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Fishery, systematics and stock dynamics of billfishes landed along the Indian coast

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Abstract

Sailfishes, marlins, spearfishes and swordfishes commonly referred to as billfishes are highly migratory species, with a worldwide distribution in tropical and subtropical oceans. The landings of billfishes along the Indian coast registered an increasing trend with an estimated landing of 14,759 t in 2019. Kerala (41%) contributed the maximum followed by Tamil Nadu (28%), Andhra Pradesh (18%), Gujarat (8%) and Maharashtra (2%) to the total billfish landings during the last decade. Mechanised gillnetter cum hook and line was the major gear landing billfishes. The major species landed during 2012-2019 were *Istiophorus platypterus* (52.2%), *Istiompax indica* (21.1%), *Makaira nigricans* (7.3%), *Xiphias gladius* (17.2%) and *Kajikia audax* (2.3%). Four of these species could be easily distinguished by COI barcodes but, the striped marlin, *K. audax* showed high sequence similarity with *K. albida* and cannot be distinguished by barcodes alone. Control region (889 bp) provided a better phylogenetic signal, consistent with that of the whole mitochondrial genome topology. The stock status plots of billfishes depicted that, all the species were in the developing and exploited phase. Growth, mortality and exploitation rates estimated for four billfishes indicated that the present fishing rates and biomass levels are at safe levels and there is considerable scope for enhancing their fishery.

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Introduction

Billfishes are large predatory fishes distributed worldwide in all oceans except in the Arctic and the Southern Ocean. Collette *et al.* (2006) recognised one extant species *Xiphias gladius* in the family Xiphidae and nine extant species under five genera, in the family *Istiophoridae* including *Istiophorus* (*I. platypterus*); two species under *Kajikia* (*K. audax* and *K. albida*), four species in *Tetrapturus* (*T. angustirostris, T. belone, T. georgii* and *T. pfluegeri*); one species in *Makaira* (*M. nigricans*) and one under the genus *Istiompax* (*I. indica*). The ITIS (2008) also followed Collette *et al.* (2006) classification and placed Istiophoridae together with *Xiphiidae* under the suborder *Xiphioidei*. The Indian subcontinent with a vast coastline of 8118 km and 2.02 million sq. km Exclusive Economic Zone (EEZ) plays an important role in securing the livelihood of the coastal people. The catch of billfishes in the Indian Ocean region reportedly tripled from 14,568 t in 1983 to 52,221 t in 1995 while annual average catch during 2002-2006 was reported to be only 24,000 t (Campbell and Tuck, 1998; Ganga *et al.,* 2008). Reports on the fishery and abundance studies of billfish from the Indian waters are limited to studies conducted by the Fishery Survey of India from their exploratory surveys (Somvanshi *et al.,* 1998; Ramalingam and Kar, 2011; Varghese *et al.,* 2005; 2013a, b; 2014; Ramachandran and Ramalingam, 2019; Gulati *et al.,* 2020; Ramachandran *et al.,* 2020; Siva *et al.*, 2021) and a few reports from the commercial longline fisheries (Silas and Rajgopal, 1962; Balan, 1981; Sudarsan *et al.,* 1988; John *et al.,* 1995; Bhargava *et al.,* 2005; Prabhakar Raj *et al.,* 2005; Ganga *et al.,* 2008; Surya *et al.,* 2021). A considerable number of studies on the biology, abundance, habitat preference and stock assessment of billfishes are available from other regions specifically from the Pacific, Atlantic and Indian oceans (Chiang *et al.,* 2004; Hoolihan, 2004; Kitchell *et al.,* 2006; Nelson and Fitchett, 2006; Hoolihan and Luo, 2007; Hinton and Maunder, 2010; Kopf *et al.,* 2010; Davies *et al.,* 2013; Pons *et al.,* 2017)

The billfishes (sailfishes, marlins, spearfishes and swordfishes) are highly migratory fishes capable of traveling long distances and considered as transoceanic species. Mark-recapture studies have revealed the inter-oceanic movement of these fishes (Orbesen *et al.,* 2008). Five Regional Fisheries Management Organisations (RFMOs), namely, International Commission for the Conservation of Atlantic tunas (ICCAT), Indian Ocean Tuna Commission (IOTC), Inter-American Tropical Tuna Commission (IATTC) and Western and Central Pacific Fisheries Commission (WCPFC) and the International Scientific Committee for Tuna and Tuna-like fishes in the North Pacific Ocean (ISC) are taking lead in coordinating research and assessment of tunas, sharks and billfishes in the various oceans and deriving management measures for the sustainability of the apex predators (Punt *et al.,* 2015). Facts on the life history parameters such as age, growth, and other population parameters in the comparative studies are essential in understanding fisheries sustainability and improving the stock assessments (Pardo *et al.,* 2013). In most countries, billfishes are typically not the primary targets of large-scale fisheries which have led to the lack of data on targeted monitoring efforts. The billfish fisheries are complex, multigear, and multinational and the assessments are therefore based on the working parties rather than the conventional assessments (Punt *et al.,* 2015). So the assessment and management of billfishes are debatably more perplexing than any other fisheries and hence, there is a need to conduct the assessment of billfishes to derive population parameters that can be used to provide estimates of their stock status. Advanced methodologies used in combination with age-structured stock assessments are dependent on the accuracy of the estimated age and growth parameters (Francis, 2016). There is an absence of reliable population parameters of billfishes from the Indian coast due to the lack of primary focus on the data collection of bycatch species, considering billfish as bycatch from fleets targeting tunas.

The present study provides details on the catch and species composition of billfishes landed along the Indian coast with a special emphasis on the phylogeny and estimation of stock parameters of the major species landed.

Materials and methods

Data on billfish landings were collected from the entire coastline of the Indian subcontinent (Fig. 1). The stock status of various billfishes was studied using the Stock Status Plots (SSP) (Kleisner 2013). For the SSPs, only those species or groups off the Indian coast were used for which the first and the last reported landings are at least 10 years apart and that there are at least five years of consecutive landings, for which the accumulated landings is at least 1000 t (Kleisner and Pauly, 2011). To determine their stock status in the given year, the species were classified, into one of these phases: (i) developing, (ii) fully exploited, (iii) overexploited, (iv) collapsed and (v) rebuilding using the criteria given in Table 1 (Froese and Kesner-Reyes, 2002; Froese *et al.,* 2012; Kleisner *et al.,* 2013). The monthly gear-wise data on the landing of billfishes (Species-level) from the maritime states from 2009-2019, available in Fishery Resource Assessment, Economics and Extension Division, ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI), Kochi was used for estimation of SSP.

Billfish tissue samples were collected during 2015-2019 and preserved in absolute ethanol and stored in 5 ml tissue storage vials for DNA barcoding. Total genomic DNA (gDNA) was isolated from the fin tissue

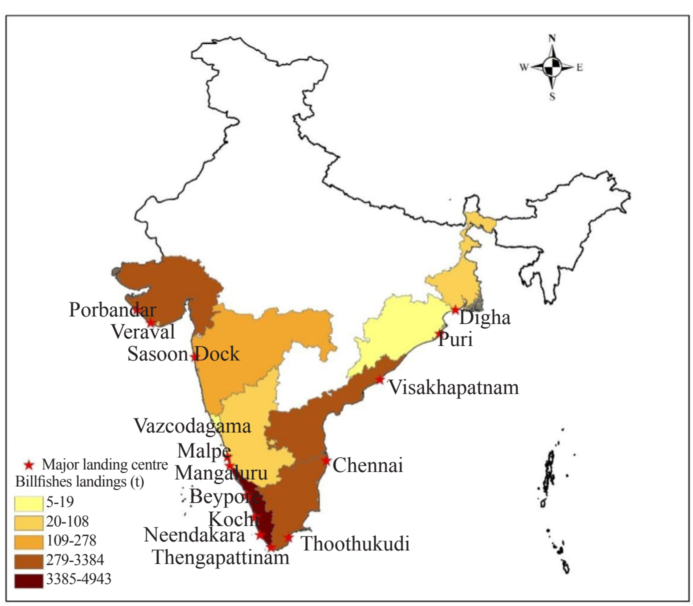

Fig.1. Map highlighting the main landing centres of India where billfish samples were collected for the study

Table 1. Criteria used to assign the exploitation stages based on landed catches (C) relative to the maximum landed catch recorded in the time series (C_{max}) (based on Kleisner *et al.*, 2013)

Status of fishery	Criterion applied
Developing	The year before Year of C_{max} and C/ C_{max}< 0.5
Fully exploited	Year before / After Year of $C_{max}$and C/C_{max}> 0.5
Overexploited	Year after Year of C_{max} and C/ C_{max}0.1- 0.5
Collapsed	Year after Year of C_{max} and C/ C_{max}< 0.1
Rebuilding	Years between collapsed and first subsequent fully exploited
Final year rules	
Developing	If C_{max} occurs in the final year, increase C_{max} by 50% and set its year of occurrence as a final year plus one

sample following the QiagenDNeasy Blood and Tissue Kit protocol. The mitochondrial COI gene was amplified using the universal primer set FishF2 (TCG ACT AAT CAT AAA GAT ATC GGC AC) / FishR2 (ACT TCA GGG TGA CCG AAG AAT CAG AA) (Ward et al., 2005). PCR reactions were carried out in MiniAmpPlus Thermal cycler (Thermo Fisher Scientific). Amplification of D-loop was achieved using the primer pair Marinefish-Dloop-Thr-F (AGCACCGGTCTTGTAAACCG)/ Marine-Dloop-Phe-R (GGGCTCATCTTAACATCTTCA) (Cheng *et al.,* 2012). PCR reactions were carried out in BIORAD T100 TM thermal cycler (Biorad, USA). The bidirectionally sequenced regions were checked in the ABI sequence scanner for quality and the raw sequences were manually edited and aligned in MEGA X (Kumar *et al.,* 2018) to generate 628 bp COI sequences and 838 bp CR sequences.

Length frequency data of billfish species was collected monthly from landing centres along the Indian coast (Fig. 1) from January 2015 to December 2019. Total landing of the species on the day of observation was noted. The daily landing and monthly landing for various resource groups were estimated based on the Stratified Multistage Random Sampling as detailed by Srinath *et al.* (2005). The mean size of the four billfishes landed during the period of study was estimated from the Lower jaw fork length (LJFL). The optimum length of four species was calculated using the equation, $\log_{Lopt} = 1.053 * \log Lm - 0.0565$, where Lm is the Length at first maturity. L_{m50} was calculated only for blue marlin females and for the remaining three species L_{m50} was taken from the literature (Varghese *et al.,* 2013, Bruno *et al.,* 2009, Cheng *et al.,* 2018 Cheng *et al.,* 2019). The length-weight relationship was assessed using the standard equation given by Le Cren (1951). The length-frequency data were grouped into 5 cm class intervals and raised for the day and subsequently for the month using the method of Sekharan (1962). The ELEFAN I (Electronic Length Frequency Analysis) module of FiSAT software (Gayanilo and Pauly, 1997) was used to estimate the von Bertalanffy growth parameters; asymptotic length (L_∞) and the growth coefficient (K). The pattern of growth of the majority of billfish species can be expressed using the von Bertalanffy growth equation given as $Lt = L_\infty (1-e^{-K(t-t0)})$. Age at zero length ($t_0$) was calculated using Pauly's empirical equation (Pauly, 1979): $\log(-t_0) = -0.392 - 0.275 \log L_\infty - 1.038 K$, where t_0 = Age at zero length, L_∞ = Asymptotic length and K = Growth coefficient. Natural mortality (M) was calculated following Pauly's empirical formula (Pauly, 1980), by taking the mean sea surface temperature as 27°C; $\ln(M) = -0.0152 - 0.279 \ln(L_\infty) + 0.6543 \ln(K) + 0.463 \ln(T)$, where L_∞ and K are the von Bertalanffy parameters and T = Sea surface temperature in degree celcius. The FiSAT software was used for the calculation of total mortality (Z) from a length-converted catch curve method based on Pauly (1983). Fishing mortalities per length class were obtained using the length-structured Virtual Population Analysis (VPA) of FiSAT. The exploitation rate (E) and exploitation ratio (U) were estimated from the equations; $E = F/Z$ and $U = F/Z \times (1 - e^{-Z})$ respectively. The recruitment pattern of the stock was analysed using Length frequency data in the FiSAT programme by giving the growth parameters L_∞ and K. The Thompson and Bell (1934) model was used to predict the yield and biomass at different levels of fishing effort.

Results and discussion

Billfishes are apex predators of the pelagic food chain, contributing substantially to the total pelagic fish landings of India. In India, billfishes are landed as bycatch of longline, troll and oceanic drift gillnet fishery which generally target oceanic tunas. The most common billfishes that landed along the Indian coast are *I. platypterus* (Indo-Pacific Sailfish), *X. gladius* (Swordfish), *I. indica* (Black marlin), *M. nigricans* (Blue marlin) and *K. audax* (Striped marlin). Rare landings of *T. angustirostis* were also reported. The landings of billfishes along the Indian coast have registered an increasing trend (Fig. 2) since the 1990s and the estimated landing during 2019 was 14,759 t. Kerala (41%), followed by Tamil Nadu (28%), Andhra Pradesh (18%), Gujarat (8%) and Maharashtra (2%) were the leading states contributing to billfish landings in the country. Mechanised gillnetter cum hooks and lines contributed more to the billfish landings as compared to the landing by other mechanised crafts and outboard-fitted crafts mainly operating handlines and gillnets. The major species that landed along the Indian coast during 2012-2019 were *I. platypterus* (52.2%), *I. indica* (21.1%), *M. nigricans* (7.3%), *X. gladius* (1.7.2%) and *K. audax* (2.3%). The landings of the billfishes along the Indian coast have shown an increasing trend since the 1990s and the estimated annual average landing during 2000-2007 was 4,317 t. Peak landings of billfishes along the east and west coast were during July-September and October-March, respectively. *I. platypterus* has earlier also been reported to be the most dominant billfish species landed in India (Ganga *et al.,* 2008). Silas and Rajagopal (1962) reported peak landing from July to September as well as November to February, and Siraimeetan (1985) reported it to be during June to October along the Tamil Nadu coast. In the present study, it was observed that the billfish landings had a more extended period along the Tamil Nadu coast indicating a possible extension of fishing grounds.

Phylogenetics of billfishes exploited from Indian waters

The COI-based phylogeny showed two major clades, one of which contained all the Indian ocean representatives and identified as

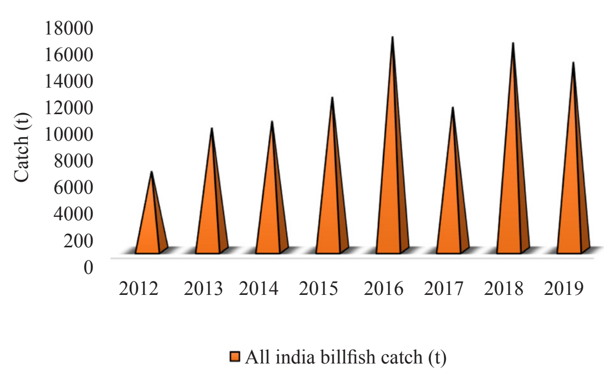

Fig. 2. Landings of billfishes (t) along the Indian coast (2012-2019)

K. audax, I. indica, M. nigricans and *I. platypterus* from Istiophoridae, while the other clade had *X. gladius* (family Xiphidae) (Fig. 3). *K. audax* and *I. indica* formed strongly supported clades with a genetic distance of 2.1% between them, whereas *M. nigricans* clustered into another clade out to the former. *I. platypterus* formed a separate group. The K2P genetic distance between all species (%) is given in Table 2.

The substantial morphological similarity of billfishes demanded exact resolution of species and hence DNA barcoding, a technique that creates a signature sequence of 650 base-pair fragments of the mitochondrial cytochrome c oxidase subunit 1 gene (COI; Hebert *et al.*, 2003a, b), that can be compared against a database of sequences from reference specimens for species identification (Hanner *et al.*, 2011), was adopted here. All the five species of billfishes available in Indian waters showed near or higher values of the 2% divergence threshold adopted for species delimitation (*e.g.*, Hubert *et al.*, 2008) and were identifiable by barcodes, whereas global results suggested that only 50% of billfishes are readily distinguishable by standard COI barcodes and the rest falls into complexes. Though, COI is the standard marker of choice in a variety of organisms, the marker alone does not provide conclusive evidence of species delineation in relatively young or recently diverged species (Hickerson *et al.*, 2006) due to the insufficient time for the accumulation of mutations. *K. audax* and *K. albida* were found to be in one complex in this study, similar to previous reports (Graves, 1998; Collette *et al.*, 2006; Shivji *et al.*, 2006), primarily due to their recent divergence.

In the mtDNA-CR based phylogeny, there were two distinct well-supported sub-clades in major clades I and II (Fig 4a). *I. indica* formed a separate group from *K. audax* in Clade II while *M. nigricans* and *I. platypterus* formed clade I. *X. gladius* remained an outgroup to

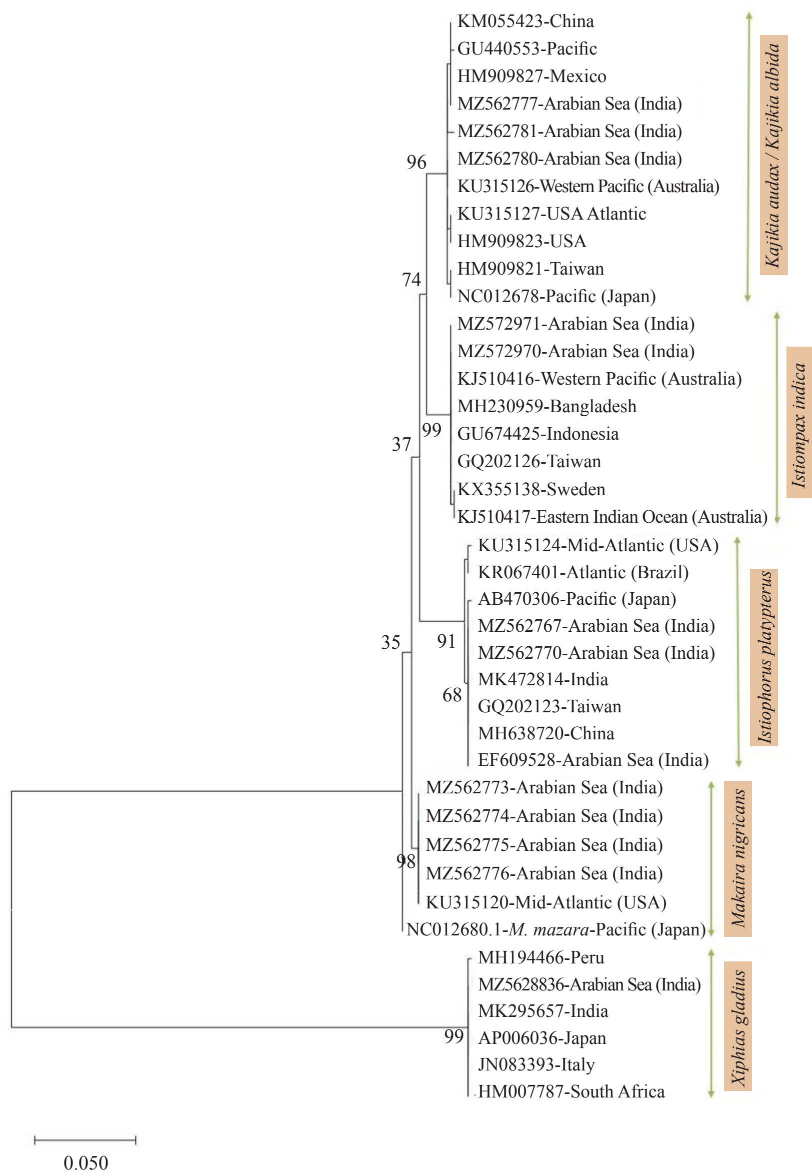

Fig. 3. Maximum Likelihood tree of billfishes of Indian waters (highlighted in red) based on partial COI sequences (628 bp) using the best fitting HKY+G model. The tree with the highest log likelihood is presented. Bootstrap support values are indicated in nodes.

Table 2. Net evolutionary divergence (K2P distance in %) between species included in this study based on COI region

Species	*I. platypterus*	*I. indica*	*K. audax/K. albida*	*M. nigricans*	*X. gladius*
I. platypterus	--------				
I. indica	3.2	--------			
K. audax/K. albida	3.4	2.1	--------		
M. nigricans	2.6	2.0	1.9	--------	
X. gladius	19.6	19.8	19.8	19.7	--------

Istiophorids in both COI and CR based phylogenetic trees. The tree topology followed a pattern of gene trees constructed using complete mitochondrial data (Fig. 4b; Williams *et al.,* 2017). The mitochondrial Control region, also called as the displacement-loop region is the most variable segment in the mtDNA that has been extensively used in population structure analysis (*e.g.,* Chen *et al.,* 2016). This region, in combination with other genes, was used for phylogenetic reconstruction in billfishes (*e.g.,* Collette *et al.,* 2006) and other groups of fishes (*e.g.,* Jin-Liang *et al.,* 2006). Universal primers (Cheng *et al.,* 2012) and extensive data availability in NCBI for this variable region in Istiphorids make it an attractive marker. It gives a strong phylogenetic signal next only to ND4 and Cytb (Williams *et al.,* 2017), amplification of which requires specially designed primers. The control region provided a result concordant with previous results using the complete mitochondrial genomes (Williams *et al.,* 2017). The preliminary results indicating genetically distinct populations in *M. nigricans* and *K. audax* went in line with the studies indicating the same from various oceans (Chen *et al.,* 2016; Mamoozadeh *et al.,* 2018) and showed the efficiency of CR in phylogenetic tree construction in billfishes.

The extant families in billfishes, Istiophoridae and Xiphiidae comprise five genera *Kajikia, Makaira, Tetrapturus, Istiompax* and *Istiophorus* in the former and the monotypic *Xiphias* in the latter. Though, Nakamura`s (1985) taxonomic classification built on morphological characters and recognised 11 species contained in three genera, molecular revision based on three mtDNA regions and a single copy nuclear marker (Collette *et al.,* 2006) increased the number of genera to five and reduced species to nine, merging the putative Atlantic and Indo-Pacific species of both blue marlin (*M. nigricans* and *M. mazara*) and sailfish (*I. platypterus* and *I. albicans*) into single, circumtropical species. As suggested by Graves and McDowell (2015), further research is required to address the unresolved placement of specific genera and improve the genetic resolution among a few closely related species within Istiophoridae.

Mean size

The minimum length, maximum length and mean size of all four billfishes studied is given in Table 3. The mean size for *I. platypterus*, *M. nigricans* and *I. indica* was much higher than the estimated L_{m50} thus allowing the fishes to breed at least once during their lifetime and indicating that the present level of exploitation is sustainable. The mean size estimated for swordfish in the present study was 132.5 cm which is a little lower than the L_{m50} (164.03 cm) of the species and immature fishes were exploited to a certain extent.

Length-weight relationship

The L-W relationship estimated for the four major billfishes (Fig. 5) are:

I. platypterus: W= 0.03990L2.57

M. nigricans: W= 0.04372L2.73

I. indica: W= 0.06882L2.65 and

X. gladius: W= 0.00537L3.14

The estimated 'b' values indicated a negative allometric growth (b<3) for all the billfishes except *X. gladius* where b = 3.14. The values estimated in the present study showed a deviation from the earlier (Table 4). These differences could mainly be due to the different basic length/weight measures used. Various length measurements of Total length (TL), Eye fork length (EFL), Lower jaw total length (LJTL), Maxillar fork length (MFL) and Lower jaw fork length were used for the estimation. However, when the LJFL was used, the 'b' values were comparable for all the species except *M. nigricans* which in most other studies recorded a value much higher than 3. This could again be attributed to the difference in the measurement of body weight as during the present study, the total weight including the weight of viscera, gills and fins was used.

Stock Status Plot

The stock status assessment of commercially exploited billfishes from the Indian waters was expressed as SSP (Fig. 6). During the assessment years (2009-19) all the species were in the developing and exploited phase. The SSP indicates that the billfish resources in most of the years were in the developing status and the level of exploitation at the optimum level in most of the species owing to its non-targeted fishery along the Indian coast.

Growth and mortality parameters of major billfish species

The population parameters of billfishes were estimated and presented in Table 5. The L_∞ estimated for *I. platypterus* by Ganga *et al.* (2012) was 262 cm LJFL from Indian waters, which is very less compared to the present study (L_∞= 310 cm) indicating an increase in the value of asymptotic length (L_∞). Since, there are some studies related to billfish stock parameters estimation from Indian waters, a comparison table depicting the growth and mortality parameters of billfishes from different regions is given in Table 6.

Biological Reference Points (BRP)

The BRP's of the four billfishes estimated are provided in Table 7 and the Thompson and Bell plots depicting the maximum biomass, virgin biomass, maximum sustainable yield (MSY) and maximum economic yield (MEY) in Fig. 7 (a, b, c and d). The assessment of *I. platypterus* predicted that at the present level of fishing (F-factor=1) the present yield is around 9,594 t; which is 1,112 t less than the estimated MSY (10,707 t) and the biomass reduced to around 57% (40,236 t) of its virgin biomass (93,394 t). In *M. nigricans*, at F=1, the catch was 37,77 t; which is 137 t less than MSY (3,914 t) and the biomass reduced to 30% (20,237 t) of its virgin biomass (28,925 t). At F=1, in *I. indica,* the catch was 3,797 t which is 138 t less than

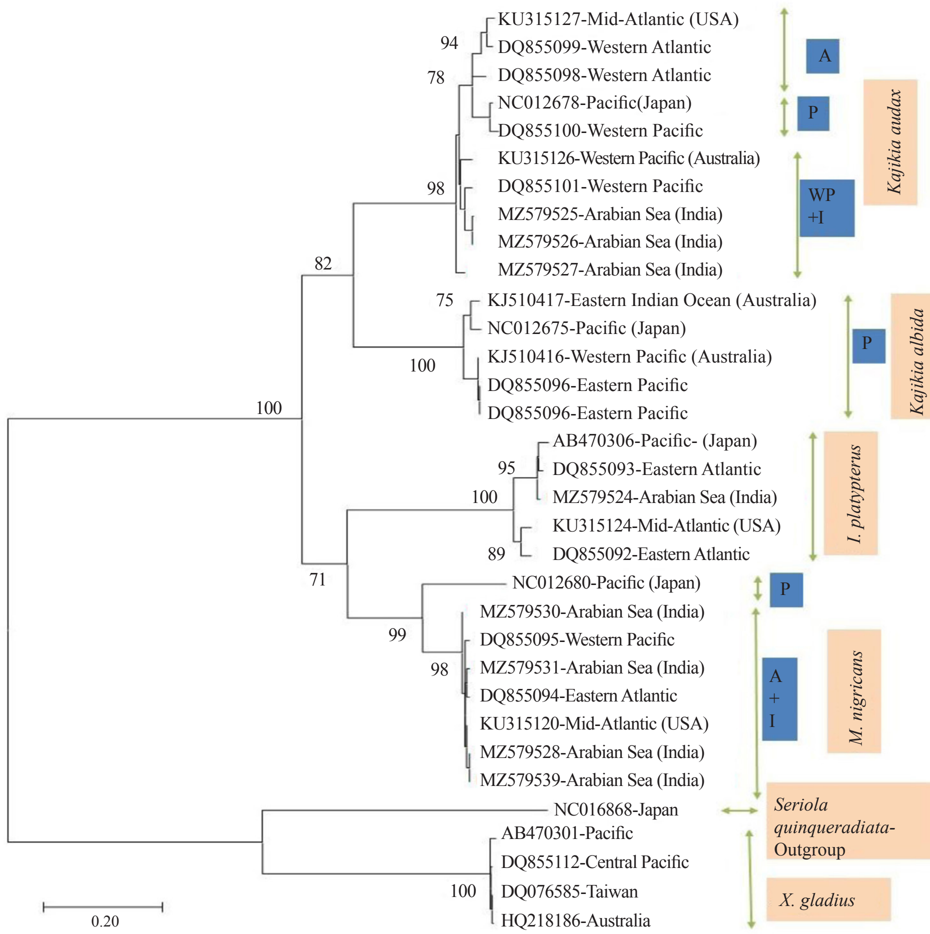

Fig. 4a. Maximum Likelihood tree based on partial CR sequences using the best fitting HKY+G model

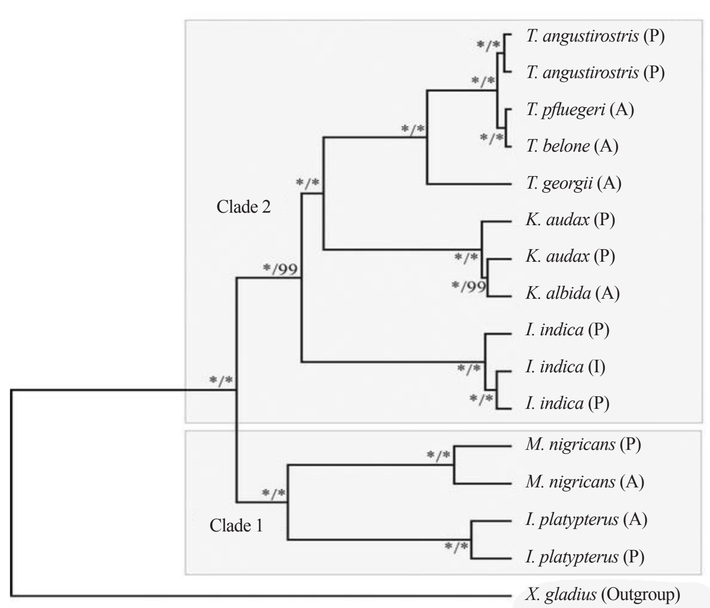

Fig. 4b. Comparison of the whole mitogenome consensus phylogenetic tree (Williams et al., 2017). P = Pacific Ocean, A = Atlantic Ocean and I = Indian Ocean

Table 3. Length range of four billfishes during the study period

Species/Growth and mortality parameters	*I. platypterus*	*M. nigricans*	*I. indica*	*X. gladius*
Sample size (n)	3120	2296	1583	3942
Maximum length (LJFL) (cm)	284.3	299.1	302.2	239.4
Minimum length (cm)	96.2	120.1	126.2	66.9
Mean size (cm)	178.8	219	225.7	146.9
Optimum length (L_{opt})	199.6	220.2	220.3	176.6

Table 4. Lenghth-weight relationship estimated for billfishes from different regions

I. platypterus		Pooled				
		Y	*X*	*a*	*b*	R^2
Ganga *et al.* (2012)	The south-eastern Arabian Sea	Weight	Length	0.024	2.65	0.85
Kar *et al.* (2015)	Andaman and Nicobar islands	Weight	Length	0.00004	2.52	0.92
Haputhantri and Perera (2014)	Sri Lanka	Body weight	Lower jaw-Total length	0.01	2.7	0.80
Uchiyama and Kazama (2003)	The north-western Hawaiian islands			6.90E-05	2.52	
Velayudham *et al.* (2012)	Parangipettai, South-east coast of India	Body weight	Total length	-5.4431	3.007	0.98
Varghese *et al.* (2013a)	Indian waters	Body weight	Total length	0.065	2.381	0.72
Present study	Indian waters	Body weight	LJFL	0.0399	2.57	0.92
M. nigricans						
Amorim *et al.* (1998)	Brazilian coast	Weight	Lower jaw Fork length	7×10^{-7}	3.47	0.93
Amorim and Arfelli (2001)	Southern Brazil	Total weight	Lower jaw Fork length	9.07×10^{-7}	3.44	0.94
Prager *et al.* (1995)	North Atlantic	Body weight	Lower jaw to Fork length	1.955×10^{-6}	3.3663	0.94
Shimose (2009)	Western Pacific	Body weight without bill, Caudal fin, Gills and Viscera	Lower jaw to Fork length	4.70×10^{-6}	3.11	0.93
Uchiyama and Kazama (2003)	Central North Pacific	Body weight	Eye to Fork length	1.3×10^{-6}	3.43	0.98
Wang *et al.* (2006)	Taiwan waters	Body weight	Lower jaw to Fork length	2.79×10^{-6}	3.24	-
Present study	Indian waters	Body weight	LJFL	0.0437	2.73	0.94
I. indica						
Wang *et al.* (2006)	Taiwan waters	Body weight	Total weight	0.000006	3.07	
Present study	Indian waters	Body weight	LJFL	0.0688	2.65	0.89
X. gladius						
Bishnupada and Ansy (2014)	Indian waters	Total weight	Lower jaw Fork length	0.00000182	3.307	0.84
Tsimenides and Tserpes (1989)	Aegean Sea	Total weight	Lower Jaw Fork length	-11.8	3.06	0.94
Megalofonou *et al.* (1995)	Mediterranean Sea	Total weight	Lower Jaw Fork length	1.6911 x 10	4.37	0.86
Akyol and Ceyhan (2011)	Turkish waters	Total weight	Lower jaw Fork length	0.0022	3	0.97
Letourneur (1998)	Reunion Island, Indian Ocean	Total weight	Maxillar Fork length	1.753×10^{-6}	3.3433	0.95
Akyol *et al.* (2005)	Aegean Sea	Total weight	Lower jaw Fork length	7×10^{-8}	3.532	0.94
Varghese *et al.* (2013b)	Indian waters	Total weight	Lower jaw Fork length	0.0000018	3.307	0.84
Present study	Indian waters	Body weight	LJFL	0.0053	3.14	0.96

Table 5. Population parameters estimated for billfishes from Indian waters

Species	L_∞ (L Infinity)	K (Growth constant)	M (Natural mortality)	F (Fishing mortality)	Z (Total mortality)	E (F/Z) (Exploitation rate)	U (Exploitation ratio)	Largest length (cm)
I. platypterus	310	0.19	0.32	0.69	1.01	0.68	0.43	284.3
M. nigricans	324.57	0.2	0.313	0.71	1.02	0.69	0.44	299.1
I. indica	332.7	0.21	0.33	0.54	0.86	0.62	0.39	302.2
X. gladius	272	0.26	0.393	0.80	1.19	0.67	0.42	239.4

the MSY (3,936 t) and the biomass was reduced to 33% (29,950 t) of its virgin biomass (44,410 t). In *X. gladius*, at the present level of fishing (F=1), the catch was 3,479 t which is only 12 t less than that of MSY and the biomass was reduced to 13% of its virgin biomass (7,139 t). The MEY, was obtained at an F-factor of 2.2, 1.4, 1.2 and 1.0 for *I. platypterus, M. nigricans, I. indica* and *X. gladius,* respectively. As per the MSY estimates, the fishing effort needs to be doubled or tripled for reaching the sustainable yield, in the case of *I. platypterus, M. nigricans* and *I. indica* while in *X. gladius* the F_{msy} was obtained at an F-factor of 1.2. As all the billfish species exploited in the count are not a targeted fishery and as no selective gears are used for this species, if the effort is increased beyond the present limit, there is a chance of negatively

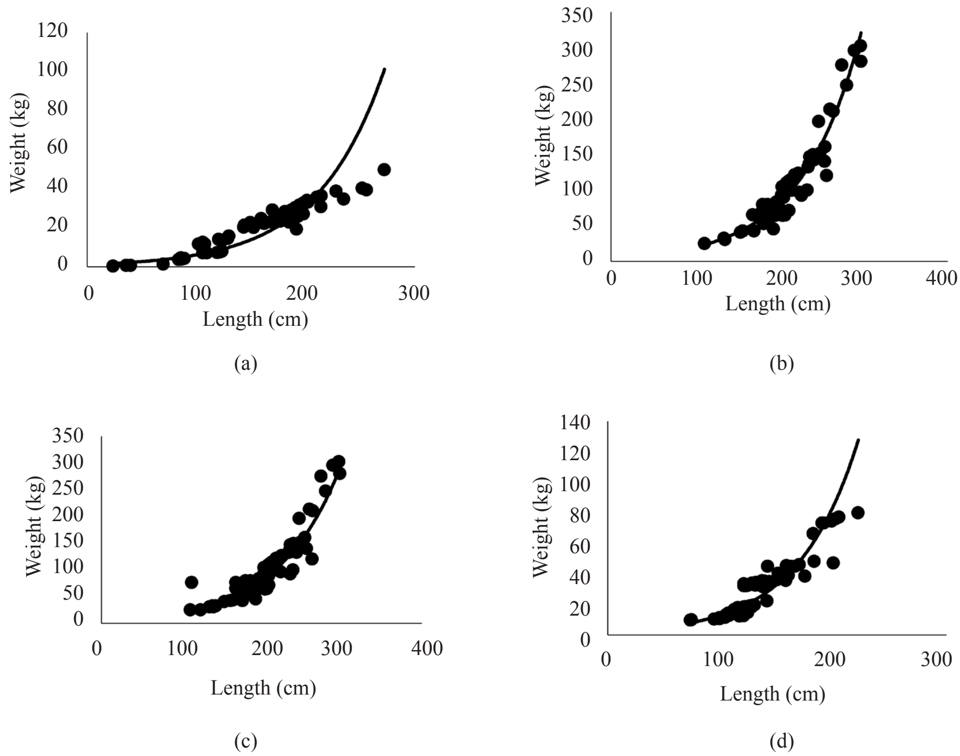

Fig. 5. Length-weight relationship of billfishes estimated from the Indian coast. (a) *I. platypterus,* (b) *M. nigricans,* (c) *I. indica* and (d) *X. gladius*

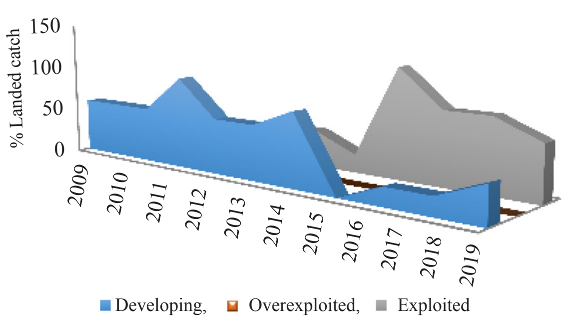

Fig. 6. Stock Status Plots of billfishes exploited along the Indian coast during 2009-2019

impacting other fish stocks. In the case of *I. platypterus, M. nigricans* and *I. indica,* continuing the present status of exploitation would help in maintaining the fishery and would hold good for devising management plans in the present multispecies, multigear fishing scenario, while in *X. gladius* continuing the mean size of the catch landed and the prevailing level of exploitation will affect its sustainability in the future, if not managed well.

The demand for billfish is increasing day by day and hence managing the resources with proper management plans is of paramount importance to avoid overexploitation in the future. The hitches to estimate growth and mortality parameters and the projected yield curves from the size frequency data using different models are always inclined to less optimism due to the sensitivity of the model to some structural assumptions (Kleiber *et al.,* 2003). The fishing effort, biomass and yield thus estimated at the present level of fishing may be significantly less than the actual in all the billfish species. With the output of the present study, control on the fishing effort could be regulated and the minimum legal size too can be implemented to avoid growth overfishing, thus ensuring healthy fish stocks which would in turn fetch better income to fishers. According to Su *et al.* (2013), the fishing pressure on females (Blue marlins) is greater than that on males emphasising the need of considering sex-specific parameters related to population processes such as natural and fishing mortality during the stock assessment. Wang *et al.* (2006) also reported the sexual dimorphic character of billfishes as being large-sized females in sailfish, swordfish, black marlin and blue marlin. Shimose *et al*. (2012) also specified the sexual difference in the migration of blue marlins related to spawning and feeding regions. Billfishes are extremely resilient to fishing pressure with their high fecundity, migratory behaviour and suppleness to inhabit tropical and subtropical oceans. The present fishing rates and biomass levels are safe for all the species of billfishes exploited from the Indian waters and offered considerable scope for enhancing their fishery. Regular monitoring and harvest regulations would add significantly to the health of the stocks. Certifying the immature fishes to survive, grow and spawn at least once in their lifetime would go a long way to sustainably managing these top predators

Table 6. Population parameters estimated for billfishes from different regions for comparison

Authors	Methods	Region	L_∞ (cm)	t_0	K (year^{-1})
I. platypterus					
Cerdenares-Ladron *et al.* (2011)	von Bertalanffy	Gulf of Tehuantepec, Mexico	180.6	-0.24	0.36
Cerdenares-Ladron *et al.* (2011)	Schnute	Gulf of Tehuantepec, Mexico	190.6	0.49	0.21
Alvarado-Castillo and Fe´lix-Uraga (1998)	von Bertalanffy	Gulf of California	207.3	-0.0016	0.75
Freire *et al.* (1998)	von Bertalanffy	Brazil	179.6	-1.24	0.14
Ganga *et al.* (2012)	ELEFAN program	South-eastern Arabian Sea	262		
Present study	ELEFAN program	Indian waters	310	-0.0519	0.19
M. nigricans			L_∞, cm (M, F)	t_0 (M,F)	K, year-1 (M, F)
Sun *et al.* (2013)	North-west Pacific Ocean	von Bertalanffy growth function	(239.4), (313.8)	(-2.366), (-0.161)	(0.145), (0.102)
Skillman and Yong (1974)	Central North Pacific Ocean	von Bertalanffy Growth function, Modal analysis of length frequency and non-linear least squares non-linear least squares	(371.1), (659.1)	(0.106), (-0.161)	(0.285), (0.116)
Chen (2001)	Western Pacific Ocean	von Bertalanffy growth function; linear function for back-calculation	(338), (420.7)	(-10.42), (-9.92)	(0.04), (0.03)
Chen (2001)	Western Pacific Ocean	von Bertalanffy growth function; power function for back-calculation	(229.7), (283.2)	(-5.21), (-4.65)	(0.11), (0.09)
Chen (2001)	Western Pacific Ocean	Richard Growth Model Coefficients,linear function for back-calculation	(346.9), (501.8)	(-6.96), -9.11)	(0.02), (0.03)
Present study	ELEFAN program	Indian waters	324.57	-0.0511	0.2
I. indica					
Sun *et al.* (2015)	Eastern Taiwan	Standard von Bertalanffy function	(305), (396.6)	(-2.27), (-1.83)	(0.125), (0.094)
Present study	ELEFAN program	Indian waters	332.7	-0.0497	0.21
X. gladius					
Valeiras *et al.* (2008)	North Pacific	Standard von Bertalanffy growth function	(271.4), (376)	(-1.543), (-2.162)	(0.121),(0.0701)
Sun *et al.* (2002)	Taiwan	Standard von Bertalanffy growth function	(207.52), (267.44)	(−1.955), (-2.302)	(0.198), (0.13)
Cerna (2009)	South-eastern Pacific off Chile	Standard von Bertalanffy growth function	(279), (321)	(−2.65), (-2.46)	(0.158), (0.133)
Present study	ELEFAN program	Indian waters	272	-0.0466	0.26

Table 7. Biological reference points estimated for billfishes

Species	*I. platypterus*	*M. nigricans*	*I. indica*	*X. gladius*
Average landings (t) (2015-19)	7542.956	1306.528	2386.623	2400.675
MSY (t)	10706	3913.36	3935.8	3491.2
M	0.32	0.315	0.33	0.392667
Z	1.02	1.01	0.86	1.023333
E_{curr}	0.686275	0.688119	0.616141	0.616234
E_{max}	0.845	0.845	0.815667	0.798667
F_{curr}	0.7	0.695	0.53	0.630667
F_{msy}	1.96	1.529	1.48	0.76
B_{curr}	40236	28924	44410	7139
F_{curr}/F_{msy}	0.357143	0.454545	0.358108	0.829825
Spawning stock biomass (t)	22503	11062	11396	3646
Standing stock biomass (t)	40236	17198	17298	7449
Total yield (t)	9593.2	3197	3023	3492
Recruitment (Nos.)	1043282	108132	94960	229110

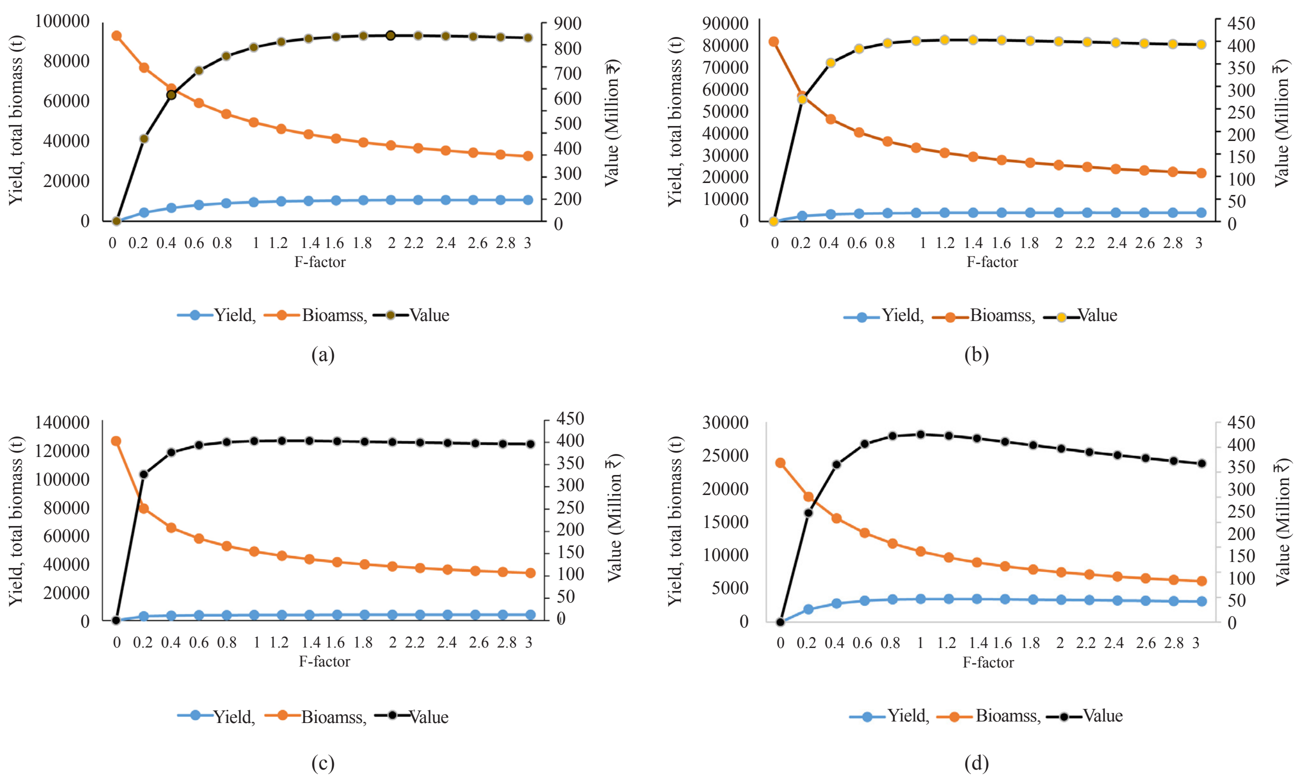

Fig. 7. Thompson and Bell estimates of billfishes from the Indian coast. (a) *I. platypterus,* (b) *M. nigricans,* (c) *I. indica* and (d) *X. gladius*

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