A Synoptic Review of the Biological & Population Dynamic Parameters on Narrow barred Spanish mackerel (*Scomberomorus commerson*) in the Persian Gulf & Oman Sea

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Abstract

Research studies on Narrow – barred Spanish mackerel has been initiated in eighties in the Indian Ocean. A synoptic review of the different research studies including size frequencies, growth and mortality parameters, biological studies, gear selectivity, environmental impacts, stock structure, stock assessment, and management advice were reviewed, discussed and reported. In 2020 ,the last stock assessment study was carried out by two data-limited methods (C-MSY and Bayesian Schaefer production model (BSM)) , in evaluating the status of Indian Ocean Spanish mackerel, both of which are based on an aggregated biomass dynamic model. The C-MSY requires only the catch series as model input and uses simulations to locate feasible historical biomass that support the catch history provided an update to the C-MSY assessment based on the nominal catch series of IOTC 1950 to 2018 and a Bayesian biomass dynamic model was also implemented to include the recently available CPUE indices of Spanish mackerel developed from the Iranian gillnet fishery carried out by the secretariat. The authors recommended that future assessments could consider more realistic population models, including age structured models that could utilize more biological and fishery data beyond simple catch series. Despite the substantial uncertainties, the stock is probably very close to being fished at MSY levels and higher catches may not be sustained.

Introduction

Tuna support some of the largest and most valuable fisheries in the world, but also provide food security for many developing and developed nations (FAO, 2018). Over half of the global tuna catch is derived from the western and central Pacific Ocean (WCPO) and the Indian Ocean, primarily comprising skipjack, yellowfin, bigeye, and albacore tunas. The populations of some of these species are approaching full utilization, particularly in the Indian Ocean (Langley ,2015). However, increasing market demands for seafood, national food security issues have led to increased targeting, or at least retention, of smaller tuna species in neritic waters, including Spanish mackerel *Scomberomorus commerson* (Lacepede, 1800). The Narrow-barred Spanish mackerel (*S. commerson*) is an epipelagic species belonging to the family Scombridae and is distributed throughout the tropical temperate Indo–Pacific, whose geographical range extends from the Western Pacific Ocean to the Western Indian Ocean. It occurs from the coasts of Japan through the Philippines and Indonesia to Papua New Guinea, and from the sub-tropical east and west coasts of Australia northwest through Malaysia and Thailand to India, Sri Lanka, and Pakistan, and finally to the Persian Gulf and the Red Sea. The species can weigh as much as 70 kg at a 240 cm fork length (FL) and live about 22 years (Grandcourt et al.,2005). The global landings of Narrow-barred Spanish mackerel have increased from 83,324 t in 1980 to >294,997 t in 2020 (FAO,2023).

Little detailed fecundity information is available for Spanish mackerel. They are open water, broadcast spawners believed to have high fecundity (Ovenden et al., 2003 in press). Each female spawns several times over the season, about 2-6 days apart, depending on the locality (Kailola et al. 1993).

Materials & methods

Size frequency data were collected from commercial catches of *S. commerson* made off the coast of the Emirate of Abu Dhabi in the Persian Gulf between October 2003 and September 2004. Fish were selected at random from landings, lengths were taken using a measuring board and recorded to the nearest cm fork length (FL). The monthly target sample size was 250 fish. Biological data were collected from specimens purchased from commercial catches between October 2003 and September 2004. Samples were obtained from 30 fish from a representative size range during the first week of each month. Reproductive studies suggest a single spawning period from April to August in the southern Persian Gulf (Grandcourt et al., 2005).

The Spanish mackerel sampling strategy is fishery dependent. Representative length, sex, and age information was collected from both the recreational and commercial fishing sectors in the four east coast regions of Queensland (Rose et al.,2006).

The size frequency data were collected by gill net commercial catches of *S.commerson* made off the coast of the Persian Gulf & Oman Sea from October 2006 to September 2007 (Kaymaram et al.,2010).

In another study, 1264 fish were collected from January 2000 to December 2001 from the southern part of the Gulf of Oman and the Arabian Sea coast of Oman. Fish were purchased regularly and directly from artisanal fishermen at several landing sites in each of six regions of Oman: Musandam, Al-Batinah, Muscat, Ash-Sharqiya, Al-Wusta and Dhofar (IOTC-2011-WPNT01-INFO9).

In the northern Persian Gulf & Oman Sea, a total of 475 specimens were collected monthly from fish-landing sites Jask, Bandar Abbas, Bandar Lengeh and Parsian from October 2008 to September 2009 (IOTC–2013–WPNT03–29 Rev_1).

Rajesh et al. (2017) collected *S. commerson* on weekly basis during January 2012 to December 2014 at Mangalore Fishing Harbor.

Fish were sampled by hook & line between April 2011 and March 2012 from shore-based locations within two management regions: southern Mozambique, in the central region to Ponta do Ouro in the south; and the South Africa/Mozambique border to Port Edward in the south (Lee & Mann ,2017). Age data were obtained from 360 of the sampled fish, consisting of 200 females, 157 males and 3 juveniles of undetermined sex (Lee & Mann,2017).

Collections of 184 specimens were undertaken for biological studies in the northern coasts of the Persian Gulf during five times between October-December 2011 and March, April and July 2012. Random samples of 30-50 fish were bought from gillnet commercial catches available at the landing sites along northern Persian Gulf (Niamaimandi et al., 2017).

A total of 4422 specimens of *S. commerson* ranging in size from 20.0 to 165.0 cm were collected randomly from all gears at Andhra Pradesh coastal waters, India for three years from January 2012 to December 2014. The specimens were measured for fork length (cm) and body weight (0.01g precision) (Mahesh et al.,2018).

The population dynamic study was conducted at four landing sites in Bone Bay waters, South Sulawesi, Indonesia from January to November 2018. The fork length was measured for 551 fish, captured by trolling lines, hand lines, surface gill nets and boat lift nets (Mallawa & Amir ,2019). Specimens of *S. commerson* were collected from June 2018 to June 2021 in the waters of central Taiwan Strait. An age–length key (ALK) for the *S. commerson* specimens was derived using the otolith direct aging data and the FLs of the 654 fish specimens (351 female specimens, 295 male specimens, and 8 juvenile specimens without sex data (Weng et al.,2021).

Another study in the southern coasts of the Oman Sea was conducted from 2000 to 2019, annual catch (tons) and effort (number of boats) data of Kingfish (Spanish mackerel) fishery was obtained from the annual 'Fisheries Statistics Book' published by the Ministry of Agriculture Fisheries and Water Resources (MAFWR) of Oman. As per the annual reports of the MAFWR, 78% of total fishing effort of Oman is directed to catch Kingfish (MAFWR, 2019; Al-Shehhi et al.,2021).

Various types of fishing gears are used for catching Kingfish, among them hand and trolling lines (HL+TL) and gillnet are the most prominent ones (MAFWR, 2019). Gear wise effort data was not available from 2000 to 2010; therefore, identifying any one specific gear as the major gear was not possible. Under such circumstances, an aggregate of all the efforts of catching Kingfish was used in the analysis. The catch per unit effort (CPUE) (Shapiro normality test: $W= 0.97$, $p = 0.83$) data were normally distributed so a generalized linear model of Gaussian family was used to assess its temporal variability. For the temporal variability of the catch and effort data generalized linear models of Poisson family were used. All the analyses were performed in R.4.0.3 (R. Core Team, 2020) considering 5% ($p < 0.05$) significance level (Al-Shehhi et al.,2021).

Length frequency

A total of 475 specimens were collected, ranging in size from 29 to 138 cm. The mean fork length of *S. commerson* was estimated 69 ±20.7 cm (±SD), with the highest frequency in 53-56 cm length range in the Persian Gulf & Oman Sea (IOTC–2013–WPNT03–29 Rev_1).

Specimens of *S. commerson* were collected from Juin 2018 to Juin 2021 in the waters of central Taiwan Strait. An age–length key (ALK) for the *S. commerson* specimens was derived using the otolith direct aging data and the FLs of the 654 fish specimens (351 female specimens, 295 male specimens, and 8 juvenile specimens without sex data). The FLs of the female and male specimens ranged from 35.0 to 159 cm and from 34.5 to 135 cm, respectively (Weng et al.,2021). The most frequently observed FLs for male (20.4%) and female (18.6%) specimens were 75 and 80 cm, respectively. The mean ages of the 351 female and 295 male specimens were 1.8 y ± 1.8 (range: 0.2–9.2 y) and 1.6 y ± 1.0 (range: 0.3–7.2 y), respectively (Weng et al.,2021).

The fork length was measured for 551 fish, captured by trolling lines, hand lines, surface gill nets and boat lift nets, in Bone Bay waters, South Sulawesi, Indonesia from January to December 2018. The results of the narrow-barred Spanish mackerel measurements showed that the minimum FL was 39.5 cm, the maximum was 149.5 cm. (Mallawa & Amir ,2019).

Gear selectivity

One of the key management issues of the *S. commerson* fishery is the selectivity characteristics of the gill nets which are the principal gear type used to target this species in the Persian Gulf & Oman Sea. This is highlighted in the assessment of Grandcourt et al. (2005) which established the mean size at first capture (29.7 cm LF) and size at which fish were fully recruited to the fishery (L100 = 62.6 cm LF) to be considerably smaller than the size at first sexual maturity for females (86.3 cm LT) and the size at which yield per recruit would be maximized (95.6 cm LF). Consequently, 94.7 % of the yield consisted of fish that were below the mean size at first sexual maturity (IOTC–2011–WPNT01–22).

The small mesh sizes of nets combined with the differential targeting of young schooling fish explains the high levels of juvenile retention throughout the region. Dudley et al. (1992) estimated the size at first capture to be between 40 and 60 cm, corresponding to an age at first capture of 4-6 months for *S. commerson* off Oman. In addition, up to 90% of the fish captured there are immature with very few reaching their third year of life (Claereboudt et al., 2004; McIlwain et al., 2005). The selectivity characteristics of the fishery for *S. commerson* off Oman are therefore remarkably similar to those in the Persian Gulf (IOTC–2013–WPNT03–27).

Feeding habits

Northern Persian Gulf

Collections of 184 specimens were undertaken during five times between October-December 2011 and March, April and July 2012. Random samples of 30-50 fish were sampled from gillnet catches available at the landing sites along northern Persian Gulf (Niamaimandi et al., 2017).
Fish were found to be the main prey item during the study period. Sardines were the most prevalent, while Indian mackerel, Ponyfish (*Leiognathus s*p.) and Halfbeak (*Hyporhamphus* sp.) were fewer essential components of the diet of *S. commerson* (Table 1).

Sardines accounted for 50- 85% of the total weight of prey items in different months, followed by Indian mackerel (*Rastrelliger kanagutra*) (10-30%), Halfbeak (*Hyporhamphus* sp.) (5-10%), Ponyfish (Leiognathus sp.) (5%), and unidentified (10-25%) in the Persian Gulf.

Although seasonal differences in diet probably reflect seasonal fluctuations in prey abundance, overall, the *S. commerson* in our study area were piscivorous, feeding largely on sardine. In comparison, Darvishi et al. (2011) reported that the stomach content of *S. commerson* in the Gulf of Oman (Hormozgan waters) consisted mainly of bony fish (91.3%). Bakhoum (2007) reported that the diet of *S. commerson* along the Mediterranean coast of Egypt included *Engraulis encrasicolus, Sardinella aurita, Sardina pilchardus* and shrimps. In Solomon Islands, Blaber et al. (1990) reported that the diet of this species mainly consists of small fishes like anchovies, clupeids and carangids.

Table 1. Percentage of composition of prey by weight found of *S commerson*, in different months in the northern Persian Gulf (2011-2012) (Niamaimandi et al., 2017)

Prey \ Months	Oct.	Dec.	Mar.	Apr.	July
Sardinella sp.	85	75	90	60	50
Hyporhamphus sp.	5	0	0	10	0
Rastrelligerkanagutra	5	0	0	10	30
Leiognathus sp.	5	0	0	0	0
Unknown item	0	25	10	20	10

Analyses of stomach contents of *S.commerson* indicated that they feed heavily on small epipelagic and carangid fishes and large schools of prey-fish are associated with large schools of narrow-barred Spanish mackerel (Kaymaram et al., 2014). Since these preys of narrow-barred Spanish mackerel feed directly on zooplankton (mainly copepods), it seems that the tunas as a top of a short food web are very efficient from the point of view of energetics (Roger, 1994).

Rajesh et al. (2017) collected *S. commerson* on weekly basis during January 2012 to December 2014 at Mangalore Fishing Harbor. Stomach of 214 narrow barred Spanish mackerel measuring from 48 to 105 cm fork length (FL) for males and 45.5 to 115 cm FL for females were analyzed to study their feeding habits. Rajesh et al. (2017) indicated that *S. commerson* is a carnivore and mainly feeds on small pelagic fishes which include *S. longiceps*, whitebaits, *R. kangurta*, *Epinephelus* spp. *Saurida* spp. and *M. cordyla*. The study has indicated seasonal variation in feeding activity. This information on feeding habits and ecological interactions of narrow barred Spanish mackerel is important particularly for the management and conservation of the fishery resources and marine ecosystem (Table 2) (Rajesh et al.,2017).

Table 2. Index of relative importance (IRI) of each food item in the diet of *S. commerson*

Index of relative importance (IRI) of each food item in the diet of *S. commerson* (Rajesh e al.,2017)

Food item	%F	%N	%W	IRI	%IRI
Semi-digested fish remains	39.60	31.95	10.76	1582.50	44.62
S. longiceps	12.00	23.61	27.07	1066.87	30.08
D. russelli	10.00	13.89	23.97	664.20	18.73
White baits	3.51	12.50	13.11	89.84	2.53
R. kanagurta	3.51	4.17	11.08	53.49	1.51
Epinephelus spp.	3.51	5.56	5.53	38.91	1.1
Saurida spp.	3.51	2.78	4.22	24.55	0.69
M. cordyla	3.51	2.78	2.23	17.58	0.5
Scombroides spp.	1.75	1.39	1.94	5.84	0.16
Shrimps	1.75	1.39	0.1	2.61	0.07

Reproduction pattern

Northern Persian Gulf & Oman Sea

The size frequency data were collected by gill net commercial catches of *S. commerson* made off the coast of the Persian Gulf & Oman Sea from October 2006 to September 2007 (Kaymaram et al.,2010). Biological data were collected during the first weeks of each month. Fish were sexed by macroscopic examination of the gonad which was dissected out and subsequently weighed to 0.1 g using an electronic balance. Spawning occurs between June and September in the northern part of the Persian Gulf & Oman Sea (Kaymaram et al., 2010) which coincides with the period which there was an increase in the gonadsomatic indices during May and June, then declines after June. Frequency of immature fish (stage 1) was shown an annual cycle with and almost complete absence during June to August. The results of maturity stages and trend of gonadsomatic indices reveal a single spawning season which peaks after June to September.

Southern Persian Gulf

Size frequency data were collected from commercial catches of *S. commerson* made off the coast of the Emirate of Abu Dhabi in the Persian Gulf between October 2003 and September 2004. Fish were selected at random from landings, lengths were taken using a measuring board and recorded to the nearest cm fork length (FL). The monthly target sample size was 250 fish. Biological data were collected from specimens purchased from commercial catches between October 2003 and September 2004. Samples were obtained from 30 fish from a representative size range during the first week of each month. Reproductive studies suggest a single spawning period from April to August in the southern Persian Gulf (Grandcourt et al., 2005). The results of Claerboudt et al. (2005) also reveal a single earlier spawning season in May and June off Oman. Spawning occurs after June-July, same as Oman Sea, In the north western part of the Persian Gulf (Kaymaram et al., 2014).

The mean size of first sexual maturity (Lm 50%) is 83.6 cm. The smallest mature and largest immature female is respectively 52 and 100 cm (Kaymaram et al., 2010). The mean sizes at first sexual maturity for males and females respectively (72.8 and 86.3 cm) (Grandcourt et al., 2005), compare to the estimated size at spawning of 75-80 cm given by Dudley et al. (1992) for males and females combined off Oman. Females are found to mature at a smaller length in the Arabian Sea than in the Gulf of Oman (Al- Oufi et al., 2004).

In total, 1264 fish were collected from January 2000 to December 2001 from the Gulf of Oman and the Arabian Sea coast of Oman. Fish were purchased regularly, directly from artisanal fishermen at several landing sites in each of six regions of Oman: Musandam, Al-Batinah, Muscat, Ash-Sharqiya, Al-Wusta and Dhofar. For both sexes, the fish collected along the Arabian Sea matured approximately 10 cm smaller than that of the Gulf of Oman (; Median test, $\chi2 = 22.3$, $p < 0.0001$ and $\chi2 = 33.175$, $p < 0.021$ for males and females, respectively) (Table 3) (IOTC-2011-WPNT01-INFO9).

A transformation of size at first maturity into age using the empirical growth equations indicates that male fish matured slightly later than females (2 months approximately) but that generally, Kingfish from the Gulf of Oman matured much later (6 months) than the Arabian Sea population.). sexual maturity for females in the Arabian Sea and Gulf of Oman were 70.7 and 80.7 cm respectively (Table 4) (IOTC-2011-WPNT01-INFO9).

Table 3. Length at first maturity of *S. commerson* measured for both sexes in two areas of the coast of Oman. The number of fish collected from the Arabian Sea was relatively large (n = 177), most of these fish were either small immature or large fish and did not fall in the size range used in the analysis (IOTC-2011-WPNT01-INF09).

	Gulf of Oman	Arabian Sea
Smallest mature male	58.4	65.8
Largest immature male	106.8	79.7
50% maturity length	84.6	76.1
n	244	20
Smallest mature female	57.1	61.6
Largest immature female	92.6	74.7
50% maturity length	80.7	70.7
n	301	23

Table 4. Parameters of the Von Bertalanffy growth function, size and age at first maturity of *S. commerson* calculated for both sexes in two areas of the coast of Oman

Region	L_∞ (cm)	K	T_0	Maturity (cm)	Age (year)
Arabian sea-males	118.82	0.652	−0.623	76.1	0.94
Arabian sea-females	133.37	0.412	−1.119	70.7	0.71
Gulf Oman-males	131.32	0.325	−1.736	84.6	1.44
Gulf Oman-females	154.32	0.173	−2.981	80.7	1.29

Indian Waters (Andhra Pradesh)

A total of 4422 specimens of *S. commerson* ranging in size from 20.0 to 165.0 cm were collected randomly and measured for fork length (cm) and body weight (0.01g precision) (Mahesh et al.,2018). Spawning season was ascertained by estimating the proportion of gravid and ripe females (V and VI) over months. Gonadosomatic index (GSI) for females was calculated as GSI = (Weight of gonad x 100)/ Weight of fish. King seer was found to spawn round the year, as evident in the occurrence of mature females in subsequent numbers throughout the year. High proportion of mature females, ranging from 31.5 % to 49.1 %, was observed between September and March, confirming it to be the peak spawning season. Annually, maturity of females ranged between 32.8 % and 38.4 % and GSI from 0.42 to 0.46. Results obtained from GSI are in full conformity to the presence of matured females. Peak GSI values ranging from 0.53 – 0.54 was observed in December and February. In general, GSI was higher during August to February.

Fecundity, in general, increased with the length and weight of the fish. Absolute fecundity ranged from 95000 eggs to 372857 eggs, with a mean of 256187 eggs. Relative fecundity per g body weight varied from 18.18 eggs to 87.02 eggs with an average of 45.79 eggs. The mature ovaries contained both maturing and mature ova. The mature ova measured from 0.9 to 1.4 mm in diameter whereas the maturing ova measured from 0.7 to 0.9 mm. The presence of yolked ova of different sizes in mature ovary for most months of the year indicated prolonged spawning. However, the largest sizes of yolked ova were encountered mostly from December to February (Mahesh et al.,2018). *S. commerson* size at first maturity is attained at about70–80 cm FL in Madagascar, Fiji and north-eastern Australia (McPherson, 1993) but not before 90–105 cm in South Africa

(Govender, unpublished). In India, at the same latitude as Oman, *S. commerson* appears to mature around 75 cm (Devaraj, 1983).

Sex ratio

Rose et al. (2006) examined 2306 *S. commerson* specimens and discovered that small specimens (60–100 cm FL) exhibited male predominance; however, female predominance (>50%) was observed among specimens with an FL of >100 cm, and specimens with an FL of >130 cm were all female. These results indicate that fishery management strategies that reduce fishing mortality among *S. commerson* with an FL > 100 cm can help protect the spawning stock biomass of this species. For example, greater proportions of female *S. commerson* are caught by longline and trolling fishery (Govender,1995; Claerdboudt et al., 2004); hence, these methods can be temporarily prohibited during the spawning season to reduce the catch of female fish. However, the catch of *S. commerson* has substantially decreased due to high demand, unregulated fishing practices, and overexploitation. To protect the *S. commerson* resource in the Taiwan Strait, Taiwan's exploitation rate should be reduced through control measures such as reduction of the length of drift gillnets and implementation of a fishing moratorium during the spawning season.

Age structure

Southern Persian Gulf

Size and age frequency data were collected from commercial catches of *S. commerson* made off the coast of the Emirate of Abu Dhabi in the Persian Gulf between October 2003 and September 2004. Fish were selected at random from landings, lengths were taken using a measuring board and recorded to the nearest cm fork length (FL) (IOTC-2011-WPNT01-22). The monthly target sample size was 250 fish (Grandcourt et al.,2005). The age-length key is given in Table 5, the maximum absolute age estimates were 16.2 years (males) and 15.3 years (females).

One growth increment consisting of a broad opaque and narrow translucent zone was formed on an annual basis with the opaque band being deposited between May and July. The first opaque band was estimated to form at 1 year of age. There was an apparent time lag of 2 months from the start of the increase in seawater temperature and the commencement of formation of the opaque band. The formation of the translucent zone, however, coincided with the decrease in seawater temperature. Absolute age estimates ranged from 0.4 to 16.2 years (males) and 0.2 to 15.3 years (females) (Fig. 1).

Table 5. Age length key for *S. commerson* in the southern Persian Gulf.

L_F (cm)	Age class																	Total
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
45	3	2																5
50	7	5	1															13
55	6	11	1															18
60	8	8	2	1														19
65	4	22		1														27
70	2	7		2														11
75		4	11		1													16
80	6	5	10	6														27
85	1	4	13	3	1													22
90		3	4	3	1	1	1	1										14
95			1	3	1	1												6
100	1	1	2	7	5		1	2										19
105		1	3	7	4	2	2	2		1								22
110			1	2	3	1		2										9
115			1	2	1	5			1	2		1						13
120				5	2	3	5					1		2	1			19
125					1	2				1				1		1	1	7
130				2		1			1	1	1				1			7
135													2					2
140												1						1
n	38	73	50	44	20	16	9	7	2	5	1	3	2	3	2	1	1	277
Mean	63.1	66.3	82.8	97.7	103.3	114.2	110.9	102.6	123.4	118.0	132.5	124.6	134.4	121.6	123.9	126.8	124.4	
S.D.	14.2	11.6	12.7	17.1	11.9	10.5	11.8	7.6	11.9	10.0	–	13.8	2.1	3.5	7.2	–	–	

The size-at-age relationships were asymptotic in form with the majority of growth occurring during the first 6 years of life and there was a high degree of individual variability in size at age (Fig. 1). Initial growth was rapid with fish reaching more than half the asymptotic size (82.8 cm LF ±12.7 cm S.D.)

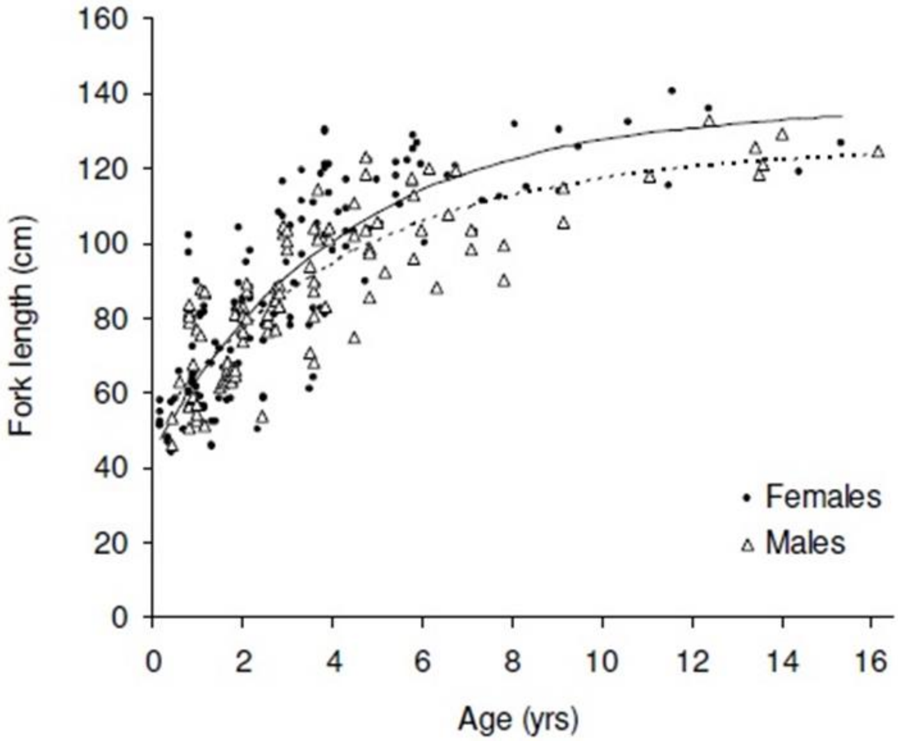

Figure 1. The Von Bertalanffy growth function fit to size at age relationships for *S.commerson* for males (n = 110) and females (n = 167).

Southern Mozambique and south Africa

Age data were obtained from 360 of the sampled fish, consisting of 200 females, 157 males and 3 juveniles of undetermined sex of the coastal waters of the southern Mozambique and south Africa. Mean age in the catch was 3.4 years for females (0.48–14.6 years) and 2.51 years for males (0.40 to 13.57 years). A clear female bias was evident in the older age classes, with only a single male older than 9 years. The numbers of males and females in the sample were similar up to age 2 years, after which greater numbers of females were captured in all the remaining age classes (Lee & Mann,2017).

Central Taiwan Strait

Specimens of *S. commerson* were collected from a Penghu fish market monthly from June 2018 to June 2021. These fish were caught using drift gillnets, trolling lines, or longlines, and juvenile fish by torchlight fishing vessels that operate in the waters of the central Taiwan Strait. The fish sampling vessels equipped with a voyage data recorder (VDR) were used to collect data regarding the location and timing of catches in the species' fishing grounds. All obtained specimens were transported to a laboratory the FL (cm) and BW (kg) were measured (n=654), and their otoliths (n= 654) were dissected for age determination. An age–length key based on the direct otolith aging and FL dataset (N = 646) was used to estimate the age composition of 3-year catches measured at landing (N = 16,133). The results verified that the *S. commerson* currently caught in the central Taiwan Strait are mainly young fish aged 1^+ to 2^+ y (Weng et al.,2021).

Torres Strait, North Queensland

New biological sampling of Torres Strait Spanish mackerel from both traditional inhabitant and non-traditional commercial fishing sectors was conducted in 2019-20 and again in 2020-21 to address a long-term critical need for updated fish age-length information. These data add to the historical fish age-length data collected 15–20 years ago during the 2000-01, 2001-02, 2002-03 and 2005-06 sampling programs (Trappett et al.,2021).

The 2020-21 pattern of Spanish mackerel age-length data shows few fish older than six years of age. Most fish were aged between 2-4 years old. Results were similar to the recent 2019-20 sampling data and were also similar to the older 2000-01, 2001-02, 2002-03 and 2005-06 sampling data.

In 2020-21, the oldest Spanish mackerel found was 12 years of age (during 2019-20 the oldest was 13). This was equal to the oldest fish measured previously being 12 years of age. Spanish mackerel were measured between 70 and 144 cm fork length (FL), with a majority between 88 and 110 cm FL (75 %).

The aged fish ranged in length between 69 cm and 144 cm FL and in age groups from 1 to 13 (Table 6, Table 7). Male fish were generally smaller and younger than the females sampled.

Table 6. Observed length and age group data summary of Torres Strait Spanish mackerel during 2020-21. Total length is provided in brackets.

Data type	Female	Male	Unknown
Min FL (TL)	81 (91)	69 (78)	70 (78)
Max FL (TL)	144 (157)	120 (131)	115 (126)
Avg FL (TL)	100 (110)	92 (102)	93 (103)
Min age	2	1	1
Max age	13	9	9
Sample size (n)	118	125	53

The age structure of Torres Strait Spanish mackerel in 2020-21 was grouped and is presented in Fig. 2. Fish ranged between 1^+ and 13^+ with the catch dominated by fish in age groups 2^+ to 4+ which comprised 79.8% of the catch. Age structures for the fishery are heavily truncated with only 2.7% of fish in age groups greater than 6^+.

Environmental impacts

Declines in population size of Spanish mackerel since around 2010 have been reported throughout Persian Gulf & Oman Sea. This is most likely driven by environmental variables as these declines are across large geographic areas, biological stocks and fisheries. Corals in the Persian Gulf exist in one of the most stressful environments with respect to high water salinity (45 ppt) and highly fluctuating sea surface temperatures (SSTs) ranging from minimum 12.8°C in winter to maximum 36.8°C in summer (Coles, 2003).

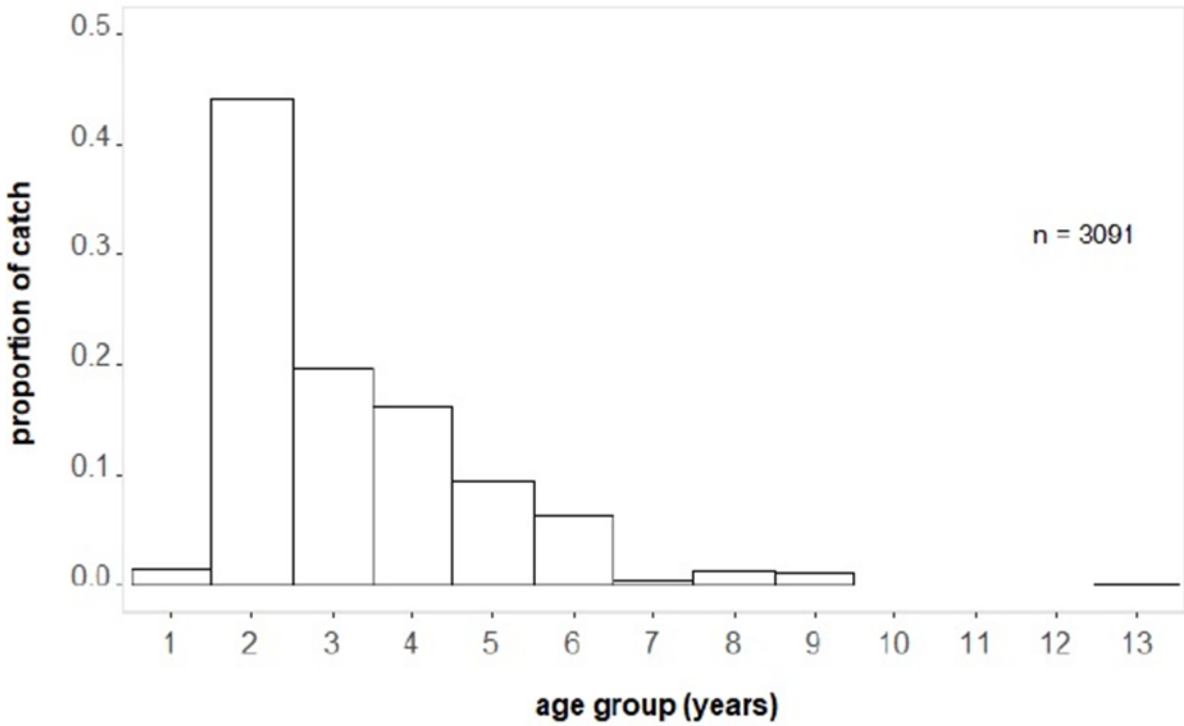

Figure 2. Age structure of the commercial Torres Strait catch in 2020-21.

Corals in this area experienced several consecutive bleaching events in quick succession starting in 2010. The impact of exceeding temperature during summer 2017 appeared afterward when two-thirds of corals were lost to mortality between April and September 2017 (Burt et al., 2019). These extreme temperature events may have influenced the Spanish mackerel populations in the area. They have most likely influenced recruitment, as temperature is an important determinant of mortality and recruitment in the early life stages of various fish species (Houde, 1987). These temperature anomalies may have also influenced spawning location and timing (Rose, 2005). This is due to water temperature linking to spawning activity and is likely to influence the seasonal development of gonads (McPherson, 2007). As periods of elevated sea surface temperatures are predicted to become more severe and frequent with climate change (Cai et al., 2014), their influence on Spanish mackerel requires further investigation and consideration in management across the region (Bessell-Browne et al.,2020).

Table 7. Measured fork length (FL) in cm at age (age group) data summary of Torres Strait Spanish mackerel during 2020-21, showing mean length and sample size for both males and females. Numbers in parenthesis are the range of lengths for each sex within each age group.

Age group	Female FL (cm) Avg (range)	Number of females	Male FL (cm) Avg (range)	Number of males	Total number
1			75 (69-80)	8	8
2	92 (81-106)	55	88 (79-98)	50	105
3	101 (88-116)	23	93 (77-102)	27	50
4	105 (94-114)	20	97 (89-103)	18	38
5	113 (102-136)	7	103 (94-110)	12	19
6	116 (105-138)	11	104 (95-108)	6	17
7			112	1	1
8	115	1	108 (107-108)	2	3
9			120	1	1
10					
11					
12					
13	144	1			1

Population dynamic parameters

Central Taiwan Strait

The growth parameters of VBGF were estimated for male, female specimens. Specifically, $L\infty$ = 144.1 cm, k = 0.39 y^{-1}, and t_0 = -0.85 y for the female specimens; $L\infty$ = 136.0 cm, k = 0.32 y^{-1}, and

t_0 = -1.49 y for the male specimens (Figs. 3 a & b). The growth-performance index (φ’) based on the abovementioned growth parameters were 9.0 and 8.7 for the female and male *S. commerson* (Table 8) (Weng et al.,2021). The estimated growth parameters (k and L∞) with a 95% confidence interval exhibited an elliptical distribution and did not overlap between sexes.

A significant difference in growth parameters was discovered between male and female specimens (Maximum likelihood-ratio test, p < 0.01). Both male and female specimens grew most quickly before the age of 1 y; however, a slight difference was observed with respect to average FL (male specimens, 69.4 cm; female specimens, 65.6 cm) at ages <1 y. At age 2 y, the growth rate of female specimens was significantly higher (t test, p < 0.001) than that of the male specimens (female specimens, 103.9 cm; male specimens, 96.2 cm). At age 3 y, the FL of the female specimens (114.5 cm) was still greater than that of the male specimens (109.6 cm). Significantly fewer male fish specimens were aged > 4 y, with only five such specimens being collected (Fig. 3b). The older group of specimens exhibited female predominance. The oldest female specimen was aged 9.2 y (159 cm), whereas the oldest male fish was aged 7.2 y (135 cm; Figs. 3a & b) (Weng et al.,2021).

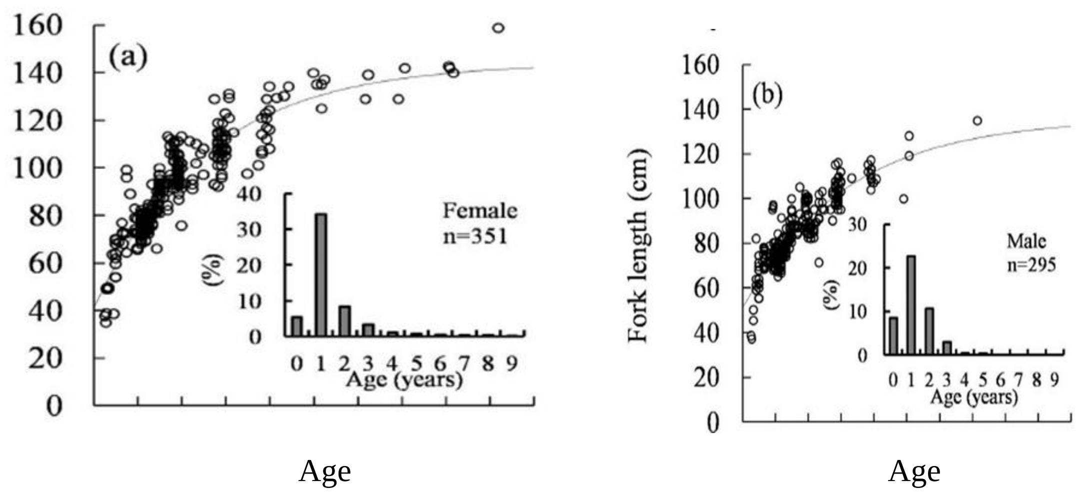

Figure 3. Von Bertalanffy growth curves fitted to *S. commerson* length at age data for (a) females, and (b) males, samples (n = 654) (Weng et al.,2021).

Table 8. Parameters of the VBGF (k and L∞), growth-performance index (φ’), and maximal age of *S. commerson* in different areas reported by different authors

VBGF Parameter		Φ′	Age (Year)	Sex	Region	Source
k	L_∞ cm (FL)					
0.39	144.1	9.0	9.2	Female	Taiwan Strait	This study
0.31	135.9	8.7	7.2	Male	Taiwan Strait	This study
0.16	130.1	7.9	6	Combined	Taiwan Strait	[26]
0.17	155.0	8.3	14	Female	North-eastern Queensland	[3]
0.25	127.0	8.3	10	Male	North-eastern Queensland	[3]
0.51	124.8	9.0	15	Female	East coast of Queensland	[25]
0.75	104.7	9.0	11	Male	East coast of Queensland	[25]
0.18	187.1	8.7	-	Combined	Indian	[19]
0.29	134.3	8.6	-	Combined	South Africa	[21]
0.28	173.6	9.0	-	Combined	Oman	[20]
0.20	151.3	8.4	20	Female	Oman	[10]
0.28	134.7	8.5	10	Male	Oman	[10]
0.31	140.4	8.7	20	Female	Sultanate of Oman	[4]
0.60	118.8	9.0	10	Male	Sultanate of Oman	[4]
0.24	136.1	8.4	15.3	Female	Southern Arabian Gulf	[24]
0.22	125.6	8.2	16.2	Male	Southern Arabian Gulf	[24]
0.31	130.5	8.6	14.6	Female	KZN and Mozambique	[23]
0.28	119.2	8.3	13.6	Male	KZN and Mozambique	[23]
0.50	148.0	9.3	-	Combined	Northern Persian Gulf	[9]
0.42	140.0	9.0	10	Combined	South of Iran	[11]

This study (Weng et al.,2021); [26, Chen ,1973]; [3, Mcpherson,1992]; [25, Ballagh et al.,2006]; [19, Devaraj,1981]; [21, Govender,1994]; [20, Al-Hosni & Siddeek.,1999]; [10, Govender et al., 2006]; [4, McIIwain et al.,2005]; [24, Grandcourt et al.,2005]; [23, Lee & Mann,2017]; [9, Niamaimandi et al.,2017]; [11, Shojaei et al.,2007].

The annual instantaneous rate of total mortality at (Z) derived from the age-base catch curve was 0.90 y^{-1}. The annual instantaneous rate of natural mortality (M) derived from the equation Pauly was estimated as 0.64 y^{-1} using the maximum age of 9.2 y. The annual instantaneous rate of fishing mortality at (F) was estimated as 0.27 y^{-1}, and the exploitation rate (E) was 0.30 (Weng et al.,2021).

Southern Persian Gulf

Size frequency data was collected from commercial catches of *S. commerson* made off the coast of the Emirate of Abu Dhabi in the Southern Persian Gulf between October 2003 and September 2004 (Grandocurt et al.,2005). Fish were selected at random from landings, lengths were taken using a measuring board and recorded to the nearest cm fork length (FL). The monthly target sample size was 250 fish. Biological data was collected from specimens purchased from commercial catches. Samples were obtained from 30 fish from a representative size range during the first week of each month. Standard length (Ls), fork length (FL) and total length (TL) were obtained using a measuring board and recorded to the nearest mm. Parameters of the Von Bertalanffy growth function for each sex and pooled size-at-age data are presented in Table 9.

Table 9. Parameters of the Von Bertalanffy growth function, coefficients of determination (r^2) and sample sizes (n) by sex for *S. commerson* (Grandocurt et al.,2005)

Parameter	All	Males	Females
k	0.21	0.22	0.24
L_∞ cm (L_F)	138.6	125.6	136.1
t_o (yrs)	-1.9	-2.3	-1.7
r^2	0.68	0.71	0.71
n	277	110	167

The results of Grandcourt et al. (2005) appear to be of the right order by comparison with a range of published estimates of Von Bertalanffy growth function parameters derived from size-at-age data (Table 10).

Table 10. Parameters of the Von Bertalanffy growth function (k and $L\infty$) for *S.commerson* derived from size-at-age data

VBGF parameter		Sex	Source
k	L_{∞} cm (L_F)		
0.24	136.1	Females	This study
0.22	125.6	Males	This study
0.21	138.6	Combined	This study
0.18	187.1	Combined	Devaraj (1981)
0.36	138.3	Combined	Dudley et al. (1992)
0.29	134.3	Combined	Govender (1994)
0.31	140.4	Females	McIlwain et al. (2005)
0.60	118.8	Males	McIlwain et al. (2005)
0.17	155.0	Females	McPherson (1992)
0.25	127.5	Males	McPherson (1992)

The total mortality rate (Z = 0.88 yr^{-1}) derived from the age-based catch curve is considerably greater than previous estimates for this species. Values of 0.61 and 0.66 yr^{-1} were obtained by Govender (1995) for *S. commerson* in South Africa. Tobin & Mapleston (2004) estimated total mortality as 0.40 and 0.35 yr^{-1} for the commercial and recreational fisheries respectively in eastern Australia, and Edwards et al. (1985) established a total mortality rate of 0.44 yr^{-1} for *S. commerson* in the Gulf of Aden. Grandcourt et al. (2005) estimated the natural mortality rate (M=0.26 yr^{-1}) which was considerably lower than the estimates of Govender (1995) which ranged from 0.45 to 0.55 yr^{-1}. Dudley et al. (1992) estimated the natural mortality rate of *S. commerson* as 0.44 yr^{-1} in the Gulf of Oman and Edwards et al. (1985) estimated a rate of 0.38 yr^{-1} for this species in the Gulf of Aden. However, these were derived from the empirical equation of Pauly (1980), which has been shown to overestimate M (Russ et al.,1998, Newman et al., 2000). Welch et al. (2002) and Hoyle (2003) used a natural mortality rate of 0.34 yr^{-1} in their assessment models for *S. commerson* in eastern Australia though this value was considered to be overestimated on the basis of total mortality rates established later on for the same stock (Tobin & Mapleston, 2004).

Stock assessment

Southern Persian Gulf, Oman Sea and Arabian Sea

Catch-effort data from 2000 to 2019 of Oman's Kingfish fishery was fit to Schaefer model (log-normal assumption) for estimating maximum sustainable yield (MSY) and biological reference points (BRPs). Carrying capacity (K), catchability coefficient (q), population growth rate (r) and MSY of Kingfish were 36,745 tons, 0.0000161, 0.382 and 3,507 tons, respectively. At present, fishing effort (ENOW) (i.e., number of boats) is 18,982, which is beyond the sustainable limit i.e. EMSY = 11,846 and if the number of boats reaches to 23,692 then Kingfish stock may collapse. All the BRPs are higher than their sustainable limits, which indicate Kingfish stock is overfished. Stock Reduction Analysis suggests that the stock was in the safe zone between 2005 and 2007, it was in the overfishing zone from 2008 to 2012 and 2013 onwards the stock is in the overfished zone. A complete ban on Kingfish fishing in Oman may allow the stock to rebuild to Biomass at Maximum Sustainable Yield in three years or limiting the annual catch at 1,500 tons/year till 2026 may yield the same result (Al- Shehhi et al.,2021)

The nominal catch time series dataset, which was available from 1950–2013 were extracted from the IOTC Secretariat database. Total catches of Spanish mackerel were decreased between 2012 and 2013 from 170 000 to 159 000 t, catches are still well above the estimated level of MSY. This is reflected in the key management reference points, which are also similar between two models (Catch-MSY method & Optimized Catch Only Method). The stock is likely to be subject to overfishing with an F_{2013}/F_{MSY} ratio of 1.23 and 1.11 for the Catch-MSY and OCOM models respectively (Martin & Shamra, 2015). These estimates also correspond well to those of the previous assessments in 2014, which were 1.08 and 1.23 (Zhou & Sharma, 2014).

Nominal catch data were extracted from the IOTC Secretariat database for the period 1950 - 2014, Results suggest that the stock is still likely to be subject to overfishing with an F_{2014}/F_{MSY} ratio of 1.07 and 1.03 for the Catch-MSY and OCOM models respectively. This ratio is slightly lower than estimated in previous years, reflecting the drop in catches reported in the last two years, suggesting that fishing mortality has declined (IOTC–2016–WPNT06–18 Rev_1).

Nominal catch data of longtail were extracted from the IOTC Secretariat database for the period 1950 – 2015. C-MSY, OCOM and stochastic SRA, provided relatively similar estimates of MSY, with mean estimates of approx. 144 000 t, 140 000 t and 130 000 t respectively, with the highest estimate produced by the C-MSY method. The estimates produced by the C-MSY and OCOM methods are also similar to previous assessment estimates. Reported catches decreased between 2012 and 2015 from 175 459 to 136 856 t, and so the current catch is below the C-MSY and OCOM estimates of MSY, but remains above the stochastic SRA estimate. Results suggest that the stock is still likely to be subject to overfishing with all models producing a F_{2015}/F_{MSY} ratio above 1.00. This ratio has been decreasing over the last few years, reflecting the recent decline in catches. Nevertheless, estimates of the B_{2015} /B_{MSY} ratio have remained similar, given that the average catches over the last 5 years (157 000 t) have been higher than all estimates of MSY. These stock status predictions across the three models suggest that the stock is considered to be 'subject to overfishing' and the C-MSY and OCOM models suggest it is also 'overfished' while the stochastic SRA suggests it is 'not overfished' (IOTC–2017–WPNT07–17 Rev_1).

Catch and effort data from the Iranian gillnet fishery in the coastal waters of Persian Gulf and Oman sea were analyzed, and applied statistical models to obtain abundance indices from nominal catch per unit effort (CPUE) for the main neritic tuna species captured in the fishery. The spatial and temporal trend of catch and effort was characterized, and standardization analysis using GLM models was conducted for Spanish mackerel using trip-level catch effort data collected from the port-sampling program from 2008 to 2017.The analyses showed that the standardized catch rates have declined for the Spanish mackerel (IOTC–2019–WPNT–17).

Time series of aggregated catch from 1950 to 2018 for the whole Indian Ocean was used to assessed the stock of neritic tuna species using optimized catch-only method. In this study, life history parameters (LHPs) are presented (Table 11) (IOTC-2020-WPNT10-16).

Table 11. Natural mortality and maximum lifespan for neritic tuna in Indian Ocean

Stock	Mean M	Median M	Sd M	T_{max}
BLT	0.797	0.649	0.453	8.4
COM	0.411	0.400	0.138	4.8
FRI	0.947	0.914	0.461	3.2
GUT	0.913	0.883	0.421	8.5
KAW	0.776	0.753	0.224	6.4
LOT	0.514	0.440	0.260	9

It is worth to point out that the r prior for Spanish mackerel may be overestimated because the Tmax = 4.8 (based on one study) may be too small. As such, it may be more appropriate to construct r prior based on M only. This leads to substantially different results. It is recommended that small Tmax should not be used for Spanish mackerel analysis and summary results in Table 12 should be adopted instead and the MSYs of Spanish mackerel were estimated between more than 110000 to 175553 t in different categories (Table 12).

Table 12. Summary output from OCOM using natural mortality M only for r prior construction for Spanish mackerel (IOTC-2020-WPNT10-16).

param	q0.1	q0.2	q0.5	q0.8	q0.9
k	570,326	704,209	1,057,118	1,590,127	2,007,273
r	0.240	0.327	0.538	0.882	1.124
MSY	110,443	121,506	141,198	162,547	175,553
S	0.225	0.262	0.373	0.538	0.620
B_{msy}	285,163	352,104	528,559	795,064	1,003,636
F_{msy}	0.120	0.164	0.269	0.441	0.562
B_{2018}	190,809	216,884	352,105	695,600	985,370
F_{2018}	0.157	0.223	0.440	0.714	0.811
B_{2018}/B_{msy}	0.451	0.524	0.747	1.077	1.240
F_{2018}/F_{msy}	0.721	0.912	1.501	2.342	2.949

Another study was carried out by the secretariat. Disaggregated nominal catch data were extracted from the IOTC Secretariat database for the period 1950–2018 (IOTC–2020–WPNT10–14).
Two data-limited methods were used in assessing the status of Indian Ocean Spanish mackerel: C-MSY and Bayesian Schaefer production model (BSM), both of which are based on an aggregated biomass dynamic model. Estimates from the C-MSY model suggested that currently the stock of Spanish mackerel in the Indian Ocean is overfished (B2018 < BMSY) but is not subject to overfishing (F2018 < FMSY).

C-MSY imposed strong assumptions on the stock abundance trend. So, a Schaefer production model (BSM) which utilized the newly available standardized CPUE indices was used. The BSM was implemented as a Bayesian state-space estimation model that was fitted to catch and CPUE. Therefore 4 models were implemented. The initial model made no assumption on the depletion level. However, the initial model (M1) indicated serious conflicts with the input abundance indices Therefore two additional models were conducted which penalize the final depletion outside the range of (1) 0.2–0.6 (M2), and (2) 0.4–0.8 (M3), respectively. A fourth model was also explored which assumed a process error of 0.1 (M4) ((IOTC–2020–WPNT10–14).

Stock status

Sampling for *S. commerson* was carried out in five different geographic locations along the Indian coast (Veraval, Mangalore and Kochi in the Arabian Sea; Chennai and Vishakhapatnam in the Bay of Bengal), during May 2013 to July 2016. The sampling area covers the majority of the geographic range of *S. commerson* in the Indian region (∼7500 Km) of the northern Indian Ocean. A total of 12 polymorphic microsatellite loci were amplified in 250 samples collected from five different geographic locations. Low FST values (0.0023–0.027), AMOVA, PCoA and the Bayesian analysis of genetic structure indicated unit stock of the species in Indian waters. Bottleneck analysis using Wilcoxon signed rank tests and Mode shift test indicated lack of recent bottleneck events across populations of *S. commerson* (Radhakrishnan et al.,2018).

The Narrow-barred Spanish mackerel exhibited the strongest genetic differentiation within the Indian Ocean. In fact, our first round of analysis including six locations revealed large differences in heterozygosity between three regions, each including two sampling locations, consistent with the presence of multiple cryptic species. Whilst our data can't determine if these regions host distinct species or just highly differentiated population, this result warranted the analysis of each of these three regions separately. The first round of stockR analysis detected four clearly distinct genetic groups. The first one was made of the NWI and NCI sampling locations (App. 4a), the second and third one corresponded to the NEI and ECI sampling locations respectively (App. 4b) and the fourth group comprised the AFS and WCS sampling locations (App. 4c). The second round of stockR analyses detected further spatial clustering within this fourth group, in which there was a hint of at K = 5 of the first round of analysis, but not within the other groups (App. 4a, 4b).

Having only 32 individuals that past quality control for NWI and NCI combined was possibly a limiting factor to detect further substructure in that region (IOTC-2020-WPNT10-10).

Investigation of the genetic population structure of the narrow-barred Spanish mackerel over the last two decades, using either mitochondrial DNA or microsatellite nuclear markers, had already showed evidence of limited connectivity. These studies generally found strong genetic population structure at the regional scale. In the Indian Ocean samples from the Persian Gulf and the Oman Sea differ from those found in the Timor Sea (Fauvelot & Borsa 2011). It seems that the Bay of Bengal also hosts a distinct population but the sample size available to Habib & Sulaiman (2017) was too low (N=5) to allow definitive conclusions. Moreover, no genetic structure was reported between the Persian Gulf, the Gulf of Oman and the Arabian Sea (Hoolihan et al., 2006) or along the coast of India (Vineesh et al. 2016) using mitochondrial DNA. Using microsatellite markers Abedi et al. 2012 did not find any genetic differentiation inside the Persian Gulf, but two different stocks were identified around the Arabian Sea, Persian Gulf & Oman Sea (van Herwerden et al., 2006). This study detected a total of four genetic groups amongst five sampling locations within the Indian Ocean, taking the understanding of the narrow-barred Spanish mackerel to a new level, from regional to local (IOTC-2020-WPNT10-10).

Results from this study suggest there has been long-term declines in the Spanish mackerel population in the Indian Ocean with steeper declines over the past 10 years. The results suggests that the population size currently ranges between 29 and 40% of unfished spawning stock biomass and is declining towards the limit reference point of 20% of unfished spawning stock biomass.

The results suggest that management action to reduce fishing mortality is required to rebuild the stock to the target reference point, taking into account high harvests experienced in 2019 and evidence of poor recruitment in recent years.

The model estimated that the overall population size of Spanish mackerel in the Queensland GoC is small, with a virgin spawning stock size of approximately 1150 to 1350 t. This small population size means that only relatively small harvests are able to be sustainably maintained through time. This is apparent with the equilibrium harvest at 60% of unfished biomass estimated to be 170 t, below the annual harvest since the early 2000s.

Grandcourt (2013) proposed to conduct coordinated regional research to clarify the spatial functioning of the Narrow-barred Spanish mackerel stock in the Persian Gulf, the Gulf of Oman, and the Arabian Sea. We supported this proposal in our previous research (Roa-Ureta, 2015). We can refine the scope of the proposal further now. Does the stock spatial dynamics across the region from the northern Gulf to the Arabian Sea involve (i) several subpopulations functioning with relative autonomy and some degree of mixing or (ii) seasonal migrations to major spawning areas off the UAE and to a lesser degree the Gulf of Oman and the Arabian Sea? A coordinated program of tagging combined with a spatially-resolved, meta-population stock assessment model could answer this question. Coordinated regional management would then devise policies that take into account commonalities at the regional scale as well as specific conditions at the local scale (Roa-Ureta et al.,2019).

Conclusion

- The threat of growth over-fishing and potential of recruitment failure associated with the intensive harvest of immature fish has been of particular concern for *S. commerson* in the north western Indian Ocean.

- The drift/set gillnet fishery requires regulation and appropriate management measures to stop growth-overfishing.

- Large quantities of immature Spanish mackerel are landed in the Indian Ocean

- Bleaching events in the Persian Gulf have occurred with increasing frequency in recent decades in association with increasing SSTs, and this has led to dramatic reductions in live coral cover and shifts in species composition on many reefs across the region.

- RECOFI implemented a seasonal fishing ban on Spanish mackerel fishing between 15 August to 15 October of each year, which has targeted the spawning time, fishing is allowed for the rest of the year and it is not impossible that illegal fishing or illegal landings takes place even during the fishing ban period (Roa-Ureta et al., 2019).

- Almost each location sampled as part of the genetic population structure of neritic tunas in the Indian Ocean from the PSTBS-IO Project was found to host a distinct genetic group which indicate that further sampling with higher spatial resolution is likely to reveal additional distinct genetic groups.

- The findings of the population structure study of Indian waters could be used in managing the commercially important species, *S. commerson* as a unit stock in Arabian Sea and Bay of Bengal of Northern Indian Ocean and reinforces the need for regional cooperation on fisheries management (Radhakrishnan et al.,2018).

Management advice

The catch in 2019 was just below the estimated MSY and the available gillnet CPUE shows a somewhat increasing trend in recent years although the reliability of the index as an abundance index remains unknown. Despite the substantial uncertainties, the stock is probably very close to being fished at MSY levels and higher catches may not be sustained.

The following should be also noted:

● Maximum Sustainable Yield for the Indian Ocean stock was estimated at 157,760 t, with catches for 2019 (159,457 t) exceeding this level;

● Further work is needed to improve the reliability of the catch series. Reported catches should be verified or estimated, based on expert knowledge of the history of the various fisheries or through statistical extrapolation methods;

● Improvement in data collection and reporting is required if the stock is to be assessed using integrated stock assessment models;

● Given the increase in Narrow-barred Spanish mackerel catch in the last decade, measures need to be taken to reduce catches in the Indian Ocean;

● Research emphasis should be focused on collating catch per unit effort (CPUE) time series for the main fleets, size compositions and life trait history parameters (e.g., estimates of growth, natural mortality, maturity, etc.);

● CPCs are requested to comply with IOTC data requirements, including total catches, catch and effort and size data for neritic tunas per Resolution 15/01 and 15/02.

● A transboundary management of Spanish mackerel fishery is suggested for the north western Indian Ocean

● Closed seasons and minimum size limits may be the most effective means of increasing spawning biomass per recruit.

● The entire ROPME Sea area (Persian Gulf & Oman Sea) has a single stock of Spanish mackerel, so it could be managed better with a transboundary initiative of the region. More scientific studies on biology and population dynamics of this species are required in the region to evaluate the vulnerabilities of the stock.

● Cooperation and coordination between IOTC & RECOFI will strengthen the management practices in the region.

● Increased mesh size (130–170 mm) regulations (Hosseini et al., 2021) for gillnets would be required along with a significant reduction in fishing effort.

● Highlight the need for further targeted research of genetic population structure to confirm the temporal stability of these results and provide a comprehensive understanding of population boundaries for these species within the Indian Ocean.

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