China Sea. In Temburong, most activities are conducted by part-time fishermen. Most fishermen in Tutong are also part-time, and they fish in Tutong Estuary and in the northwest of Tutong. The main fishing area in Belait is in the sea north of Belait and in Belait River.

Gear Distribution. The main inshore fishing gears are:

Ring net *(ancau)*
Trammel net *(andang karan)*
Gill net with larger mesh sizes *(andang jarang)*
Pot or trap *(bubu)*
Tidal weir *(kabat)*
Gill net for mullets/shads *(pukat kembura/kuasi)*
Beach seine without bag *(kikis/ambit)*
Large corral *(kilong)*
Small corral *(lintau)*
Hand line/long line *(pancing/rawai)*
Ring net for black pomfrets *(panau)*
Cast net *(rambat)*
Drift gill net for night operation *(rantau)*
Lift net *(selambau)*
Intertidal funnel barrier net *(tugu)*

Fishing gears popularly used in Brunei Darussalam are: trammel nets, hand lines, intertidal funnel barrier nets, gill nets with large mesh, traps or pots, drift gill nets, ring nets and cast nets (Appendix 4).

The predominant species caught by each gear type are shown in Table 6.5. It appears that each gear is quite specific in the species it captures. A large proportion of the catch from most gears mainly consisted of two to three species. For example, trammel nets are specific for the capture of shrimp, and large corrals, for sardines. Each gear with its corresponding resource could, therefore, be regarded in a very broad sense as a separate fishery. The commercially important species, with their local and scientific names are listed in Appendix 5.

According to yield (Table 6.5), funnel barrier nets (36%) contribute the biggest amount to overall inshore fish catch, followed by trammel nets (20%); small purse seines (15%); and ring nets for black pomfret (8%).

Inshore Fishing Grounds. Inshore fisheries primarily operate inside Brunei Estuary and the coastal water (Fig. 6.1 and 6.2). Some of the *bubu*, *pancing* and *panau* gears are sited around 15-fathom depth.

Penaeid shrimp fisheries are concentrated in the extensive estuarine system that lies southwest of Brunei Bay Proper. This fishing ground is of considerable importance. Fishermen from the fishing communities on South China Sea Coast operate close to the shore in small boats, while a few communities especially from Kg. Batu Marang operate pots, long lines and drifting gill nets on the shoals to the north and northwest of Tutong and to the northwest of Muara. The Champion Fields area is a popular line fishing ground for catching large fish.

Inshore fisheries use traditional gears and small boats powered by outboard motors. The open wooden plank inshore boats (7.6 m) are powered by an outboard engine in the 25 to 40 hp range. In the more exposed areas, the boats are larger and powered by at least two outboard motors in the 40 to 55 hp range.

Preliminary Catch/Effort Analysis from Brunei-Muara District. The catch and effort data were collected and described in the unpublished work of Abdul Halidi Mohd. Salleh entitled

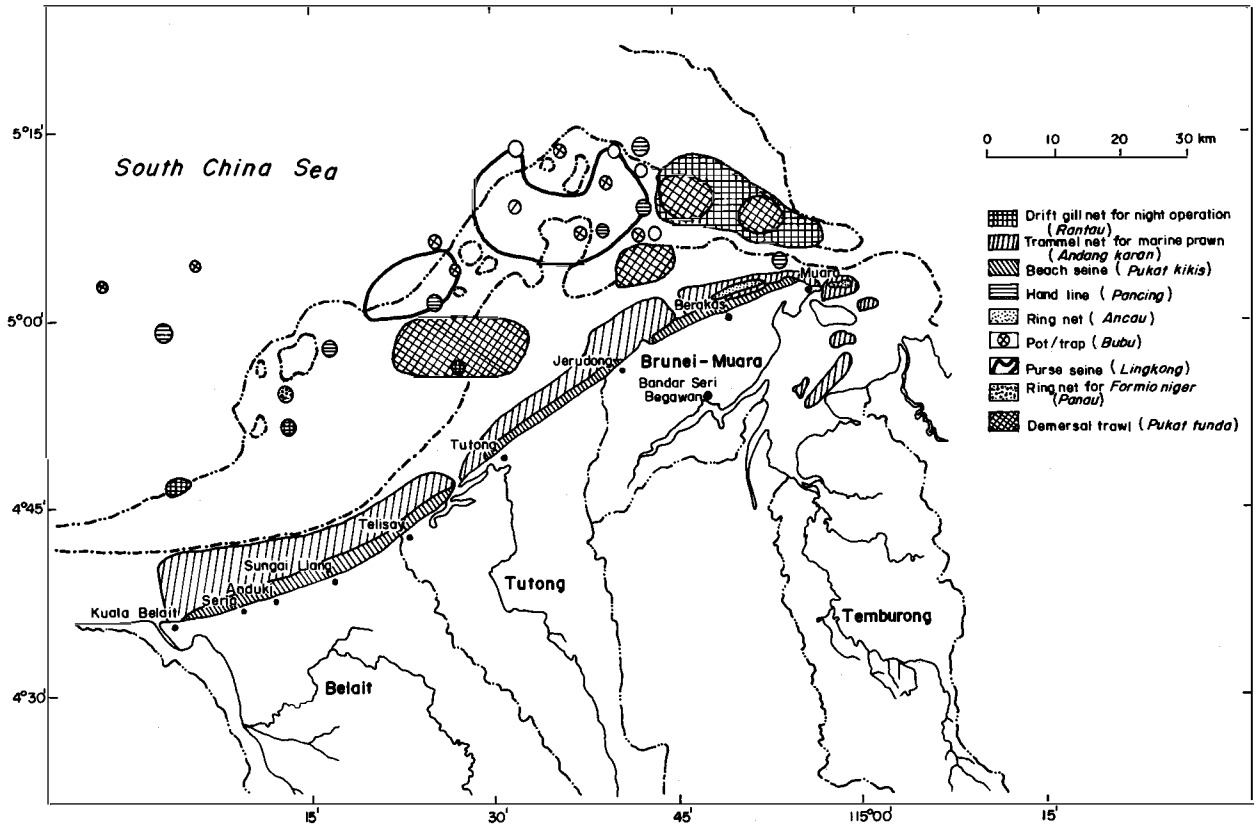


Fig. 6.1. Brunei Darussalam coastal fishing grounds according to gears.

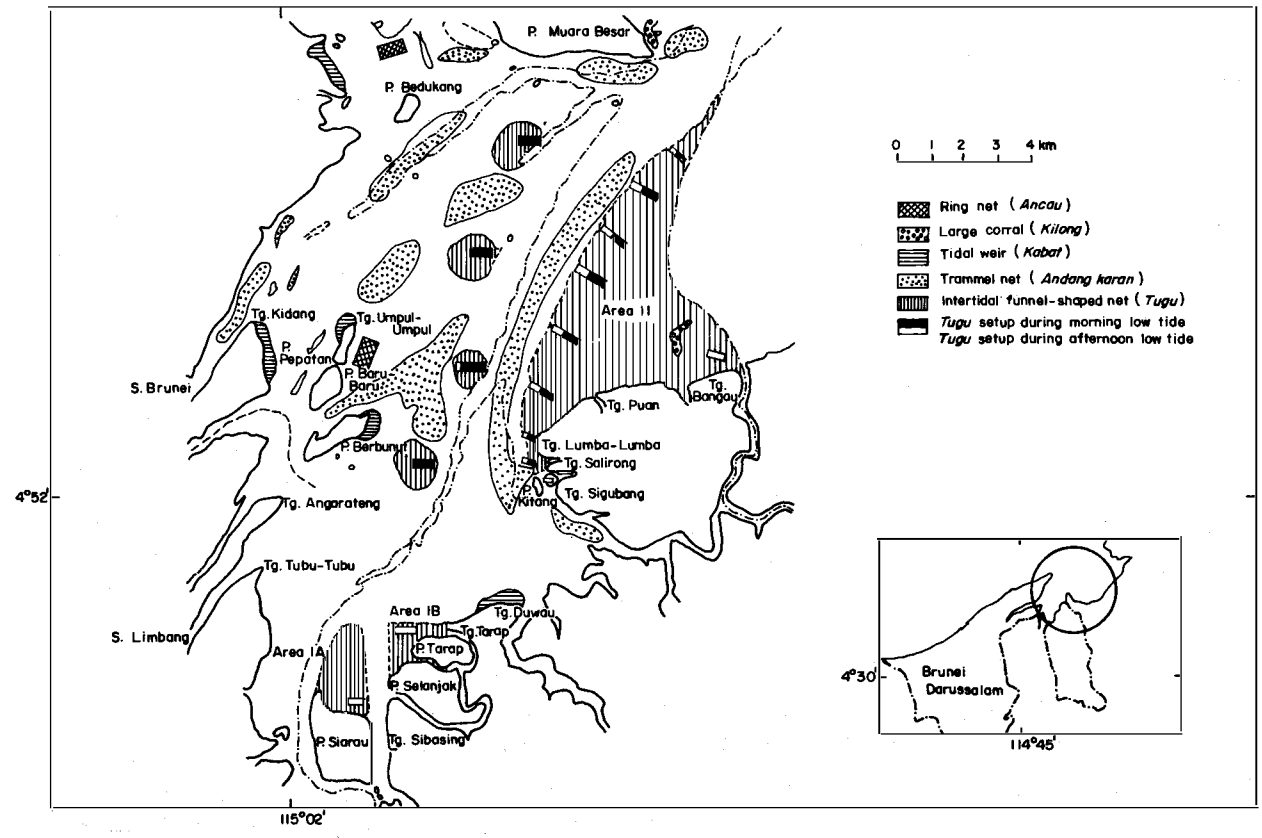


Fig. 6.2. Brunei Estuary fishing grounds according to gears.

"Preliminary analysis of catches by full-time fishermen in the Brunei and Muara District of Negara Brunei Darussalam from October 1979 to December 1986," which is an output of a training he had at ICLARM. Essentially, the fishing villages were divided into four districts (Fig. 6.3). Interviews of full-time fishermen selected at random (by area or village and by type of gear used) were made. These fishermen were identified and interviewed on a monthly basis on how much they caught per trip and how many trips they made per month. The data were on the marketable fish, but most probably some noncommercial species were also included.

The yield per month was then totaled for each year. The effort was measured by multiplying the number of active gears and the number of days active per month to give "gear-days". The monthly total for each year provided the annual effort. The catch per unit effort (CPUE) was calculated by dividing the annual total yield with the annual total effort. A regression of the catch/effort against effort was then conducted and the slope (b) and intercept (a) were used to estimate the MSY and optimum effort level (Table 6.6) (Ricker 1975).

The assumptions here were that each gear was selective (Table 6.5) and the species caught could be considered in isolation. It was also assumed that the fish communities responded quickly to exploitation (which may be reasonable because most species were short-lived and fast-growing). This analysis was an empirical attempt to derive at least some working models and hypotheses for inshore fisheries assessment using available data by DOF. The analysis does not claim to present an exact picture of the stocks in Brunei Estuary.

Analyses of 13 gears showed a declining catch/effort with increasing effort for 11 of the gears (Fig 6.4). Six of the gears gave good (negative) correlations between catch/effort and effort information ($R^2 > 0.50$). The greatest effects of effort were seen for the tidal weirs ($R^2 = 0.73$). Adding up all the MSY for each gear (Table 6.6), a total of about 13,300 t was obtained. The existing inshore catch was about 2,330 t. It seems that inshore areas could support more effort than they are now supporting, even if one accounts for overlap among the catches of the various gears. It would also appear from Table 6.6 that the trammel nets exceeded the effort level for MSY as did the tidal weirs and the cast nets. This assumed a 20 days/month active period.

Confidence levels could be placed for the values if the original monitoring data (available in DOF) were used for calculations. However, more points on the catch/effort versus effort plots and more empirical data on the actual accessibility of species to different fishing gears are needed to refine inshore fisheries assessment.

No data, however, on the catch taken by part-time fishermen are available. There is substantial removal from Brunei Bay by these fishermen. Methods to estimate their catch should be developed to more accurately evaluate the present status of stocks in the bay.

Seasonal Fluctuation of Catch. Halidi noted that there was a distinct seasonality in catch for most gears and that there was a decline in the annual catches of lutjanids while there was an increase in annual catches of leiognathids (Fig 6.5-6.6). Lutjanids are caught mainly by pots, traps and long lines (Table 6.3). It was suggested that the removal of the piscivorous lutjanids may have resulted in the observed increase of leiognathids. The latter are not high-valued. It would be prudent to regulate the exploitation of lutjanid predators by regulating the number of traps. The calculated maximum allowable number of trap licenses (Table 6.6) is 7, and the existing licences for traps are 36. More data points are needed to improve the significance of the calculations and interpretation.

Leiognathids are caught by gill nets, and Table 6.6 shows an underexploitation of this group. Again, the values are not statistically significant. More data are needed.

In view of the extreme importance of inshore fish and shrimp stocks to Brunei Darussalam fishermen, it is vital that immediate measures are taken to conduct a survey to obtain the necessary data base on fish stocks and optimal yield. These measures can help in

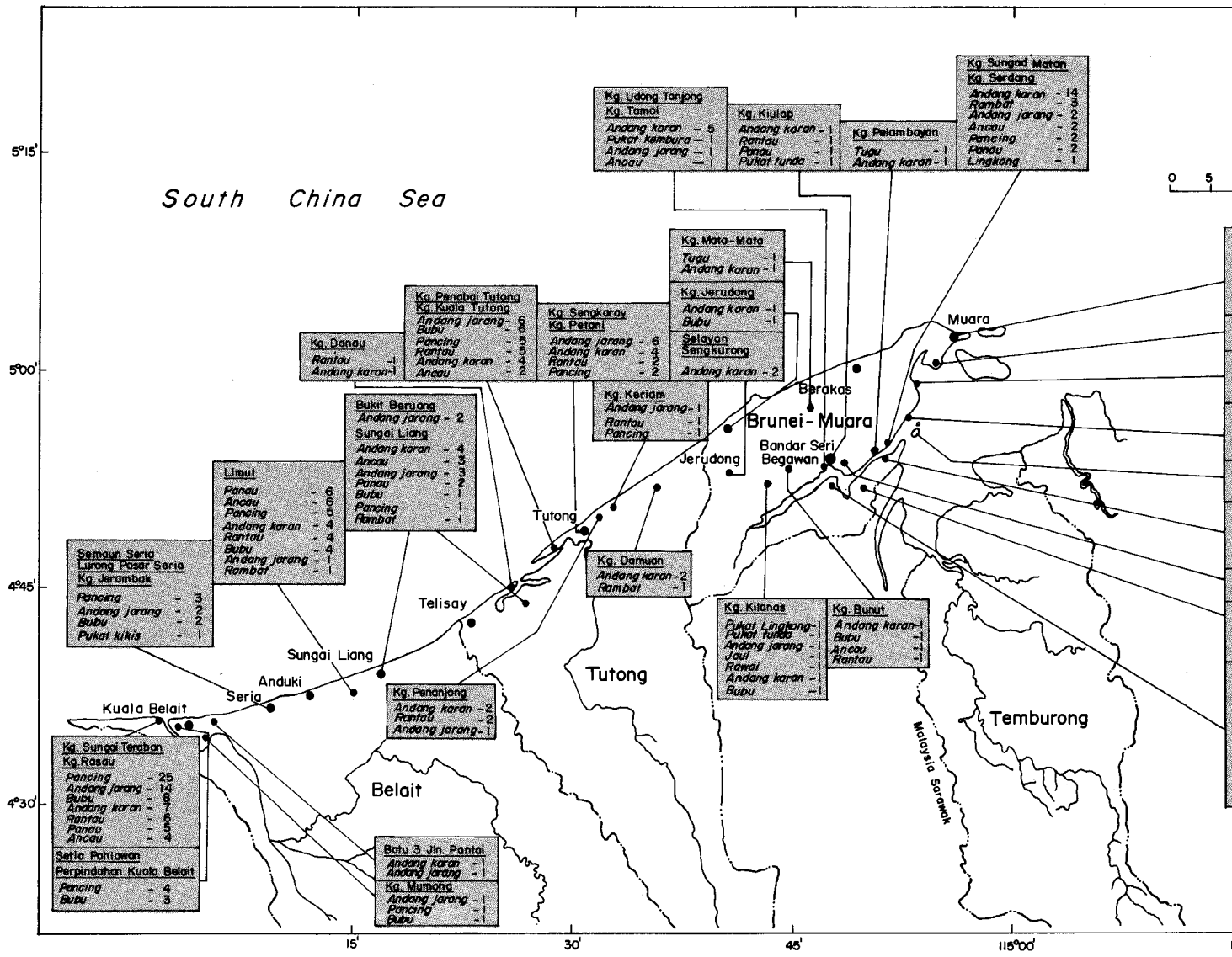


Fig. 6.3. Distribution of fishing gears by villages of full-time fishermen, 1986.

Table 6.6. Preliminary estimates of maximum sustainable yield (MSY) and effort of each inshore fishing gear.

	r^2	a	b	MSY (t)	fopt[a] (gear days)	No. of ge (20 days/ Active
Ancau (small purse seine)	0.94	-0.10	7.1×10^{-5}			
Andang (trammel net)	0.58	0.04	-6.2×10^{-7}	565	29,979	124.91
Andang jarang (gill net)	0.21	0.03	-4.6×10^{-3}	391	24,464	101.93
Bubu (trap/pot)	0.02	0.06	-1.7×10^{-5}	48	1,644	6.85
Kabat (tidal weir)	0.73	0.11	-5.3×10^{-5}	51	982	4.09
Pukat Kembura (gill net for *Mugil*)	0.10	0.03	-9.3×10^{-7}	163	13,157	54.82
Kilong (large corral)	0.67	0.06	-2.5×10^{-5}	40	1,278	5.32
Lintau (small corral)	0.71	0.11	-1.8×10^{-5}	185	3,243	13.51
Pancing (hand or long line)	0.12	0.03	-3.4×10^{-6}	50	3,811	15.88
Panau (ring net for *Formio niger*)	0	0.11	-5.3×10^{-6}	552	10,229	42.62
Rambat (cast net)	0.27	0.04	-7.9×10^{-6}	35	2,114	8.81
Rantau (drift gill net for night operation)	0.34	0.03	1.9×10^{-5}			
Tugu (intertidal funnel barrier net)	0.31	0.33	-3.9×10^{-5}	11,232	4,222	17.59

[a]fopt = optimum fishing effort.

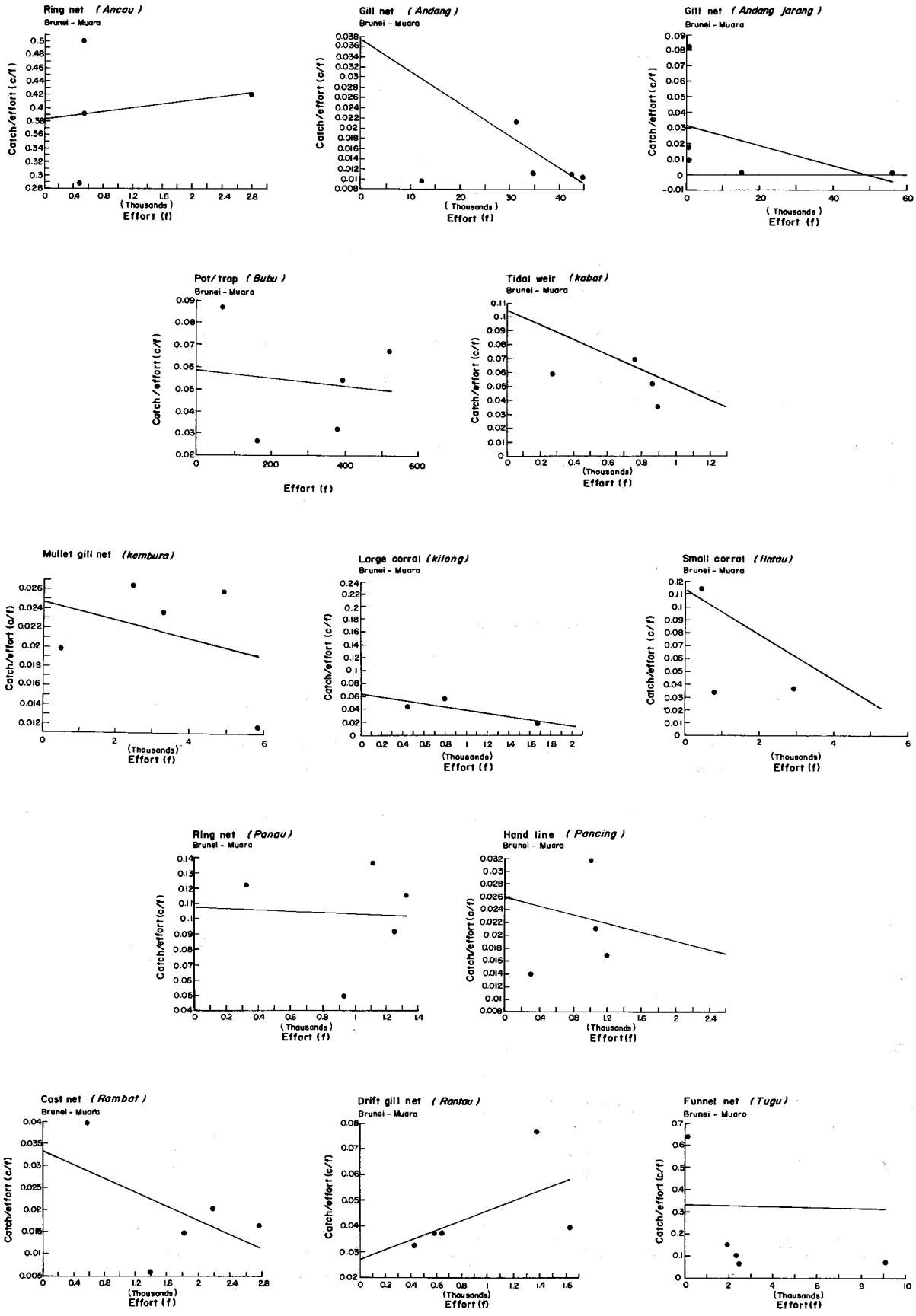


Fig. 6.4. Catch unit effort per fishing gear (regression), 1982-1986.

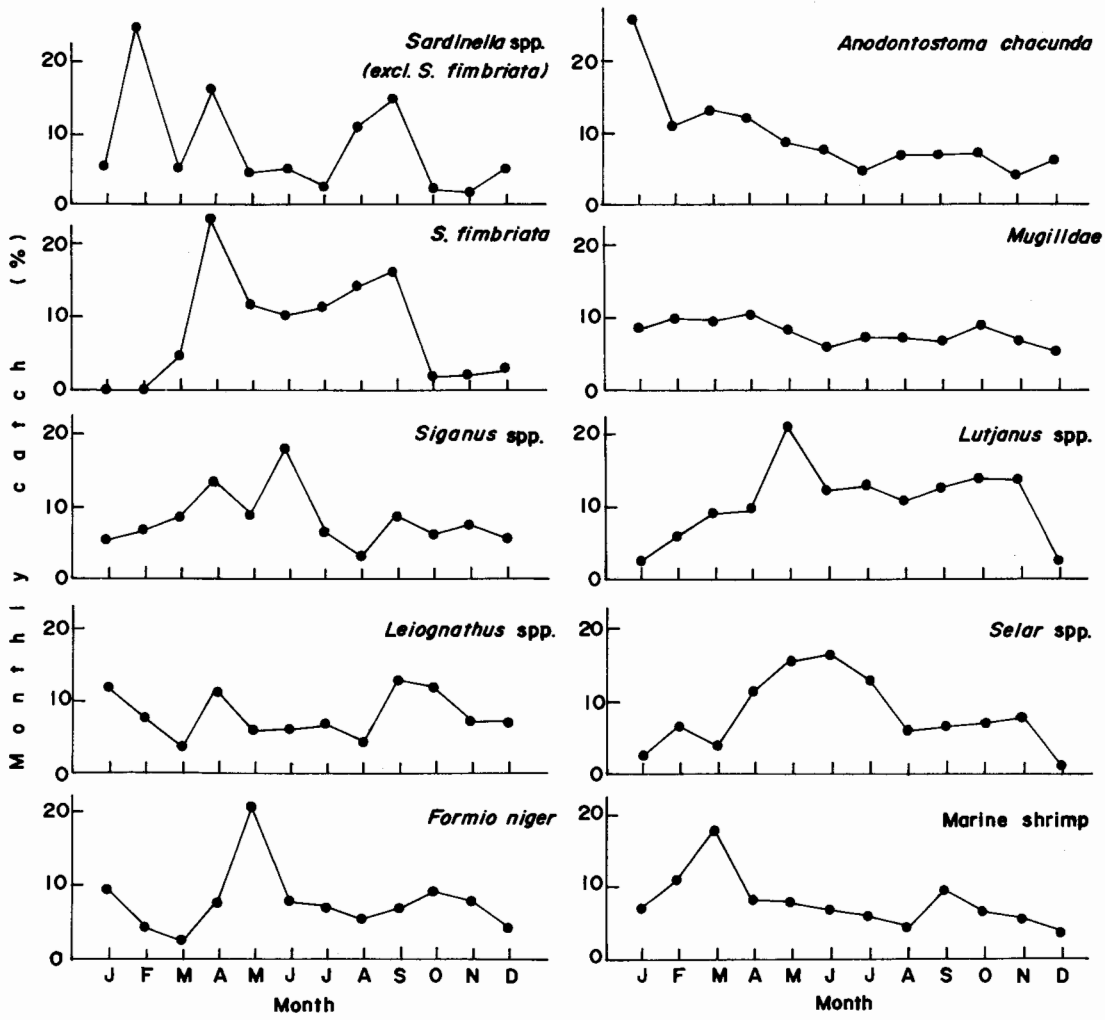


Fig. 6.5. Seasonal changes in the catch of 10 major species groups caught in Brunei and Muara District, Brunei Darussalam, 1982-1986.

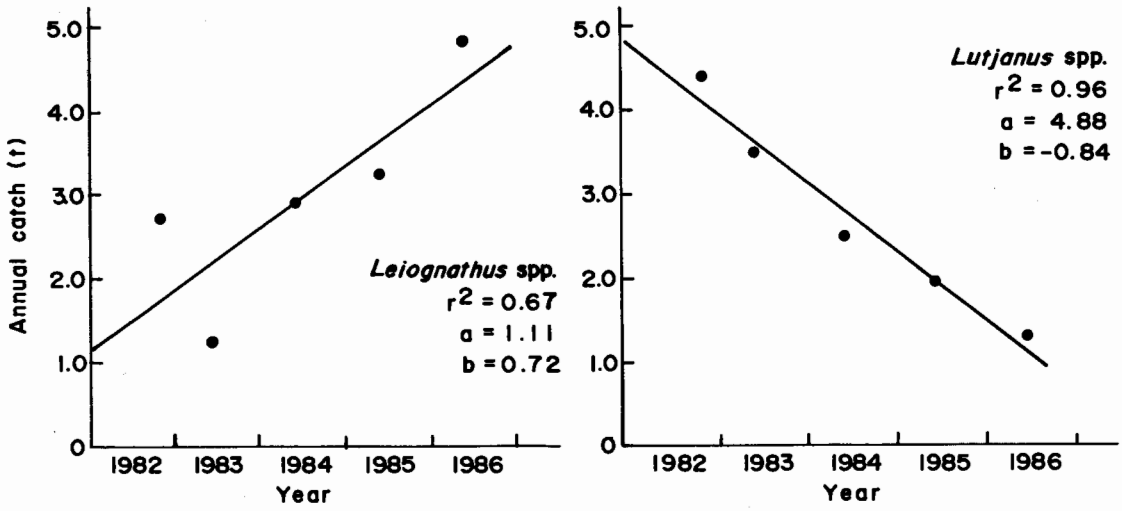


Fig. 6.6. Interyear trends of catch in two demersal fish genera from Brunei and Muara District, 1982-1986. Note strong decrease of the long-lived lutjanids and the increase of leiognathids, possibly due to release of predation pressure.

formulating proper development and management strategies. DOF has already finalized plans for conducting such a survey.

Inland freshwater fisheries

Freshwater fish and prawn catches are very small. They originate mainly from Temburong and, to a lesser extent, from Tutong and Belait. The annual freshwater fish catches (t) are:

	1980	1981	1982	1983	1984
Freshwater fish	3.68	8.11	6.84	3.68	7.07
Udang galah (M. rosenbergii)	17.03	31.26	29.10	19.74	44.09
Total	20.71	39.37	35.94	23.42	51.16

The freshwater species caught in Belait River comprises *Notopterus* spp., *Wallago* sp., *Mystus* sp., *Rasbora* spp., *Pangasius* spp., *Scleropages* spp., *Macrobrachium* and *Clarias* spp. (Idris pers. comm.).

Offshore fisheries

Offshore Fisheries Resource Surveys. The history of efforts to develop Brunei Darussalam's offshore fisheries was described by Beales (1982). The first survey was conducted by MV Saripah/MFV Tinggiri in 1949 to 1950. The next was by FRV Manihine in 1955. Surveys by MFV Arapan Tei and MFV Berjaya in 1968 indicated for the first time that there was fish production potential from offshore areas. Between 1979 and 1981, DOF conducted an offshore resource survey in two separate strata (Fig. 6.7). The total area under survey was 9,381 km^2. Stratum 1 (inshore) ranged from the shore to 46 m (25 fathoms) with an area of 3,533 km^2 of which only 1,466 km^2 or 41.5% was considered accessible to trawling (Table 6.7). Of the marketable catch in this stratum, about 60% was *Leiognathus*. Stratum 2, from 46-m (25 fathoms) to 184-m (100 fathoms) isobath, has an area of 5,848 km^2; and 4,905 km^2 or 85% was considered accessible to trawling.

The survey conducted in 1979 to 1980 proved to be a watershed in the sense that the results were used as basis for trawl fishery development.

The department decided to tackle the issue of trawl fishery development in several phases. Thus, though there was a certain maximum number (without overexploitation) of vessels which could have been issued with licences immediately, DOF opted to take a

Table 6.7. Fisheries resource (potential yield up to 100-fathom isobath).

Area	Stratum 1 (Total area = 3,533 km^2) Accessible to trawling	Stratum 1 (Total area = 3,533 km^2) Inaccessible to trawling	Stratum 2 (Total area = 5,848 km^2) Accessible to trawling	Stratum 2 (Total area = 5,848 km^2) Inaccessible to trawling	Total
Demersal (t)	9,425	13,285 (estimated)	4,329	772 (estimated)	27,811
Pelagic (t) (estimated)	9,000		3,500		12,500
Total					40,311

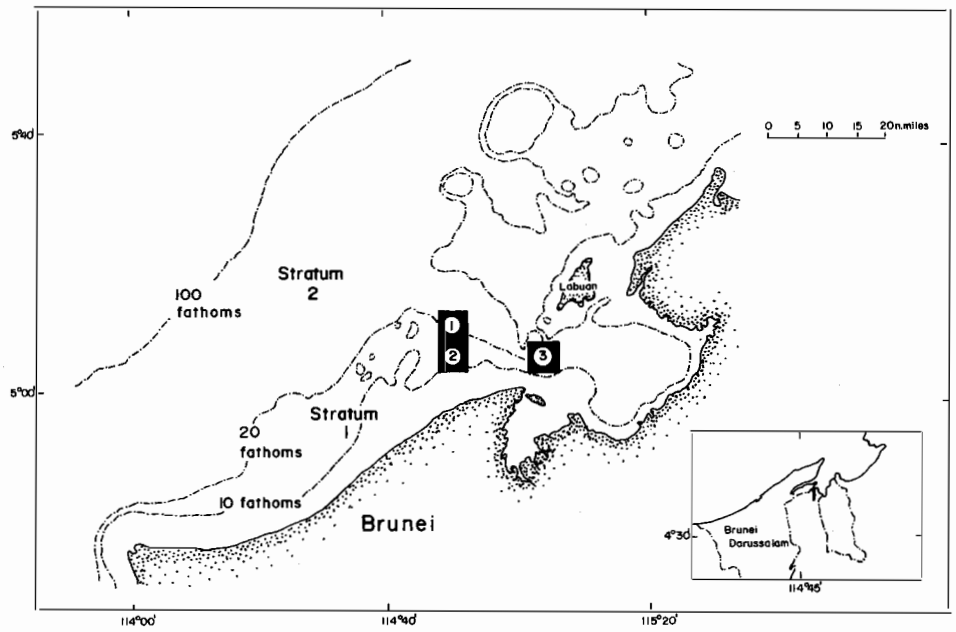


Fig. 6.7. Shelf off Brunei Darussalam, showing position of the three squares monitored from 1979 to 1986 and Strata 1 and 2 areas. Note that Square 3 is within a zone where trawling is illegal.

conservative approach and to issue licences in phases. After each phase, the fisheries would be monitored (to ensure the prevention of overexploitation) before the next batch of trawlers would be released. The department preferred this approach as it did not want fisheries to undergo rapid overdevelopment based on overoptimistic resource results or pure overzealousness in the issuing of licences and then face difficulties in whittling down the size of the fishing fleet. This situation has been and is being experienced by other countries. The approach would also serve a dual purpose: first, to prevent overexploitation of fish resources, and second, to ensure that trawlers would have sufficient resources for their exploitation on a sustainable basis.

In mid-1982, DOF initiated plans to issue five trawler licences to Brunei Darussalam citizens. The Department was swamped by more than 90 applications on the initial call for licences. These were shortlisted, and after interviews, five were selected. One of the licences was issued to a cooperative, which was not taken up subsequently due to some internal difficulties within the cooperative. Four licences were issued, and in 1984, the four trawlers were launched. Three of the vessels were newly made (two in Sarawak, one in Sabah) while the fourth was a second-hand one.

Exploitation of Offshore Demersal Fisheries. This fisheries started in 1984 with four wooden stern trawlers of about 15 m length overall (LOA). They are fitted with a mechanical split drum trawl winch of 1.5 to 2.0 t barrel pull. The vessels, *Sri Kilanas, KPI Merdeka, Sri Kiulap* and *Sri Setia,* are each fitted with a compass, radar, echo sounder and VHF transceiver. These requirements are based on the regulations imposed by DOF. The trawlers use an otter trawl modified for fish catch.

The most abundant fish in the catch belong to tha families Leiognathidae (55%), Mullidae (6%), Carangidae (5%), Aridae (5%), Sciaenidae (4%) and Nemipteridae (3%).

The mean annual catch of the four offshore demersal trawlers is given in Table 6.8. The projected annual production from the entire fleet is about 110 t of marketable catch. However, in practice, about 30% or more of the fish caught are discarded as unmarketable. Hence, the catch

Table 6.8. Total mean annual catches of purse seiners and trawlers in Brunei Darussalam.

Purse seine no.	1985	1986
1	42.37	78.02
2	42.45	158.16
3	118.82	98.22
4	46.69	139.06
Total	250.33	473.46
Trawler no.		
1	39.74	21.06
2	9.49	17.96
3	8	41.63
4	12.07	32.69
Total	109.18	113.34

figures would be much higher than the landing figures shown in Table 6.8.

Regulatory Measures. DOF imposed strict regulations on trawler operators. These were necessary largely in view of the extensive submarine oil pipelines which could be damaged during trawling operation. Also, there is a need to ensure that the usual fishing grounds for small-scale fishermen were not encroached upon by the trawlers. Among the regulations are:

1. Skippers must attend and pass a course in Fishing Technology and Navigation conducted by DOF.
2. All trawlers must be fitted with radars, echo-sounders and radios.
3. All trawlers must carry on board the "Fisheries Map" and other admiralty charts. DOF has prepared two sets of fisheries maps based roughly on Admiralty Chart 2109 but incorporating the position of oil pipelines and other oil industry structures as well as marking areas prohibited for fishing, for the use of trawler fishermen.
4. Trawl fishing is not permitted within an area of 3 miles from the coast (within the Green Line on the Fisheries Maps) which is an area exclusively reserved for small-scale fishermen.
5. Trawler operations would be permitted only out of Muara.
6. The cod-end mesh size should not be smaller than 38 mm.
7. Trawling is not permitted within 1 mile from submarine oil pipelines and other oil industry structures.
8. All trawlers must complete a monthly logbook giving details of catch, number of haul, area of operation, duration of haul, expenditure and income, etc.
9. All trawlers must comply with relevant regulations of the Marine Department (MD) in addition to those imposed by Fisheries Laws.

In 1986, DOF, as part of the phased development of trawling in Brunei Darussalam, initiated the issuance of more trawl licences. Also as part of this development, a course on Fishing Technology and Navigation for trawler skippers and assistant skippers was conducted with the assistance of the Navy of the Royal Brunei Darussalam Armed Forces.

DOF also engaged the services of a ship's surveyor to draw vessel diagrams for a standard trawler design to be followed by all persons involved in the trawler scheme. This was to ensure properly designed vessels with appropriate trawl machinery and provision for safety requirements and others. This new batch of trawlers is expected to be launched in 1988.

a need to investigate its possibility to eliminate it as a cause of the apparent demersal fish stock decline.

3. The decline in C/f data could also be reflective of the natural, long-term fluctuation due to fluctuations of recruitment. Hence, a comprehensive survey is necessary to determine the actual state of the fish stocks.

Having considered several possible reasons for the apparent decline in demersal stocks, DOF is taking active steps to conduct a survey of the demersal stocks in both Strata 1 and 2 to ascertain whether there is any actual decline and to assess the current magnitude of the fish stocks.

Offshore pelagic fisheries

The offshore pelagic fishery takes place mainly at depths of over 30 m as purse seines are usually of about 30 to 40 m deep. This fishery started only in 1985 in Brunei Darussalam. In 1986, DOF issued licences to seven locally owned purse seines; at present only five are actively operating.

Table 6.8 shows that the total production from active purse seines in 1986 is about 470 t. However, these data are incomplete because there have been months when the logbooks were not available. Taking into account these months, the catch has been extrapolated and the total production is estimated to be 800 t (compared to about 120 t from demersal trawlers). Generally, pelagic fish are considered to be all of marketable quality but there are times when *Sardinella* spp. are discarded at sea.

Most of these purse seine operations are conducted in Stratum 1 (Fig. 6.1) because fishermen usually conduct day-trips and return just before the next market peak hour at around 3 pm. There was no assessment of pelagic stocks of Brunei Darussalam waters; but from extrapolation of the assessment of pelagic stocks for Malaysian waters, Stratum 1 has been estimated to have a potential of 9,000 t, whereas Stratum 2 has about 3,500 t of pelagic fish.

The net income, excluding expenditure for ice, fuel, food and wages, ranges from B$3,000 to B$29,000 per month per vessel in 1986 to give an average of about B$15,000 per month. This figure does not also include expenditure on repairs and maintenance of the vessel, nets, etc. This turnover is much higher than that for demersal trawlers which is about B$5,200. Nevertheless, the operating costs for purse seines are much higher than for trawlers. Though the cost for a vessel is about the same for both operators (almost of the same size and shape apart from the special equipment which has to be incorporated in either vessel), the amount of manpower needed on a purse seine is 12 to 15 men, and only 4 to 5 men on a trawler.

The following are requirements on purse seines:

1. Vessel must have VHF radio.
2. The skipper must pass the Fishing Technology and Navigation course conducted by DOF.
3. There must be no fishing within the 3-mile zone from the coast.
4. It is mandatory to carry the fisheries map and other admiralty charts on board the vessel.
5. It is mandatory to complete the monthly fishing logbook and to submit this to DOF.
6. It is necessary to observe pertinent MD regulations.

DOF has not, as yet, conducted any survey of pelagic fish stocks. Included in the Fifth National Development Plan (1986 to 1990) are plans to conduct a survey of pelagic fish stocks in the coastal waters. The results of the survey will yield estimates of stock size, potential yield, species composition and others which will be used to plan the further development of pelagic fishery.

Aquaculture

CATALINO DE LA CRUZ, KHOO HONG WOO
BEATO PUDADERA AND VICTOR WONG

Since 1976, many detailed studies and recommendations were made to develop aquaculture. Previous consultants who studied the aquaculture potential of Brunei Darussalam are Crown Agents for Overseas Governments and Administrations (1976); ULG Consultants Ltd. (1983); and Huszar Brammah and Associates (1986). Crown Agents, in 1976, observed that there are tremendous potentials for both freshwater and brackishwater aquaculture. The National Development Plan at that time called for the development of commercial and subsistence pond culture. However, one of the main constraints was the system of land tenure. Investors would not invest without security of land tenure.

Freshwater aquaculture

Freshwater aquaculture annually contributes about 1 t which is a negligible amount compared to the total fisheries production in Brunei Darussalam.

Past Activities. Freshwater fish culture activities began in 1975 when DOF established the Freshwater Fishfarm Centre at S. Jambu, where production trials were since carried out.

In 1983, ULG Consultants Ltd. reported at least four attempts by the private sector/farmers to culture fish or giant freshwater prawn in Temburong. Detailed notes on these were provided: Borneo Fish Farm Limited, Haji Yusof's Farm, Sim Bak Peng Pond and Kg. Selangan Gravel Pits.

Borneo Fish Farm Ltd, located near Kg. Biang, was of commercial scale with an area of about 160 to 200 ha. Area leased was 730 ha; but only one, a 0.4 ha pond was constructed and about 1.6 to 2.0 ha was cleared. The species cultured was freshwater prawn, *M. rosenbergii.* Severe leakage and bund erosion following heavy rain resulted. The area was underlain with gravel, and rising water table forced holes in the pond. Flooding was also a major problem. An important lesson was learned: that thoroughness in site selection is important. The project, however, showed that freshwater shrimp could be cultured in Temburong. Less ambitious projects were advised by ULG Consultants.

Haji Yussof's Farm at Kg. Batu Apoi, built since 1963 and which consisted of two ponds (750 m^2 and 300 m^2), also faced flooding problems. Sim Bak Peng started his pond (0.4 ha) in 1978. Theft and flooding were two of his problems. There was no information on the gravel pit ponds in Kg. Selangan.

At present,the freshwater fishfarms operating in Brunei Darussalam are smallholders and backyard units (MOD-DOTCP No. 5, 1986c). Pond design and management are poor. Nine fishfarms are in Temburong; three in Tutong District, inclusive of one in Sinaut Agricultural Training Centre; one in Belait; and three in Brunei/Muara. Several species are cultured such as *udang galah*, common carp, grass carp, bighead carp, silver carp, *Puntius* and red tilapia.

The CRMP survey team discovered a smallholder (not listed in MOD-DOTCP No. 5, 1986c) along S. Brunei in Kg. Junjongan with 4 ponds of 600, 800, 1,000 and 3,000 m^2 in size. The ponds were poorly designed and due to lack of technical know-how, the operator stocked one of the ponds with 1,500 pieces of *Puntius*, bighead and grass carps. All the fish died within a day after stocking due to the saline condition.

At Kg. Belais in Temburong along S. Pandaruan, another farm had seven 500 to 2,000 m^2 ponds without sluice gates or drainage facilities. Soil was not compacted. These poor pond construction and design indicate the importance of extension services to farmers.

Area Under Cultivation. Now, the total area being used as earthen ponds for freshwater aquaculture is approximately 6 ha. This area consists of 48 units of ponds scattered all over the state in the four districts. Most of these ponds are either manually constructed (if less than 0.04 ha) or dug by excavators (if 0.10 to 0.40 ha). The latter are few as the cost of excavation is relatively high (about B$3 per m^3 of earth). Since manpower is scarce and labor charges are exorbitant, most of the owners have small-sized ponds on TOL, and there is little incentive to increase ponds due to restrictive land tenure system.

There still seemed to have some sign of interest in freshwater fish culture among local residents and immigrants from neighboring countries, but tangible progress is not evident. Success in the commercial operation of earthen fishponds in neighboring countries such as Indonesia and Malaysia has helped stimulate small investment for constructing fishpond. But inadequate technical knowledge of the entrepreneur is the main cause of most failures. Much of these attempts seem to lack seriousness or determination for success as evident by little or no attention being paid in choosing the proper site for fishponds. Usually the excavation of earth is in excess of the water table; and bunds are poorly constructed or not compacted at all, enhancing greatly the possibility of erosion and final collapse of bunds during very heavy rainfall.

Pond Management and Yields. Most, if not all, ponds owned are poorly managed. Frequently, fish fry for first stocking are made available by DOF free-of-charge as incentive to local pond owners with subsequent stock supplied at nominal price. The stocking of fish fry is carried out by the staff of DOF. Thereafter, much of management is left to individual operators, most of whom could only devote part-time attention because they have other jobs to attend to. Most ponds are managed on a more or less subsistence type farming and much of the fish produced is utilized for home consumption rather than as cash crops that add to farm produce. Very few farms have hired labor due to high labor cost (MOD-DOTCP No. 5, 1986c). Because of this, ponds are full of weeds. Fish predation, escape or disease are not given due attention.

Production from a 6-ha aggregate pond area is far below the production capability of a properly managed fishpond. Pond yields of freshwater fish are estimated to be less than 0.75 t/ha/year compared to 1 to 2 t/ha/year in neighboring Malaysia (Ubaidillah 1985).

Development Potential. Freshwater fish culture in ponds. Under the sectoral studies in the Master Plan, certain areas were identified for inland pond culture development. In addition, there is considerable change in the present land use compared to that 20 years ago. A large percentage of smallholder swamp rice land has been abandoned. This development offers possibility for converting areas with sufficient water into fish culture. Carps, giant prawn and tilapia (*Oreochromis niloticus)* are potential cultivable species.

Freshwater fish cages. There may be some possibility of establishing shallow fish cages (2 to 4 m^2) on the major rivers in each of the districts. Rivers with substantial width, depth and adequate freshwater flow rate with minimal salinity intrusion can be considered for such purpose. There are also some water reservoirs where cage culture may be introduced. Freshwater species such as the common carp (*Cyprinus carpio*) and tilapia (*O. niloticus*) with salinity tolerance of 6 ppt and 30 ppt, respectively, can be cultured in floating netcages. Between the two species, the common carp has better preference in the domestic market. The red tilapia hybrid may still require promotion, although its culture and marketability have already been proven in neighboring countries.

Coastal aquaculture

As early as September 1977, DOF had embarked on programs to examine mariculture potential in Brunei Darussalam's estuarine waters. Currie (1979a) investigated the feasibility of oyster (*Saccostrea cucullata*) culture in Muara. Settlement and growth on asbestos substrate were investigated. Spatfall peaks occurred in November and June, corresponding to periods following increased rainfall. Maximum densities of spat occurred in the 0.9 to 1.2 m range above chart datum.

Lindley (1982) investigated the growth of green mussel (*Perna viridis*) between November 1979 and August 1980. Spats imported from Singapore were found to have satisfactory growth. The absence of natural spatfall and the occurrence of red tides were mentioned as constraints for the development of rope culture of the green mussels.

A commercial green mussel farm named GAMAFCO was established in 1985. The farm, located at P. Kaingaran Channel envisaged to produce 40 t of mussels for the local market in 1986 (MOD-DOTCP No. 5, 1986c). It has a total of 25 rafts, with each raft capable of holding 270 strings of about 5 m long. GAMAFCO reported a production of 25 to 30 kg (whole body weight) of mussel per string in 8 to 12 months culture period. However, the target capacity was not reached because of seed supply and marketing problems.

The farm also engaged in rearing grouper in netcages. So far, it has marketed 162 pieces of grouper of about 800 g, average body weight. The entire farm is operated by a production manager, a marketing manager and two laborers.

Shrimp culture has been favorably considered by past and present fisheries administrations for possible commercial development. As early as 1969, the then Director of DOF, Dr. Bikenmeier, suggested the establishment of shrimp ponds using tidal swamps similar to traditional shrimp trapping practice in Malaysia and Singapore. While ecological conditions in Brunei Darussalam were favorable for such a purpose, the high construction cost during that time made such a venture unprofitable. According to the early calculation, it would take 20 years at maximum production to recover the capital cost. High domestic and export demands for penaeid shrimp as well as the national policy to diversify national economy are the main reasons for DOF to continue exploring the farming potential of penaeid shrimp in the country.

Development Potential. Based on existing physical maps, the ULG Consultants Ltd. identified approximately 1,000 ha of mangrove swamps suitable for brackishwater pond culture of shrimp and 59 ha for freshwater ponds.

The Aquaculture Development Plan, however, identified about 2,000 ha which could be developed for pond culture during the next 20 years with a long-term ceiling of 5,000 ha (MOD-DOTCP No. 5, 1986c). The report recommended that "if conditions permit, brackishwater shrimp culture should be chosen in preference to growing freshwater prawns". The economic analysis conducted showed that semi-intensive freshwater shrimp culture is most unviable and unlikely to be of commercial interest due mostly to heavy capital costs of pond development.

About 4,000 ha of potential sites were identified for cage and raft culture. The financial analysis by the consultant indicated that marine cage culture farms supplying live marine fish such as groupers, sea bass, snappers and other species for domestic market would be a very profitable enterprise for potential fishfarmers. Small-scale commercial operation by owners/operators with part-time-fisherman hired labor is envisaged.

Economic analysis indicated that mussel raft culture was marginally viable (MOD-DOTCP No. 5, 1986c). On the other hand, aquarium fish culture was reported to be technically feasible for export operation.

Potential Sites. According to MOD-DOTCP No. 5 (1986c), there are about 12,000 ha of coastal land out of 21,700 ha of gley soils identified by Hunting Technical Service Ltd. which can be used for brackish- and freshwater aquaculture. Most of these are in Temburong area within

Selirong and Labu Forest Reserves and in the area south and southwest of Bandar Seri Begawan (Fig. 6.12). Areas in Tutong and Belait constituted a small proportion compared to that in Temburong.

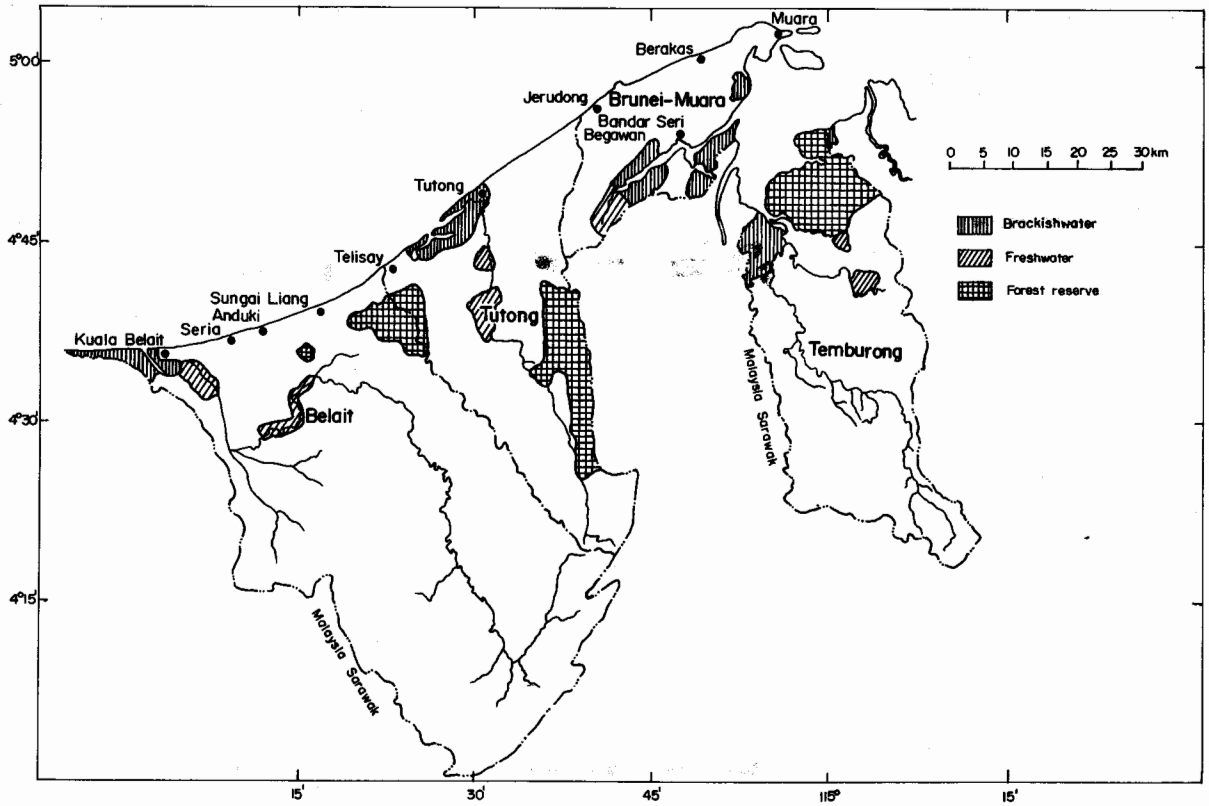


Fig. 6.12. Potential aquaculture sites (adapted from MOD-DOTCP No. 5, 1986c).

According to DOTCP (1987a): "the potential for aquaculture in Belait is not great". The few suitable areas in Labi either conflict with smallholder agriculture or are situated in remote areas. Similarly, the areas in Tutong are also limited. In Temburong, brackishwater culture can be established in Labu area of Selirong Wildlife Sanctuary which was considered by the report as undesirable in that it might "disrupt the natural breeding and nursery habitats of species exploited by the inshore fishery". Areas identified for mechanized rice cultivation are also suitable for aquaculture, pending detailed survey of individual sites.

Other areas for aquaculture include sand and gravel extraction pits (Fig. 9.3).

In Temburong, the specific sites identified by ULG Consultants are:

1. S. Pandaruan Valley
   a. Kg. Simbatang to Kg. Bakarut
   b. Kg. Maniup and Kg. Bagangan
   c. Kg. Ujong Jalan - S. Puni Kechil
2. S. Temburong Valley
   a. South of Kg. Batang Duri
   b. S. Merutop, near Selangan Agricultural Station
   c. Gravel pits between S. Merutop and Kg. Bukok
   d. Kg. Estet, north of Kg. Lagau
3. S. Batu Apoi Valley
   a. Kg. Batu Apoi, which is an existing fishfarm
   b. Gravel pit at Kg. Luagan
   c. North of the main road at Kg. Batu Apoi (100 ha)
   d. West of Kg. Labu (12 ha)
   e. Kg. Senukoh - S. Senukoh area

f. Kg. Piasau - Piasau
g. Mangrove fringe, about 1,000 ha (75% of coastal mangrove in the area)
h. Temburong Coastal Plain - not good for freshwater culture
i. Along Bangar-Labu Road - limited area adjacent to S. Buaya, S. Betayan, Kg. Nagalang Ering, Kg. Nagalang Unat, S. Lakium and S. Peradayan
j. Gravel pits at S. Temburong valley area

4. Other areas with water
   a. Rivers: Temburong, Brunei, Tutong and Belait
   b. Lakes: Tasek Merimbun, Luagan Lalak and Luagan Kandol
   c. Reservoirs: Bandar Seri Begawan, Jerudong, Benutan (under construction), gravel pits at Putat
   d. Anduki, sand spits at Seria

The total estimated potential area for pond culture was 2,000 ha, including freshwater and brackishwater (MOD-DOTCP No. 5, 1986c). The areas identified by the Master Plan for cage culture were the:

1. Area to the west and southwest of Serasa Causeway;
2. P. Kaingaran and P. Chermin and the mainland coast;
3. Brunei Estuary;
4. Larger creeks of Temburong mangrove forest; and
5. Estuarine creeks of S. Tutong.

Manpower and infrastructure facilities

Technically trained manpower and appropriate support facilities, including production inputs, are prerequisites to developing the aquaculture industry in Brunei Darussalam. The present number of qualified technical personnel in the country working in aquaculture is not enough to support a full-scale development program. More technical expertise has to be obtained if commercial aquaculture fishfarms, especially the high technology systems, have to be developed.

There are already some existing government support facilities such as Muara Fisheries Station, which has a small hatchery which produces *udang galah* postlarvae (PL) for stocking at its S. Jambu freshwater farm and for limited supplies to farmers.

The freshwater prawn hatchery produced 12,212 PL (1 cycle) in 1982; 59,809 PL (5 cycles) in 1983; 71,079 PL (6) in 1984; 85,244 (5) in 1985; and 168,183 (6) in 1986. The facility has 10 units of 1 t tanks; 3 units (10 t) tanks and 2 units (2 t) conical tanks.

The main core of technical personnel, under a Fisheries Officer, of Muara pilot hatchery are: one Assistant Fisheries Officer; one Junior Fisheries Assistant; six Junior Hatchery Assistants; one aquarist and one laborer.

The freshwater fishfarm center at S. Jambu is located north of Jalan Gadong near Kg. Mata Mata. It has three pond units of 0.41 ha; three 0.20 ha; two 0.10 ha; thirteen 0.04 ha and a 0.30 ha lake. The site has a total area of 9 ha with 2.82 ha of water surface.

The facilities at S. Jambu Fishfarm would be upgraded to serve as Inland Aquaculture Centre. The center would be a model demonstration area with facilities for research and development. Training programs for pond operators would be initiated while those for middle-level technicians (or managers) could be integrated into the agricultural program in institutions such as the Sinaut Agricultural Training Centre.

DOF also runs a pilot marine cage culture unit at Serasa for rearing of sea bass to broodstock size. The unit at present has 3,682 sea bass. Employed are three regular staff, three watchmen and two casual laborers. An expatriate officer is in-charge of the farm operation.

Part of the Fisheries Work Plan is to build an aquaculture complex inclusive of a hatchery and grow-out facilities for marine shrimp and sea bass culture. An interim hatchery would be installed along the Serasa floating cage farm and would be used for training staff and for seed production of sea bass and marine shrimp in late 1987 while waiting for the proposed aquaculture complex to be completed.

Selection of high priority sites for development

The present survey focused on the selection of suitable sites for possible pilot farm establishment. The survey was based on the list of sites identified in the Master Plan and that by ULG Consultants Ltd. in 1983. The following are the potential sites which the survey team visited (Fig. 6.13):

1. Temburong District
   a. Kg. Piasau-Piasau
   b. S. Senukoh
   c. Kg. Belais
   d. Labu River and adjacent land areas
   e. Temburong River and adjacent land area
   f. Bangau River and adjacent land area
   g. Pandaruan River and adjacent land area
2. Belait District
   a. Kg. Labi-Wasai Kadir Waterfall
   b. Belait River up to Kuala Balais
   c. Belait River
   d. Badas
   e. Anduki Sand Pit
3. Tutong District
   a. Tutong River
   b. Kg. Seribangun
   c. Seri Kenangan
   d. Jambatan Tutong
   e. Telamba River
   f. Kg. Keramut
   g. Tg. Danau
   h. Rambai and towards Kg. Meimbun
4. Brunei/Muara District
   a. Batu Marang
   b. Tg. Lumut
   c. Kg. Pudak Cove
   d. P. Kaingaran
   e. Brunei Bay
   f. Kg. Kota Batu
   g. Brunei River and adjacent land
   h. Crocodile Beach
   i. Tungku Beach
   j. Jerudong Beach
   k. Jerudong Reservoir and adjacent area
   l. Luahan Reservoir and adjacent area
   m. Mulaut/Wasan and Junjungan area
   n. Serasa area

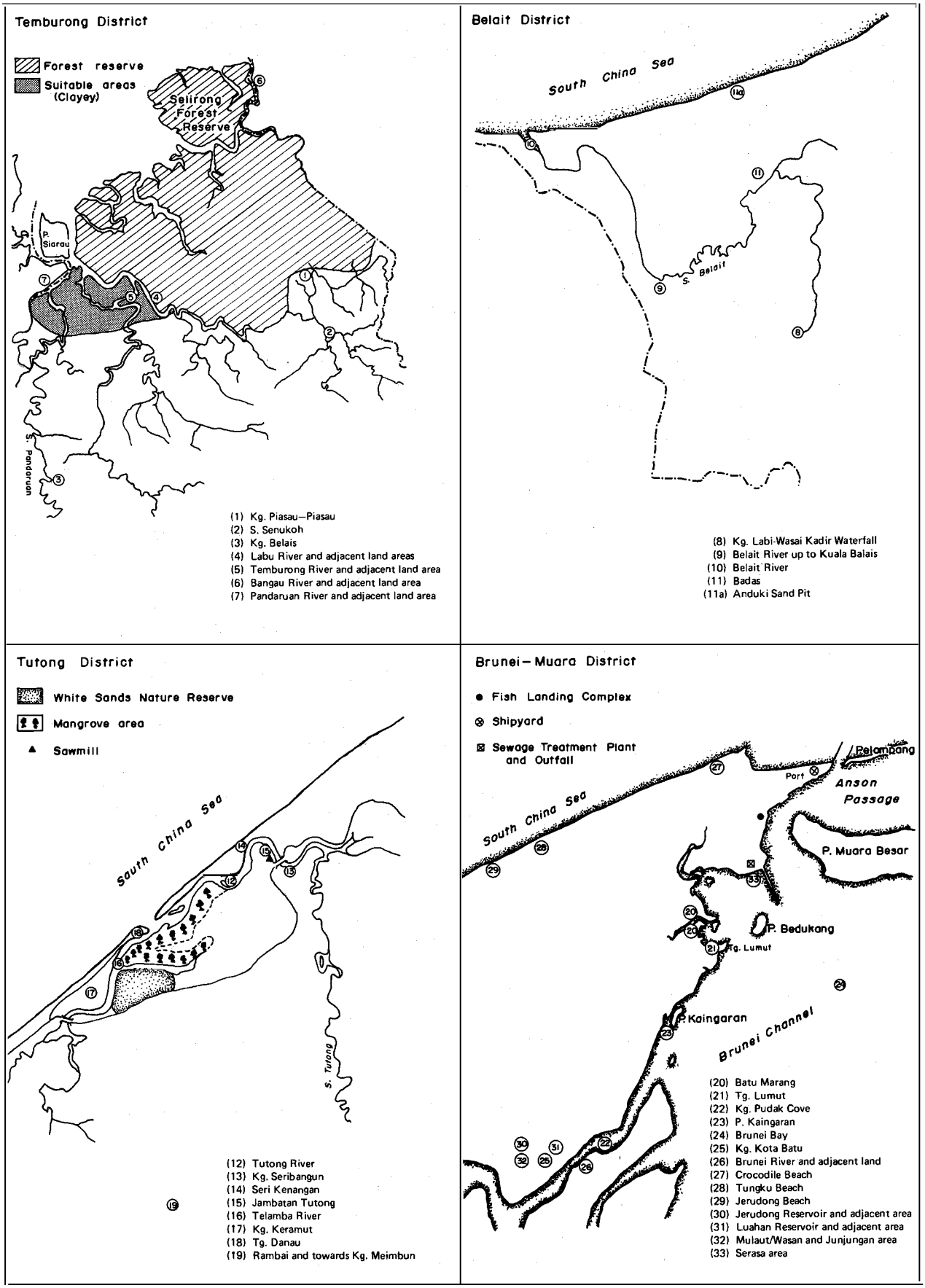


Fig. 6.13. Locations of sites evaluated.

Freshwater Aquaculture. The potential sites for pond and cage culture were examined in more detail by the CRMP survey group. Except for the location, the ecological requirements of the two culture systems are similar. Hence, the general conclusions were based on these:

1. Availability and characteristics of water
   a. Depth and width of river, flow rate and upstream tidal influence
   b. Water quality and extent of salinity intrusion
   c. Possible effects of extended drought
   d. Pollution threats
   e. Potential conflict of usage (riverine navigation, domestic water use, etc.)
2. Availability and area of land for pond construction
   a. Soil characteristics (topography, texture and presence of acid sulfate)
   b. Nature of land occupancy/ownership
   c. Accessibility
   d. Current land use (potential conflict of land use)
3. Availability of manpower
4. Availability of amenities, e.g., potable water, electricity, etc.
5. Other constraints

Based on existing data base and guided by the above conclusions, the potential for large-scale freshwater pond fish culture in Brunei Darussalam is limited because of these reasons:

1. Limited freshwater supply - There are no large freshwater rivers that could be used as the main source of water supply for large-scale pond development. The prolonged period of dry spell (April-May 1987) caused several tributary streams to run dry. This condition helped the survey team in confirming and eliminating some identified potential areas by previous consultants. Although groundwater may be explored as possible source, the cost of using such may be too expensive.
2. Limited availability of suitable sites - Most of the sites surveyed were located on the banks of rivers or their tributaries. The vegetation bordering these riverbanks, especially in the upper reaches, is usually peat swamp forest which is indicative of soil type characterized by higher peat content and lower percentage of clay. There is a need for more excavations to provide material for bund (levee) construction and for greater pond management measures to neutralize higher acidity content of the soil. These will certainly make pond construction and production inputs prohibitively expensive.

The absence of sizeable lakes/reservoirs or dams would, no doubt, hinder plans to develop freshwater fishponds further inland. The proposed construction of reservoirs/dams in the 20-year development plan would provide opportunity for freshwater aquaculture in the inland areas. Smaller-sized earthen fishponds (0.5 to 1 ha) may be commercially viable under the present condition.

The culture systems considered suitable for freshwater are earthen pond, cage (in reservoirs) and intensive (in running or recirculating water systems) (Table 6.10).

Coastal Aquaculture. In considering the suitability of the sites for coastal aquaculture, the survey team based its recommendations on the following criteria:

1. Technical suitability of the site to the hatchery and the various aquaculture systems based on:
   a. Water quality and supply (for all systems)
   b. Soil quality (especially for earthen pond culture
   c. Current speed (especially for cage and pen culture
   d. Predator and fouling (for all systems)
   e. Relationship between tidal fluctuation and land elevation (pond culture)
   f. Accessibility (for all systems)

Table 6.10. Suitable sites and recommended systems for aquaculture.

Location	Suitability	Remarks
Freshwater		
Piasau-Piasau	Earthen pond fish culture	Limited water supply; sufficient to only 1 ha pond
Kg. Senukoh	Earthen pond fish culture	Upstream Senukoh River, capable of supplying more than 50 ha
Jerudong Reservoir	Cage culture	Very hilly surroundings; limited cage due to small size of reservoir
Luahan Reservoir	Cage culture and recirculating pond system	Recirculating system of fish culture may be integrated system with agricultural crop production (vegetables); economic feasibility needs verification
Mulaut/Wasan	Earthen pond fish culture	May be integrated with rice cultivation; insecticide application to rice cultivation needs to be monitored
Kg. Belais	Earthen pond fish culture	About 7 ponds of 500 m^2 exists; needs extension support
Labi-Wasai Kadir Waterfall	Running water fish culture	Operation limited to wet season only; about 2-3 sites identified for 100 m^2; needs further economic verification
Labi-Telingan	Running water fish culture	Operation limited to wet season only; about 1-2 sites identified for 100 m^2; needs further economic verification
Brackishwater		
Belait River, 5 km from mouth	Pond culture	About 5-10 ha for shrimp culture; unsuitable for cage culture (fast river flow)
Tutong River		Unsuitable for cage culture (fast river flow); wide salinity fluctuations
Kg. Seribangun (LAI/58, 2/58 Pte 4/69 Gaz. 5274 P634, SL-between 5274 and LAI/58)	Pond culture	Shrimp, 10 ha available
Seri Kenangan (Lots 3367, 1869,1882)	Hatchery and pond culture	Sea bass/shrimp, 10 ha available
Jambatan Tutong Senekaran (Pte 377, 378, 1271; between 1271 and 4169SL)	Pond culture	Shrimp, about 5 ha available
Telamba River		Not suitable for cage culture (fast river flow)
Kg. Keramut	Hatchery and pond	Sea bass/shrimp, 10 ha available

Continued

Table 6.10 (continued)

Brunei-Muara Serasa Bay	Cage and small pens	Sea bass, grouper Small pen ("Amakusa" type); may be constructed on selected sites; further investigation needed
Batu Marang	Pond culture	Shrimp, 10 ha
Tg. Lumut	Pond culture	Shrimp, 40 ha
S. Brunei/Kg. Pudak	Cage culture	Sea bass, grouper; limited area
P. Kaingeran	Cage culture	Sea bass, grouper; limited area
Brunei Bay	Cage culture	Sea bass, grouper; more area available; further site selection needed
Kg. Kota Batu	Mussel spat development	Mussel culture
Labu Estuary	Pond culture	At least 1,000 ha available for shrimp/fish production; at present, far from available infrastructure facilities
Temburong Estuary	Pond culture	Not suitable for cage culture; at least 1,000 ha available for shrimp production; at present, far from available infrastructure facilities

g. All amenities such as road, electricity and potable water supply (for all systems)
h. Possible source of pollution (for all systems)

2. Applicability of aquaculture under conditions in Brunei Darussalam especially regarding:
   a. Intensification of culture system (intensive, semi- and extensive methods)
   b. Integration with riverine community or existing fishing activities
   c. Small- or large-scale commercial development
3. Suitability of culture species with special consideration on:
   a. Domestic demand
   b. Export potential
   c. Production potential

An assessment of brackishwater sites (Table 6.10) indicated that the possible aquaculture systems for seed and grow-out production in Brunei Darussalam are: (1) shrimp/fish hatchery; (2) cage culture; and (3) intensive/semi-intensive pond culture. The hatchery, which is needed to support aquaculture development, requires good seawater that is free from contamination and a salinity of not less than 30 ppt. The availability of wild spawners should also be considered. Thus, the sources of wild spawners should be verified.

Floating cage culture is not suitable to a water depth of 10 to 15 m. Although many of the sites evaluated have lesser depth, the design of the cage may be modified to fit prevailiing depths in selected sites. The sites should be able to accommodate a number of small farms with an area not less than 20 m^2 each.

Intensive pond culture for grow-out requires basic amenities such as electricity for running pumps; aerators, filters and cold storage facilities; and freshwater supply aside from brackishwater for salinity regulation. Tidal fluctuation in relation to land elevation is not so important because filling and exchange of water in ponds is done by mechanical pumping.

The semi-intensive method also requires the above basic amenities. Water exchange is either by pumping or tidal exchange. In the latter, a tidal range of 1.5 to 2.0 m is preferred.

Economic viability should be assessed before any aquaculture system in both freshwater and brackishwater areas is adopted and the selected site is developed. Comprehensive assessment is beyond the scope of the present survey, although initial financial analysis for prominent aquaculture systems (pond culture of shrimps) is included (see below).

Eighteen brackishwater sites located in the four districts were evaluated. The physicochemical parameters of each site are shown in Table 6.11. The suitability and the priority of each site for aquaculture development are based on the total scores secured (by each site) for a specific culture system. The selection is based on a number of criteria (Table 6.12), each with a score point from 0 to 10 (see Appendix 6). The positive and negative aspects of each site in relation to its potential for aquaculture are in Table 6.13.

Several sites are selected and confirmed for brackishwater aquaculture (Table 6.10). The priority sites are Serasa Bay, Tutong and Kg. Pudak Cove which ranked among the top three of the seven sites investigated (Appendix 6). Serasa Bay, though relatively shallow, is a priority area because of its relatively calm water, adequate tidal exchange and proximity to basic amenities. But it also is faced with potential pollution threats from Muara's industrial and port development sites. For intensive pond culture, the priority areas are Serasa and Tutong. A cautionary factor, however, is the limited availability of freshwater for regulating salinity of pondwater. While approximately 1,000 ha in Temburong District have been identified by previous consultants as potential sites for shrimp farming using earthen ponds, present assessment is that the area is constrained by lack of infrastructure facilities due to its remoteness. Areas in Brunei-Muara and Tutong Districts present better choices for pilot farms (Appendix 6).

Serasa Bay, Tutong and Telamba River were considered and subjected to ranking analysis for a government hatchery and an aquaculture complex. However, in view of the development programs at Muara, potential pollution threats have to be determined. The survey team focused on the evaluation of the development potential of Serasa Bay for the proposed hatchery complex. A number of pollution sources, however, were pinpointed in Serasa Bay. These are:

1. Muara Sewerage and other domestic sewage sources - The operation of Muara Sewerage would not have any immediate effect on ongoing activities in the bay since treated sewage discharges would be diluted as they flow through Anson Passage into the bay. Direct impact on aquaculture activities would probabaly be minimal and may, in fact contribute to the nutrient load in the bay. However, hygienic considerations would require proper control of sewage discharges to conform to environmental standards. This is because Serasa Sand Spit is a recreational area for swimming, surfing and angling. Organic loads from Brunei Bay, such as from Kg. Air and Pintu Malim Sewage Treatment Works, would not pose significant pollution threats since pollutants are diluted by the time these reach Serasa Bay.
2. Industrial sources - At present, there are two food processing; three garment/ shoemaking; and brick-, pottery- and tile-making factories in Muara (MOD-DOTCP No. 12, 1986h). A fish landing complex was built in Muara Port. Although most of the industrial wastes of light industries would be channeled through a sewerage system, there is still considerable pollution from offals and fish wastes during landing at Muara which may increase organic load along the area, including Serasa. Such situation may lead to eutrophication within Muara Port area. Future factories to be established would mainly be light industries where effluent discharges would undergo secondary treatment.
3. Shipping and other water traffic docking at Muara Port - Oil and other hydrocarbon compounds are pollutants discharged from shipping activities. Although most oils

Table 6.11. Water and soil characteristics of brackishwater sites.

Site/characteristics	1	2	3	4	5	6	7	8
1. Salinity (ppt)								
Surface	0.4-21.2	4.2-32.9	0.4-20.5	0.5-31.0	0.5-31.0	34	34	34
Bottom	0.4-28.4	21.8-32.9	0.4-31.4	1.7-32.9	1.7-32.9	35	34	35
2. pH								
Surface	5.5-6.0	7.8	7.7	7.8	7.8	8.5	8.4	8.5
Bottom	7.9	7.8	8.0	7.8	7.8	8.4	8.5	8.4
3. Oxygen (mg/l)								
Surface	2.6-3.0	4.0	5.0	4.0	4.0	5.9	5.9	5.9
Bottom	2.6-3.9	3.5	4.2	3.5	3.5	5.1	4.5	5.1
4. Turbidity (Secchi disc) (m)	2	1.75	1	2	2	1.75	1.75	1.75
5. Temperature (°C)								
Surface	30	29	29.5	29	29	29.2	29.2	29.2
Bottom	27	29	29.0	29	29	29.2	29.2	29.2
6. Depth (m)—high tide	10	3	4	5	5	4	4	4
7. River soil		Sandy	Sandy	Sandy silt	Sandy	Sandy	Muddy sand	Sandy
8. Shore clay pH								
9. Shore soil type	Clayey	NA[a]	Sandy	Sandy	Sandy	NA[a]	Sandy	NA[a]
10. Potential pollution source	Shiprepair yard	Domestic waste/litter	Sawmill/ domestic sewage	Sawmill/ domestic sewage	Sawmill/ domestic sewage	Domestic waste/litter	Domestic waste/litter	Domestic waste/litter
11. Flow rate (cm/sec)		0-200				0-100		

[a]Not applicable

Key to brackishwater sites:

1. Belait River (8 km from mouth)
2. Tutong River
3. Tutong-Kg. Seribangun
4. Tutong-Seri Kenangan
5. Tutong-Jabatan Tutong
6. Tutong-Telamba River
7. Tutong-Kg. Keramut
8. Tutong-Tg. Danau
9. Brunei-Muara-Serasa Bay
10. Brunei-Muara-Batur Marang
11. Brunei-Muara-Tg. Lumut
12. Brunei-Muara-Kg. Pudak Cove
13. Brunei-Muara-P. Kaingeran
14. Brunei-Muara-Brunei Bay
15. Brunei-Muara-Kota Batu
16. Brunei-Muara-Labu River
17. Temburong River
18. Temburong-Labu Land at intersection

9	10	11	12	13	14	15	16	17	18
20-31	30	30	32	32	15-30	16.5-25.5	15	4-22	14-22
27-30	30	30	30	30	23-30	18.9-26.8		22-24	18-24
7.5-8.9	8.9	9.2	9.2	9.2	6.7-6.8	7.0-7.4	6.9	6.8-6.9	6.8-6.9
7.0-8.9	8.9	8.9	8.9	8.9	7.0-7.5	6.3-7.4		6.8-6.9	6.8-6.9
4.5	4.5	4.5	4.5	4.5	4.5	3.4-7.5		3.8	3.1-3.8
4.4	4.5	4.5	4.2	4.2	4.2	4.0-5.8		3.2	2.6-3.2
1	0.9	0.9	0.9	0.9	0.5-0.9		2	1.03	0.87-1.03
28.5	28.5	28.5	29	29	27.5-29	29.1-30.4	29	29.1	26.7-27.2
28.5	28.5	28.5	29	29	27.3-39	29.6-30.4		29.1	26-27
5	1	1	22	8.5	3-22	9.3		6.5	6.0-6.5
Silty sand	Silty	Silty	Silty	Silty				Silty	Silty
4.4	4.75	4.75							3.1-3.7
Sandy mud	Clayey mud	Clayey mud	NA[a]	NA[a]	NA[a]	NA[a]	Clayey mud	NA[a]	Clayey mud
Nil—from port domestic waste sewage	Domestic litter	Domestic litter	Domestic litter	Domestic litter		Domestic sewage	Nil	Nil	Nil
0-20			0-17	0-11			12	22-27	22-34

Table 6.12. Criteria used to evaluate suitability of sites for brackishwater aquaculture development.

Criteria	Hatchery	Intensive/semi-intensive Pond system	Cage
1. Salinity range during dry and wet seasons	x	x	x
2. Sudden change of salinity during dry and wet seasons	x	x	x
3. Turbidity during dry and wet seasons	x	x	x
4. Present pollution level and future threats (>10 yr)			
Oil and petroleum	x	x	x
Agricultural chemicals/sawmills	x	x	x
Eutrophication (domestic wastes, sewage)	x	x	x
5. Amenities and accessibility			
Distance to and from airport	x	x	x
Power and water supply	x	x	x
6. Availability of land for acquisition	x	x	
7. Administration and infrastructure support	x	x	x
8. Pull factors for labor	x	x	
9. Availability of land/area for future expansion	x	x	x
10. Near intensive/semi-intensive grow-out facilities	x		
11. Near hatchery	x	x	x
12. Soil characteristics for earthen ponds			
pH		x	
Clayey soil		x	
Elevation		x	
13. Flow characteristics of water			
Removal of waste from bottom			x
Oxygen level			x
Flow rate			x
14. Other site characteristics			
Depth			x
Fouling			x
Shelter			x

Table 6.13. Positive/negative factors of each culture system.

Site	Culture system	Positive factors	Negativ
Piasau-Piasau	Freshwater pond	Reservoir did not dry up; water flow can supply 1 ha	Isolated case
Kg. Senukoh	Freshwater pond	Can supply 50 ha	May have some saltw barrage across river r detailed soil and wate needed
n Reservoir	Cage nets in the 1/2 ha reservoir	To be integrated with farming	2-3 cages; isolated ef
	Recirculating lined-pond system in adjacent land.	Integrate with farming; 2 lots very suitable for this system; piped water to supplement natural water from reservoir in dry season (2-3 ha)	No data on productio
Jerudong Reservoir	Cage culture		No flat adjacent area
Mulaut/Wasan	Freshwater pond	Integrate with rice	Effects of insecticide insufficient water in d
Kg. Belais: S. Pandaruan	Freshwater pond	Started by farmers' own initiative	Not enough extensio
Labi-Wasai Kadir Waterfall	Running water system	Nil	Limited to wet seasor
Badas at Belait River	Freshwater pond	Nil	Competes with dome peaty soil; few people
Belait River up to Kuala Balai	Freshwater pond	Nil	Water still saline (10 no inhabitants
Rambai towards Kg. Merimbum	Freshwater pond	Nil	Insufficient water
Belait River	Cage net	Nil	Remote; fluctuating s fast-flowing during rai
Tutong River	Cage net	Nil	Remote; fluctuating s fast-flowing during ra
Seribangun	Brackish intensive grow-out	Nil	Land may not be ava nearby, 12 in the area fluctuation in salinity
Seri Kanangan	Brackish intensive grow-out; hatchery	Good source of high salinity water	Competes with zonin recreation
Jambatan Tutong	Brackish intensive grow-out	Nil	Land may not be ava nearby; 12 in the area fluctuation in salinity
Telamba River	Cage net		Shallow; fast-flowing salinity fluctuation aft
Kg. Keramut	Brackish intensive grow-out	Nil	Land may not be ava
Tg. Danau	Hatchery	High saline water available from the sea	Too near the river mo drops after rain

Table 6.13 (continued)

Serasa Bay	Hatchery Cage net Brackish intensive grow-out	Tolerable water condition, water flow fast enough to clear the channnel bottom Near to other facilities; Water does not fluctuate drastically after a rain	Salinity just at lowe Area too shallow ar
Batu Marang	Brackishwater, semi-intensive	Near to hatchery and other facilities	Too shallow; water, sedimentation
Tg. Lumut	Brackishwater, semi-intensive/intensive	Near to hatchery and other facilities	Too shallow; water, sedimentation
Kg. Pudak Cove	Cage net	Deep enough; available electricity and other amenities	Possible conflict wit
P. Kaingaran	Cage net	Water flow, sufficient	A bit shallow Area not large enou
Brunei Bay	Cage net	Area large enough to supply many colonies of netcage	Area needs further may be considered exposed to the wea
Kg. Kota Batu	Raft (mussel)	Nil	Nil
Labu River and land	Brackishwater, semi-intensive/intensive	Lower reaches, suitable; clayey	Elevation, a bit low; ponds or larger
Temburong River and land	Brackishwater, semi-intensive/intensive	Lower reaches, suitable; clayey	Elevation, a bit low; ponds or larger
Bangau River and land	Brackishwater, semi-intensive/intensive	Water in lower reaches, suitable	A bit peaty Elevation, a bit low; ponds or larger
Pandaruan and land	Brackishwater, semi-intensive/intensive	Lower reaches, suitable; clayey	Elevation, a bit low; ponds or larger
Brunei River and land	Brackishwater, semi-intensive/intensive	Nil	Too near populated
Crocodile Beach	Hatchery	Good marine water	At present, electricit not easily accessibl
Tengku Beach	Hatchery	Nil	Area not large enou recreation
Gerudong Beach	Hatchery	Land can be acquired; belongs to agriculture	High-energy beach; with intake pump of

remain afloat, some compounds like benzene, toluene, xylenes and others are soluble in water and particularly toxic to marine organisms (Blumer 1971; Chua 1984).

Hydrocarbon levels in the coastal waters of the east coast of Peninsular Malaysia were between 0.03 ppm and 0.13 ppm. Higher concentrations were recorded near villages where human activities are higher. Nearshore samples have higher concentrations than offshore ones, and the levels also vary with depth. In Manila Bay, levels measured were between 1.25 and 6.98 ppm; and in Indonesian waters, between 0.3 and 11.5 ppm.

Analysis of water samples from Serasa Bay showed a level of 4 to 8 ppm for oil and grease. The high values may be due to the possible entry of oil-contaminated water from Muara Port area. However, the levels are too low to have any significant effect on the aquatic biota in the bay. Toxicity studies on oil for *P. monodon* showed that LC_{50} at 48 hours was about 13 to 25 ppm. Such levels may be achieved only through a major oil spill. On the other hand, effects of long-term low-level exposure to oil and hydrocarbon compounds is not known.

The water circulation pattern in the area was investigated. A preliminary experiment using home-made drogues was conducted on 14 and 18 May 1987 for ebbing (neap) and rising (spring) tide conditions, respectively. On the 14th (from 1300 to 1500 hours), Drogues 9 to 11 were placed in the inner part of Serasa Causeway, near the floating farm. The ebbing tide carried the drogues past the tip of the sand spit into the outer part of the causeway towards P. Muara Besar. The flow rate was about 12 m/minute (20 cm/second). Data showed that the fast flow would be able to flush out any waste materials that may accumulate under the cage farm and that fair water exchange occurred during the ebbing tide.

During the rising tide on 18 May, Drogues 1 to 4 were placed on the outside of Serasa Causeway at the 0900 hour. Movements were monitored at 15 minutes interval (Fig. 6.14). Drogues 1 and 2 placed nearer the Serasa causeway entered Serasa Bay area while Drogues 3 and 4 entered Brunei Estuary past the eastern shore of P. Bedukang. Within one hour, the drogues entered Serasa Bay and moved towards P. Salar.

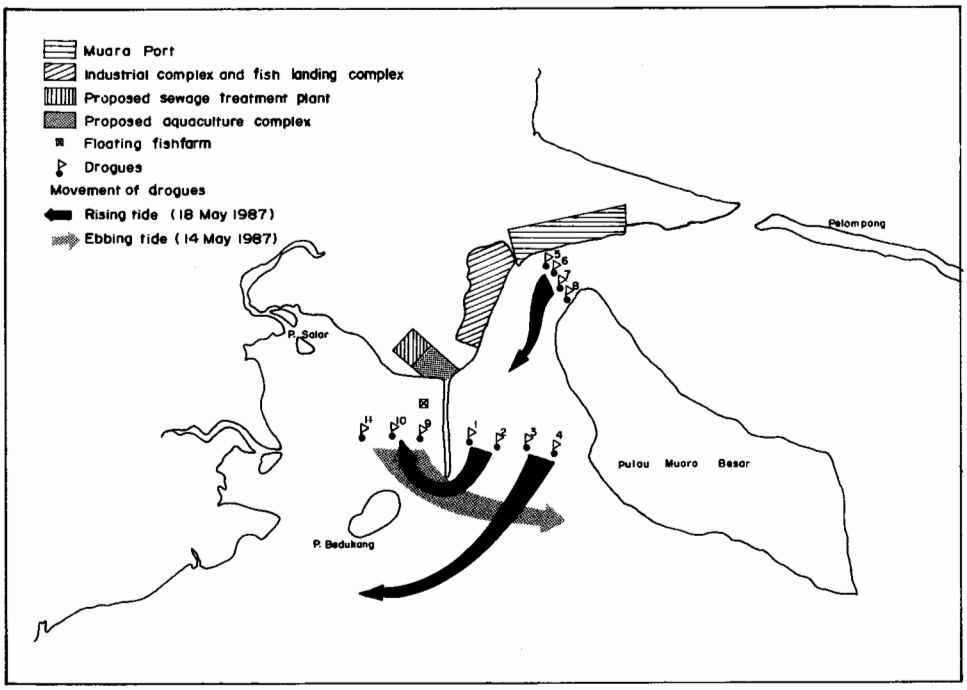


Fig. 6.14. Drift pattern, Serasa/Muara Port area.

Drogues 5 to 8, released in Muara Port area at 1125 hour at rising tide, drifted towards Serasa Causeway. Based on the study, pollutants that may be released at Muara Port area would definitely enter Serasa Bay.

With such water movement, oil leaks from docking ships at Muara Port would, therefore, be an important concern for any aquaculture activities in Serasa Bay. Multisectoral approach towards proper port and waterways management is necessary to ensure early warning of possible oil spills. Regular monitoring in Muara Port and Serasa Bay is essential to ensure that water quality is within acceptable limits.

As a practice, water for aquaculture purpose, particularly for hatchery, must undergo floculation and treatment to ensure good quality. Alternately, the hatchery may be sited elsewhere such as in Crocodile Beach in Muara or in Seri Kenangan in Tutong; while grow-out operations would still be at Serasa Bay. Furthermore, a contingency plan is imperative in the event of a major pollution in the area, especially of oil spill.

Viability of aquaculture systems

Cage Culture. Stationary or floating cage culture of grouper and sea bass appears to be the most suitable aquaculture system because of the low capital cost; adequate calm water bodies such as Brunei Estuary; and availability of well-developed technology. The main cost items are feeds, cage and labor, assuming that relatively cheap fish fry from the government hatchery is available.

Cage farm yield is relatively higher than that of fishpond. Farm yield ranging from 5 to 27 kg/m^2 was reported for grouper and sea bass (Chua and Teng 1980).

The system is easily managed and the technology from Hongkong, Thailand, Malaysia and Singapore is readily transferred. The financial viability of the system in Brunei Darussalam may need more verification and the source for cheap trash fish as feed has yet to be determined.

Intensive/Semi-intensive Pond Culture. Brackishwater and freshwater pond culture could be developed in Brunei Darussalam. However, the latter has limited commercial potential. So, the development of brackishwater pond culture must be given more attention. Both finfish and shrimp can be used. Between the two, shrimp is a much better choice in view of its high domestic and export demand and the availability of transferrable technology. Shrimp farming was earlier reported to be nonprofitable due to its slow payback period (20 years) (MOD-DOTCP No. 5, 1986c). However, recent technological advances on shrimp culture in the Southeast Asian region might have changed the picture. Shrimp farming, therefore, deserves a second look.

Depending on stocking density and production inputs, shrimp farming may be classified as extensive, semi-intensive and intensive. Among the three methods, semi-intensive and intensive culture are considered appropriate in Brunei Darussalam because of manpower shortage, high labor cost, limited land resources and economic capability of potential investors.

The main difference between the semi-intensive and the intensive systems lies in the stocking density. The former has a lower stocking density. As such, the semi-intensive system may or may not fully depend on formulated feeds if natural feed in ponds can be increased; whereas, the intensive system is fully dependent on good quality formulated feeds. Both systems, though, require skillful production management, particularly in feeding and maintenance of good water quality. Pond yields are 4 to 10 t/ha for *P. monodon* and 5 to 7 t/ha per year for *P. merguiensis* and *P. indicus* under the semi-intensive system. While yields of 50 to 100 t/ha per year have been claimed with four cycles per year for the culture of *P. japonicus* in Singapore by Hitachi Zosen Shipyard, it is always advisable to consider an attainable yield of

approximately 10 to 20 t/ha per year. The long-term economic viability of growing *P. japonicus* is questionable, considering that this subtropical and temperate species does not occur in Southeast Asian waters and the broodstocks have to be continously imported from Japan.

Shrimp Farming. The CRMP team concentrated on developing designs/plans of fishfarms for semi-intensive and intensive culture systems with shrimp *P. monodon* as the cultured species. The detailed plans/designs were used to estimate the investment and operating cost for each system, which served as the bases for financial analysis. The assumptions used in this analysis are in Table 6.14.

Table 6.14. Assumptions used for the different culture systems analyzed for Brunei Darussalam.

Item	Semi-intensive earthen pond	Intensive concrete-lined earthen pond	Intensive concrete-walled pond
Stocking density	5-10/m^2	20-30/m^2	20-30/m^2
Feed	Commercial	Commercial	Commercial
Water management	Tidal + pump; daily exchange of 10-20%	Pump + aeration, 50% replacement and frequency of 15-17 times/crop	Pump + aeration, 50% replacement and frequency of 15-17 times/crop
Pond size	0.5 ha/unit	0.25 ha/unit	0.25 ha/unit
Pond development cost/ha, B$	213,429	658,170	934,713
Culture period	120 days; 2.5 crops/yr	120 days; 3 crops/yr	120 days; 3 crops/yr
Harvest size	30-35 g	30-35 g	30-35 g
Survival rate	70%	70%	70%
Production/yr	3-6 t	9-18 t	9-18 t

The semi-intensive culture system consists of a proposed 10-ha (water area) farm composed of 20 units of earthen grow-out ponds, 0.5 ha each. The layout and design elevations of pond bottom, dikes and gates are fitted to the prevailing tidal characteristics in Port Muara and land elevation in Labu/Temburong site.

The intensive culture system has two designs. One has pond partitions made of earthen dikes lined with concrete, while the other has reinforced concrete walls as pond partitions. The farm area for each design is 5 ha. Both designs have the pond bottom lined with thick gauge plastic, which has a layer of good quality clayey soil.

The two designs may be constructed on a site having previous soil as well as on slightly elevated areas that may not be effectively reached by tidal fluctuation. Obviously, concrete-lined earthen pond needs large quantity of earthwork whereas the concrete-walled pond needs very little.

The following is a financial evaluation of shrimp farming under Brunei Darussalam conditions in semi-intensive earthen pond culture system and intensive culture in concrete-walled ponds and concrete-lined earthen ponds.

1. Capital investment costs - In Tables 6.15 to 6.17 are the capital investments for semi-intensive earthen ponds and intensive ponds and the estimates of annual depreciation for farm facilities.

2. Estimated costs and production revenues - In this analysis, constant prices are assumed for simplicity of presentation; and assuming that if there may be changes in the general price level, no changes in relative price will occur; that is, prices of inputs and outputs will change at approximately the same rate.

Production costs and expenses (Tables 6.18 to 6.19) vary between the semi-intensive and the intensive systems. However, production expenses for intensive shrimp farming in both concrete-walled and concrete-lined ponds are assumed to be the same.

Table 6.15. Investment analysis for a proposed 10-ha semi-intensive shrimp (*P. monodon*) farm.

Item	Unit	Year life	No. of units	Cost/unit (B$)	Total cost (B$)	Annual depreciation (B$)[a]
Pond development	ha	-	10	213,429	2,134,290	-
Farm building	m^2	15	100	500	50,000	3,333
Equipment:						
Pump and engine + house	each	5	2	25,000	50,000	10,000
Nets, buckets, boxes, etc.		2	-	-	10,000	5,000
Vehicles (pick-up):						
4-wheeled	each	10	1	25,000	25,000	2,500
6-wheeled	each	10	1	45,000	45,000	4,500
Total investment					2,314,290	
Total depreciable investment					180,000	25,333
Investment/ha					231,429	

[a]Computed using straight-line method with zero salvage value.

Expenses for the purchase of shrimp fry/seed are the major production cost items comprising about 43% and 59% of the total input cost for the semi-intensive and the intensive systems, respectively. Expenses for lime (if there is acid sulfate problem), comprising about 28%, are the next major production cost for the semi-intensive system; while feed costs, contributing about 38% of the total, rank second for the intensive system. Other production expenses include those on electricity (for intensive system), gasoline and oil and teaseed cake purchases. The total costs for material inputs are B$56,760/ha for the semi-intensive system and B$159,390/ha for the intensive one. Labor; repair and maintenance; and miscellaneous (for general operation) costs also contribute to the total variable or operating expenses.

Costs are generally classified into fixed or variable. Fixed costs are those that are incurred whether production is carried out or not. In this analysis, fixed costs consist of depreciation and interest on cash operating expenses. The latter is classified as a fixed noncash expense to represent the opportunity cost of capital since the investor's own money is used. Interest is calculated at 4% of the total variable expenses to approximate the interest earnings

Table 6.16. Investment analysis for a proposed 5-ha intensive shrimp (*P. monodon*) farm on concrete-lined earthen ponds.

Item	Unit	Year life	No. of units	Cost/unit (B$)	Total cost (B$)	Annual depreciation (B$)[a]
Pond development						
Pond construction	ha	-	5	558,170	2,790,850	-
Pond plastic lining	ha	5	5	100,000	500,000	100,000
Buildings (office, living quarters, storage)	m^2	15	70	500	35,000	2,335
Equipment						
Axial flow pump with motor	each	5	2	5,000	10,000	2,000
Paddlewheel aerators (2 hp)	each	5	40	675	27,000	5,400
Nets, buckets, boxes, etc.		2		5,000		2,500
Vehicles (pick-up)						
4-wheeled	each	10	1	25,000	25,000	2,500
6-wheeled	each	10	1	45,000	45,000	4,500
Total investment					3,437,850	
Total depreciable investment					647,000	119,235
Investment/ha					687,570	

[a]Computed using straight-line method with zero salvage value.

because they fail to consider the timing of incomes and expenses. The second level, known as discounted indicators, consider the timing of incomes and expenses. The reason for discounting is to consider the decrease in the future value of money, that is, the present value of money is greater than its future value. These discounted indicators include benefit-cost (B/C) ratio, net present value (NPV) and internal rate of return (IRR).

Based on the analysis, the cash payback period of the project alternatives is relatively long with values of 15.8 years for the semi-intensive; 8.9 years for the concrete- walled ponds; and 6.4 years for the concrete-lined ponds. The long payback period for the semi-intensive earthen ponds is largely due to the cost contributed by applying lime to correct projected acidity problem. When there is no acidity problem, the cash payback period is 7.6 years.

The ROI, which represents the earning of the investment, is highest for the concrete-lined ponds at 15.73%, followed by the concrete-walled ponds with ROI of 11.23%. The semi-intensive system earns only about B$0.06 for every dollar of investment or 6.32% ROI.

The discounted measures provide a more accurate indication of the profitability of investment alternatives. The three projects have B/C ratios ranging from 1.03 to 1.18. The NPV, which measures present value of the future benefits from the project, including the residual value of investment, is highest for concrete-lined ponds with NPV of B$1,365,455; followed by concrete-walled ponds with NPV of B$1,172,421; and lowest for semi-intensive system with NPV of B$188,239. The higher the net present value, the more desirable a project becomes. Between the two pond designs for intensive prawn farming, the concrete-lined pond design has a higher NPV because it is more profitable vis-a-vis the initial investment cost. In other words, even with less amount of investment, the concrete-lined pond design could generate benefits as a concrete-walled pond design could but which requires higher initial investment.

The IRR is perhaps the most widely used indicator of profitability because it is a dynamic measure. The IRR measures the true profitability of a project. Enterprises with IRR greater than the opportunity cost of capital is considered profitable. The higher the IRR, the better. The percentage in excess of the opportunity cost of capital represents pure profit. Based on the analysis made, concrete-lined ponds for intensive culture system have the highest IRR (15.21%), followed by concrete-walled ponds (11.04%) and semi-intensive system (5.0%). Without liming, the IRR of semi-intensive system is 14.6%. Shown in Table 6.20 is the comparative summary of the profitability tests on semi-intensive and intensive farming of shrimp.

Table 6.20. Comparison of profitability of semi-intensive and intensive shrimp (*P. monodon*) farms.

Profitability indicator	Semi-intensive	Intensive	
	earthen-pond	Concrete-walled	Concrete-lined
Cash payback period (yr)	15.80	8.91	6.40
Rate of return on investment/ROI (%)	6.32	11.23	15.73
Benefit-cost ratio (B/C)	1.03	1.13	1.18
Net present value (NPV) (B$)	188,239	1,172,421	1,365,455
Internal rate of return (IRR) (%)	5.00	11.04	15.21

The intensive system in concrete-lined ponds, which has the highest profitability, is the choice for investment. The intensive system in concrete-walled ponds, while profitable based on the analysis and assumptions made, does not exhibit stable viability. In short, adverse changes in input and output prices would result to decreased profitability. For example, a decrease in the price of shrimp from B$20 to B$18/kg would reduce both the investment earning by 50% (B$0.13 to B$0.06) and the IRR by about 5 to 6.18%. On the other hand, the intensive system in concrete-walled pond would remain profitable with an IRR of about 10% and a B/C ratio of 1.10.

The semi-intensive system is barely able to pay for its cost with a B/C ratio of 1.03 and an IRR of 5.0%. A 10% decrease in output prices or increase in fry and feed cost would render the operation unprofitable. However, it is indicated elsewhere that the cost of lime is the main factor that decreased the profitability of earthen ponds. If the anticipated problem on occurrence of acid sulfate soil is quickly neutralized, then the cost item for lime would become minimal. This would improve the profitability of the semi-intensive earthen ponds considerably.

5. Sensitivity analysis - Profitability analysis assumes that all necessary production factors for normal farm operation are fully satisfied. Assumptions are based on attainable production levels from countries with the needed skills and years of experience in shrimp farming. Although Brunei Darussalam may be able to hire the technical expertise, there still is the great possibility that actual production in the shrimp farm during implementation may fluctuate or fall short of the assumed or target production. Therefore, a sensitivity analysis was done for the proposed 5-ha intensive farming operation to determine how sensitive the projections would be to changes in production levels and market prices. The impact of changes in production levels and fluctuations in the market selling price of shrimp to the project's net income was evaluated (Table 6.21). Changes in input prices were assumed to remain at a relatively constant level.

At a market price of B$18 to 20/kg, the farm would be incurring losses up to the fifth year of operation if actual production output is only 60% of the target value. If the price goes down to B$15/kg, losses would be incurred up to the fifth year at production output of 80% of the target value. If actual production is 90% or higher, a profit would be realized during the third year.

Although the profitability analysis shows that shrimp farming is economically viable, the sensitivity analysis indicates that its viability is greatly affected by production levels lower than assumed and by fluctuating market price. Therefore, serious considerations should be given to these possibilities before making the final decision on whether Brunei Darussalam should venture into shrimp farming.

Coastal Agriculture

PRESCILLANO M. ZAMORA

Brunei Darussalam is not an important agricultural country (Stewart 1986). Only a small land area is devoted to agriculture and a very small proportion of this is utilized for crops and livestock in the coastal zone. Agricultural crop plants and livestock being farmed along the narrow strip of coastal land were noted in the following sites in the four districts surveyed:

1. Belait District
   a. Mukim Kuala Belait
   b. Mukim Seria
   c. Anduki Forest Reserve
   d. S. Lumut
   e. Mukim Liang Besar-Telisay Boundary
2. Tutong District
   a. Mukim Telisay
   b. Mukim Danau
   c. Mukim Pekah Tutong
   d. Mukim Keriam
3. Brunei-Muara District
   a. Mukim Sengaurong
   b. Mukim Gadong
   c. Berakas Forest Reserve
   d. Mukim Mentiri
   e. Mukim Serasa
   f. Mukim Pakan Muara
4. Temburong District
   a. Mukim Selirong
   b. Mukim Labu
   c. P. Siarau

Table 6.21. Annual profit or loss incurred from intensive shrimp farm if attained production falls short of target production and at varying market price (noncash fixed cost

Attained target production (%)	Yr 1 Production (kg/ha)	Yr 1 Profit/loss (B$)	Yr 2 Production (kg/ha)	Yr 2 Profit/loss (B$)	Yr 3 Production (kg/ha)	Yr 3 Profit/loss (B$)	Yr 4 Production (kg/ha)	Yr 4 Profit/loss (B$)
	Shrimp price at $20/kg							
50	4,500	-138,592	6,750	-91,112	8,663	-50,476	8,663	-48,095
60	5,400	-120,592	8,100	-64,112	10,395	-15,836	10,395	-13,455
70	6,300	-102,592	9,450	-37,112	12,128	18,824	12,128	21,205
80	7,200	-84,592	10,800	-10,112	13,860	53,464	13,860	55,845
90	8,100	-66,592	12,150	16,888	15,593	88,124	15,593	90,505
100	9,000	-48,592	13,500	43,888	17,325	122,764	17,325	125,145
	Shrimp price at $18/kg							
50	4,500	-147,592	6,750	-104,612	8,663	-67,802	8,663	-65,421
60	5,400	-131,392	8,100	-80,312	10,395	-36,626	10,395	-34,245
70	6,300	-115,192	9,450	-56,012	12,128	-5,432	12,128	-3,051
80	7,200	-98,992	10,800	-31,712	13,860	25,744	13,860	28,125
90	8,100	-82,792	12,150	-7,412	15,593	56,938	15,593	59,319
100	9,000	-66,592	13,500	18,888	17,325	88,114	17,325	90,495
	Shrimp price at $15/kg							
50	4,500	-161,092	6,750	-124,862	8,663	-93,791	8,663	-91,410
60	5,400	-147,592	8,100	-104,612	10,395	-67,811	10,395	-65,430
70	6,300	-134,092	9,450	-84,362	12,128	-41,816	12,128	-39,435
80	7,200	-120,592	10,800	-64,112	13,860	-15,836	13,860	-13,455
90	8,100	-107,092	12,150	-43,862	15,593	10,159	15,593	12,540
100	9,000	-93,592	13,500	-23,612	17,325	36,139	17,325	38,520

Agricultural crop plants

A narrow strip of coconut (*Cocos nucifera*) trees fringes the coastal land of Mukim Kuala Belait. This land, together with Tutong District, is estimated to cover not more than 250 ha. In Brunei Darussalam, the coconut may be regarded as food rather than as source of vegetable oil. Coconuts are unlikely to be productive. Many of those sold in the market come from Sarawak (Stewart 1986).

Reported in S. Liang area is a continuing roadside strip development of homeyard vegetable and fruit tree gardens and poultry units. The estimated gross area devoted to this development is 800 ha.

Watermelon (*Cucumis melo)*, cashew (*Anacardium occidentale)* and coconut are cultivated in Kg. Danau, Tutong District.

Banana (*Musa sapientum*) and pineapple (*Ananas comosus*) are grown on a limited scale on the slopes of the recently burned coastal hills and narrow valleys in Mukim Mentiri, Brunei-Muara District.

There is a 20-ha farmland situated on the edge of a mangrove area near the headwaters of S. Brunei in Kg. Jungjongan. This farm grows various types of crop plants and raises livestock (Table 6.22). Along the coast of Temburong District, which is fringed by mangroves, no crops are grown.

Table 6.22. Crop plants and livestock being farmed in the 20-ha farmland at the edge of a mangrove area in Kg. Jungjongan near the headwaters of S. Brunei. (Noted during the CRMP survey team visit on 27 April 1987.)

- Crop plants
  - Fruit crops
    - Banana (*Musa sapientum*)
    - Orange (*Citrus*)
    - Lime (*Citrus*)
    - Jackfruit (*Artocarpus heterophyllus*)
    - *Cempedak* (*Artocarpus*)
    - *Guayabano* (*Annona reticulata*)
    - Mango (*Mangifera indica*)
    - Papaya (*Carica papaya*)
    - Guava (*Psidium guajava*)
    - *Cainito* (*Chrysophyllum cainito*)
    - Coconut (*Cocos nicifera*)
    - Watermelon (*Cucumis melo*)
  - Root crops
    - Cassava (*Manihot utilissima*)
    - *Gabi* (*Colocasia esculentum*)
  - Vegetables
    - Leafy vegetables
      - *Kangkong* (*Ipomoea aquatica*)
      - Shrubby *malunggay (Sauropus androgynous)*
    - Fruit vegetables
      - Tomato (*Lycopersicon esculentum*)
  - Pasture crop
    - Napier grass (*Pennisetum purpureum*)
- Livestock
  - Fowl
    - Chicken
    - Other species
- Cattle
  - Cow

Livestock

The Jerudong Cattle Fattening Station and the Luahan Cattle Breeding Station, both covering about 290 ha, are used for breeding and fattening cattle for local consumption. Another 1,400 ha of coastal land between Padang Terbang Anduki and Lilas Village have been developed into small farms and poultry units, aside from housing sites and industrial sites. Increase and expansion of these agricultural enterprises are expected to form the basis of future development because the area contains only reasonable agricultural land near the markets of Kuala Belait and Seria (MOD-DOTCP No. 1, 1986a).

In the coastal zone of Brunei-Muara District is McFarm, a 485-ha cattle breeding farm in Mukim Gadong. This farm is a combined private-government enterprise run by the Mitsubishi Corporation of Japan.

Integrated into the farming system of the 20-ha farm at the headwaters of S. Brunei in Kg. Jungjongan are cattle and poultry units. In the various stages of preparation during the team's visit (29 April 1987) were several ponds of different dimensions for culturing fish.

There are no livestock farms in the coastal strip of Tutong and Temburong Districts.

Economic aspects

Coastal agriculture could be presumed to be contributing a very small revenue to Brunei Darussalam economy. Fruit crops, vegetables and livestock found in most *kampongs* in the coastal zone supply immediate family requirements, that is, on a noncommercial scale. Most commercial scale farming is undertaken further inland beyond the 1-km strip of coastal land set for the present coastal resource survey.

The following are the several difficulties confronting coastal agriculture in Brunei Darussalam which make it most unlikely to prosper and become a dominant factor in the nation's economy:

1. Generally, the coastal soils are not very fertile.
2. The coastal areas are often waterlogged, very acidic and subjected to flooding. Thus, agricultural productivity that depends on good drainage could not be practiced profitably.
3. The climate is hot and humid and does not encourage long and sustained physical labor as is required by productive agricultural endeavors.
4. Oil and natural gas sectors, which have replaced agriculture as an important source of revenue, have caused many people in the rural areas to move to towns to seek better jobs and higher incomes. As a consequence, the number of people involved in agricultural activities rapidly declined. The only full-time farmers are the Chinese market gardeners. Majority of the farmers are part-time only who find employment in the nonagricultural sectors (Stewart 1986).

Coastal Forestry

PRESCILLANO M. ZAMORA

About 80% of the total land area of Brunei Darussalam is covered with forests of various types. However, only a small proportion of the total forest cover is found within the coastal zone. To assess the status of coastal forestry in the country, field surveys (9 April-7 May and 4-14 June 1987) of the coastal strip were conducted and (2) secondary sources of information were reviewed.

Forest types

The forests are important as: (1) source of timber for the local market; (2) means of soil and water conservation; and (3) natural habitats for a wide variety of wildlife (plants and animals).

According to the Master Plan, the principal forest types are the: (1) beach forest; (2) mangrove forest; (3) freshwater swamp forest; (4) peat swamp forest; (5) heath forest; (6) mixed dipterocarp forest; (7) secondary forest; (8) montane forest; and (9) mixtures of these. Five of the types occur within the coastal zone: (1) beach forest belt; (2) mangrove forest; (3) peat swamp forest; (4) heath forest; and (5) secondary forest.

Based on a cursory examination of maps and other materials and supplemented by field observations, these forest types, as they occur along the coast, apparently range from the most extensive to the least extensive in areal extent, as follows:

1. Most extensive : secondary forest
2. Intermediate I : mangrove forest
3. Intermediate II : heath forest
4. Intermediate III : peat swamp forest
5. Least extensive : beach forest

As may be gleaned from Table 6.23, the occurrences of the five types in the four major districts of Brunei Darussalam are:

1. Beach forest occurs along the coast of Belait, Tutong and Brunei-Muara Districts.
2. Mangrove forest occurs in the estuaries and along the banks of rivers in Belait, Tutong, Brunei-Muara and Temburong Districts and around islands, e.g., P. Siarau, Temburong District.
3. Peat swamp forest occurs in the coastal area northeast of S. Liang, Belait District and near the boundary between Belait and Tutong Districts.
4. Heath forest makes up the whole of Berakas Forest Reserve, Brunei-Muara District.
5. Secondary forest occurs in portions of three of the four districts, in Anduki Forest Reserve, Belait District; Pekan Tutong in Tutong District, Sengaurong, Gadong, Merinti; and Serasa, Brunei-Muara District.

It could be seen in Table 6.24 that five of the six mangrove forest subtypes are found in various places within the coastal zone of the four districts. Table 6.25 gives the dominant or distinctive species of plant and the soil types in the coastal areas occupied by the five forest types. The most typical species in the beach forest is *Casuarina equisetifolia*. The most dominant species of the mangrove swamp forest are *bakau minyak (Rhizophora apiculata)* and *nipah (N. fruticans)*. The most distinctive species in the peat swamp forest is the endemic

Table 6.23. Forest types within the 1-km wide strip of coastal land fronting South China Sea, along banks of watercourses and the numerous tributaries of these, and around islands in the four districts of Brunei Darussalam.

Forest types	Belait	Tutong	Brunei-Muara	Temburong
Beach forest	x	x	x	-
Mangrove forest	x	x	x	x[a]
Peat swamp forest	x	-	-	-
Heath forest	-	-	x[b]	-
Secondary forest	x[c]	x	x	-

[a]Selirong Forest Reserve, Labu Forest Reserve.
[b]Berakas Forest Reserve.
[c]Anduki Forest Reserve.

seringawan (Shorea albida). The most distinctive tree in the heath forest is *C. nobilis*. The secondary forest is made up of a mixture of species of various fast-growing life forms. It harbors no distinctive or dominant species.

Forest reserves

Table 6.26 shows the forest reserves in three districts, with portions extending into the 1-km wide strip of coastal land. No forest reserves are located in the coastal area of Tutong District. The forest reserve in the coastal zone of Belait District is Anduki Forest Reserve; in Brunei-Muara District, Berakas Forest Reserve; in Temburong District, Selirong and Labu Forest Reserves.

The Anduki Forest Reserve is essentially a mixed swamp forest in a very degraded state brought about by frequent fire occurrences. According to DOTCP (1987a): "The gazetting of this 915-ha reserve should be revoked since it has already suffered severe damage from fire, oil exploration and the construction of roads and power lines and since it is beyond the power of the Department of Forestry to prevent further encroachment."

The Berakas Forest Reserve is a typical heath forest. There are only 3,455 ha of undisturbed heath forest in Brunei Darussalam today (DOTCP 1987c). In addition, this forest is a fragile habitat easily damaged by fire, felling or off-road vehicles. Once the top peaty soil layer is removed, degradation sets in, and it is very difficult to control. Heath forest soil is useless for agriculture for which reason the Master Plan has recommended that this forest habitat be preserved intact as far as possible.

Of the forest types found in the coastal zone, only the mangrove forests in Selirong and Labu Forest Reserves have been presumed to have high economic potential.

Management Issues

Among the five mangrove forest subtypes, only that of *bakau* subtype (*R. apiculata)* is presumed to have commercial potential at present. According to the field surveys conducted, *bakau*: (1) in pure or almost pure stands, covers an area of 5,774 ha which is almost entirely confined to Selirong and Labu Forest Reserves; and (2) is found in mixture with other species in 1,945 ha. However, no data on the volume of standing timber of the resource are available to date. It is, thus, suggested that an inventory survey of *bakau* forest be made as an initial step in the determination of its economic potential and in planning its management.

A very unique type of forest, the heath (or *kerangas*) forest constitutes a negligible 0.6% (3,455 ha) of the total land area of Brunei Darussalam, of which Berakas Forest Reserve (329

Table 6.24. Mangrove forest types within the 1-km wide strip of coastline fronting South China Sea, along the banks of watercourse, and the tributaries of these and around islands.

State of occurrence	Mangrove forest subtypes[a]					
	1	2	3	4	5	6
Belait District						
S. Belait		x			x	
S. Lumut						x
Tutong District						
S. Tutong	x	x				
Brunei-Muara District						
Merinti	x					
Pekan Muara (northern tip)	x					
West coast	x					
Temburong District						
Selirong Forest Reserve		x				
Labu Forest Reserve		x				
P. Siarau		x		x	x	
S. Bangau		x				
S. Aloh Besar		x				
S. Duwau Besar		x				
S. Temburong	x			x	x	

[a]1: Undifferentiated (mixture of species).
2: *Bakau (Rhizophora apiculata).*
3: *Nyireh bunga (Xylocarpus granatum)* does not occur within the coastal strip.
4: *Linggadai (Bruguiera gymnorrhiza).*
5: *Nipah (Nypa fruticans).*
6: *Nipah-dungun (Nypa fruticans-Hereteira globosa).*

Table 6.25. Dominant or distinctive species and soil types in the coastal areas occupied by the five forest types.

Forest types	Dominant distinctive species	Soil types
Beach forest	*Casuarina equisetifolia*	Sandy
Mangrove forest subtypes	*(Rhizophora apiculata, Nypa fruticans)*	Saline
Undifferentiated[a]	No single dominant or distinctive species.	Saline
Bakau	*R. apiculata*	Saline
Nyireh bunga	*Xylocarpus granatum*	Saline
Nipah	*Nypa fruticans*	Saline
Nipah-dungan	*N. fruticans-Heritiera globosa*	Saline
Peat swamp forest[b]	*Shorea albida*	Peaty
Heath forest[b]	*Casuarina nobilis*	Sandy
Secondary forest[b]	No single dominant or distinctive species.	Clayey

[a]Mixture of several species, e.g., the mangrove patch just outside the riverside wall of the Sultan's Palace harbors *Avicennia alba, Sonneratia alba, R. apiculata, Sonneratia caseolaris, R. mucronata, Excoecaria agallocha* and *Ceriops tagal.*
[b]Mixture of numerous species, characteristic of each forest type.

Wildlife (has tourism and education potential)

Proboscis monkey	Various water birds
Various seabirds	Sea turtles

The above is not a complete list. For example, several land-based parks in the main urban centers are not mentioned. Nevertheless, the primary resources of interest are included; most are undeveloped or unprotected. Many are proposed for management, development or strict protection in the form of marine, nature and/or wildlife reserves. Such areas are consistent with controlled tourist and public education. Below are several outstanding issues regarding these areas and their use:

1. Many beach areas have potential for use as recreation and tourist sites, but protection and management are lacking.
2. Several offshore coralline areas have potential for recreation and tourism, but proper management, protection and access are lacking.
3. Numerous islands in Brunei Bay with mangrove forest and wildlife have potential for recreation, tourism and education, but proper management, protection, access and facilities are lacking.

Industry

ALAN T. WHITE

This section focuses on the current and potential environmental impacts of industrial development in the coastal zone. The most significant and obvious ones, such as chemical pollution and soil erosion, are highlighted. Geographical areas and industries of concern are noted.

MOD-DOTCP No. 6 (1986d) and 12 (1986h) provided data on trends in industrial development. Observations along the coast and interviews with government employees and coastal residents provided first-hand information. A chemical analysis of water samples submitted to the Director of DOF by Chemical Laboratory (Singapore) Pte. Ltd. supplied data on chemical (oil) concentration levels at three sampling sites.

Industries and trends

The oil and gas economic sector accounts for more than 75% of the gross domestic product in Brunei Darussalam. All installations are located in the coastal areas or offshore. Other important industries to the coast are quarrying, construction, transportation and communication and limited agriculture. Each of these increased its level and employment by at least 30% per annum (1981-1985). These sectors are important for their present and potential environmental impacts on coastal waters.

Greater Bandar Seri Begawan and Muara are the main growth areas. Most old and new non-oil and nonresource-based industries, which tend to be relatively nonpolluting, are located here. Industries in which products are high-value added and which rely on imported raw materials are also generally located here.

Regional growth areas of Belait, Tutong and Temburong Districts are current and potential locations for resource-intensive industries such as sawmills, ricemills and other agro-

based industries. Shipyard and engineering industries serving the oil sector are in Kuala Belait. Resource-based, construction and other engineering-related industries all have potential for polluting coastal resources.

The oil and gas industry is in the area around Seria and Lumut. Further downstream activities of this industry would logically be located in this area, too. A petrochemical industry such as hydrocarbon cracking plant (to produce raw materials for oil-based paints and chemical dyes) and energy-intensive industries such as steel and urea plants could also be located in Seria-Lumut area. These industries require careful EIA because of their potential for serious pollution.

Industrial impacts

Extractive Industries. Industries based on deposits of gravel and sand (used in construction mainly as concrete aggregates) and brick and pottery earth clays for ceramics are well-established in some coastal areas. Jerudong, Tengku, Tutong and Belait are major sites. These activities, if done directly on coastal beaches or adjacent land, normally cause coastal erosion in some form. Or, if done inland, could cause soil erosion which ultimately runs off to marine waters. The implications are apparent where beach sands are very fine and muddy or the inshore waters are laden with silt after heavy rainfall.

Nonresource-based Industries. Most such industries are composed of small- to medium-sized manufacturing plants which are not highly polluting. Most are located in Bandar Seri Begawan-Muara area with a focal point around Serasa, near the deepwater port. Pollutants from individual facilities are particular to each and should be considered in EIAs. One generalized impact for such an industrial complex as Serasa is soil erosion from construction activities and clearing of vegetation. This impact may have serious effects on marine water quality, especially in an enclosed bay area.

Also, industries which require shipping would have impact on the water quality in the port area through the presence of more ships. Tests made on water samples taken from pumped seawater of Muara Fishery Station hatchery, 17 m away from the jetty off the station and of Serasa area, showed relatively high levels of oil, grease and hydrogen sulfide as compared to acceptable international standards. This pollution is presumably the result of ordinary shipping activity.

Petrochemical Facilities. Offshore oil drilling has some impacts on the surrounding waters from the dispersal of drilling muds and drilling coolants. Such impacts may be minimized if preventive measures would be taken. Other details on the present and potential pollution threats of petrochemical facilities are in Chapter 7.

Construction. This involves most industries in their incipient phase and also transportation and communication. In the above-mentioned prime development areas of Brunei Darussalam, there is much construction from housing, industry and roads. This construction requires clearing and levelling of land. When close to the coast, the immediate impact is erosional runoff during and after construction activities. This impact could be minimized by requiring careful EIA for each project and by rehabilitating unnecessarily cleared land with trees and plants or retaining walls to prevent erosion. Such erosional sites are very noticeable in Bandar Seri Begawan-Muara area.

Issues

The main issues identified in relation to industrial development are:

1. Coastal erosion caused by construction of industrial sites, housing, roads and other projects;
2. Oil-based pollution from shipping and/or other industries in Brunei Bay-Serasa area;
3. Oil-based pollution from runoff, cleaning waters and accidental spills in the vicinity of Seria-Lumut Beach areas;
4. Oil-based pollution from potential major spills during drilling operations or shipping in offshore waters;
5. Coastal erosion caused by various quarrying activities during and after mining of sand, gravel and clay from sites in Belait, Tutong, Jerudong, Tungku, Berakas and Muara Beach areas;
6. Chemical pollution resulting from small industries located on the waterfront in Bandar Seri Begawan-Muara area and which discharge into the bay; and
7. The lack of provisions for dumping of toxic waste by large or small industries.

Chapter 7
Pollution

M.W.R.N. DE SILVA

Although Brunei Darussalam does not suffer from major pollution problems, such as those faced by her more industrialized ASEAN neighbors, there are several issues that need to be considered to keep pollution of the coastal area to a minimum.

Published scientific data on pollution in the coastal area are almost nonexistent. However, several short-term studies have been carried out on specific subjects by consultants or consultant groups for the government. Although several government departments are involved in monitoring some environmental parameters on a routine basis, much of the information remains unpublished, but is used for making immediate policy decisions.

Sources

Offshore oil production

The present offshore production sites of Brunei Shell Petroleum Co. Ltd. are indicated in Fig. 9.2. Although steps are taken by Brunei Shell to minimize adverse environmental impacts due to offshore oil production, the possibility of accidental oil pollution and sedimentation effects during drilling operations could not be overruled. The oil well blowout in 1981 that resulted in some contamination of the shoreline and the smaller spill in 1984 are evidences of this ever present potential environmental hazard.

There is no National Contingency Plan to combat oil spills. However, it is noteworthy that Brunei Shell has developed an oil spill contingency plan for their use. The company maintains oil- containment and reclamation equipment as well as a stock of chemical dispersants. Further, it carries out a regular environmental audit.

Oil terminal and liquified natural gas (LNG) plant operations

Brunei Shell discharges wastewater from their crude oil terminal operations in Seria (Fig. 5.4) into S. Bera, a small river in the vicinity. The effects of this oil-contaminated water on the benthic community of the area are reported in a study commissioned by Shell Brunei (Leong et al. 1984).

Air pollution due to oil and gas industries seems to be minimal as the former industry has been promoting clean burning of waste oil by mixing it with gas, and the latter, by flaring the waste gas from tall stacks.

Solid waste and sewerage disposal

Most of the designated solid dumping or tipping grounds fall outside what is considered as the coastal area in this study, with the possible exception of the one in Muara.

Solid waste collection and disposal in Brunei Darussalam is the responsibility of the various municipal boards, district offices and Brunei Shell, based on the locality concerned. Collection, as a whole, tends to be more frequent and regular in urban areas than in others. Apart from household solid waste, the indiscriminate abandoning of old cars on undeveloped land has become an environmental concern, particularly from an aesthetic point of view. Many of the beaches used as recreational areas lack facilities for garbage collection and disposal, resulting in the accumulation of large numbers of cans, plastic bags and other rubbish. This makes the areas not only aesthetically unpleasant but also dangerous to recreational use.

Two areas of particular concern from the point of view of solid waste disposal are Anduki Sand Pit and Kg. Air. The tipping of rubbish into part of Anduki Sand Pit is obviously causing pollution of the waters in an area earmarked for recreation and possibly with some aquaculture potential, too. The government's concern regarding waste disposal in Kg. Air is reflected in its contracting out a study on waste management of the village completed in 1986.

The sewage discharge points are indicated in Fig. 5.4. In Brunei Muara District, there are several sewage treatment plants with discharge outlets into S. Brunei Estuary, Brunei Bay or directly into the South China Sea. There are two sewage treatment plants in Tutong District, one in Tutong town and the other in Penanjong, both of which discharge effluent directly into South China Sea. Both Kuala Beliat and Seria have sewerage systems discharging into Beliat River and S. Bera, respectively, but neither system has treatment plants at present. The 1982 Sewerage Master Plan already proposed treatment plants for these two systems.

The discharge of untreated effluent into S. Brunei by approximately 29,000 people living in Kg. Air, which may result to water pollution, is a cause of concern to the government.

Pollution of the beach areas due to short sewerage outfalls and discharge of untreated effluent into small rivers and streams is a problem worthy of corrective attention.

Mining and dredging (see Chapter 3's section on mineral resources).

Deforestation and land clearance for development

Deforestation and land clearance practices without proper erosion control methods have caused major erosion problems. Increased silt and sediment loads that enter the sea through estuaries, rivers and streams, apart from causing direct impacts on benthic communities, could cause indirect damage to benthic plant communities by radically altering the light regime of the water column.

Agriculture and other contributing industries and activities

Brickworks, road material production plants and forest fires contribute to air pollution. Of these, forest fires are of particular interest as they cause a haze which could affect the health of

the people, particularly those with bronchial problems, and to a limited extent, also affect the local climate.

At present, there is no evidence to indicate that limited agricultural activities caused measurable pollution problems. However, some farmers indulge in the excessive use of pesticides, as indicated by the high levels of pesticides in vegetables monitored by the Department of Agriculture (DOA).

Baseline Studies

An environmental baseline study of the macrobenthos in the vicinity of the crude oil terminal in Seria has been carried out by Leong et al. (1984). Apart from sampling the macrobenthic community in S. Bera in Seria and control sites in S. Lumut and S. Tali, selected environmental parameters such as hydrocarbon levels, particle size distribution of the sediment and hydrological data were also considered during the study. The results indicated a much lower population of macrobenthic organisms in the intertidal zone at the discharge site at S. Bera when compared with those found in S. Tali and S. Lumut. The study also indicated the following:

1. The effects of the discharges on the intertidal zone were very localized.
2. In the subtidal zone, there was a reduction in macrobenthic populations at S. Bera when compared with those at S. Lumut. S. Tali, located between S. Bera and S. Lumut, had fewer subtidal organisms when compared with S. Lumut and had more when compared with S. Bera. Here, too, the distribution patterns of the macrobenthic organisms corresponded with hydrocarbon distribution patterns.
3. The effects of the discharge from S. Bera appeared to be more widespread in the sublittoral zone.
4. At the three sites, analysis indicated that a substantial part of the hydrocarbons found were of petrogenic origin. The close correlation of the hydrocarbon levels with the macrobenthic communities suggested a causal relationship between the two. From what is known of the biology of the organisms, Leong et al. (1984) concluded that the hydrocarbon levels largely determined the distribution pattern of the macrobenthic organisms in the study areas.

S. Brunei is an important river system not only because it flows into Brunei Bay, which is important from the fisheries point of view, but also because it contains the unique "Water Village," Kg. Air, of some 29,000 people. The effect of discharging of untreated raw sewage (into the river by the village) on the quality of the river and of the fisheries products has been of grave concern to the government. So, the government commissioned Syed Muhammad and Hooi Consultancy Firm in 1984 to study water quality and pollution in S. Brunei. The major findings of this study were:

1. The present level of sewage discharges into the estuary does not seem to have any drastic effects on the ecosystem of the estuary. However, a reduction in diversity and an increase in the biomass of some animals were found in the vicinity of the main points of sewage discharges, including Kg. Air.
2. Phytoplankton production in S. Brunei was limited to the upper meter of the water column as a result of the rapid attenuation of sunlight.

purposes. The department has also developed the capability for water analysis for the following parameters: turbidity, color, suspended solids, iron, manganese, free and combined residual chlorides, nitrates, nitrites, pH, dissolved oxygen, biological oxygen demand (BOD), chemical oxygen demand (COD), phosphate, ammonia (NH4+), sulfides, chlorides, F-content, SVI, volatile S. S., Coliform count and *E. coli.*

MD has the responsibility of monitoring oil spills, but has limited capability to combat large spills. The department's tugboat *Sumpit Sumpit* is equipped with sprayers and is able to disperse small oil spills.

Action Plans

Aside from the issues on industries identified in Chapter 6, the following are also exigent:

1. A National Contingency Plan for the control and mitigation of oil spills;
2. A regular program for the monitoring of water quality, particularly, in Brunei Estuary and Brunei Bay area; and
3. A regular program for monitoring the sediment levels in the coastal waters, particularly, in Brunei Estuary and coral reef areas.

Chapter 8
Institutional and Legal Framework

ALAN T. WHITE, M.W.R.N. DE SILVA AND
PENGIRAN SHARIFUDDIN BIN PENGIRAN HAJI YUSOF

Government Organizations

"At present no sector of the Government is specifically charged with the responsibility for conserving and managing Brunei Darussalam's natural environment." This statement culled from DOTCP's Negara Brunei Darussalam master plan special report on wildlife conservation and management (1987c) sets the stage for the complicated issue of deciding what agency or agencies would be responsible for formulating and implementing a CRM plan.

In broad terms, most environmental or resource-related management decisions fall within MOD. At present, the following departments within their respective ministries are in one way or another linked to management issues pertaining to the coastal resources of Brunei Darussalam:

Ministry	Department
Development	Town and Country Planning
	Forestry
	Fisheries
	Public Works (JKR)
	Land
	Agriculture
Culture, Youth and Sports	Museums
Communications	Marine
Education	University of Brunei Darussalam

Jurisdictional rights of these departments (Table 8.1) overlap at times. Thus, attempts should be made to harmonize laws to simplify enforcement.

Department of Town and Country Planning (DOTCP)

This department was designated the role of making recommendations which concern national development in a planning capacity. It is also responsible for informally looking after environmental concerns such as soil erosion, impact assessment, resource use conflicts and

Table 8.1. Full or partial legal jurisdiction over selected coastal activities.

Activities	Agency responsible/concerned						
	Town and Country	Fisheries	Forestry	Marine	Public Works	Museum	Lands
Mangrove conversion	o	o	#	x	o	o	#
Fish exploitation	o	#	x	x	x	o	x
Beach	#	o	x	o	x	x	o
Sand mining	#	o	x	x	x	x	#
Oil drilling	#	o	x	#	o	x	o
Shipping and port construction	o	o	x	#	#	x	o
Marine parks and reserve	o	o	x	o	x	#	o
Sewage discharge	o	o	o	o	#	x	x
Industrial discharge	o	o	x	o	#	x	x
Pesticide discharge	o	o	#	o	o	x	x
Pollution control	o	#	o	#	#	x	x
Resource planning	#	#	#	o	o	o	o
Resource management	#	#	#	o	o	o	o
Aquaculture development	o	#	o	o	o	o	#
Human settlement	#	x	o	x	o	x	#

Legend: #: responsible; o: concern; x: no relationship.

habitat degradation. Responsible for coordinating the country's Master Plan, DOTCP is aware of all the complexities that exist in developing a practical plan for resource management. Despite these responsibilities, DOTCP has no institutional provision for implementation and management. A new department has been prepared by DOTCP to cover all environment-related issues and resource management problems with enforcement powers.

Department of Forestry (DOFor)

This department is mandated to preserve and conserve, as well as through managed commercial exploitation, to provide for sustainable and permanent regenerating forest reserves. It is, thus, responsible for issuing licences to exploit and maintain forests on public lands and to monitor their harvesting so that they are sustainable and ecological. Some of the enforcement problems faced by the department are illegal housing in forest areas and monitoring licencees who harvest mangroves for poles and charcoal in areas outside of those designated or which exceed the permitted quantities.

Department of Fisheries (DOF)

This is responsible for the management of fisheries resources and related habitats in a manner which would maximize benefits in terms of fish catch now and in the future. It is expected to develop fisheries resources and to devise methods of enhancing current production by means of aquaculture, artificial habitat enhancement and more effective exploitation. The department issues licences for offshore trawling and monitors small-scale inshore and offshore fishing. It is responsible for enforcing laws on fishing activities and concerns itself with pollution and other environmental problems which affect water quality and fisheries resources.

Department of Public Works (DPW)

It is charged with construction and maintenance of most government-supported utilities such as roads, sewage treatment and water supply plants. It is responsible for clearing coastal areas for construction of government facilities; mining sand and gravel for construction; monitoring water quality in rivers and estuaries in relation to human settlement areas; setting tolerable pollution levels for rivers and bay/port area; and maintaining public lands to prevent erosion.

Department of Museums (DOM)

Its main functions are to serve as a repository of cultural, archaeological and natural exhibits, literature and archival material; to provide public education; and to encourage research in keeping with the aims and objectives of the department. Although not its main mandate, the museum is also responsible for designating several important areas for conservation purposes which are intended to protect natural biota and habitat areas for endangered species.

Marine Department (MD)

It is mandated, along with its other duties, to maintain public waterways for transport. It is responsible for demarcating waterways and maintaining safety and monitoring water quality in relation to shipping and industrial discharge. The department also has overall jurisdiction over the removal of sand, soil, gravel, shingle and others from beaches. The main institutional conflicts are: (1) the extent to which the department has jurisdiction over marine areas with respect to natural resources (e.g., offshore dredging and its impact on marine resources); and (2) the overlap of water quality monitoring with the interests of DPW and of DOF.

Land Department (LD)

This department's primary functions are to administer and control land uses in accordance with Brunei Darussalam's land code and land regulations; and to provide advisory services to the public on land matters.

Department of Agriculture (DOA)

DOA's primary functions are to implement government projects in the production of essential food items; development of commercial farming; improvement of varieties; and development of suitable technologies through research. DOA also facilitates production through extension, advisory services, subsidiary schemes and market outlets.

Ports Department

This department provides port facilities for shipping and has jurisdiction over unclaimed land bordering the port.

University of Brunei Darussalam (UBD)

The University's Department of Biology has courses on living coastal resource components and is also involved in conducting studies on coastal habitats.

Nongovernmental Organizations (NGOs)

There are only a few nongovernmental organizations (NGOs) in Brunei Darussalam with interests in coastal resources for recreational purposes. Some of these are interested in nature conservation and have members knowledgeable on the country's wildlife and coastal ecosystems.

The Brunei Sub Aqua Club does scuba diving in offshore and coastal waters and has interest in healthy reef areas. The club could be utilized on a voluntary basis as is done in other countries for monitoring and other studies on coastal resources and habitats and for the construction of artificial FADs.

The Brunei Nature Society is interested in the preservation, conservation and public awareness aspects of nature and could be involved in marine wildlife monitoring and protection.

The Brunei Yacht Club operates from Muara. Its cooperation was sought by DOF for the monitoring of red tides when these were reported from Sabah.

Environmental Education

Education regarding the environment and the wise use of natural resources is almost nonexistent in Brunei Darussalam. Such education, however, could be carried out by the Ministry of Education (MOE) at elementary, secondary and tertiary levels; could most likely fall under the departments of MOD which are concerned with coastal resources, i.e., fisheries, mangroves, wildlife, coral reefs, etc. DOM could play a crucial role in information dissemination as it is directly concerned with the collection and organization of data on the environment.

tidal flooding which was probably encouraged by previous beach sand mining, in addition to oil extraction. Serious thought needs to be given to the overall-cost benefit ratios of beach sand mining being carried out in Kg. Tungku between S. Tengah and S. Dalam, keeping in mind its contribution to sedimentation and the consequent adverse effects on the marine environment in addition to erosion problems. Although steps are being taken to turf denuded areas in new development sites, other erosion control measures need to be taken for all areas where vegetation has been denuded both in the coastal and further inland areas. A feasibility study to control beach erosion was commissioned by DPW.

Potential Management Issues

Natural coastal resources depletion

Due to the stable and satisfactory economic situation based primarily on the oil and gas industry, the other natural coastal resources in Brunei Darussalam have been prudently exploited. However, with the envisaged diversification of the economy under the government's Fifth National Development Plan and the Negara Brunei Darussalam Master Plan, depletion of these resources could become an issue of concern. The following natural coastal resources (Fig. 9.2) are identified as being in need of immediate attention.

Fisheries. Fish form an important protein source for the people of Brunei Darussalam with a per capita consumption rate of approximately 40 kg/person/annum. At present, the local fish and shrimp catch accounts for about 50% of the country's requirement. Based on existing catch statistics, there is an apparent annual decline of 7.7% in offshore demersal fish stocks (see Chapter 6). Possible causes for this decline include:

- Artifacts due to the particular statistical treatment applied for obtaining the interannual comparisons;
- Localized decline of fish stocks in the limited number of trawl survey sites which might not reflect the general situation;
- The exploitation of a virgin stock progressing towards stabilization; and
- Illegal trawling.

There is a need to determine the exact cause(s) of the decline. DOF is planning to conduct a demersal resources survey of the waters concerned aside from its regular stock monitoring program. This would be timely and useful for the long-term fisheries management. Although the extent on which illegal trawling is done in the waters of Brunei Darussalam is considered minimal, a thorough investigation is necessary to determine the actual status of this activity. Surveillance and enforcement need to be stepped up to contain any illegal fishing activity, particularly, in view of the planned increase in the country's trawling fleet. The offshore oil-related structures serve as effective FADs, and their economic impact on fish biomass production should be considered in the formulation of the management plan.

The dominant role played by traditional fisheries points out the need to ensure that supporting inshore resources and stocks are properly managed and protected. The present estimates only take into account the production of full-time fishermen and not those of the many part-time fishermen which could be substantial.

Initial indications suggest that there might be a scope for the expansion of inshore fisheries. However, before any plans for expansion are formulated, it is imperative that a stock survey in inshore and estuarine areas be undertaken to establish reliable estimates of potential

yield and fishing effort, among others. Such a study is already being planned by DOF and should be able to provide valuable information for long-term management.

The exploitation of freshwater fish is apparently at minimum levels and could be increased, although information on potential yield is yet to be available. A stock assessment of the freshwater regions and the four main rivers is necessary.

Mangroves. This profile indicated that the mangroves of Brunei Darussalam rank among the best preserved in the ASEAN region and that they have a high regenerative capacity. Although not yet considered as major issues, the following could lead to the degradation or depletion of mangroves:

- Clearing of mangroves for human settlement, potential aquacultural operations and other developmental activities;
- Illegal logging;
- Traditional use of mangrove resources; and
- Pollution.

However important the mangroves are, it is inevitable that some mangrove areas in Brunei Darussalam would succumb to the pressures of development. Only planned development and rational management would enable the people to enjoy the exploitation of mangrove resources and their by-products on a sustained basis. There is a need to clearly establish the boundaries of mangrove areas which are crucial to coastal and estuarine fisheries and which have a high regenerative capacity so that controlled exploitation could be carried out for traditional uses. Once these areas are identified on a priority basis of importance, planned management becomes a possibility. There is always a need to be vigilant to prevent illegal logging and similar activities in the mangrove areas.

Coral Reefs. Very little is known about the coral reefs of Brunei Darussalam. However, even the limited studies done during the CRMP study indicated that although the percentage of living corals tended to be relatively low (3-40%), the diversity of hard corals was fairly high (52 genera in 3 reef areas). Although fish diversity was not high when compared to those of other ASEAN countries, there were several commercially important fish such as siganids, caesionids, serranids, lutjanids and mullinids.

Although no recent damage to the reefs by the use of explosives were observed during the survey, occasional use of these was reported. There is a need to be on constant guard against the use of explosives as their devastating effects on coral reefs and related fisheries are well-documented. Sedimentation could have adverse effects, particularly on nearshore reef areas. The low coral cover and damage on the reefs of Pelong Rocks and P. Punyit could have been due to sedimentation. Further investigations in these areas are warranted. Pollution is another identified potential, if not present, threat to coral reefs.

Since there is a dearth of proper scientific information on the country's coral reefs, there is a need to obtain more data, particularly for other areas (Fig. 9.1). Furthermore, in view of the limited reef resources, it is imperative to focus attention on preventing their degradation and destruction. The extent of the present and potential threats to the reefs should be researched further. The use of artificial substrates on denuded parts of reef flats could enhance reef life and should be considered as an extension of the Artificial Tyre Reef Project of DOF. While artificial substrates could help restore some disturbed or naturally poor habitats, they would not be able to replace a healthy coral reef ecosystem. Thus, a management plan for coral reefs is considered necessary.

Aquaculture

The introduction of aquaculture has both positive and negative implications. The positive effects are reduced dependency of fish supplies from other countries and a possible source of

Conceptual Framework for a Coastal Area Management Plan

The CRMP field survey strengthened the existing data base, developed from secondary sources, for planning the management strategies of the coastal area of Brunei Darussalam. The basis of a successful management plan is the coordinated actions of both the government and the concerned coastal communities for rational utilization of the renewable resources on an environmentally sustainable level. Over 86% of the population and 50% of the towns and villages are located within 1 km from the coast. Almost all the major economic activities of the nation operate within the coastal area; hence, the need for multisectoral and integrated planning.

A written coastal area management plan signifies the political will to systematically manage the resources based on sound management philosophy. The value of such a plan is that it specifies the course of actions or guidelines that could be used by resource managers or decisionmakers for daily management actions.

The major justifications to the development of a coastal area management plan for Brunei Darussalam are:

- Present economic developments are mainly concentrated in the coastal area.
- Renewable coastal resources are limited and, hence, of great importance to the nation.
- At present, many resources are not yet fully exploited, and the nation has not yet experienced major environmental pollution problems. Hence, it is timely to develop plans for orderly and rational utilization, particularly of living coastal resources, before the resources are overexploited or placed under serious environmental stress.
- Increased population is expected to exert greater pressures on the limited coastal resources in the future.

Based on these justifications, the coastal area management plan framework for Brunei Darussalam should cover the following elements:

1. Purpose
2. Scope (resources affected)
3. Legislative authorities
4. Boundary (geographical areas, zones)
5. Resources and their utilization
6. Resource use conflicts (current and potential)
7. Existing legal and management framework
8. Existing and potential threats and implication for management
9. Management plan proper: goals and objectives; management strategies for action; administration (implementation); surveillance and enforcement; and plan evaluation

Background information from secondary sources and on-site survey are essential data bases for formulating a plan that is enforceable by legal authority and acceptable by concerned sectors of the coastal communities. The following are pre-requisites for developing management strategies:

1. Resource characteristics
2. Socioeconomic values of coastal resources
3. Socioeconomic characteristics of coastal communities
4. Extent of economic development zones and possible environmental impacts
5. Types and extent of environmentally critical areas
6. Sources of current and potential environmental threats
7. Management issues, causes and effects
8. Legal and institutional framework
9. Perspectives of implementing agencies and communities

The integration of individual management strategies developed to address issues of special areas such as Brunei Estuary or development areas/commodities, such as inshore fisheries, coral reefs and mangroves, would form the main focus of the national management plan for the entire coast.

The main goal of the plan should focus on the long-term management of the resources, which is obtainable through various management actions developed. Examples of such actions are the strict enforcement of the ban on the use of explosives to fish and controlling sand mining and mangrove destruction.

The important component of the main plan should consist of specific guidelines for daily management of specific resources or special area within the coastal zone. The plan should also specify activities required to maintain or restore the value of different resources. An example is enhancing a habitat by installation of artificial reefs and control over extractive activities such as regulation of fishing effort and gear.

The plan should also identify data gaps and research needs necessary for periodic environmental assessment, resource valuation and improvement of monitoring and enforcement procedures.

One of the main programs of the plan is the need to manage human activities, particularly those that degrade the environment or deplete the resources. Hence, successful implementation of the plan's programs depends on the cooperation of the majority of the concerned sectors of the communities. As such, the plan should include activities that would help in implementation through public education program and dialogues and consultations with local communities. An effective interpretive plan greatly decreases resistance to implementation.

Another important element for successful implementation is the political will to protect the environment from further degradation and the commitment to ensure sustenance of the resources for the generations to come. Interpretive planning should always include community leaders, politicians and high officials in the administration.

Sufficient funds and adequate enforcement capability, must, however, be available to implement the plan. Further, the plan should have a fixed duration (three to five years) for implementation and should be reviewed, assessed, evaluated and subsequently improved with the availability of new data and experience.

Existing Data Base for Plan Formulation

This profile presented information which form a substantial data base for the formulation of a draft coastal area management plan. While more refined data bases are needed, this work identified the types, extent and economic significance of the major coastal resources, covering mangroves, estuarine mudflats, coral reefs, seagrasses, algal beds, openwater, artificial habitats and mineral resources. The relative importance of the coast for human settlement, transportation, communication, and industrial and other development potentials were also defined in this study. The sensitive habitats and other environmentally critical coastal areas were zoned (Fig. 9.1 and 9.3), although their geographical boundaries need to be better defined. The zones in the maps represent areas of importance which are either sensitive to developmental impacts or sites of present or potential industrial development. A conceptual plan for mangrove management is shown in Fig. 9.4, and the methodologies and approaches are given in Appendix 2.

Current and potential sources of environmental threats have also been identified, hence, providing basis for mitigative measures. While legislative authorities governing environmental

management in Brunei Darussalam have yet to be defined; and numerous data gaps on the assessment of fish and shrimp stocks, role of mangrove in inshore fisheries sustenance, rate of coastal erosion, socioeconomic valuation of coastal resources, and others have yet to be completed, the existing data bases are adequate for the preparation of a CRM plan framework on which the final plan could evolve. There are sufficient background data bases which could be used to address some of the major management issues.

When, What and How to Plan

This coastal profile is useful in providing the much-needed baseline data for preliminary planning. This planning interprets government policy, legislation and system. On-site planning, on the other hand, involves setting up objectives; conducting surveys; refining boundaries/zones; determining areas/systems for special intensive management measures; developing national or site management plans; and implementing these. It is, therefore, advisable to form a small planning team at the early phase of the project. The team could be expanded, depending on the scope of work. The team should include planner(s); economist(s); sociologist; marine specialists in fisheries, ecology, biology; and government representatives.

One of the major duties of the team is to prepare the coastal area management plan. Views from the various sectors of the community need to be considered for inclusion. An educator would also be useful in interpretive planning. The viewpoint of a legal office would be required throughout the planning and the implementing stages.

Data Gaps and Research Needs

1. Fish and shrimp resource assessment. Inland, inshore and offshore fish and shrimp stocks have to be properly assessed to determine whether they are declining; have reached MSYs; or could further be exploited. Proper study is required to assess and develop a management strategy for inshore fisheries, especially shrimp fishery. The catch monitoring system should be improved to include sampling of the chosen fishermen's catches as well as identification, weighing and length-frequency data of their catches. This study should take into account the pressures exerted by full-time and part-time fishermen. A pelagic resource survey is required to decide on proper exploitation plans, while a more detailed assessment of the demersal stocks would confirm the decline of these resources before further introduction of a more industrial type of fishing. These studies are already being planned and would be undertaken by DOF staff.

2. Erosion rates. Studies on erosion, its rates and effects on coastal dynamics are necessary. These should include the effect of sedimentation on marine life, the effect of longshore drifts on sand movement; and an examination of hydrological conditions. A thorough hydrological study of Brunei Estuary is necessary, especially in view of the development plans within the surrounding areas. Monitoring of the erosion of Pelompong Sand Spit is essential to further determine remedial measures, aside from those taken at present. The loss of this sand spit could have adverse effects on Muara Port and other areas within Brunei Estuary.

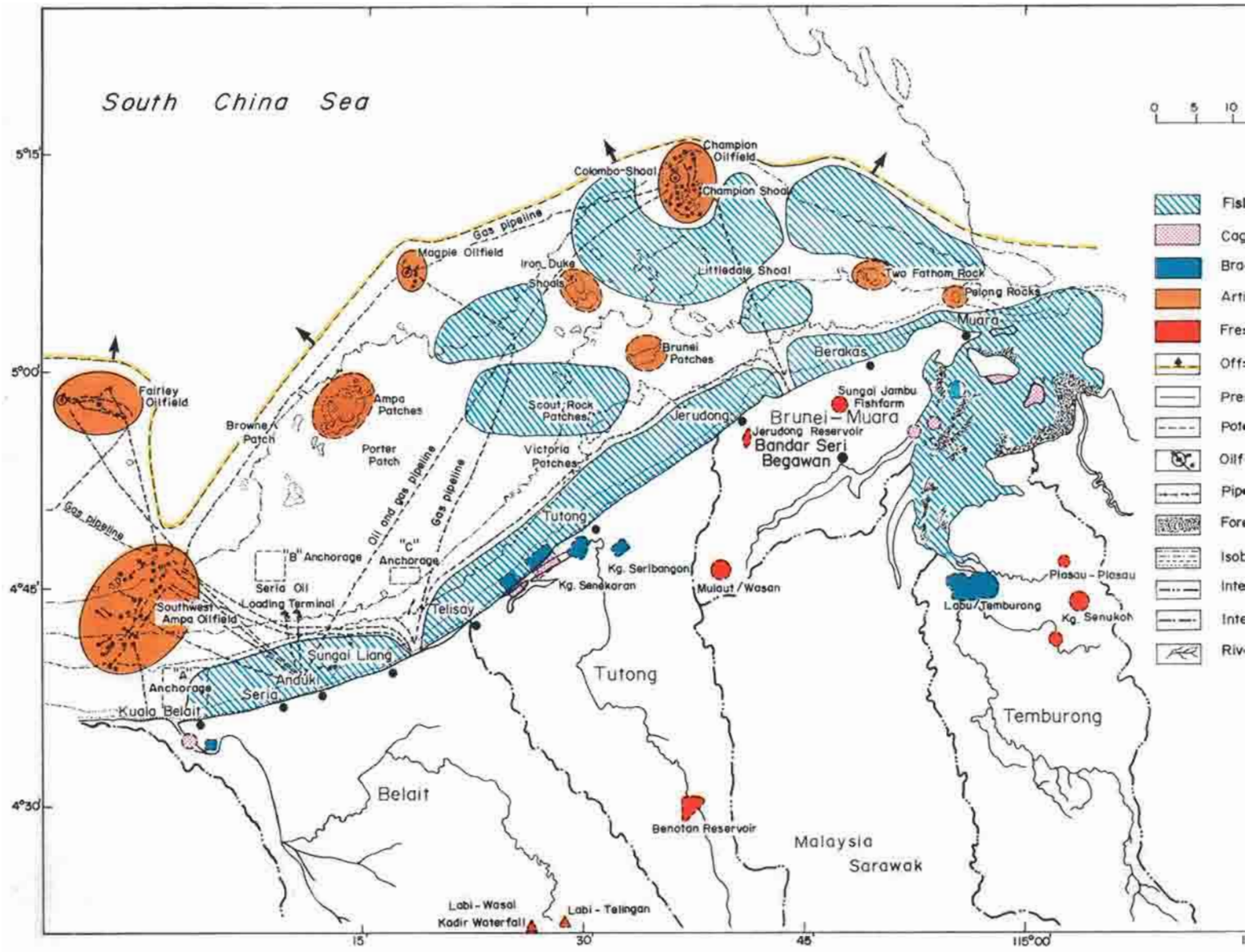


Fig. 9.3. Present and potential fisheries resources and aquaculture in Brunei Darussalam.

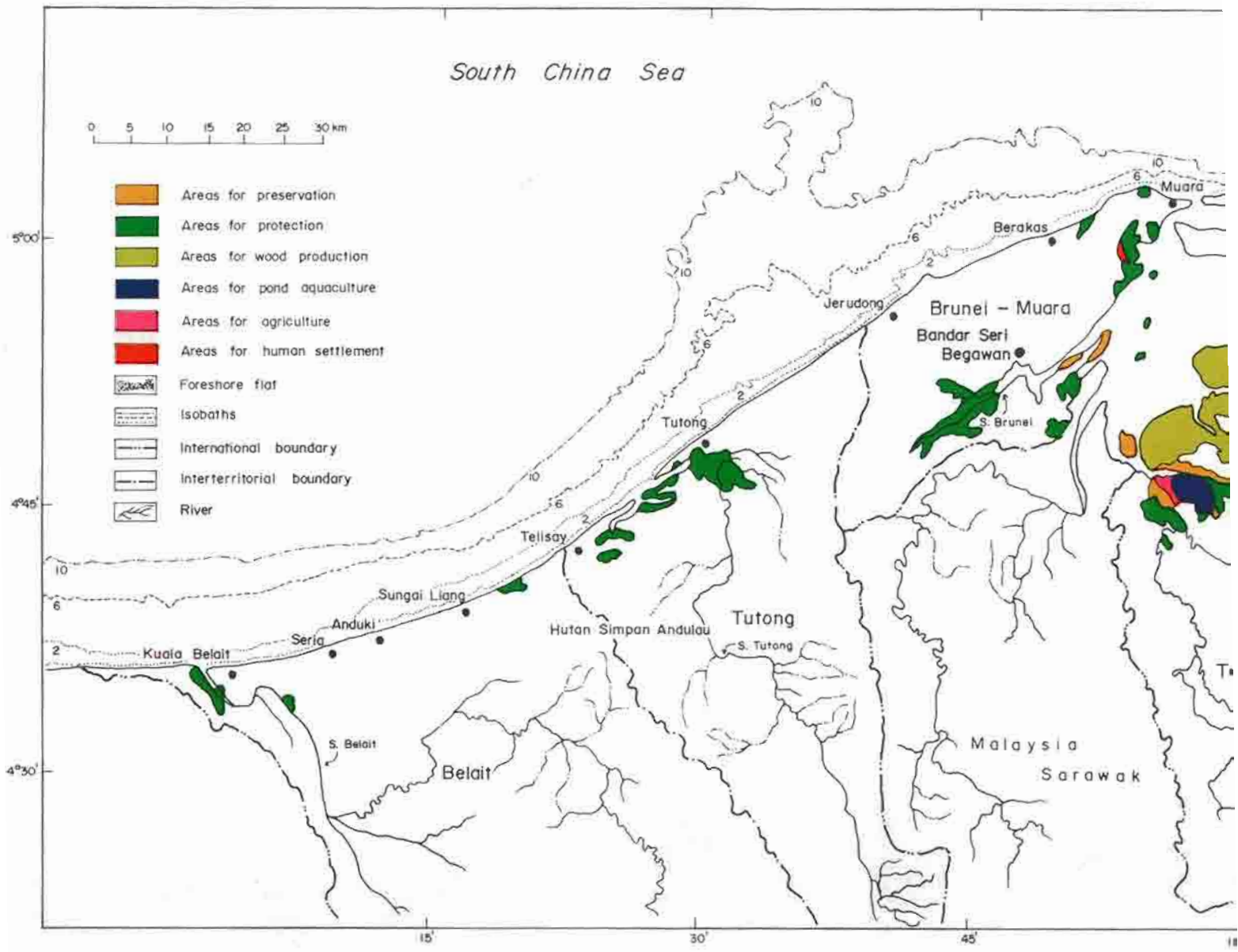


Fig. 9.4. Conceptual management strategy for the mangroves of Brunei Darussalam.

3. Mangrove and fisheries linkage. Qualitative and quantitative studies on mangrove-dependent fisheries are needed to quantify the contribution of mangroves towards inshore fisheries. This information would help policymakers to decide on the extent of mangroves which could make way for development. Studies on the structure and dynamics of the mangrove ecosystem and the determination of stand volume are also required.

4. Socioeconomic valuation. An analysis of the nature of the dependency of coastal populations on natural resources is useful in the development of management strategies, such as in designating areas for conservation. Traditional utilization compatible with sustainable yield could be allowed to continue. What is needed, though, is a comprehensive survey of the natural resources, in particular, mangroves and coral reefs, to determine their extent and condition and the pressures exerted by traditional and other uses.

5. Artificial reefs and resource enhancement. The use of artificial structures to enhance fish life has a potential. More studies could be made to quantify the fish populations attracted to oil-related structures and tire reefs. To encourage the development of reef-related organisms, other sites have to be studied to determine suitability. The use of other materials and designs may turn out to be a worthwhile investment because of their resource enhancement capabilities. This would help overcome the limitation of reef areas within the territorial waters. Using artificial reefs is part of the five-year development plan of DOF. Hence, efforts should be intensified to include economic valuation of such FADs.

6. Water quality. A water quality study would help establish baseline data useful for future comparisons as well as formulate a management scheme for water quality.

7. Aquaculture. The present studies suggest that further investigations especially of the economic viability of some aquaculture systems would be useful. The setting up of fully operational demonstration-scale units would be useful for sea bass cage culture and hatchery, shrimp farming and freshwater carp/tilapia farming.

8. Development of institutional framework. An analysis of the jurisdiction and enforcement ability of the various institutions concerned with the coastal zone is required to arrive at a model framework containing legislative and administrative capabilities to deal adequately with coastal zone management.

Appendix 1
Definition of Terms

Mangrove. The word *mangrove* covers two different concepts. In the first concept, it denotes species of plants (some 20 to 40) which belong to several unrelated families but possessing similar physiological characters and structural adaptations with similar habitat preferences:

Acanthus ebracteatus, A. ilicifolius (Acanthaceae)
Aegiceras corniculatum (Myrsinaceae)
Avicennia alba, A. marina, A. officinalis (Verbenaceae)
Bruguiera cylindrica, B. gymnorrhiza, B. parviflora, B. sexangula (Rhizophoraceae)
Ceriops decandra, C. tagal (Rhizophoraceae)
Excoecaria agallocha (Euphorbiaceae)
Lumnitzera littoralis, L. racemosa (Combretaceae)
Nypa fruticans (Palmae)
Osbornia octodonta (Myrtaceae)
Rhizophora apiculata, R. mucronata (Rhizophoraceae)
Scyphiphora hydrophyllacea (Rubiaceae)
Sonneratia alba, S. caseolaris, S. ovata (Sonneratiaceae)
Xylocarpus granatum, X. moluccensis (Meliaceae)

In the second concept, *mangrove* denotes a complex of plant communities found as a belt of varying width along the tropical shores of sheltered creeks, lagoons, deltas and islands below the high tide mark. These edaphic communities are the result of the constantly changing conditions brought about by river deposits; formation of sand bars; lagoons; temporary swamps caused by alterations of river channels, lake borders and drainage patterns; tidal movements of salty water or brackishwater in estuaries as well as for considerable distances upstream; and even the effects of wave action along seacoasts on the deposition of silt, mud or sand. Although mangrove species may extend beyond the level of the highest tides, Schimper (1903) defined *mangrove* and *tidal forests* (which he regarded as synonymous) to include the whole formation below the high water mark.

Mangrove area. This includes mangroves (see above) plus water courses, etc.

Mangrove plants. These include species of plants associated with and more or less exclusive to the mangrove habitat. Nonexclusive species are those which may be important in the mangrove habitat but which are not restricted to it.

Mangrove resources. These refer to components of the mangrove ecosystem that are exploited in a wide variety and are used with different intensities because of socioeconomic demands. The components include the biological (plants and animals) and the physical (area of coastal land in which the biological components live) elements. Saenger et al. (1983) defined the mangrove resources of a region as consisting of the following:

Appendix 2
Methodologies and Approaches for the Development of a Special Area Management Plan

Introduction

Decisions on the use of Brunei Darussalam's mangrove ecosystems in the future should be based on adequate knowledge of the resource so that unanticipated and irrevocable loss of invaluable mangrove resource could be avoided.

The first step for proper management is the development of a national mangrove management plan (NMMP). The plan--its framework and detailed preparation should be developed by an expert multidisciplinary group.

Simultaneous with the development of the NMMP is the establishment of the mangrove data base. Linkages to maintain information flow between the two are essential to ensure incorporation of the latest findings into the NMMP (Fig. 3.1). The NMMP should consist of assessment and management of the mangrove resource.

Steps for the Development of the NMMP

1. Assessment of the mangrove resource
   a. The basic status of the resource is determined.
   b. Three aspects of assessment are involved:
      i) Resource inventory and delineation
         a) Maps and inventories of Brunei Darussalam's mangroves should be made,including the flora and fauna of the mangrove ecosystem and the geographic distribution and extents of these.
         b) The methodologies for data acquisition may include air photography, satellite remote sensing techniques, ground truthing and reduction of published and unpublished data.
         c) The mangrove areas should be mapped together with related seagrass beds, coral reefs and delta systems and even associated watershed because management activities have trans-system effects.
      ii) Resource utilization
         a) Present and potential utilization patterns should be qualified so that needs could be met on a sustainable yield basis. This qualification involves a broadly based assessment of the role of mangroves in Brunei Darussalam.
         Site-specific details should include: (1) direct products; (2) indirect products

able or conversion activities that lead to the destruction of the resource.

b) Formulating the strategies

(1) For effective management, strategies should be formulated to cover ecological, social, economic, legislative and administrative aspects.

(2) Ecological strategies should include: (a) establishment of criteria to be satisfied before the resource may be allocated for nonsustainable or conversion uses; (b) delineation of areas necessary for sustainable uses; and (c) development of criteria for selecting necessary areas for preservation.

(3) Social and economic strategies should include requirements for benefit-cost analysis of proposed new uses of conversions.

(4) Legislative strategies should consider the adequacy of existing legislation to implement the: (a) ecological strategies; (b) design of resource regulation covering those activities; and (c) effective implementation of any bilateral or multilateral agreements between Brunei Darussalam and its immediate neighbors (Sarawak, Sabah).

(5) Administrative and fiscal strategies should be concerned with the grass roots implementation, enforcement, quality control and monitoring of the other strategies. The needs for training programs and experiment stations should also be assessed.

c) Reviewing strategies

(1) If they are to meet the changing needs of the people or the changing conditions of the resource, the strategies to be implemented should remain flexible within the broad limits of the overall management objectives. Flexibility is best achieved through periodic reviews of the strategies.

(2) Reviews should take the form of: (a) an evaluation of the performance of the strategies; and (b) identification of research needs that may have arisen during the review period; and (c) any necessary modification of the strategies.

(3) The opportunity for interested parties to provide input to the review process would be beneficial.

b. Implementation of the NMMP

i) This should be the responsibility of the Negara Brunei Darussalam government.

ii) This will occur only if the plan is accepted or supported by the public; the political representatives at all levels of the government; and the professionals planning or managing the coastal resources.

iii) An educational program should precede the presentation of the NMMP for legislative action or interagency adoption as policy.

iv) During the implementation period of the plan, there should be a continuing program of public education about mangroves, their uses and services and how to maintain them.

Justification: These areas harbor many species of animals, some of which are very unique (e.g., proboscis monkey, crab-eating monkeys, silver leaf monkey, flying foxes, birds, etc.) that need to be protected to prevent their loss.

Constraint: Knowledge on the biology and ecology of these unique species, which is an important input to the formulation of proper wildlife management, is nonexistent.

Solution: Research on the biology and ecology of the species should be made.

Zone 2: Areas for protection

Areas: Mangrove strips lining embankments of major rivers and associated estuarine systems (including mudflats), e.g., S. Belait, S. Tutong, S. Liang, S. Brunei, S. Temburong and mangrove areas near productive fry and fishing grounds such as Brunei Bay should be protected.

Justification: These areas are needed for maintenance of full potential of Brunei Darussalam fisheries resources; protection of land resources against wave erosion; and controlling sedimentation. They are also needed as buffer zones and natural landscapes.

Constraints: The relationship between the mangrove areas and their associated natural fisheries in fishing grounds is not known.

Solution: Research to determine the ecological and economic relationships of mangrove forest and natural fisheries should be undertaken.

Zone 3: Areas for wood production

Areas: The present use of the Selirong Forest Reserve and the Labu Forest Reserve is for wood production, provided it is done on a sustainable yield basis. After intensive surveys, other areas may also be used for the same purpose.

Justification: These mangrove areas contain large concentrations of pure or almost pure *bakau* forest (mainly *R. apiculata*). This species is preferred for charcoal, firewood and pole production because of its very high calorific content (4,000 to 4,300 cal/kg) and very durable quality. The high concentration of this resource makes its managed exploitation economical.

Constraint: No data on the stand volume of the resource, which are highly essential as basis for silvicultural management, are available.

Solution: An intensive and detailed forest inventory survey should be made to determine the volume of the resource to serve as basis for estimating its economic potential and for management planning.

Zone 4: Areas for agriculture

Area: A mangrove area west of Lumapas, which is being eyed for pond aquaculture, has been tagged as a possible site for mechanized rice culture.

Justification: The mangrove cover in the area consists of a mixture of *bakau minyak*, *nipah* and *nipah-dungun* subtypes. Except for the small area of *bakau minyak* which ecological status is unknown, these subtypes are, at present, without significant economic value to the population.

Constraint: The environmental impact of converting a mangrove area into such elimination uses as agriculture is not known.

Appendix 4
Artisanal Fishing Gears Used in Brunei Darussalam

Ancau (ring net). This gear is used for catching sardines and sergestid shrimps and is operated during calm seasons in the bay and coastal areas. The operators first look for schools of fish and then lay out the net around the school. When this is done, the rings under the net are pulled together to trap the fish; and the net is pulled into the boat.

Andang jarang (gill net - larger mesh size). The gear is made from monofilament or nylon (PA) with mesh size ranging from 51 to 76 mm. The gear is fitted with floats and sinkers to stay at the bottom of the riverbed or sea bottom around the coastal areas. The soaking time is from six to eight hours. The catches are usually pony fish, hard tail scads, croakers, etc.

Andang ketam (gill net for crabs). There is no special gear for catching crabs. The nets usually used are made from old *rantau*, *andang jarang* or *andang karan*. These are modified with floats and sinkers. These gears are set in the evenings and picked up the next morning.

Bintur (crab lift net). This is a shallow and baited lift net, 457 mm x 457 mm in size for catching river crabs. It is made up of a wide-meshed (about 51 to 76 mm) polyethylene net mounted on weighted bamboo crosspieces. The baits used are usually brackishwater catfish, rays or sharks.

Bubu (pot/trap). This gear is usually made of chicken wire mesh and set up near coral reefs in the open sea. The usual size for pots is 1.8 m x .9 m x .9 m; and it has a mouth to trap entering fish. Fishermen visit their pots once a week. The catch is usually composed of snappers, groupers, etc.

Other versions of pots used in the rivers or streams are usually made of woven bamboo with the mouth facing the oncoming flow of water. The mouth is made in such a way that after entering the pot, the fish cannot escape.

Kabat (tidal weir). This gear is used at the mudflats around the mangrove fringe areas. It is made of polyethylene nets of 25.4 mm mesh size and set up like a letter "C" around a mangrove fringe area during high tide. The gear is used to be made of woven bamboo. The catches, consisting of both shrimp and fish, are picked up on the mudflat during low tide.

Lingkong (purse seine). This gear is for catching pelagic fish like species of jacks and sardines in the offshore areas using on board vessel with power blocks. The purse seine (about 18 m LOA) has a small wooden boat (skiff) to hold one end of the net, while the main vessel goes around the fish which congregate around the FAD fixed a few days earlier. The rings under the net are pulled together to trap the fish and then lifted onto the main vessel. The skiff is also used to congregate all the fish grouped around a number of FADs into one FAD. The nets are usually made of polyethylene of 25.4 mm mesh size and of about 600 m in length.

Lintau (small corral). The structure is just like a *kilong* but is smaller and usually set up near the beaches of mangrove fringe areas, as opposed to *kilong* which are set up in the deeper waters of the bay and not at the beaches (mudflats).

speed on the best compromise. The catches are multispecies demersal fish like snappers, groupers, pony fish, jacks, sharks, rays, etc. The gear is usually towed for about 1 to 1 1/2 hours.

Rambat (cast nest). This is usually used in the rivers of Brunei Estuary and is operated all year round. The materials for this cast net are either monofilament or nylon with mesh size of 25.4 to 12.7 mm for small fish or shrimp. Bigger nets with mesh size of 63.5 to 76.2 mm are used for *kitang (Scatophagus argus)*. The length of the nets is around 2.4 to 6 m and even up to 7.2 m. Cast net of over 7.2 m length is called *rambang.*

Rantau (drift gill net). This gear is only used offshore at night and drifted for 3 to 4 hours. The net is made of nylon of 51 to 102 mm mesh size, 3.6 to 10.8 m deep and 300 m in length. One end of the net is tied to the boat to serve as a sea anchor since the gear has no sinkers. On the other end of the net, a kerosene lamp is fixed to warn unwary passersby.

Rawai (long line). This gear is used both in rivers and in sea. It consists of a main line, branch lines (snoods), hooks, sinkers and floats. The usual number of snoods used by the local fishermen is 99, of about .9 m in length and 1.5 to 1.8 m apart. Sardines are usually used as baits. It takes about 1 hour soaking time before the gear is pulled into the boat. Catches are usually sharks, snappers, groupers, rays, etc.

Selambau (lift net). This gear is usually set up near the coastal areas of the bay. The net is usually made of nylon of about 12.7 mm mesh size. *Selambau* operation needs only at least three fishermen: two to pull the ropes on each side and one to collect the catch, which is mostly mullets.

Tabih. This gear is used to trap fish in small rivers by blocking the river mouth completely with polyethylene net of about 25.4 to 31.75 mm mesh size; 1.8 to 3 m in length; and 6' in height. *Tabih* is used to be made of woven bamboo. The catches are picked up during low tide.

Tugu (intertidal funnel-shaped or funnel net). The fishermen have to set up a "home" for *tugu* first. The home is made of mangrove poles and fixed into the water so that it can stand strong water currents during low tide. *Tugu* is set up in the water using two stakes with one on each side of the "mouth," a few hours before the strong current of the low tide. The gear is predominantly used for catching small shrimp. However, small fish such as grey mullet, pony fish and others are also caught. Small fish are caught because of the net's mesh size, about 25.4 to 31.75 m at the cod-end, and 44.45 mm at the mouth.

Family	Scientific name	Local (Brunei) name
	Hilsa spp.	*Kirang-kirang*
	Sardinella gibbosa	*Aur-aur bulat*
	S. fimbriata	*Tamban*
	Sardinella spp.	*Tamban/aur-aur*
Cynoglossidae	*Cynoglossus* sp.	*Pila-pila lidah*
Dasyatidae	Unidentified sp.	*Pari*
Diodontidae	*Cyclichthys* sp.	*Buntal-berduri*
Drepanidae	*Drepane punctata*	*Saphee*
Echeneidae	*Echeneis naucrates*	*Gami*
Engraulidae	*Stolephorus bataviensis*	*Pusu*
	S. heterolobus	*Pusu*
	S. indicus	*Pusu*
	Thryssa sp.	*Pusu*
Ephippidae	*Ephippus orbis*	*Kakas*
Fistularidae	*Fistularia* sp.	*Kurik buaya*
Formionidae	*Formio niger*	*Duai hitam*
Gerreidae	*Gerres filamentosus*	*Kapas-kapas*
	G. abbreviatus	*Bangsa*
	Pentaprion longimanus	*Kapas-kapas terbang sisek*
Harpadontidae	*Harpadon nehereus*	*Lumi-lumi*
Holocentridae	*Adioryx* sp.	*Semperiding takat*
Labridae	Unidentified sp.	*Tadongan*
Lactariidae	*Lactarius lactarius*	*Kelapa-kelapa*
Lagocephalidae	*Lagocephalus* sp.	*Buntal bilis*
Leiognathidae	*Gazza minuta*	*Bilis pilajau*
	Leiognathus bindus	*Bilis*
	Leiognathus sp.	*Pulut-pulut*
	L. daura	*Bilis*
	L. equulus	*Pulut-pulut*
	L. fasciatus	*Bilis*
	L. leucisus	*Bilis*
	L. smithursti	*Bilis*
	L. splendens	*Bilis*
	Secutor insidiator	*Bilis*
Lethrinidae	*Lethrinus lentjan*	*Anduping*
	L. miniatus	*Lausu*
Lobotidae	*Lobotus* sp.	*Pelayak*
Loligoidae	*Loligo* sp.	*Sotong*
Lutjanidae	*Caesio* spp.	*Sulit*
	Lutjanus spp.	*Sulit/Langisi/ ketambak/barahan*
	L. johnii	*Barah-barahan*
	L. malabaricus	*Merah*
	L. russelli	*Ketambak pagar*
	L. sanguineus	*Mambangan*

Family	Scientific name	Local (Brunei) name
	Priacanthus sp.	*Semperiding*
	Priacanthus tayenus	*Semperiding*
Psettodidae	*Psettodes erumei*	*Pila-pila duai*
Rachycentridae	*Rachycentron canadus*	*Banglos*
Scaridae	*Scarus* sp.	*Bayan*
Scatophagidae	*Scatophagus argus*	*Kitang*
Sciaenidae	*Johnieops* spp.	*Gelama*
	Johnius dussumieri	*Gelama*
	Johnius sp.	*Gelama/terusan*
	Unidentified sp.	*Jarang gigi*
Scombridae	*Rastrelliger brachysoma*	*Rumahan bini*
	R. kanagurta	*Rumahan laki*
	Scomberomorus commersoni	*Tenggiri batang*
	S. guttatus	*Lamading lulok*
	Euthynnus affinis	*Tongkol/bakulan/ songkok-songkok*
Scorpionidae	*Pterois* sp.	*Lapu manok*
Scyllaridae	*Thenus orientalis*	*Satak kukoran*
Sepioidae	Unidentified sp.	*Kelabutan*
Sergestidae	*Acetes* sp.	*Bubok*
Serranidae	*Cephalopholis* sp.	*Kerapu*
	Epinephelus fasciatus	*Kerapu merah*
	Epinephelus sp.	*Kerapu*
	E. tauvina	*Kerapu laki*
	Plectopomus leopardus	*Pangantaran*
Siganidae	*Siganus canaliculatus*	*Belais lamun*
	S. virgatus	*Belais kepayang*
	S. javus	*Belais*
Sillaginidae	*Sillago maculata*	*Usus pasir*
	S. sihama	*Usus kuning*
Siluridae	Unidentified spp.	*Jahan, utok, manyong*
Soleidae	*Zebrias zebra*	*Pila-pila*
	Solea sp.	*Pila-pila*
Sparidae	*Argyrops spinifer*	*Awat-awat*
Sphyraenidae	*Sphyraena barracuda*	*Lingkoh*
	Sphyraena sp.	*Alu-alu*
Stromateidae	*Cubiceps pauciradiatus*	*Duai*
	Pampus argentus	*Duai puteh*
	Psenes cyanophrys	*Duai*
Sygnathidae	*Hippocampus* sp.	*Punggok*
Synodontidae	*Saurida* sp.	*Pengual-badok*
	S. tumbil	*Pengual-badok*
Tetraodontidae	*Tetrodon* sp.	*Piasau-piasau*

Appendix 6
Choice of Site for Aquaculture Systems

I. Hatchery	Serasa	Total	S. Tutong (Seri Kenangan)	Total	Telamba	Total
A. Water characteristics during dry season						
1. Salinity	5		10		10	
2. Sudden changes in salinity	10		10		5	
3. Turbidity (needs filtration)	5	20	5	25	5	20
B. Water characteristics during wet season						
4. Salinity	5		10		5	
5. Sudden changes in salinity	10		10		5	
6. Turbidity (needs filtration)	5	20	5	25	5	15
C. Present pollution levels						
7. Oil and petroleum	0		10		10	
8. Agricultural chemicals	10		5		5	
9. Eutrophication (domestic wastes, sewage)	5	15	10	25	10	25
D. Future pollution levels (> 10 years)						
10. Oil and petroleum	0		5		5	
11. Agricultural chemicals/ sawmills	10		0		0	
12. Eutrophication (domestic wastes, sewage)	5	15	5	10	5	10
E. Amenities and accessibility						
13. Distance (to port and airport)	10		10		5	
14. Municipal power source	10		10		10	
15. Municipal water source	10	30	10	30	10	25
F. Institutional and legal framework						
16. Availability of land for acquisition	10		5		5	
17. Administrative infrastructure	10		10		5	
18. Pull factor for workers	10	30	5	20	5	15
G. Others						
19. Availability of land for future expansion	5		5		5	
20. Near intensive grow-out facilities	10		10		10	
21. Near semi-intensive grow-out facilities	10	25	5	20	5	20
Total	155		155		130	
Rank	1		1		3	

III. Semi-intensive shrimp farm	Kg. Seri-Bangun	Total	B. Marang Tg. Lumut	Total	S. Tembur S. Labu Jtn	Total	S. Pa
A. Water characteristics during dry season							
1. Salinity	10		10		10		
2. Sudden changes in salinity	5		10		5		
3. Turbidity (needs filtration)	5	20	5	25	5	20	
B. Water characteristics during wet season							
4. Salinity	5		10		5		
5. Sudden changes in salinity	5		10		5		
6. Turbidity (needs filtration)	0	10	5	25	0	10	
C. Present pollution levels							
7. Oil and petroleum	10		0		10		
8. Agricultural chemicals	10		10		10		
9. Eutrophication (domestic wastes)	10	30	5	15	10	30	
D. Future pollution levels (> 10 years)							
10. Oil and petroleum	0		0		10		
11. Agricultural chemicals	5		10		5		
12. Eutrophication (domestic wastes)	10	15	0	10	10	25	
E. Amenities and accessibility							
13. Distance (to port and airport)	10		10		5		
14. Municipal power source	10		10		0		
15. Municipal water source	10	30	10	30	0	5	
F. Soil characteristics for earthen ponds							
16. Suitable pH	5		5		5		
17. Suitably clayey	10		10		10		
18. Elevation (drainage and cost)	10	25	5	20	5	20	
G. Institutional and legal framework							
19. Availability of land for acquisition	5		0		10		
20. Administrative infrastructure and support	10		10		0		
21. Pull factor for workers	8	23	10	20	0	10	
H. Others							
22. Availability of land for for future expansion	0		0		10		
23. Near intensive grow-out facilities	10		10		0		
24. Near hatchery	10	20	10	20	0	10	
25. Bonus points for special factors (easy accessibility by sea)			10		5		
Total	173		175		135		
Rank	2		1		3		

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