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Assessments of marine fisheries resources in West Africa with emphasis on small pelagics

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Contents

Director’s Foreword

This Fisheries Centre Research Report (FCRR) highlights two important issues when addressing fisheries management matters. First, there is no such thing as ‘no data’. Fisheries scientists have tried to overcome this for decades. This has included developing stock assessment methods with limited requirements and creating databases with parameter estimates useful for stock assessments. Still, while there may be very little data available except for fisheries catches, there is a difference between that and no data. No data gives the impression that, officially, no catches are being made, and as researchers in the *Sea Around Us* initiative have shown time and again, this is rarely the case. Data collection may be more difficult and require more work, but data can be found.

Which brings me to the second point. One of the best ways to gather that limited data is to speak to those who are doing the fishing. This means ongoing communication with artisanal or small-scale fishers, local buyers, and others who are better able to provide information about local conditions.

The *Sea Around Us*, with the MAVA Foundation and the *Commission Sous-Régionale des Pêches, (CSRP)* hosted the training course, which resulted in the papers presented in this report, in Dakar, Senegal in 2019, with invited participants from Cape Verde, The Gambia, Guinea, Guinea-Bissau, Liberia, Mauritania, Senegal, and Sierra Leone. The participants’ contributed applications of the CMSY and/or LBB method based on data that they brought along, and while, in some cases, these data were preliminary, they provided insights into how to perform assessments of small pelagic stocks in the CSRP area. Further, it shows the power of cooperation at the international level.

I applaud the *Sea Around Us*, MAVA Foundation, CSRP, and the participants of this training course for their contributions.

Evgeny Pakhomov
Professor and Director
Institute for the Oceans and Fisheries (IOF)

Preface and Acknowledgments

Fisheries have to be managed if they are not to end up overexploiting their resource base. Yet, how often have we heard that reasonable effort control or other essential management tools cannot be implemented because "there are no data"? Fisheries scientists have worked for decades on how to overcome this issue. Some scientists have been developing stock assessment methods with limited requirements, while others have been working on creating databases with data useful for assessing any exploited stock in the world.

These efforts converged during the training course entitled "*Utilisation de la méthode CMSY pour l'évaluation des stocks ouest-africains*" held in September 23-27 2019 in Dakar, Senegal, hosted by the Regional Sub-Commission for Fisheries (*Commission Sous-Régionale des Pêches, CSRP*) with the support of the MAVA Foundation, for participants from Cape Verde, The Gambia, Guinea, Guinea-Bissau, Liberia, Mauritania, Senegal and Sierra Leone. The stock assessment methods that were taught, CMSY and LBB, were developed by Dr. Rainer Froese and colleagues. These methods require a minimum of data to provide estimates of B/B_{MSY}, i.e., the current biomass of an exploited stock relative to the biomass that generates maximum sustainable yield (MSY).

The course was successful because delegates from each of the participating countries contributed applications of the CMSY and/or LBB method based on data that they brought along. A number of these applications should, however, be considered to be very preliminary. In the LBB case, the length-frequency (L/F) data analyzed did not necessarily reflect the wealth of L/F data available in the CRSP countries. In the CMSY cases, the national data used did not generally reflect the fact that the stock in question (e.g., of sardinella) may range over the Exclusive Economic Zones (EEZ) of two or more CRSP countries.

The short contributions presented in this report should be seen as tentative in terms of their specific results. However, they certainly express that the CMSY and LBB methods are well-suited for use in the CRSP region, and that the course participants will be using these methods in the future.

To illustrate the power of international cooperation and to obtain reliable assessments of small pelagic stocks in the CSRP area, a chapter has been included detailing how national data can and should be pooled into (sub-)national assessments of 14 shared stocks of small pelagic fishes. We hope that this chapter and the report as a whole will be found useful to all countries of the sub-region even though we translated contributions originally in French or Portuguese into English.

We hope that the general conclusions from these assessments will be that:

- There are enough L/F and catch data series in the CRSP region for stock assessments to be performed, i.e., it is no longer the case that "there are no data"; and

- Policymakers in the CRSP region must face the fact that assessing the major stocks in the region indicates overexploitation - a reduction of fishing effort is necessary to maintain abundant catches.

As editors of the report, and the *Sea Around Us* resource persons at this course, we take this opportunity to thank the MAVA Foundation, the CSRP, particularly Mr. Mika Diop, and the workshop participants and authors of the contributions herein for their enthusiasm and diligence. We also thank the FishBase and SeaLifeBase teams of Quantitative Aquatics in Los Baños, the Philippines for help preparing the resilience and biomass 'priors' made available to the participants and for ensuring the coverage of the small pelagic species occurring in the region.

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Vancouver, September 2020

Stock assessment of blackspot picarel (*Spicara melanurus*) and mackerel scad (*Decapterus macarellus*) in Cape Verde waters, Northwest Africa[1]

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Abstract

The stock status of two pelagic species caught in the waters around Cape Verde, Northwest Africa, the blackspot picarel (*Spicara melanurus*) and mackerel scad (*Decapterus macarellus*), were estimated using a length-based Bayesian biomass estimator (LBB) and a Monte-Carlo method (CMSY) that estimates fisheries references points (MSY, F_{MSY}, B_{MSY}) from a time series of catches. The length-frequency data used in the LBB method were collected from the fish market of São Vicente Island during the period 2004 to 2018. The catch data used in the CMSY method were obtained from the artisanal and industrial fisheries, as recorded by the official statistical collected at the island's landing sites from 1986 to 2015. The results show that the *S. melanurus* stock is overfished and depleted, while the *D. macarellus* stock is currently at risk of being overfished. In both cases, prudent management would recommend a reduction of fishing effort until these stocks show signs of recovery.

Introduction

Fishing activities in the Exclusive Economic Zone of Cape Verde, in Northwest Africa, are traditionally divided into artisanal and industrial fisheries, based on fleet characteristics, especially boat length and engine power (see Belhabib *et al*. 2016 in Appendix A).

The artisanal fleet consists of small wooden boats with lengths ranging from 3 to 11 m, equipped with outboard engines of up to 25 hp (INDP 2011). These boats, which have neither catch nor effort limits, operate inside 3 nautical miles from the coast (INCV 2016). Various fishing gears are used, the main ones being handlines, purse seines, gillnets and beach seines (MAAP 2004).

The industrial fleet consists of larger vessels up to 25 m and an inboard engine of up to 500 hp (MAAP 2004); this fleet operates from 3 nautical miles to about 12 miles

Approximately 150 commercially important fish species are caught in Cape Verde (González and Tariche 2009). Species belonging to the 'oceanic pelagic' group, such as tuna, which occur throughout the Atlantic Ocean, make up most of the catch. These are followed by 'coastal pelagic species,' a group composed mainly of small pelagic fish. Species belonging to the 'demersal' group contribute least to the catch of Cape Verde.

Blackspot picarel or '*dobrada'* (*Spicara melanurus*; Figure 1) is a small pelagic fish of the Sparidae family. It occurs on the shelf of Cape Verde and Madeira, and ranges from Senegal to Angola, usually over depths ranging from 100 m to 250 m (Reiner 2005; see also FishBase; www.seaaroundus.org). They feed mostly on small crustaceans (Monteiro 2008) and grow to a maximum fork length (FL) of 30 cm (34 cm total length, or TL). However, the most common size of mature individuals is 25 cm FL (Monteiro 2008). It is a protogynous hermaphrodite (Costa 2007). Microscopic analysis of gonads collected monthly for one year identified four peak spawning periods in January and February, April, July, and November (unpublished data). A subsequent study suggested that the species spawns throughout the year (Tariche and Martins 2011).

[1]Cite as: da Luz A. and N. Vieira. 2020. Stock assessment of blackspot picarel (*Spicara melanurus*) and mackerel scad (*Decapterus macarellus*) in Cape Verde waters, Northwest Africa, p. 5-17 *In:* M.L.D. Palomares, M. Khalfallah, J. Woroniak and D. Pauly D (eds.). *Assessments of marine fisheries resources in West Africa with emphasis on small pelagics.* Fisheries Centre Research Report 28(4), UBC, Vancouver, Canada.

Mackerel scad or '*cavala preta*' (*Decapterus macarellus*; Figure 2), which has a circumglobal distribution, has an elongated and cylindrical body. The ventral part of the fish is black and the dorsal is bluish to green. The common length in the catch is around 30 cm TL, with the maximum recorded length reaching 46 cm TL. There is no apparent sexual growth dimorphism (Prado and Bearez 2004). Mackerel scad feeds predominantly on small fish and macroplanktonic crustaceans in the water column, and fall prey to wahoo, skipjack, yellowfin tuna, bigeye tuna and dolphinfish (Weng and Sibert 2000).

Active during both day and night, mackerel scad can be found at temperatures from 13 to 28°C (Ramlochan 2016). Shiraishi *et al.* (2010) studied this species in Japanese waters, and the results indicate that its maximum age is around eight years and that spawning occurs from April to July, when they are two years old and have an average size of 25.8 cm FL (or 28 cm TL). In Hawaiian waters, spawning occurs from April to August; apparently, they mature at 18 months, at a standard length (SL) of 24.5 cm (27.5 cm TL; Clarke and Privitera 1995). In Cape Verde, studies indicate that spawning activity peaks from July to September, when their length at first maturity is 20 cm FL (Tariche and Martins 2011). Blackspot picarel and mackerel scad are considered to be Cape Verde populations, distinct from those along the African mainland (Almada and da Veiga 2016).

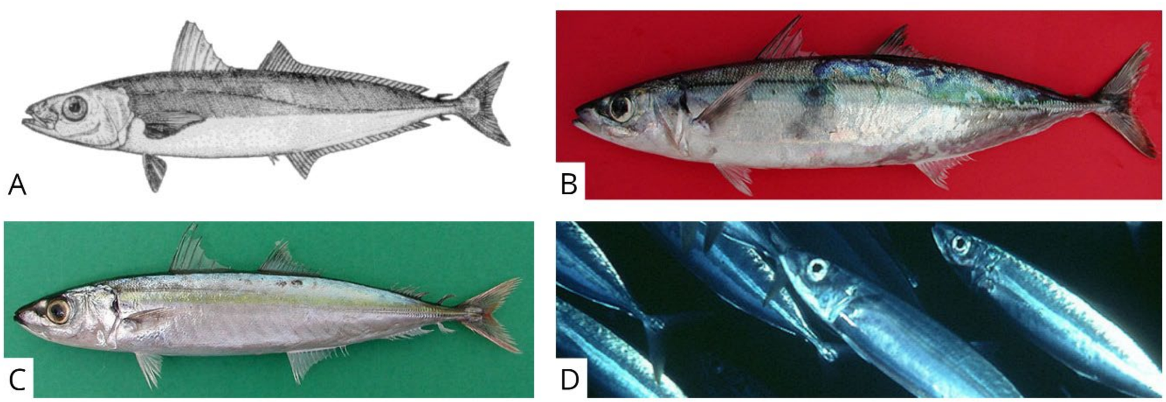

Figure 2. Mackerel scad or '*cavala preta*' (*Decapterus macarellus*) A) as Canada drawn by Ms Susan Laurie Bourque; B) and C) photos from Cape Verde by Rui Freitas; D) underwater photo by John E. Randall (from FishBase; www.seaaroundus.org).

Methods

Froese *et al.* (2018) described a length-based Bayesian method (LBB) method for the analysis of length-frequency data representing the catch composition of fisheries (see also Palomares *et al.* 2020, this vol.). This method provides estimates of asymptotic length (L_∞, or L_{inf}), mean length at first capture (L_c), relative natural mortality (M/K), and relative fishing mortality (F/M) as means over the time and age range represented in the length-frequency (L/F) sample. These input parameters were used with standard fisheries equations provided in the LBB R package to estimate current biomass relative to unexploited biomass (B/B_0). This permitted the estimation of the optimal length at first capture (L_{c_opt}) that would maximize catch and biomass for a given fishing effort, thus, estimating a proxy for the relative biomass capable of producing maximum sustainable yields (B_{MSY}/B_0). The L/F data used for this are given in Table 1 for blackspot picarel and in Table 2 for mackerel scad.

LBB, as a Bayesian method, requires 'priors'; for blackspot picarel, we provided FL_{inf} = 35 cm, as estimated from $L_{inf} = 0.95 \cdot L_{max}$ (i.e., the largest size in the sample, 36.7 cm; see Table 1). For mackerel scad, the priors were FL_{inf} = 41 cm and K = 0.45 year^{-1}, from Vieira (2019).

Table 1. Length-frequency data of blackspot picarel or '*dobrada*' (*Spicara melanurus*) sampled from the fish market of Mindelo (Sao Vicente Island), and representing the commercial fishery from 2005 ('05) to 2018 ('08). The length classes are defined by their lower-class limits.

LF (mm)	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18
90				3										
100				3										
110				1										
120	1			1										
140	5													
150	9		1	10										7
160	13		11	28					12	1				8
170	17	1	17	39	2	1		1	60	13	3			8
180	37	19	41	30	17		1	32	75	36	30	1		2
190	55	62	82	65	65	18	7	78	123	77	84	6	5	4
200	150	101	121	85	135	77	26	174	223	118	132	31	12	18
210	286	158	114	135	250	153	60	155	239	145	128	64	36	41
220	273	170	132	154	278	199	137	109	199	168	124	139	80	65
230	259	176	113	180	251	203	181	131	133	141	93	117	162	48
240	213	129	130	131	179	219	239	125	128	112	96	123	210	31
250	144	78	134	100	137	185	213	112	94	113	86	98	210	10
260	54	57	172	63	126	153	119	93	101	88	75	87	217	1
270	9	21	92	24	51	105	58	22	54	62	41	52	119	3
280	1	4	29	5	6	25	4	5	5	26	29	15	52	
290		2	4	1	2	1		3	1	9	24	6	10	
300			2								14	3		
310											4			
320							1							
330			2		1									
350							1							
360							1						1	
370							1							
Total	1526	978	1197	1058	1500	1339	1049	1040	1447	1109	963	742	1114	246

Froese *et al.* (2016) introduced a Monte Carlo-based approach, the CMSY method, to estimate fisheries reference points (MSY, F_{MSY}, B_{MSY}) and a time series of biomass from catch data and broad priors for the intrinsic rate of population growth (r) of fish stocks and constraints on the biomass relative to carrying capacity (k, or B_o) at the beginning (B_{start}/k) and end of the biomass series (B_{end}/k). Resilience priors (i.e., range of r values) for fishes are easily obtainable from FishBase (www.fishbase.org) and for invertebrates from SeaLifeBase (www.sealifebase.org); see Palomares *et al.* 2020, this vol.).

To complement the CMSY method, we used the Bayesian state-space implementation of the Schaefer surplus-production Model (BSM) provided by Froese *et al.* (2016), which combines CPUE data with the CMSY logic to estimate the catchability coefficient of a fishery (q = catch/(effort·biomass)), allowing the derivation of a Schaefer-type surplus-production model. The key advantage of BSM over CMSY is that the addition of CPUE data reduces the uncertainty inherent in an assessment.

The official landings data used in this work were recorded from 1986 to 2015 by the National Institute of Fisheries Development (INDP). Data collection for the artisanal fleet is based on systematic sampling (Shimura 1984). Cape Verde has 97 landing sites for the artisanal fleet, of which 17 (i.e., 18 % of total coverage) are sampled regularly given their importance with regard to the number of boats; jointly, they represent over 50 % of the total catch, and are raised to the landings for the whole archipelago. Landings data of industrial fishing vessels are collected in the harbours of Sal, São Vicente, and Santiago Islands. The landings of the artisanal and industrial fleets were aggregated as total catch in tonnes (Table 3) for use in the CMSY analysis.

FishBase suggests that blackspot picarel is in the 'medium' resilience category, i.e., with r ranging from 0.2 to 0.8 $year^{-1}$. In contrast, FishBase assigned mackerel scad to the 'high' resilience category, with r = 1.08 $year^{-1}$ (range of 0.71-1.62 $year^{-1}$). These ranges were used as priors in the CMSY, along with the results of the LBB analyses, which were used as priors for the relative biomass 'windows,' e.g., for biomasses between the starts and ends of the catch time series (B_{int}/k), and for the relative biomass remaining at its end (B_{end}/k).

Results

Blackspot picarel (Spicara melanurus)

The LBB analyses (Figure 3) show that the L/F data for the 2005-2006, 2008-2011 and 2014-2017 had the expected shape, suggesting good fits. The method estimated (median across years) L_{inf} = 34.8 cm, L_{opt} = 22 cm, L_{c_opt} = 20 cm, M/K = 1.72, and F/M = 2.72. Estimates for the average of the last three years (2016-2018, shown as '2017') were L_{c50} = 21.7 cm, L_{c95} = 24.5 cm, L_{mean}/L_{opt} = 1.1, L_c/L_{c_opt} = 1.1, F/M = 1.8, F/K = 2.7, Z/K = 4.1 and B/B_o = 0.32. The best fitting year is 2010 (B/B_o = 0.17; range of 0.11-0.26). Data for 2015, corresponding to the last year of the catch time series, resulted in an estimate of B/B_o = 0.34 (0.16 - 0.60). The relative biomass ranges for 2010 and 2015 were used in the CMSY analysis as intermediate and end biomass windows, respectively.

Table 2. Length-frequency data of mackerel scad or '*cavala preta*' (*Decapterus macarellus*) sampled from the fish market of Mindelo (Sao Vicente Island), and representing the commercial fishery from 2004 ('04) to 2018 ('08). The length classes are defined by their lower class limits

LF (mm)	'04	'07	'09	'10	'11	'14	'15	'17	'18
160			1						
170			1						
180			2						
190		3	5					1	
200		5	31	1	1				
210	9	9	76	5	4			1	
220	62	53	154	15	18	10		19	
230	101	173	68	43	51	45		63	
240	45	369	89	42	59	38		16	1
250	48	480	142	51	63	14		24	26
260	59	882	273	113	103	21	6	82	89
270	20	877	354	157	144	109	39	21	143
280	19	470	389	210	307	115	76	29	127
290	13	224	204	226	351	32	39	17	117
300	2	56	127	188	180	20	42	23	124
310		19	59	121	72	48	56	3	56
320		1	34	62	31	71	45	2	26
330			20	40	10	11	28	9	14
340			13	22	1	3	10	6	4
350			11	2	1	1	4	5	
360			9			1	2	5	1
370			4						
380			5						
390			2					2	
400		1	3						
420			1						
430			1						
470			1						
480			1						
Total	378	3622	2080	1298	1396	539	347	328	728

In addition to the priors mentioned above, the CMSY analysis was run with a starting biomass range for B_{1985}/B_0 = 0.6-1.0. This is based on a hypothesis posited by Mundt (2012) that the decline in the per capita food supply from fish and fishery products in Cape Verde since 1981 is related to the decrease in catches due to possible illicit fishing by foreign vessels. Trindade-Santos *et al.* (2012) suggested that dynamite fishing was employed in the years prior to 1985, i.e., the start of a fisheries development programme that encouraged the use of purse seines in artisanal fisheries. Thus, we assumed that the biomass level in 1985 was below 1.0, but might still have been higher than 0.5.

The resulting CMSY analysis came up with nearly 2,000 viable trajectories for 882 r-k pairs, with r = 0.557 (0.395-0.785) and k = 3.7 (2.37-5.77) providing an estimate of MSY = 516 tonnes year^{-1} (0.406-0.654), and a relative biomass (B/k) in 2015 of 0.361, with and exploitation (F/(r/2) of 1.56. This lead, for 2015, to B/B_{MSY} = 0.995 and F/F_{MSY} = 1.15. Figure 4 presents the graphic representation of the resulting analysis, management and Kobe plots for blackspot picarel.

Table 3. Catch (tonnes) time series for blackspot picarel (*Spicara melanurus*) and mackerel scad (*Decapterus macarellus*) from Cape Verde waters (INIP 1986-1991; INDP 1992-2015).

Year	*S. melanurus*	*D. macarellus*
1986	137	–
1987	118	–
1988	94	–
1989	204	1671
1990	81	1001
1991	135	1263
1992	194	2169
1993	162	1427
1994	254	1948
1995	245	1585
1996	392	1751
1997	166	2984
1998	666	3015
1999	773	2707
2000	1195	1864
2001	500	1379
2002	540	2232
2003	859	1830
2004	643	1741
2005	542	2181
2006	350	2627
2007	238	2855
2008	424	2387
2009	441	1771
2010	439	1749
2011	200	2163
2012	200	2643
2013	308	2214
2014	312	151
2015	581	644

Mackerel scad (Decapterus macarellus)

The LBB analyses (Figure 5) show that the L/F data for the years 2007, 2009-2011, and 2018 had the expected shape, suggesting good fits. The LBB method estimated the following values (median across years): FL_{inf} = 40.9 cm, L_{opt} = 27 cm, L_{c_opt} = 25 cm, M/K = 1.59 and F/M = 4.75. Estimates for the average of the last three years (2016-2018; '2018') are L_{c50} = 28.7 cm, L_{c95} = 32.8 cm, L_{mean}/L_{opt} = 1.1, L_c/L_{c_opt} = 1.1, F/M = 5.4, F/K = 8.6, Z/K = 10 and B/B_0 = 0.026. The best fitting year is 2010 (B/B_0 = 0.11; 0.074-0.16). The L/F data of 2015, i.e., the last year of the catch time series, provided an estimate of B/B_0 = 0.34 (0.23-0.48). These results were used in the CMSY analysis as intermediate and end biomass windows, respectively.

We assumed that this stock was affected by the same factors affecting other pelagic fisheries in Cape Verde (Mundt 2012 and Trindade-Santos *et al.* 2012). Thus, the CMSY analysis was run with a starting B/k range for 1985 of 0.6-1.0. The resulting CMSY analysis produced over 1,700 viable trajectories for 1,359 r-k pairs, with r = 1.19 year^{-1} (0.957-1.48), k = 8,040 tonnes (5,880-11,000) providing an estimate of MSY = 2,400 tonnes year^{-1} (1,990-2,890). The estimated relative end biomass (in 2015) was B_{end}/k = 0.296.

The Bayesian Schaefer model (BSM) results were q = 0.0972 (0.0837-0.113), r = 1.2 year^{-1} (1.02-1.41) and k = 7,120 (6,180-8,190), providing an estimate of MSY = 2,130 tonnes year^{-1} (2,020-2,250) and relative biomass (B_{end}/k) for 2015 of 0.401. This leads to B/B_{MSY} = 0.802 and F/F_{MSY} = 0.609 for 2015. Figure 6 presents the graphic representation of the resulting analysis, management and Kobe plots for mackerel scad.

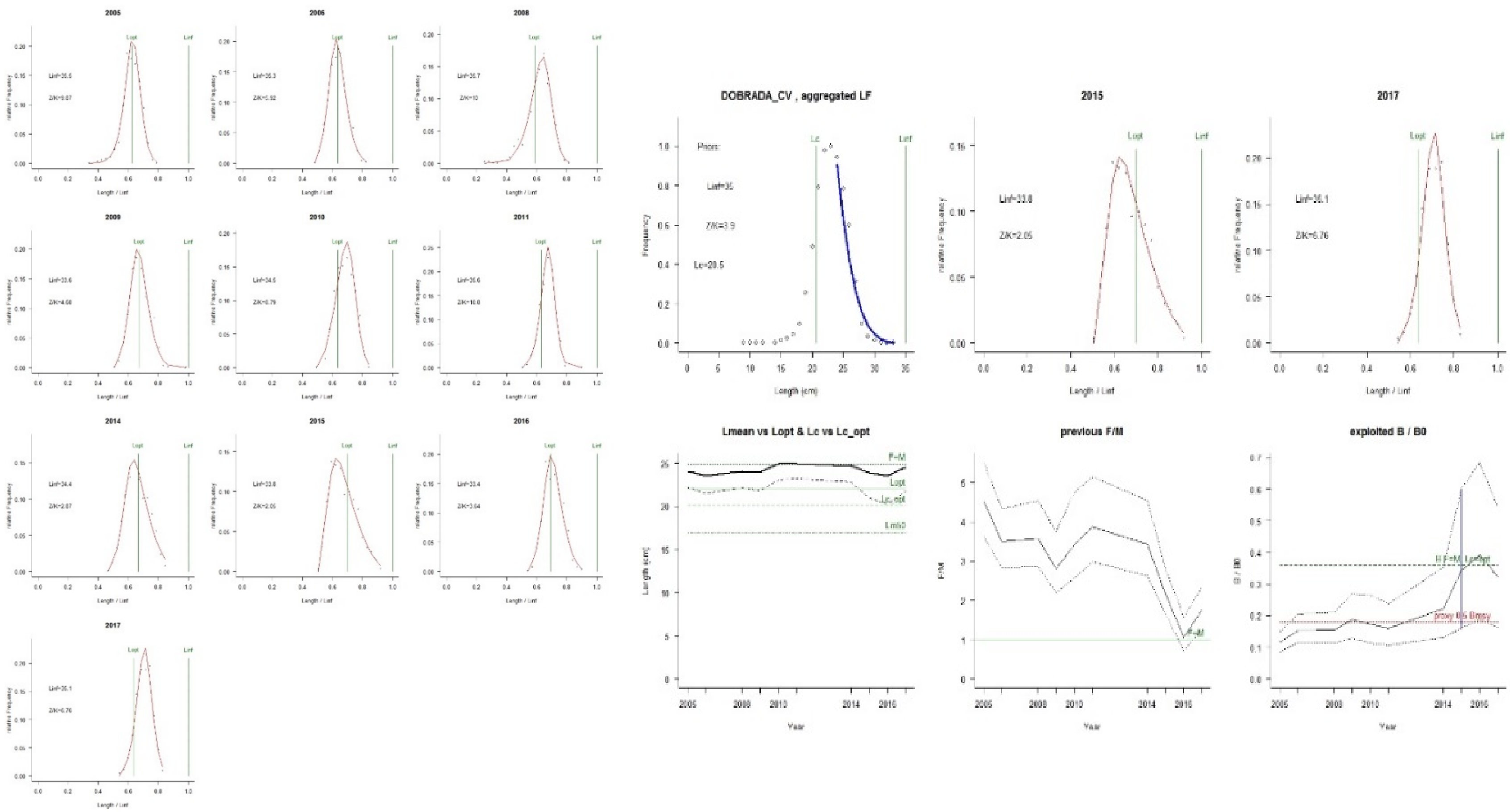

Figure 3. Results of the length-based Bayesian method for estimating biomass reference points (LBB) from length-frequency data for blackspot picarel (*Spicara melanurus*) sampled from commercial fisheries of Mindelo, Cape Verde from 2005 to 2018. The panels on the left, representing the years 2005-2006, 2008-2011, and 2014-2018 exhibited the expected shape, suggesting a good fit. Right panels: Final result of LBB showing data for selected (2015, i.e., end year of the catch time series) and middle year of the last 3 years of available data (2017).

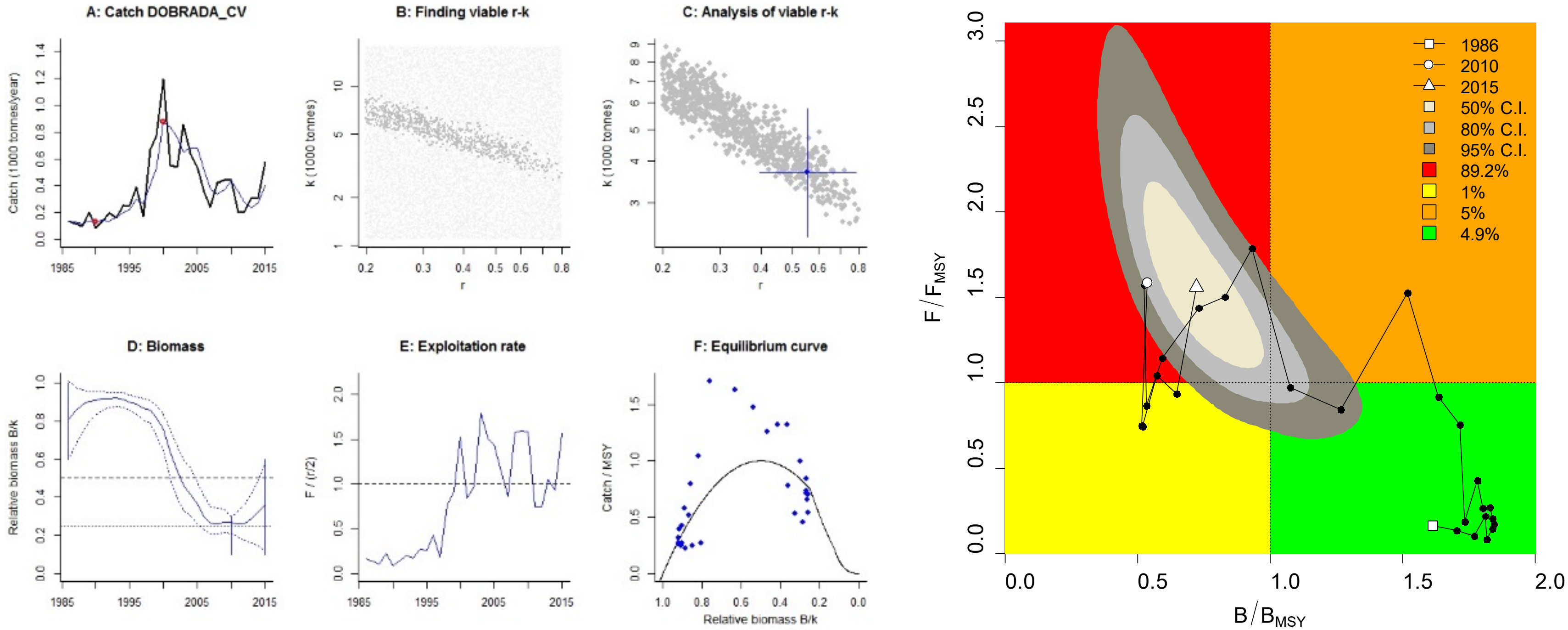

Figure 4. Results of the CMSY/BMS stock assesment for the blackspot picarel (*Spicara melanurus*) based on total landings reported by INDP for the period 1985-2015. Upper left panel: A: Catch; B-C: panels identifying viable r-k pairs, with estimates of r = 0.557 (0.395-0.785), k = 3.7 (2.37-5.77); this allows tracing the biomass trajectory (D) and the exploitation rate (E) and obtaining (in F) an estimate of MSY = 516 tonnes·year^{-1} (406-654). Right: Kobe plot tracing the evolution of the fishery.

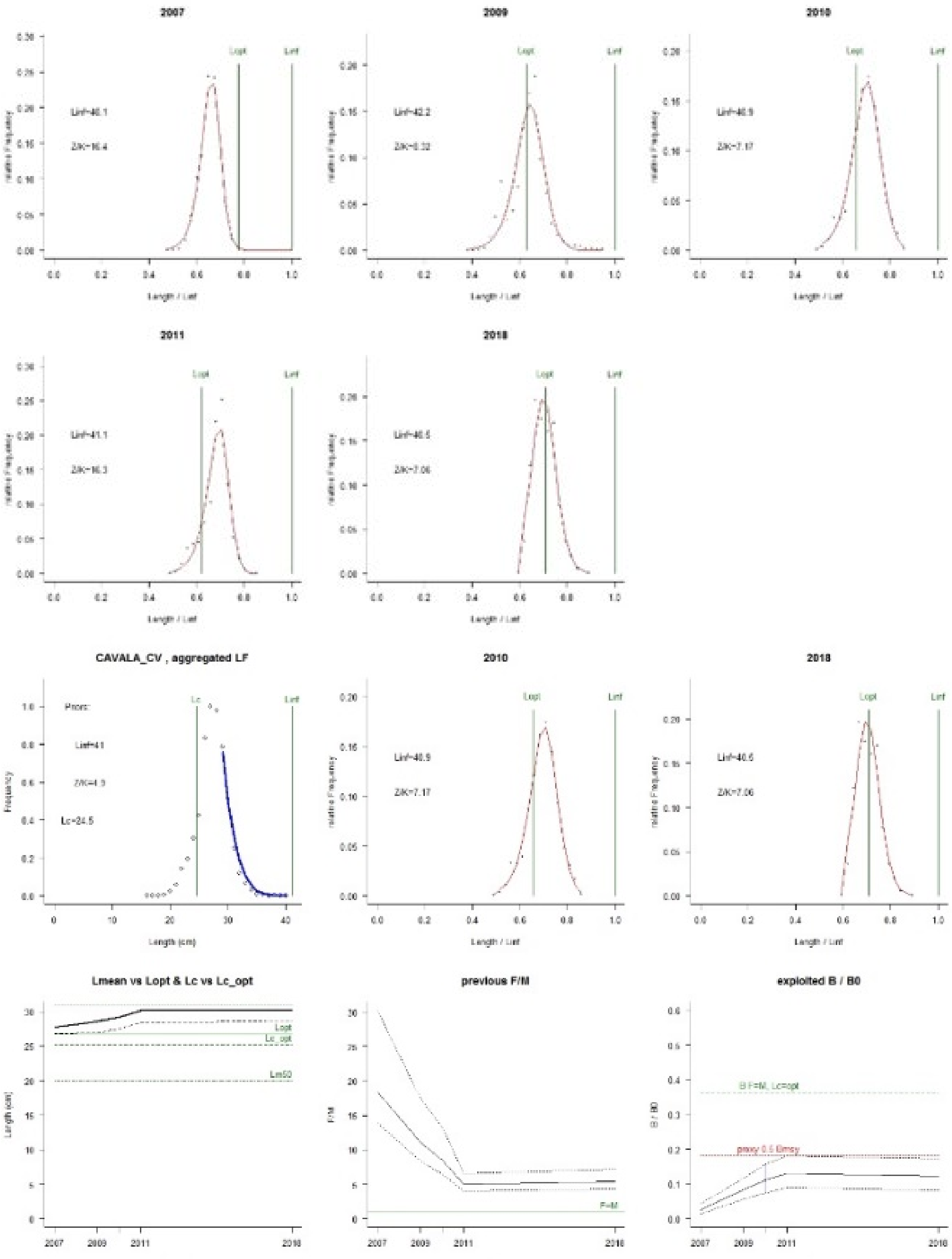

Figure 5. Results of the length-based Bayesian method for estimating biomass reference points (LBB) from L/F data for mackerel scad (*Decapterus macarellus*) sampled from commercial fisheries of Mindelo, Cape Verde from 2005 to 2018. Upper and middle panels: data for the years 2007, 2009-2011, and 2018, which had the expected shape suggesting a good fit. Lower panel: Final result of LBB showing data for the last 3 years of available data (2018).

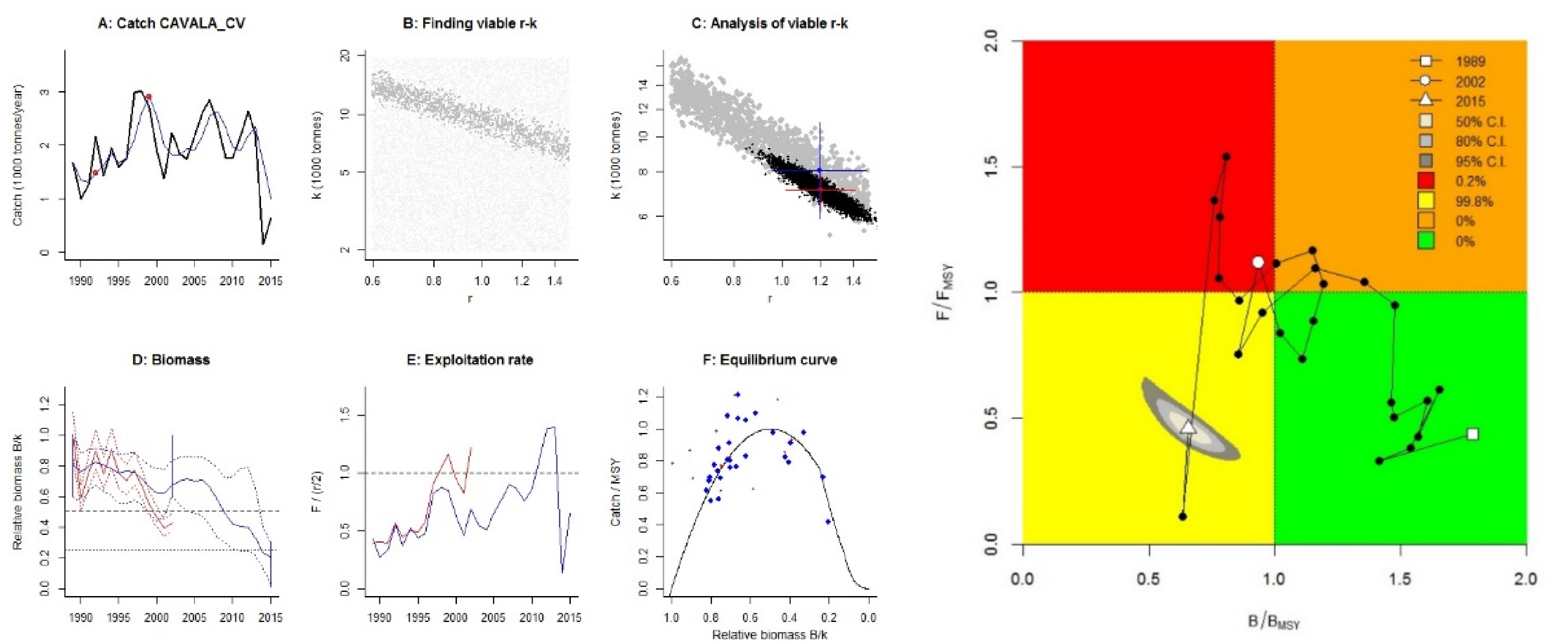

Figure 6. Results of the CMSY/BMS stock assesment reference points (CMSY) for the mackerel scad (*Decapterus macarellus*) in Cape Verde, based on total landings reported by INDP for the period 1989-2015. Upper left panel: A: Catch; B-C: panels identifying viable r-k pairs, this allows tracing the biomass trajectory (D) and the exploitation rate (E) and obtaining (in F) an estimate of MSY. Right: Kobe plot tracing the evolution of the fishery.

Discussion

The LBB results for blackspot picarel (*Spicara melanurus*) of FL_{inf} = 34.8 cm, L_{opt} = 22 cm, and L_{c_opt} = 20 cm are the first estimates for Cape Verde and other regions where the species occurs. Note, however, that some of the L/F data used in this study (Table 1) failed to generate an LBB plot exhibiting a good fit; this suggests that some samples were not representative of the commercial catch. The estimate of L_{inf} is compatible with the estimate of mean length at first maturity of 17 cm in Tariche and Martins (2011).

The CMSY results, which are well constrained, suggest that this species has reached a critical state in Cape Verde. However, a slight recovery is recorded for 2014 and 2015. The inclusion of 2016-2018 catch data would be the next step to improve this analysis and determine if this recovery continued.

This study is the first to provide a viable estimation of biomass and MSY for this resource in Cape Verde. Previous studies (DeAlteris 2012) attempted to estimate these parameters but failed due to the lack of life-history information on blackspot picarel. Although this species occurs in other regions, its fisheries are not studied, perpetuating the lack of life-history data and assessments. This study provides a preliminary set of data for blackspot picarel that can be used for the region where the species occurs.

Our results suggest a critical state of blackspot picarel in Cape Verde waters, which may require for a precautionary risk-based approach to reduce fishing effort pending further studies to a better understand its biology and the establishment of appropriate management scenarios. As noted for blackspot picarel, the L/F data for mackerel scad (Table 2) in the LBB analysis contained years where the data did not fit the expected pattern, suggesting similar sampling problems.

The LBB results for mackerel scad suggested FL_{inf} = 40.9 cm; this is higher than the first estimate of Almada (1997), at L_{inf} = 31.4 cm, but similar to the estimate in Vieira (2019) of FL_{inf} = 40.6 cm (for K = 0.45 $year^{-1}$), who also presented an estimate of mean length at first maturity (L_m) of 20 cm.

The MSY estimate for mackerel scad obtained in this study, of 2,400 tonnes·$year^{-1}$, is about half of the previous 5,000-6,000 tonnes·$year^{-1}$ by Almada (1997) and 4,700 tonnes·$year^{-1}$ by Stobberup and Erzini (2006). However, it is very close to the recent estimate by DeAlteris (2012) of 2,500 tonnes·$year^{-1}$. This decline of MSY estimates suggests a decline in the carrying capacity of the waters around the Cape Verde islands, possibly due to ocean warming. This phenomenon is affecting fish and fisheries globally (Cheung *et al.* 2013), from the Eastern Mediterranean (Keskin and Pauly 2018) to China (Liang *et al.* 2018). Small pelagic fish such as mackerel scad are susceptible to abiotic changes (Barange *et al.* 2018; Sumaila *et al.* 2011; Castillo *et al.* 1996; Pauly and Keskin 2017), which are exacerbated around islands such as those of the Cape Verde Archipelago. This may explain what appears to be the disappearance of mackerel scad from the waters of the archipelago (Vieira 2019).

Mackerel scad in Cape Verde waters benefits from conservative management measures in addition to those already being applied, i.e., imposing a minimum catch size of 19 cm fork length and a closed season of two months corresponding to the peak of the reproductive season (Tariche and Martins 2009). Similar measures would also help rebuild the stock of blackspot picarel.

Acknowledgements

We thank the *Sea Around Us* team, the Sub-Regional Fisheries Commission for West Africa, and the MAVA Foundation.

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Appendix A: Summary of data on the Cape Verde marine fisheries, 1950-2010.

CAPE VERDE[1]

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Sarah Harper,[a] Kyrstn Zylich,[a] Dirk Zeller,[a] and Daniel Pauly[a]

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Cape Verde is an archipelagic country off northwest Africa (figure 1) with a dry climate that belies the country's name ("Green Cape"), and it imports most of its food. Fisheries are thus important to the 500,000 inhabitants and the growing number of tourists. However, the artisanal and industrial sectors are monitored at only 15% of the landing sites (Stobberup et al. 2005).

In the 1950s and 1960s, the artisanal sector dominated the total catches allocated to Cape Verde's EEZ; however, the industrial sector steadily increased and generated the bulk of the catch by the 2000s (figure 2A). Total domestic catches were estimated by Santos et al. (2012) at about 6,300 t/year between 1950 and 1963 and reached a peak of 30,000 t in 2005 (figure 2A). Overall, domestic catches were 1.9 times the landings supplied to the FAO; the small foreign catches were taken mainly by France and Spain (figure 2B). Catches consisted mostly of mackerel scad (*Decapterus marcellus*), yellowfin tuna (*Thunnus albacares*), and picarels (*Spicara* spp.), whose contribution recently increased (figure 2C). One particularly worrisome aspect of Cape Verdean fisheries is the use of dynamite to augment catches. Although suppressing this form of destructive fishing is difficult, it will have to be done, given the growing importance of local fish to Cape Verdeans.

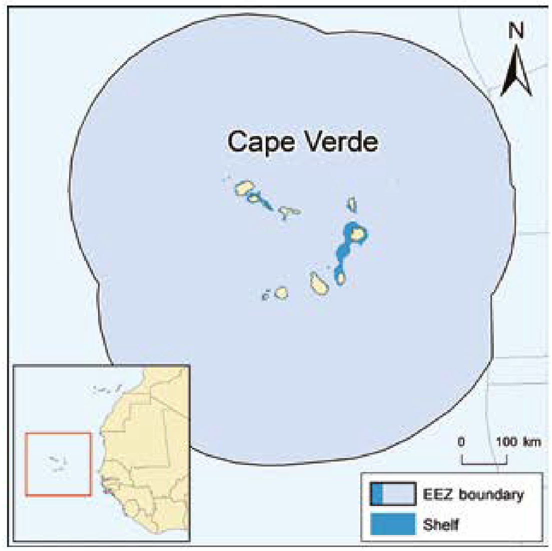

Figure 1. Cape Verde has a total land area of 4,000 km² and an EEZ of 797,000 km².

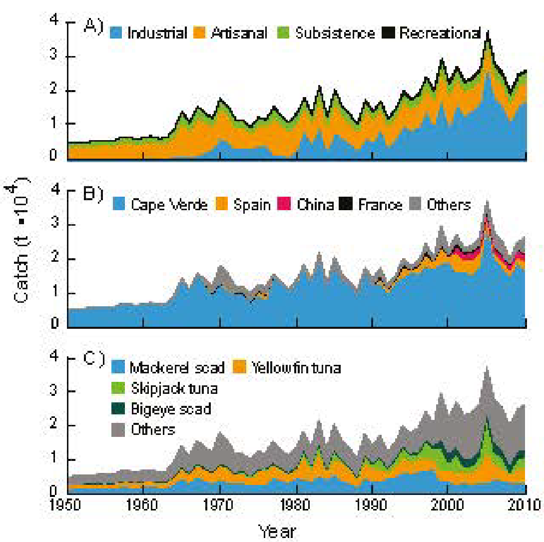

Figure 2. Domestic and foreign catches taken in the EEZ of Cape Verde: (A) by sector (domestic scores: Ind. 1, 1, 4; Art. 4, 4, 4; Sub. 2, 2, 2; Rec. 2, 2, 4; Dis. 2, 2, 2); (B) by fishing country (foreign catch are very uncertain); (C) by taxon.

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Preliminary CMSY stock assessment of bonga shad (*Ethmalosa fimbriata*) in The Gambia[1]

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Abstract

Bonga shad (*Ethmalosa fimbriata*; Family Clupeidae), which is widespread in West Africa, is an important item in the diet of people in The Gambia. Here, we present a stock assessment of bonga shad based on a local catch time series from 2005 to 2018. These catch data were analyzed with the CMSY and BSM methods, the latter complemented by CPUE data. The results that were obtained were very tentative because the available catch data were incomplete. They suggest overfishing, with current B/B_{MSY} = 0.892, F/F_{MSY} = 1.32, and an estimate of MSY of about 15,000 tonnes per year. These and related estimates may be useful as 'priors' to a regional assessment of bonga shad.

Introduction

In 2017, the artisanal sector in The Gambia, contributed 80 % of the domestic marine fisheries landings, most (75 %) of which were small pelagic fish; this continued a long-term trend (see Appendix A). Of this, bonga shad (*Ethmalosa fimbriata*; Family Clupeidae; see Figure 1) is the most important (Marcus 1984; Scheffers *et al.* 1972).

The number of canoes in the artisanal fleet in The Gambia in 2017 was between 1700 and 1800 canoes, which have exclusive fishing rights to waters extending out to 9 nautical miles (nm). Vessels of 250 Gross Registered Tons (GRT) or less are allowed to fish between 9-12 nm. There are no restrictions beyond the 12-mile limit.

The marketing of the artisanal catches involves part of the landed fish being sold wholesale to fish traders for onward retailing to consumers, while another part, such as catfish, bonga shad, and sardinella, is sold to artisanal processors for processing (smoked and/or dried) using processing methods that involve labor-intensive technology, such as salting and sun-drying or smoking with firewood, and that provided numerous livelihoods, primarily to women.

These arrangements, however, have recently changed due to the establishment of much-contested foreign-owned fishmeal production plants for the processing of bonga shad and sardinella (*Sardinella aurita* and *S. maderensis*). This has led to an increase of artisanal fishing effort and a lack of fish for local human consumption (Pauly 2019; see Palomares *et al.* 2020, this vol.). Many fishers targeting small pelagics sell these particular species to the fishmeal factories because of the good price margin compared with the local market; this has induced various disruptions. When the factories are saturated, fish is not processed, resulting in substantial post-harvest losses. The access right given to Senegalese fishers under the Senegal-Gambia fisheries agreement led to an intensification of their effort, due to a similar turn toward fishmeal production in, and export by Senegal (Pauly 2019; Palomares *et al.* 2020, this vol.).

This study aims to provide insights into the current status of the bonga shad stock in The Gambia, and to inform a Northwest Africa regional assessment of the bonga shad resources.

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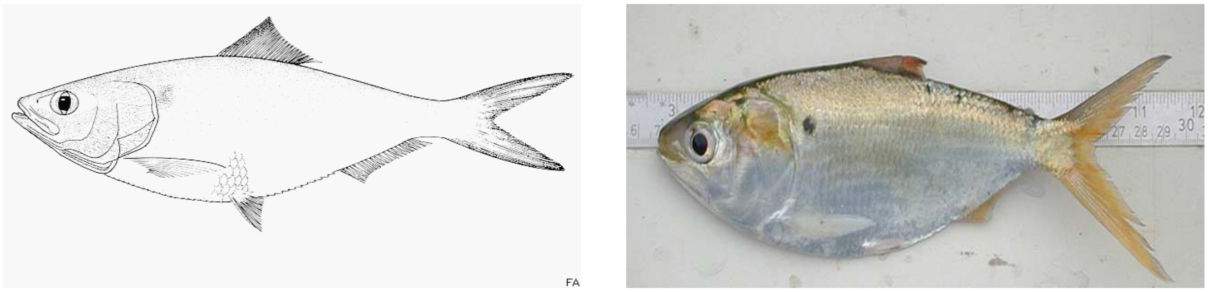

Figure 1. The Bonga shad (*Ethmalosa fimbriata*). Left: FAO morphologically representative line drawing; Right: photo from The Gambia by J-D Durand (images FishBase (www.fishbase.org).

Materials and Methods

Artisanal fisheries catch and effort are estimated through a data collection system called the Catch Assessment Survey (CAS). Data from annual CAS consist of catch and effort statistics from a sample of the fishing units per gear type at a sample of fish landing sites for ten fishing days per month. Altogether, 6 canoes are sampled for 10 fishing days – 5 days in the first fortnight and 5 days in the second fortnight each month. Three raising factors are applied (landing, frame, and time) derived by dividing the number sampled by the total number of landing sites, canoes, and fishing days, or dividing the number of active boats by those sampled. The raising factor for months was determined by dividing the numbers of days in the month by the number of days sampled to aggregate the monthly estimate. Table 1 presents the artisanal catch of bonga shad and effort data used here for our CMSY and BSM analyses (Froese *et al*. 2016; see Palomares *et al*. 2020, this vol. for details). These data do include landings sold directly to fishmeal plants, which introduces enormous uncertainly in the analyses presented here.

Table 1. Catch[a] and effort of the artisanal fishery for bonga shad (*Ethmalosa fimbriata*) in The Gambia.

Year	Catch (t)	Effort (trips)
2005	14978	24783
2006	13187	19890
2007	13876	21760
2008	11743	24990
2009	12577	26880
2010	12586	33170
2011	15661	36992
2012	14052	37584
2013	11098	21068
2014	16881	27479
2015	17559	24951
2016	15060	19329
2017	28446	54576
2018	17724	32952

a) Note that these catches are incomplete (see text).

Results and Discussion

Figure 2 shows the results of our preliminary assessments of bonga shad (*Ethmalosa fimbriata*) along the coast of The Gambia; this analysis suggesting that bonga shad is slightly overexploited, with current $B/B_{MSY} = 0.892$, $F/F_{MSY} = 1.32$ and an estimate of MSY of about 15,000 tonnes·year^{-1}.

However, the data's incompleteness in Table 1 suggests that these results are very tentative, and should be reassessed with a more complete catch time series, which includes bonga shad delivered directly to fishmeal plants.

Acknowledgments

Thanks are due to the MAVA Foundation and the Sub-Regional Fisheries Commission for West Africa for the opportunity to participate in the workshop that led to this contribution, and to the four *Sea Around Us* team members who acted as instructors to the course.

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Pauly, D. 2019. Micronutrient richness of global catches. *Nature*, 574: 41-42. doi.org/10.1038/d41586-019-02810-2.

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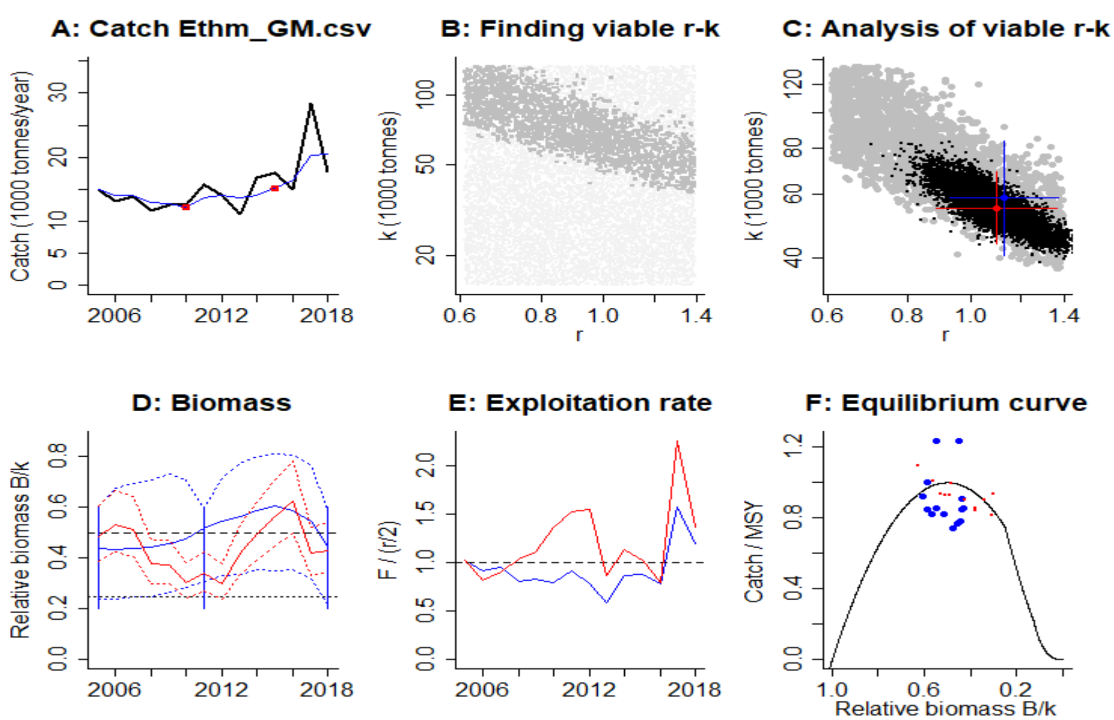


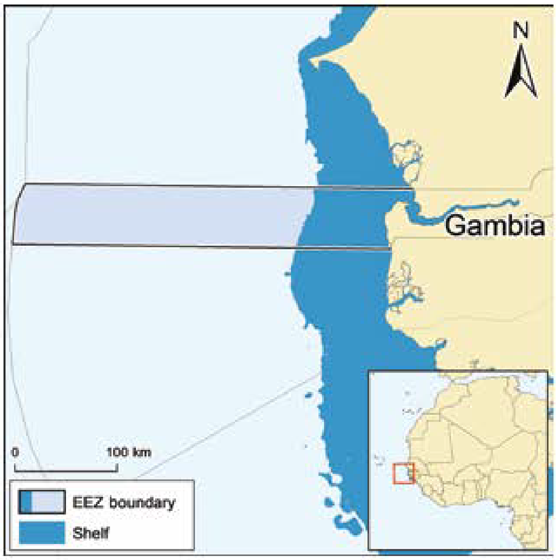
Figure 2 Illustrating the CMSY and BSM assessments of bonga shad (*Ethmalosa fimbriata*) in The Gambia, based on the catch data in Table 1 (incl. the CPUE data, used for the BSM analysis; see red lines and dots). As might be seen, these assessments suggest a slight overfishing, which is likely to be overoptimistic because the catch data are incomplete (see text).

Appendix A: Summary of data on the marine fisheries of The Gambia 1950-2010.

GAMBIA[1]

Dyhia Belhabib,[a] Asberr Mendy,[b] Dirk Zeller,[a] and Daniel Pauly[a]

[a]*Sea Around Us*, University of British Columbia, Vancouver, Canada [b]Commission Sous-Régionale des Pêches, Dakar Sénégal



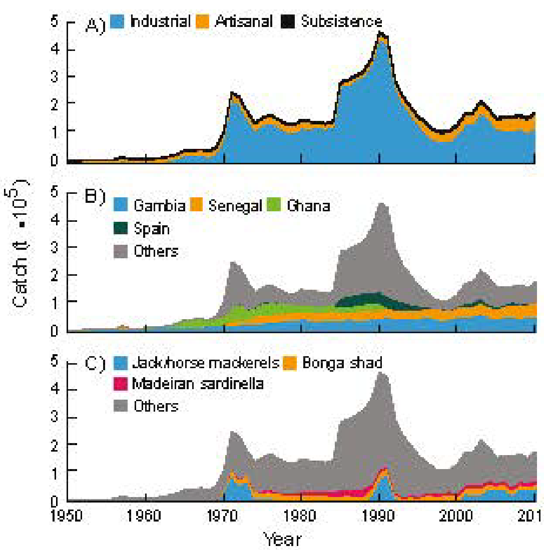


Figure 1. The Gambia has an average width of 32 km, and its EEZ, of 22,700 km², is similarly narrow; its shelf covers 5,810 km².
Figure 2. Domestic and foreign catches taken in the EEZ of The Gambia: (A) by sector (domestic scores: Ind. 3, 3, 3; Art. 2, 3, 3; Sub. 2, 3, 3; Rec. 2, 2, 3; Dis. 2, 3, 3); (B) by fishing country (foreign catches are very uncertain); (C) by taxon.

The Gambia ("the Smiling Coast of Africa") is one of Africa's smallest coastal states. Despite the small size of the Gambian EEZ (figure 1), the catch of the legal and illegal foreign fisheries, reconstructed by Belhabib et al. (2013), is high. Industrial catches (including discards) contributed the bulk of the total reconstructed withdrawals, and the artisanal and subsistence fisheries (much of the latter involving women gathering shellfish along the mangrove-lined banks of the Gambia River) generated smaller contributions (figure 2A). The rest is contributed by a nascent recreational fishing industry catering to foreign tourists. Gambian domestic catches, on the other hand, increased from 5,700 t in 1950 to 47,000 t by 1980 and oscillated between 46,000 and 66,000 t/year in the 2000s. Overall, domestic catches are 2.5 times the data submitted to the FAO (see also Behabib et al. 2015). Total allocated catch in the EEZ is predominantly from foreign vessels such as those of Senegal, Ghana, and Spain (figure 2B). Despite a massive industrial trawl fishing effort (especially in the 1980s and 1990s), the key species in The Gambia continue to be horse mackerels (*Trachurus* spp.) and bonga shad (*Ethmalosa fimbriata*), a locally popular species roughly similar to herring (figure 2C). However, its catch is declining, which, along with climate change (Jaiteh and Sarr 2011), further jeopardizes food security in The Gambia, notably by increasing fish prices, and threatens the thousands of jobs these fisheries generate.

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Stock assessment of bonga shad (*Ethmalosa fimbriata*) and bobo croaker (*Pseudotolithus elongatus*) in Guinean waters[1]

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Abstract

Bonga shad (*Ethmalosa fimbriata*) and bobo croaker (*Pseudotolithus elongatus*) are important fishery resources in Guinean coastal waters. Their biology and distribution are briefly presented. The status of their fisheries in Guinea is assessed using the LBB and CMSY/BSM methods for bonga shad, and the CMSY/BSM methods for bobo croaker. Both species show strong overfishing symptoms and require a reduction of fishing effort to attain the biomass level that would lead to sustainable, higher catches, i.e., MSY.

Introduction

The West African Republic of Guinea has a wide continental shelf of 43,000 km², making up about 40 % of its Exclusive Economic Zone (EEZ) of 109,000 km² (Figure 1; see also Appendix A). Fishing is important in Guinea; it is a major source of livelihood and food security for the Guinean population (Chavance *et al*. 2004; and see contributions in Domain *et al*. 1999). Bonga shad (*Ethmalosa fimbriata*; Figure 2, left panel) and bobo croaker (*Pseudotolithus elongatus*; Figure 2, right panel) are economically and nutritionally the most valuable species within Guinean waters. The artisanal fishery mainly targets these stocks, and this study aims to assess their status using the LBB and CMSY/BMS methods.

Bonga shad (*Ethmalosa fimbriata*) belongs to the Clupeidae Family and ranges from Mauritania to Angola (see FishBase; www.fishbase.org). Bonga shad, which mainly occurs in shallow coastal areas at 0 to 20 meters depth, is a euryhaline species often found around large rivers' mouths. It can spend part or all of its life in the myxohaline zones of rivers, estuaries, delta and lagoons (Bah *et al*. 1991; Dominique 1982). Figure 3 illustrates the distribution of bonga shad fishing grounds in Guinea.

Bobo croaker (*Pseudotolithus elongatus*) is a species of the Family Sciaenidae; this species occurs along the coast of West Africa from Senegal to Angola. Bobo croaker is a critical marine living resource in Guinea, targeted by benthic trawlers, nets, beach seiners, and lines. It is sold fresh, salted, dried or smoked. Some of the catch is exported to Asian countries.

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[1] Cite as: Soumah, M., O.T. Camara and A.I. Bah. 2020. 2020. Stock assessment of bonga shad (*Ethmalosa fimbriata*) and bobo croaker (*Pseudotolithus elongatus*) in Guinean waters, p. 22-31 *In:* M.L.D. Palomares, J. Woroniak, M. Khalfallah and D. Pauly D (eds.) *Assessments of marine fisheries resources in West Africa with emphasis on small* pelagics. Fisheries Centre Research Report 28(4), UBC, Vancouver, Canada.

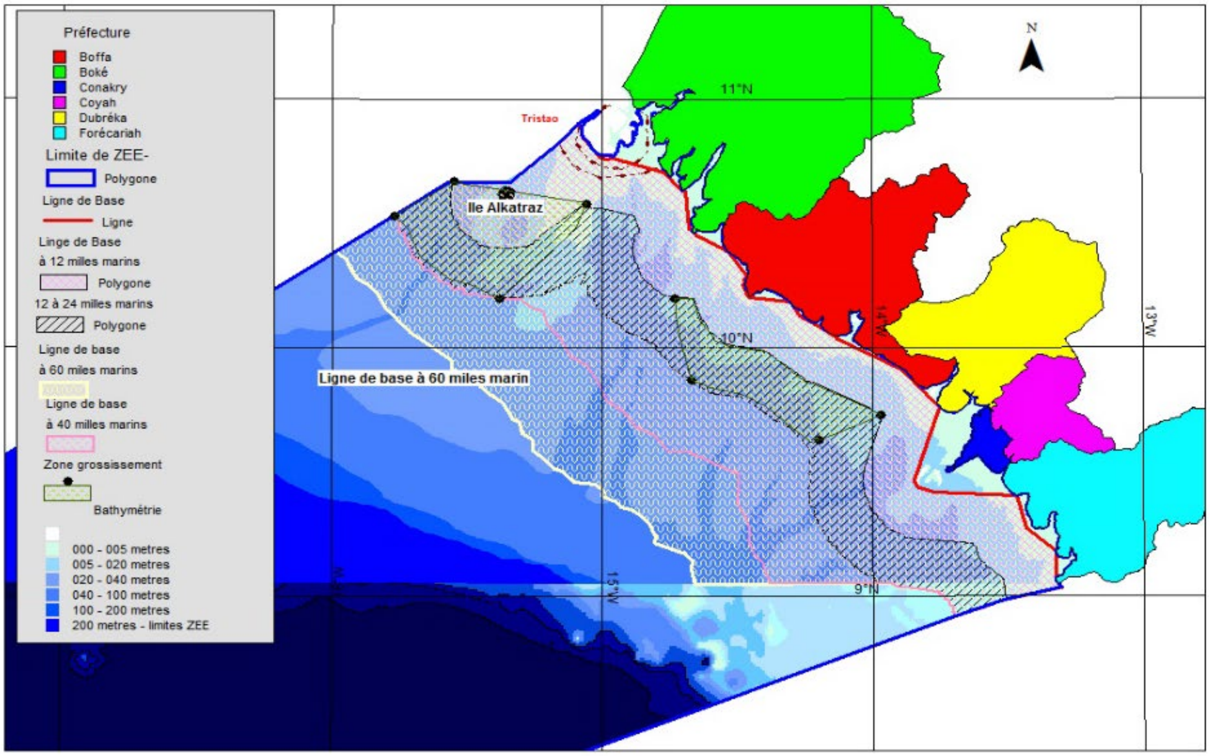

Figure 1. The Exclusive Economic Zone (EEZ) and coastal population of Guinea (from Domain et al. 1999).

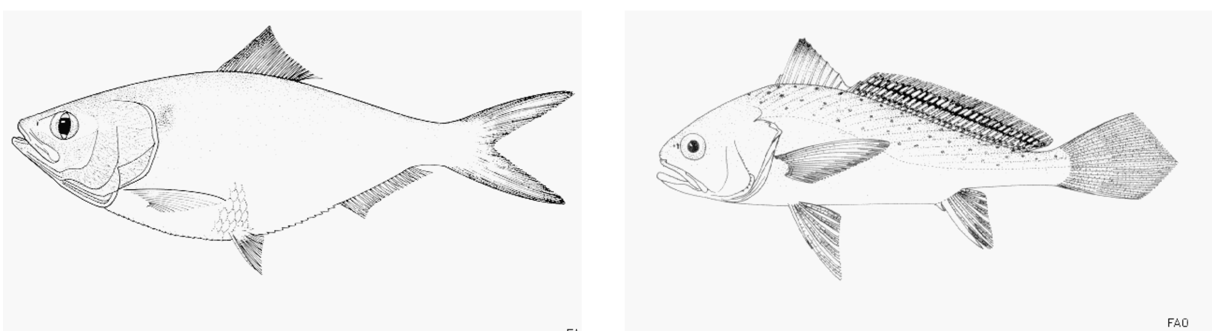

Figure 2. FAO morphologically representative line drawings of the Bonga shad (*Ethmalosa fimbriata*, left panel) and of the bobo croaker (*Pseudotolithus elongatus*, right panel) (images FishBase (www.fishbase.org).

Bobo croaker is euryhaline, and thus its juveniles usually occur in coastal areas of low salinity and river estuaries. In Guinea, they occur in the Rio Corubal and Nunez Rivers estuaries in the north, Konkouré near Conakry, and the Mellacorée River in the south (Domain 1989). On the other hand, the adults are further offshore, some of them having been caught at depths of up to 37 m (Gascuel *et al.* 2004). Some spawning seems to occur throughout the year. In Guinea, the length at which 50 % of the bobo croaker become mature is 26 cm, and by 35 cm, 100 % are mature. Most of the catch consists of individuals between 6 and 38 cm (Sidibé 1998). Figure 3 illustrates the fishing grounds of some the Guinean marine fisheries.

Materials and Methods

The catch data used here are from the National Center for Fisheries Sciences of Boussoura (CNSHB). This institution was created in 1995, with the support of the Research Institute for Development (IRD), to collect artisanal catch data from landing sites sampled along the Guinean coast and industrial catch data via scientific observers on board of authorized industrial fishing vessels.

The artisanal fishery sampling system is based on several parameters: the geographic strata, the vessel types, and fishing activity (e.g., fishers being full- or part-time), with samples collected once every 10 days. In 2017, the sampling system was reviewed with a monthly follow-up of 15 days at each sampled site.

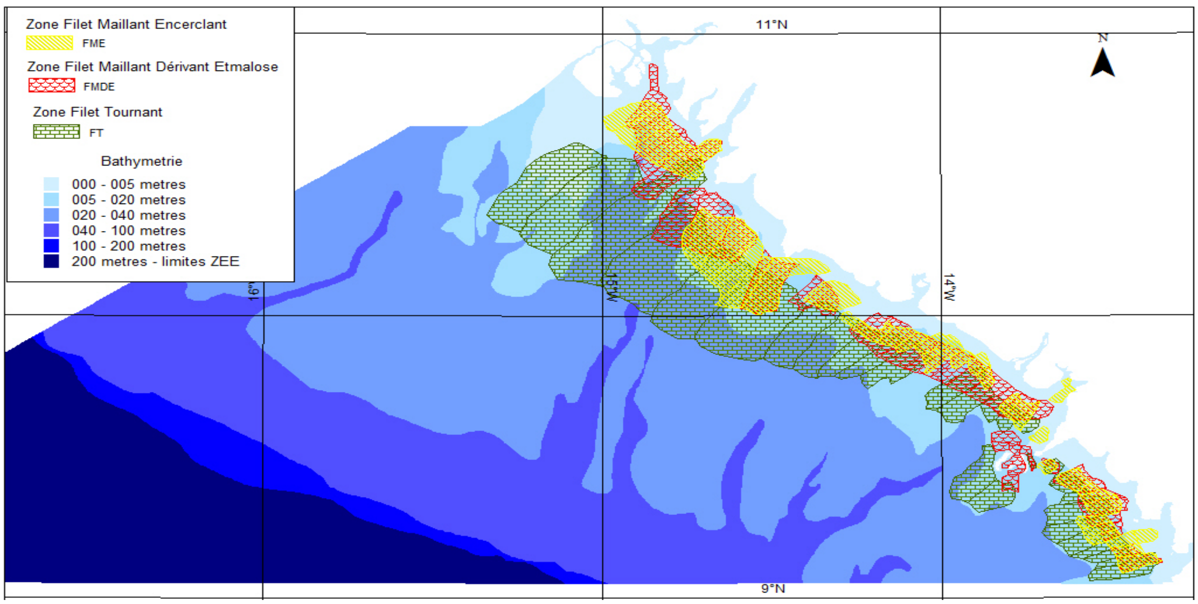

Figure 3. Fishing grounds off the Guinean coast (from Domain *et al*. 1999). The color yellow shows the areas where surrounding gill nets are deployed; the red color shows where drift netting for bonga shad occurs; the blue colors refer to different depths.

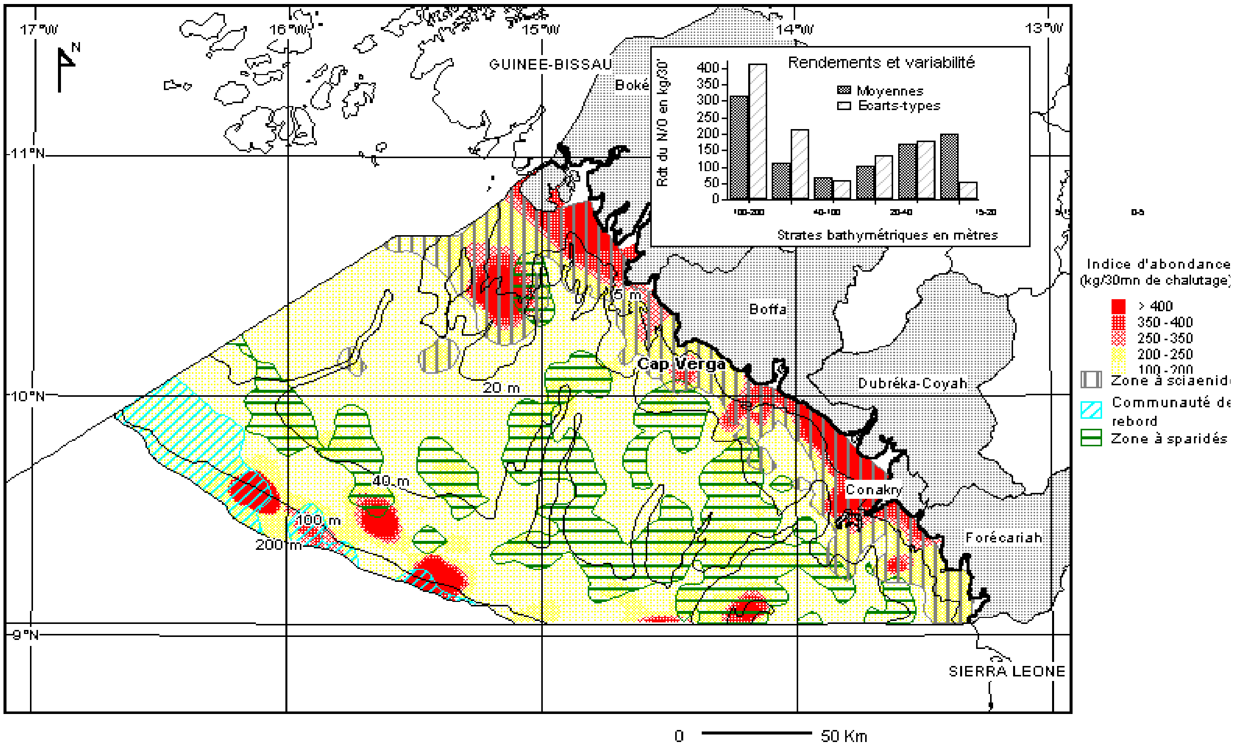

Figure 4. Illustrating the main fishing grounds of demersal fish in Guinea, with emphasis on the Sciaenidae (from Domain *et al.* 1999).

For the industrial fishery, all licensed vessels take scientific observers onboard who systematically collect catch and fishing effort data. Examples of the length-frequency (L/F) data collected in the process are given in Tables 1 and 2. Table 3 presents the catch data used in our analyses.

The LBB method requires only length-frequency data and a few priors to estimate asymptotic length (L_{inf}), mean length at first capture (L_c), relative natural mortality (M/K), and relative fishing mortality (F/M) as an average for the age groups represented in the length-frequency sample. The priors were generated by the software implementing the LBB method and need not be documented here. The output parameters allow the estimation of current to unexploited biomasses (B/B_0) (Froese *et al.* 2018; see Palomares *et al.* 2020, this vol.).

Table 1. Length-frequency data sampled in 2018 for bonga shad in Guinea.

Length (mm)	Frequency	Length (mm)	Frequency
40	77	230	4630
50	215	240	6708
60	603	250	5043
70	735	260	4673
80	703	270	3275
90	473	280	3226
100	187	290	2295
110	196	300	2046
120	513	310	1047
130	528	320	578
140	1036	330	253
150	1102	340	167
160	1549	350	71
170	1892	360	47
180	2311	370	27
190	3114	380	9
200	4112	390	21
210	3508	400	11
220	3912	--	--

Table 2. Catch (tonnes) data for bonga shad and bobo croaker in Guinea, 1995-2018.

Year	Bonga shad	Bobo croaker
1995	23,596	4,350
1996	26,051	3,841
1997	29,529	6,639
1998	27,852	4,898
1999	16,890	3,679
2000	29,015	8,822
2001	38,454	9,974
2002	36,450	9924
2003	52,788	13,763
2004	32,438	9,300
2005	12,577	8,257
2006	26,726	9,726
2007	27,870	5,514
2008	32,935	8,288
2009	48,342	9,684
2010	39,402	8,084
2011	46,593	8,245
2012	59,653	6,243
2013	74,924	7,312
2014	53,988	4,236
2015	33,052	3,289
2016	65,003	6,773
2017	96,954	10,257
2018	72,645	7,270

The CMSY method (Froese *et al.* 2017) estimates key fishery reference points (MSY, F_{MSY}, B_{MSY}), the relative size of the stock (B/B_{MSY}) from a time series of catch data and ancillary information. This information consists of 'priors' for the intrinsic population growth rate (r) and for stock biomass relative to carrying capacity (k), i.e., unexploited biomass (B_o). Other priors are the relative biomasses at the start of the period for which catch data are available (B_{start}/k), at some intermediate year (B_{int}/k), and at the end of the catch time series (B_{end}/k). The priors used here were those generated by the software implementing the CMSY method and need not be documented here (but see Palomares *et al.* 2020, this vol.).

Results and Discussion

The available L/F data did not allow application of the LBB method to bobo croaker and thus was used only for bonga shad (Figure 5).

The LBB method yielded estimates of the ratios M/K = 1.14 (0.862-1.36) and F/M = 4.77 (4.24-5.72), respectively, with confidence intervals of 95 %. The relative biomass is evaluated at B_{end}/k = 0.11 (0.073-0.16).

Figure 6 summarizes results graphically of the CMSY analysis for bonga shad (see Table 4 for numerical results). The Kobe plots in Figure 8 summarize the data in Figures 6 and 7.

Based on the above results and given the importance of food and livelihood security for the Guinean population of bonga shad, bobo croaker, and other fish likely to be similarly overfished, it appears necessary to improve the management of the fisheries targeting these.

Thus, we recommend the following:

- Strict enforcement of regulations on fishing gear, prohibiting the use of monofilament and small-mesh nets;
- Improvement and encouragement of fishing effort data collection;
- Sharing information on the state of stocks with all the stakeholders;
- Raising awareness and involve fishers in the co-management of the fishery resources;
- Limit fishing effort, especially in the estuaries where juveniles reside;
- Limit the activities of non-selective gears and monitor the mesh sizes;
- Apply precautionary measures; do not exceed the mean annual catch of the last 5 years.

Table 3. Length-frequency data sampled in 2018 for bobo croaker in Guinea.

Length (mm)	Frequency	Length (mm)	Frequency
5	5	27	489
7	14	29	253
9	5	31	202
11	30	33	366
13	37	35	1025
15	403	37	1257
17	1391	39	1229
19	2127	41	929
21	1538	43	898
23	2219	45	231
25	1033	47	105

In terms of increasing the involvement of stakeholders in the management of the bonga shad stock, and small pelagics in general, we recommend the following:

- Facilitate the importation and marketing of fishing gears that meet sustainability standards;

- Encourage the construction of fish smoking centers equipped with improved "chorkor-type" smokehouses that consume little wood, respect the environment, provide better smoking quality and help protect the workers' health.

Table 4. Numerical results of CMSY stock assessments of bonga shad and bobo croaker in Guinean waters (with 95% confidence interval).

Parameter	Units	Bonga shad	Bobo croaker
r (resilience)	year^{-1}	1.13 (0.98-1.37)	0.73 (0.68-0.78)
k (Carrying capacity	t·10^3	199 (131-299)	44 (38-52)
MSY	t·10^3	58 (36-86)	8.1 (6.8-9.7)
B_{end}/B_0	--	0.37 (0.12-0.5)	0.29 (0.03-0.39)

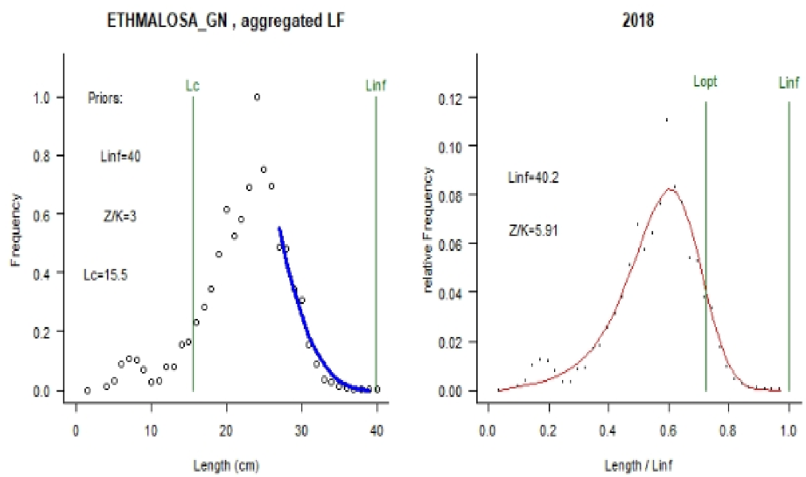

Figure 5. Application of the LBB method to length-frequency data from the fishery for bonga shad in Guinean waters for the years 2010 (left) and 2018 (right).

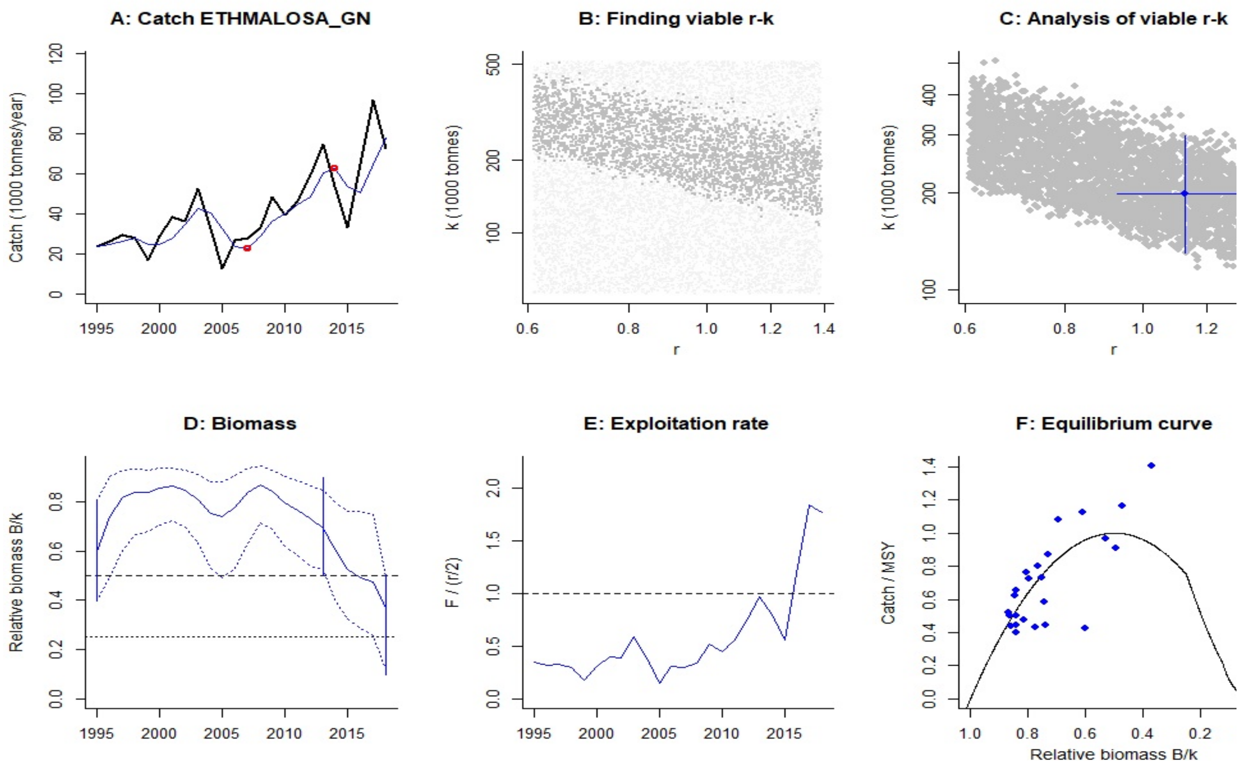

Figure 6. Graphical representation of the CMSY result for bonga shad in Guinea (see also Table 4).

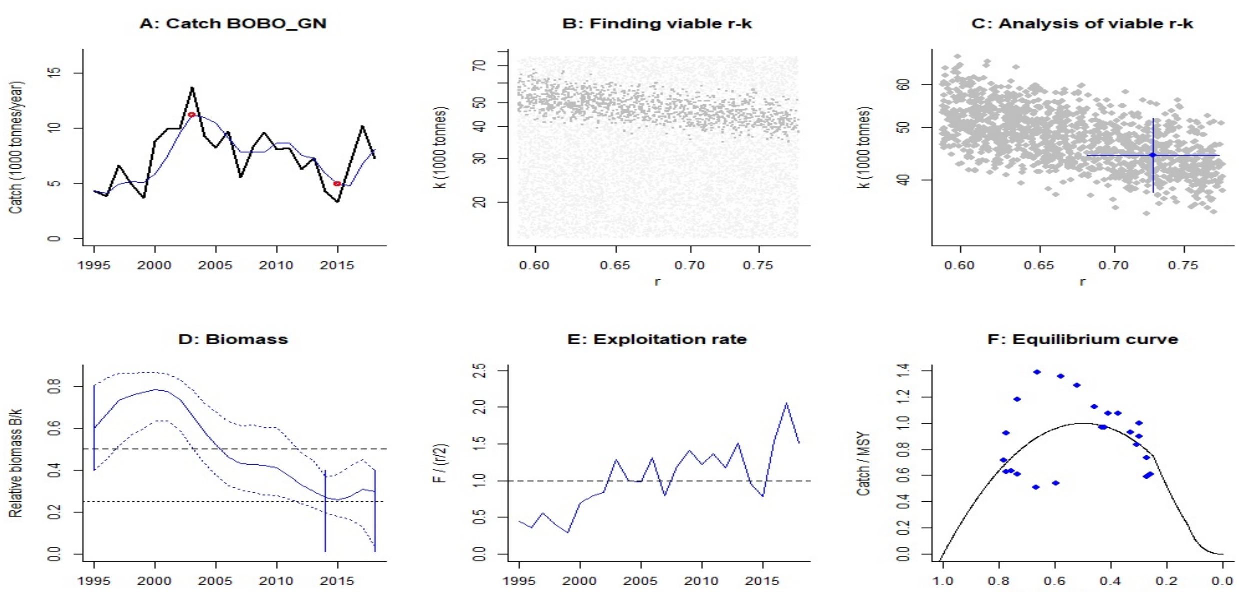

Figure 7. Graphical representation of the CMSY result for bobo croaker in Guinea (see also Table 4).

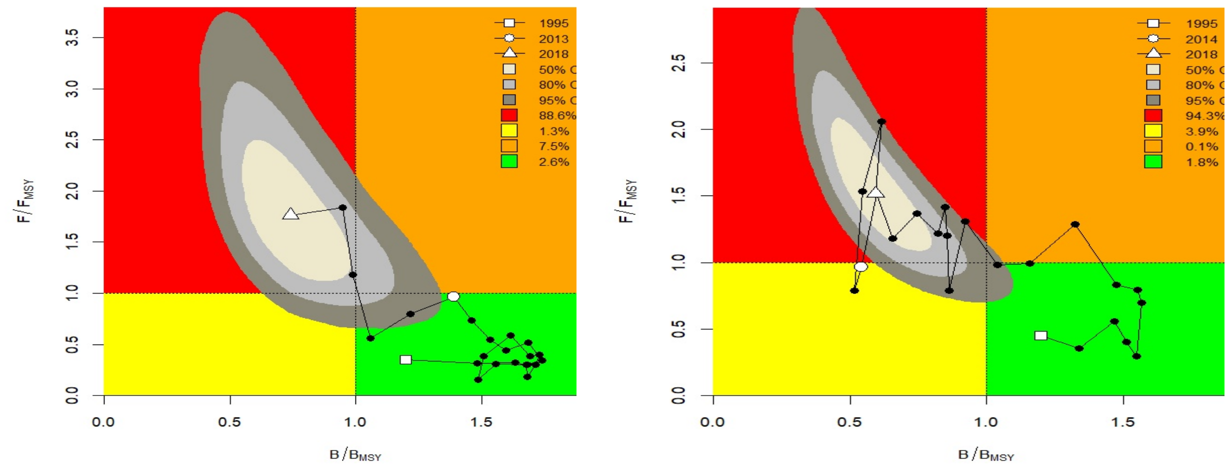

Figure 8. Kobe plots for 2 species caught in Guinean waters: (left panel) bonga shad, summarizing the data in Figure 6 and Table 4; and (right panel) bobo croaker, summarizing the data in Figure 7 and Table 4.

Acknowledgements

We thank the *Sea Around Us* team, the Sub-Regional Fisheries Commission for West Africa, and the MAVA Foundation.

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Appendix A: Summary of data on the marine fisheries of Guinea, 1950-2010.

GUINEA[1]

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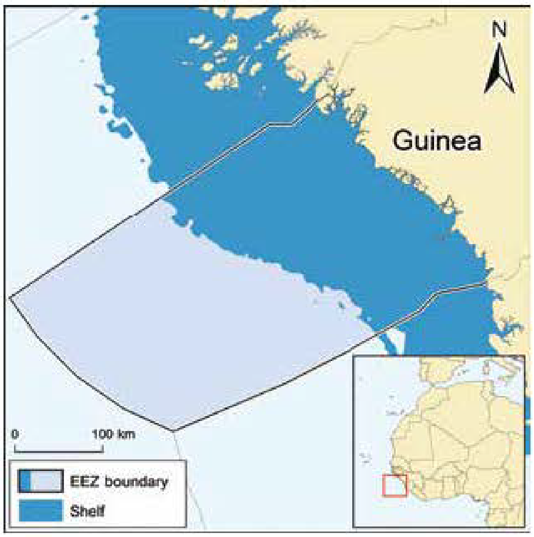

Figure 1. Guinea has a continental shelf of 50,000 km² and an EEZ of 109,000 km².

Guinea is a poor country in northwest Africa that has the largest continental shelf in the region (figure 1). However, only part of the artisanal and industrial domestic fisheries catches is officially reported (Domain 1999). Industrial, artisanal, and subsistence catches along with discards by the domestic and foreign legal and illegal fisheries were reconstructed by Belhabib et al. (2012). Industrial catches dominate total removals in Guinea's EEZ (figure 2A). The reconstructed domestic catch was 48,000 t in 1950, reached a peak of 178,000 t in 1985, and declined to 126,000 t in 1999, followed by an increase to about 230,000 t in 2010. Reconstructed domestic catches were 4 times the data supplied to the FAO, yet this was only a small component of the removals from Guinea's EEZ, at least when compared with the foreign fishing by, for example, Spain and Russia (figure 2B). Figure 2C summarizes catches by taxa, dominated by cephalopods (largely from foreign vessels), bonga shad (*Ethmalosa fimbriata*), and other small pelagic species (e.g., *Sardinella* spp.). Overexploitation and the lack of monitoring of foreign fleets have negative repercussions for local fishing communities, which are expanding their fishing grounds to catch fish whose individual size is shrinking. All of this is inducing massive changes in the structure and functioning of the ecosystem (Laurans et al. 2004), as indicated also by the occurrence of the "fishing down" phenomenon.

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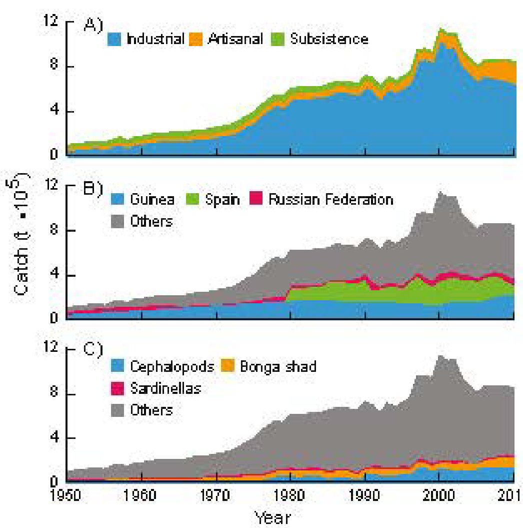

Figure 2. Domestic and foreign catches taken in the EEZ of Guinea: (A) by sector (domestic scores: Ind. 2, 4, 2; Art. 2, 3, 4; Sub. 2, 2, 2; Dis. 4, 4, 4); (B) by fishing country (foreign catches are very uncertain); (C) by taxon.

Assessment of the lesser African threadfin (*Galeoides decadactylus*) and southern pink shrimp (*Farfantepeneaus notialis*) in Guinea-Bissau[1]

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Abstract

This contribution presents an analysis using the catch-only CMSY method and the BSM method, to assess the stock of lesser African threadfin or '*barbinho*' (*Galeoides decadactylus*) and the southern pink shrimp stock (*Farfantepeneaus notialis*), both caught in the north of Guinea-Bissau's Exclusive Economic Zone. For *G. decadactylus,* maximum sustainable yield (MSY) was estimated at 3,189 tonnes·year^{-1} (95 % CI: 2,834-3,588), with B_{MSY} = 11,330 (CI: 9,013-14,245); current catches (4,554 t in 2018) exceed the estimated MSY. The stock of *F. notialis* was also found to be overexploited. Unless fishing pressure is reduced, the rapid decline in biomass of these two species will continue.

Introduction

Guinea-Bissau, which has an Exclusive Economic Zone (EEZ) of 36,125 km^2, is in West Africa and shares a border with Senegal in the Northwest and with Guinea in the East (see Appendix A). Many marine fish species are heavily exploited by industrial, artisanal, subsistence, and recreational marine fisheries (see www.seaaroundus.org).

This study concerns itself with two species; first is the lesser African threadfin, or '*barbinho*' (*Galeoides decadactylus*), a member of the family Polynemidae. This threadfin is widespread at depths of 10-70 m along African coastlines from Algeria and Morocco in the North to Angola and Namibia in the South (Daget 2003; Motomura 2004; Njock 1990; Sanches 1991; see also FishBase; www.fishbase.org). In Guinea-Bissau, *G. decadactylus* occurs along the northern coast and is caught by both the artisanal fisheries and as bycatch of the industrial shrimp trawling fleet. It is the second most important species in the marine fisheries catch of Guinea-Bissau, to which it has contributed about 4 % since 2000.

The second species is the southern pink shrimp (*Farfantepenaeus notialis;* ex. *Penaeus notialis*), which has a wide distribution on both sides of the Atlantic. In the West, it ranges from the Caribbean to Cabo Frio in Brazil. In the East, it ranges along the coast of West Africa, from Mauritania to Angola (Alioune 2015; Holthuis 1980; Schneider 1990; Showers 2012; see www.sealifebase.org).

In the Exclusive Economic Zone (EEZ) of Guinea-Bissau, this shrimp is most abundant between 11°30′ and 12°50′ North and 17°00′ and 17°30′ West. The adults prefer temperatures below 24°C and salinities of 35 psu. Currently, *Farfantepenaeus notialis* is one of the most valuable commercial shrimp species in Guinea-Bissau. Some of its catches originate from the Cache River's estuary and are marketed both locally and in neighboring Gambia and Senegal.

[1] Cite as: Barri, I, J. Pinto Gomes and S. Sadibo Mané. 2020. Assessment of the lesser African threadfin (*Galeoides decadactylus*) and southern pink shrimp (*Farfantepeneaus notialis*) in Guinea-Bissau, p. 32-37 *In:* M.L.D. Palomares, J. Woroniak, M. Khalfallah and D. Pauly (eds.) *Assessments of marine fisheries resources in West Africa with emphasis on small pelagics*, Fisheries Centre Research Report 28(4), UBC, Vancouver, Canada.

Material and methods

The catch and related data on the lesser African threadfin originate from industrial trawlers ranging in length from 18 to 60 m using mesh sizes of about 70 mm. These data were obtained by onboard observers keeping daily records of the number and duration of hauls, days fishing, areas and depths fished, and ultimately total catches. The observers measure individual fish and hence generate critical data for assessing any species caught by the industrial fishery. Unfortunately, an equivalent procedure for generating catch and related data from artisanal fisheries doesn't exist. The limited information available from the artisanal fisheries is based on local names, which do not distinguish between species such as the lesser African threadfin and its relatives.

The data used for assessing southern pink shrimp were extracted for the years 2000 to 2018 from Guinea-Bissau's *Yearbook of Fisheries Statistics* and originate from observers' reports onboard industrial fishing vessels. These data were subsequently encoded via Microsoft Excel by the Department of Statistics, Information, and Publications of the Center for Applied Fisheries Research (*Centro de Investigação Pesqueria Aplicada*, or CIPA) of the Fisheries Ministry.

The CMSY method consists of identifying, from a range of likely values of r and k, those pairs of values generating biomass trajectories that are compatible with observed catch time series and constraints ("priors") and express current knowledge about a fishery (Table 1; see Froese *et al.* 2016, and Palomares *et al.* 2020, this vol.).

Table 1. Priors used to constrain the biomass trajectory of *G. decadactylus* in the EEZ of Guinea-Bissau.

Constraint	Low	High	Source
Resilience[a]	0.32	0.73	FishBase
B_{end}/k	0.048	0.083	LBB
B_{end}/k	0.01	0.30	
B_{int}/k	0.01	0.50	
B_{start}/k	0.20	0.60	

a) Resilience refers to r, the intrinsic rate of population growth.

The prior for r (=resilience) for *G. decadactylus* was 0.49 year^{-1} (range 0.32-0.73 year^{-1}) from FishBase (www.fishbase.org), based on its major traits (maximum length, growth parameters, fecundity, etc.). While the catch time series starts in 2000, it can be safely assumed that the fishery began much earlier. In the 1970s and 1980s, both Portuguese and Spanish trawlers were operating in the waters of Guinea-Bissau. It can be assumed that the biomass of *G. decadactylus* was already substantially lower than carrying capacity. Also, we assumed a biomass between 0.2 and 0.6 of carrying capacity in 2000, with relative biomass (B/k) ranging between 0.01 and 0.5 in 2010, and 0.01 and 0.3 in 2018.

Based on an application (not shown) of the LBB method (Froese *et al.* 2018) to a set of length-frequency data, we obtained a range of 0.048 to 0.083 for the ratio that serves here as a prior on B_{end}/k, i.e., the fraction of the carrying capacity remaining in 2018. Finally, a time series of catch-per-effort (CPUE) data ranging from 2000 to 2016 was introduced into the analysis, thereby allowing a transition from the catch-only CMSY method to the slightly more elaborate BSM methods (Froese *et al.* 2017).

The application of the CMSY method to southern pink shrimp followed the same methodology.

Results and Discussion

Figure 1 summarizes the results for *G. decadactylus*; its Panel C shows the blue cross close to the red cross, which signifies that the CPUE data (and the results of the BSM method) are compatible with those of the CMSY method, which doesn't use CPUE data. This reasonably good match between the estimated biomass trajectory and the CPUE series is illustrated in Panel D, with Panel E furnishing additional evidence. The dot around and especially above the BSM equilibrium curve suggests, as does Panel E, that *Galeoides decadactylus* is currently heavily overfished, and that the downward trend in its biomass (Panel D) will accelerate if fishing effort is not reduced.

Well-managed, this fish could produce an estimated MSY of 3,189 tonnes·year^{-1}. However, this would require reducing the current exploitation rate. The uncertainty due to the non-availability of reliable artisanal catch data makes it impossible to provide more detail about this stock.

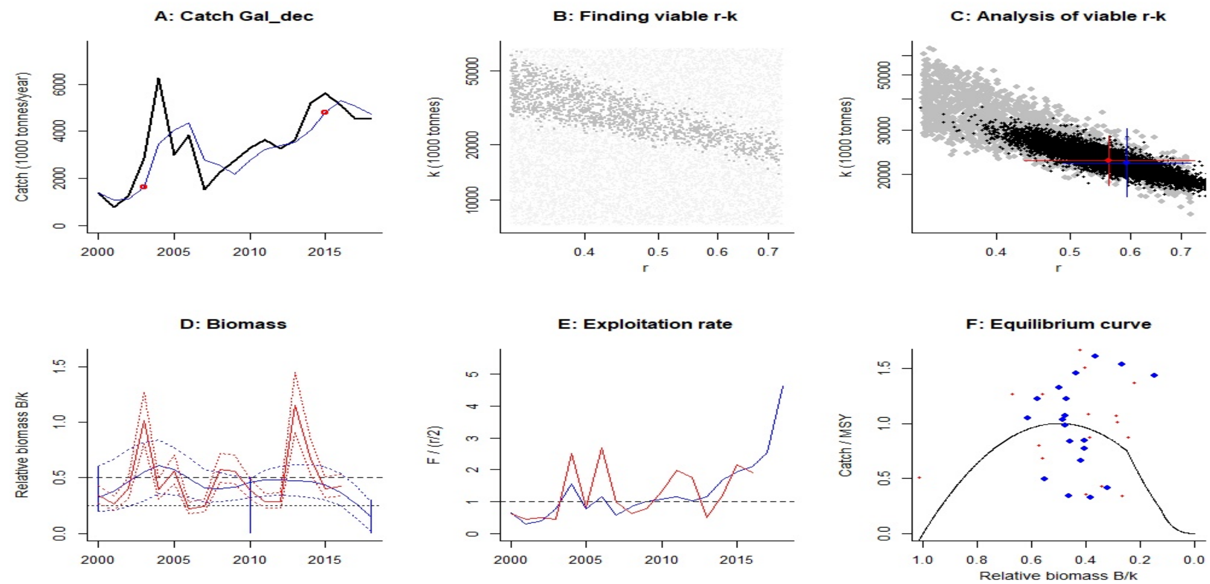

Figure 1. Stock assessment of lesser African threadfin (*Galeoides decadactylus*) in Guinea-Bissau using the CMSY BSM method (see text).

Figures 2 and 3 summarize our results with regards to southern pink shrimp. The catch data show a clear peak in 2004 (Figure 3A), which also saw a high level of fishing effort. This high catch appears to have depleted the stock (Figure 2D), whose biomass declined after that, despite the much-reduced catches.

However, this likely dynamic is not corroborated by the trend in CPUE, which exhibits a marked peak in 2010 (Figure 2D). This mismatch is why the blue and read crosses are quite distant from each other (Figure 2C), which suggests that the BSM model that usually reduces the uncertainty of the CMSY method has failed to do so here.

Nevertheless, the stock of *F. notialis* in the North of Guinea-Bissau appears to be overfished (see Figures 2D and 3). We recommend a more in-depth analysis, perhaps with a longer catch time-series and a different or verified CPUE time-series. However, we anticipate that the results will be similar, indicating the need to reduce effort.

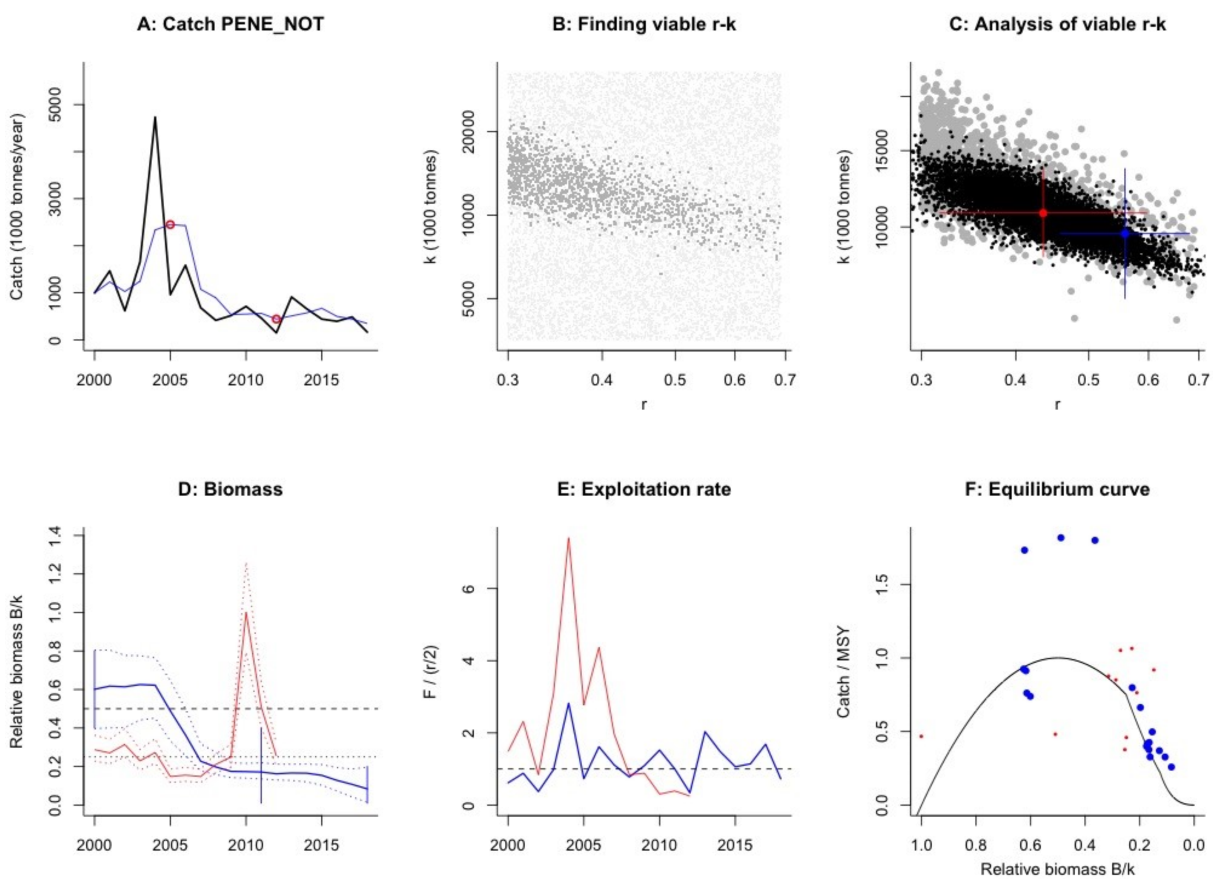

Figure 2. Result of CMSY and BMS stock assessment of southern pink shrimp (*Farfantepenaeus notialis*) in the north of the EEZ of Guinea-Bissau. Panel A documents the catches used for the assessments; the cross, lines and dots in red refer to the BSM analysis, and are derived from the CPUE series in Panel D (see text).

Acknowledgments

Our thanks go to the Minister for Fisheries, Dr. Maria Adiato Nandigo, for her support of Guinea-Bissau's Fisheries Observers Program, and to the Director General of CIPA for his implementation of this program. We also thank the Sub-Regional Fisheries Commission for West Africa and the MAVA Foundation for enabling our participation in the course during which this paper was written, and the *Sea Around Us* team – Drs. M.L.D. Palomares, M. Khalfallah, and D. Pauly and Ms. J. Woroniak – for their assistance in performing our analysis and translating and editing our contribution.

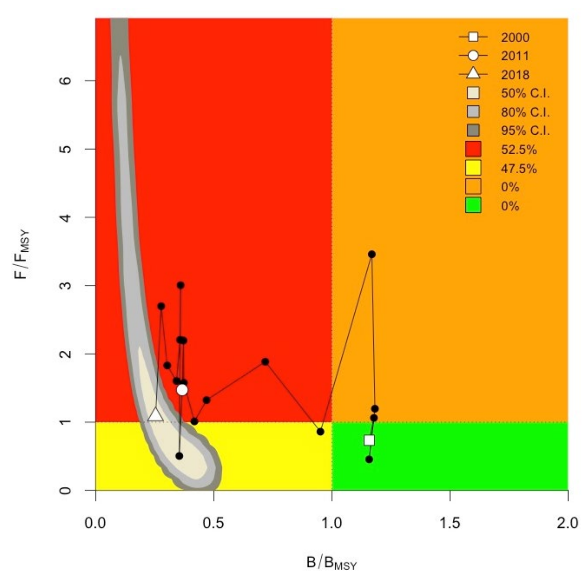

Figure 3. Kobe Plots showing – in different form – the data of Panel D and E of Figure 3 on southern pink shrimp (*Farfantepenaeus notialis*) in the north of the EEZ of Guinea-Bissau (see text).

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Appendix A: Summary of data on the marine fisheries of Guinea-Bissau, 1950-2010.

GUINEA BISSAU[1]

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Guinea Bissau, located in northwest Africa (figure 1), has a large continental shelf adjacent to an intricate lagoon system, whose productivity is enhanced by a coastal upwelling and riverine nutrients, respectively. These are optimal conditions for coastal fisheries. However, a difficult history, including a long war of liberation from Portuguese colonialism, had made the country one of the poorest in the world, with little monitoring of its fisheries, despite the strong dependence on fisheries for income and food security (Tvedten 1990). The main sector identified is the industrial sector, which includes both foreign and domestic vessels (figure 2A); the foreign component is represented by Russia, South Korea, China, and others (figure 2B). Domestic catches, as reconstructed by Belhabib and Pauly (2015), increased from 13,500 t in 1950 to 44,000 t in 2000 and averaged 33,400 t/year in the late 2000s. These reconstructed catches from Guinea Bissau, including a growing woman-dominated subsistence sector, were estimated to be 10 times the data reported by the FAO on behalf of Guinea Bissau. Figure 2C summarizes catches by taxon, with sea catfishes (family Ariidae), horse mackerels (*Trachurus* spp.), and tonguefishes (Cynoglossidae) being most important. The contribution of largely artisanally caught fish species such as bonga shad (*Ethmalosa fimbriata*) and croakers (Sciaenidae) to the total catch, not visible on the graph, appear to be decreasing over time, while subsistence catches of bivalves have increased.

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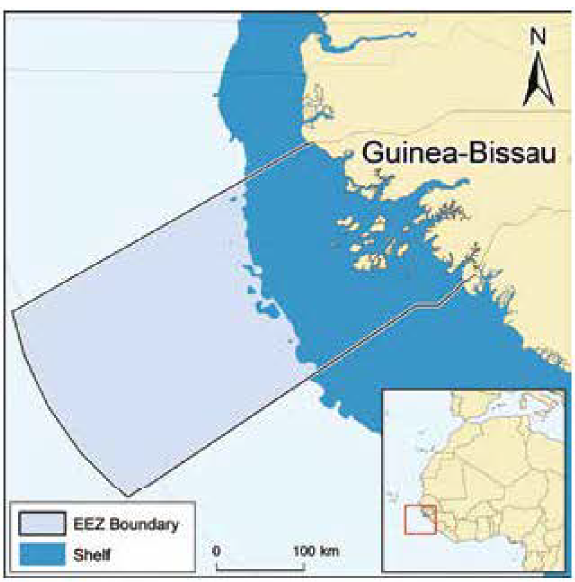

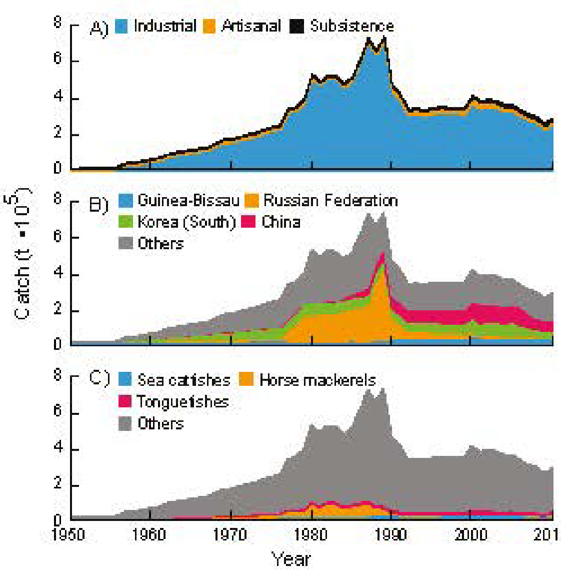

Figure 1. Guinea Bissau (EEZ: 106,000 km²) has a continental shelf of 38,200 km². Figure 2. Domestic and foreign catches taken in the EEZ of Guinea Bissau: (A) by sector (domestic scores: Art. 3, 3, 3; Sub. 2, 3, 3; Rec –, 2, 4); (B) by fishing country (foreign catches are very uncertain); (C) by taxon.

Stock assessment cassava croaker (*Pseudotolithus senegalensis*) in the EEZ of Liberia[1]

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Abstract

The growth and mortality parameters and the stock status of the cassava croaker (*Pseudotolithus senegalensis*) were estimated using a length-based Bayesian biomass estimator (LBB) and a Monte-Carlo method that estimates fisheries reference points from the catch, resilience, and relative abundance indicators (CMSY). A length-frequency histogram from 5,161 specimens sampled in 2019 was used with LBB. Catch and effort data for the years 2009 to 2018 were used to calculate fisheries reference points using CMSY. The LBB analysis suggests a 2019 biomass level below 20 % of the original biomass. The CMSY analyses suggests MSY at 744,000 t·year^{-1} for a value of SB_{MSY} of 2,230,000 t and an F_{MSY} of 0.33 year^{-1}. However, current (2018) biomass is only 34 % of the original level; this identifies cassava croaker as a strongly overexploited stock. These results corroborate the IUCN Red List findings, which assigned cassava croaker to the 'Endangered' category in 2009. The continued overexploitation of fish stock in Liberia implies that Liberians are at risk of losing a fish that they depend on for food.

Introduction

Liberia has an exclusive economic zone (EEZ; see Appendix A) that extends 200 nautical miles offshore into relatively warm waters with low nutrient content. Liberia's coastline stretches from Grand Cape Mount County, Liberia, and the Sierra Leone border, to Maryland County, Liberia, and the Côte d'Ivoire border. The continental shelf has an irregular shape (narrow at some points and wider at others). The widest part is Liberia's central region, and extends from Côte d'Ivoire to Robertsport in Liberia, with an average width of 34 km. An inshore exclusion zone (IEZ) reserves the six nautical miles closest to shore for the sole use of small-scale fishing activities - trawling is not allowed inside the IEZ.

The marine fisheries of Liberia comprise industrial and small-scale fisheries (see Appendix A). The industrial fleet includes demersal trawlers targeting shrimps and demersal fish such as sole, grunts, snappers, and croakers, while large pelagic vessels target tuna and related species.

Cassava croaker (*Pseudotolithus senegalensis*), known in Liberian markets as 'cassava fish' (Edwards *et al.* 2001; see Figure 1), belongs to the large and varied Sciaenidae family. It has a short spinous dorsal fin and a moderately long body with a convex head and snout and lateral eyes (Boesman 1963; Longhurst 1966). It mainly feeds on shrimps and juvenile fishes (Nunoo *et al.* 2013). This species is distributed widely along the coast of West Africa from Senegal to Angola (FishBase; see www.fishbase.org).

Nunoo and Nascimento (2015) assessed the cassava croaker in the IUCN Red List as 'Endangered' because of the continued decrease in population trends across its distribution range, for example, a 37 % biomass

[1] Cite as: Wehye, AS (2019) An analysis of the *Pseudotolithus senegalensis* stock in Liberia, p. 38-49 *In:* M.L.D. Palomares, M. Khalfallah, J. Woroniak and D. Pauly (eds.) *Assessments of marine fisheries resources in West Africa with emphasis on small pelagics*. Fisheries Centre Research Report 28(4), UBC, Vancouver, Canada.

decline from 1,046 tonnes in 2000 to 664 tonnes in 2006 of the population inhabiting the Guinea Current Large Marine Ecosystem.[1]

Despite this, a further increase in catches is expected (Kay *et al.* 2014; Nunoo and Nascimento 2015), fueled by high demand for local consumption and for export to Asia. Cassava croaker is exported to China and Korea, and its value recently doubled from 1 to 2 $US per pound (Wehye *et al.* 2017). Hughes *et al.* (2012) reported that Liberia is very vulnerable to a decline in fisheries because of its low adaptive capacity and the importance of fish from a food security perspective. This situation is further exacerbated by the pressure by illegal fishing fleets from neighboring countries (Sherif 2014). Pressure also comes from distant-water fleets, e.g., from China and Korea (Subah 2010; Braimah 2012; Belhabib *et al.* 2013; Mallory 2013; Glassco 2017; see also Belhabib *et al.* 2016 in Appendix A), which are likely to infringe into the country's IEZ (see EJF 2013; Gorez 2017).

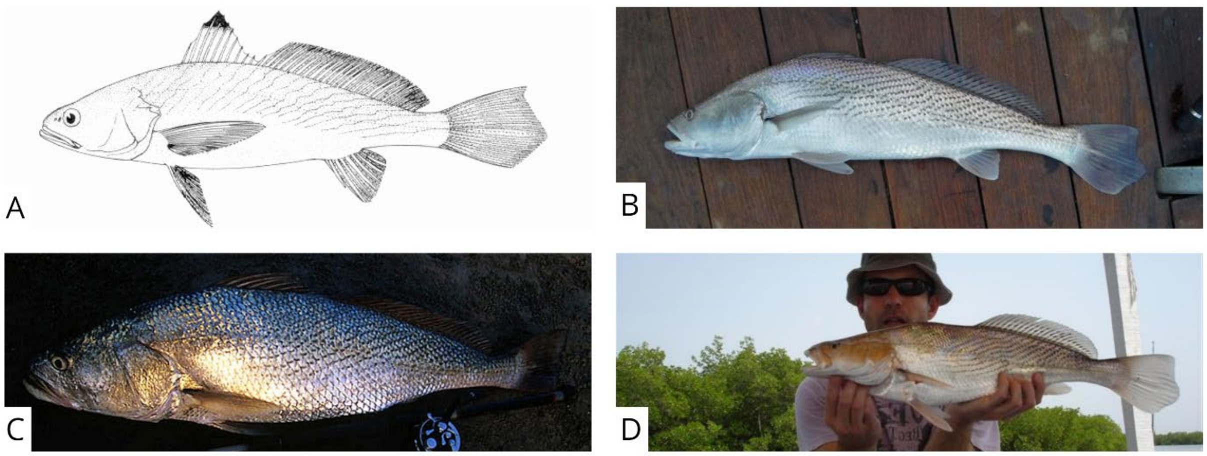


Figure 1. Images of the croaker, *Pseudotolithus senegalensis*, obtained from FishBase (www.fishbase.org): A) morphologically correct line drawing from the FAO; B) from Guinea-Bissau by Theo Modder; C) from Gambia by Johnny Jensen; and D) from Gambia by Hans Wullems.

[1] Cassava Croaker in the IUCN Red List: https://www.iucnredlist.org/species/49217798/49222499.

Materials and Methods

The National Fisheries and Aquaculture Authority of Liberia (NaFAA) landings data (Table 1) used for this analysis were collected from the artisanal (small-scale) and industrial (large-scale) fisheries. Artisanal fishery data are collected by trained fisheries enumerators assigned to selected landing sites. The small-scale canoes are classified into motorized and non-motorized canoes. Non-motorized canoes are categorized by gear and by fishing segment as non-motorized gill net, non-motorized hook and line, non-motorized long line, non-motorized set net and non-motorized ring net. Motorized canoes are categorized as motorized set net and motorized gill net. Artisanal fisheries dominate the landings of *Pseudotolithus senegalensis* (Table 1) in Liberian waters.

Table 1. National Fisheries and Aquaculture Authority of Liberia data for artisanal and industrial fisheries *Pseudotolithus senegalensis* landings from the Liberian EEZ. The catch per unit of effort (CPUE) data is based on the total number of artisanal canoes.

Year	Artisanal		Industrial		Total catch (t)	CPUE
	Catch (t)	%	Catch (t)	%		
2009	270	71	110	29	380	3.424
2010	507	81	117	19	624	3.610
2011	324	70	138	30	462	3.511
2012	450	74	158	26	608	3.525
2013	563	37	973	63	1536	3.807
2014	423	73	156	27	579	3.165
2015	620	78	178	22	798	3.396
2016	675	82	151	18	826	3.432
2017	1,292	98	31	2	1323	3.170
2018	1,142	96	52	4	1194	3.148

Data from the industrial fishery were collected by fisheries observers. The catches (consisting of retained and discarded catch) of vessels with two hauls per day were all sampled; 3 of 4 vessels with four hauls per day were sampled, and 3 of 5 vessels with five or more hauls per day were sampled. The weight of the catch of hauls *not* sampled were estimated based on the catch of similar hauls.

Landings data for artisanal and industrial fisheries were collected using mobile phones and submitted through an online platform exclusively used by the NaFAA enumerators and observers. The data was downloaded and transferred to a database platform (OpenArfish) that integrated all catch data for the industrial and artisanal sectors by gear type. Catch per unit of effort (CPUE) was estimated as the weight of landings of artisanal fishery divided by the number of boats operating on an annual basis.

A length-based Bayesian biomass estimator (LBB; Froese *et al.* 2018) was used to estimate the asymptotic length (L_{inf}) and related ratios, notably M/K, the ratio of the growth coefficient (K) to natural mortality (M) based on the 2019 length-frequency (L/F) data collected from the small-scale fishery within the EEZ of Liberia (Table 2). The LBB model also estimated the ratio of current to unexploited biomass (B/B_o) from the length-frequency data in Table 2 with the priors L_{inf} = 66.7 cm and Lc_{50} = 35 cm obtained from Wehye *et al.* (2017). The biomass index (B/B_o) resulting from this analysis was used as a prior in the Monte-Carlo model to estimate fisheries reference points (MSY, F_{MSY}, B_{MSY}) described below along with resilience (i.e., a proxy for measuring the productivity of the stock) obtained from FishBase (www.fishbase.org) and the catch and CPUE data in Table 1.

As stated in Palomares *et al.* (2019), the Monte Carlo approach to estimate maximum sustainable yield (MSY) using catch data (CMSY) was first proposed by Martell and Froese (2013) and later updated in Froese *et al.* (2016). This approach was built on the Schaefer (1954, 1957) model to estimate MSY from a catch time series and ancillary information. The CMSY method consists essentially of tracing random trajectories of its likely biomass for a given exploited stock and identifying the trajectories that remain viable while accommodating the catches taken from that population and a few other constraints (Palomares *et al.* 2019).

The selection of the constraints or priors used in the LBB and CMSY analyses is discussed with the results (see Palomares *et al.* 2020, this vol.).

Results and Discussion

The LBB method suggested a L_{inf} of 69.7 cm for the cassava croaker in Liberia, which is higher than previous estimates obtained from length-frequency data fitted to the von Bertalanffy growth function (Table 3). Wehye *et al.* (2017) noted that the cassava croaker stock in Liberia is overexploited, which suggests that in 2019, the stock is at about 20 % of the original biomass (Table 3; Figure 2).

Because the catch data (Table 1) available for the CMSY analysis stem only from the most recent decade, historical information was needed to account for the cassava croaker's fishery evolution in previous decades. The following information was obtained from the scientific literature and used to extract a realistic estimate of initial relative biomass (i.e., for the start of the time series in 2009).

Table 2. L/F data (in cm total length) of cassava croaker, *Pseudotolithus senegalensis* collected in 2019 from the small-scale fishery from the 9 coastal counties of Liberia.

Length	Frequency
20	42
25	42
30	121
35	215
40	869
45	830
50	992
55	212
60	102
65	280
70	168
75	126
80	168
85	84
90	32
95	100
100	98
105	70
110	90
115	35
120	60
125	243

Table 3. Summary of general reference points for the Liberian stock of *Pseudotolithus senegalensis* estimated using data in Table 2 and the LBB model (Froese *et al.* 2018) compared with results from Wehye *et al.* (2017; Liberia), Sidibé (2003; Guinea) and Sossoukpe (2011; Benin).

Parameters	This study	Liberia	Guinea	Benin
L_{inf}	69.7 cm	66.7	60.8	43.0
L_{opt}	52 (cm)	-	-	-
L_{c_opt}	47	-	--	-
M/K	1.04 (0.792-1.32)	2.85	-	-
F/M	2.3 (1.5-3.4)	-	--	-
L_{c50}	40.5 (39.9-41.2 cm)	33.84	-	25.5
L_{c95}	52.4	-	-	-
Y/R'	0.062 (0.032-0.096)		-	-
B/B_O	0.18 (0.094-0.28)	-	-	--
B/B_{MSY}	0.47 (0.24-0.72)	-	-	-

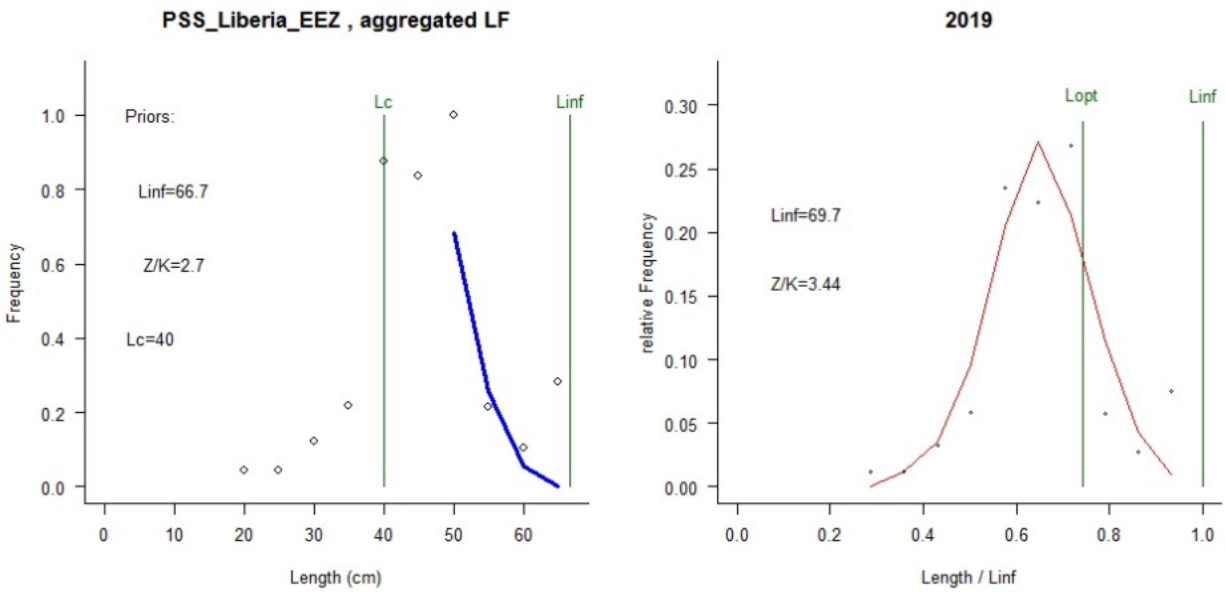


Figure 2. Results of the Bayesian length-based (LBB) method of Froese *et al.* (2018) applied to the stock of *Pseudotolithus senegalensis* exploited by Liberia's small-scale fishery in 2019. Left panel: length-frequency data fitted to the prior L_{inf} = 66.7 cm and L_{m50} = 35 cm obtained from Wehye *et al.* (2017). Right panel: result of the Monte Carlo fitting indicating L_{inf} = 69.7 cm and L_{opt} at about 75 % of L_{inf}.

Kru's artisanal fishers were observed by European explorers in the 1500s, plying the coastal stretch of West Africa in fishing canoes that resembled "weaver's shuttles" (de Surgy 1969). Migrant Fante fishers increased the numbers of artisanal fishers from Ghana in the early 1900s (Haakonsen 1991), followed by other migrant fisher groups (Popoh, Lebou, and Ga; see Subah 2010), most of whom were fishing illegally in Liberian waters due to the absence of surveillance (Haakonsen 1991). The artisanal fishing fleet's dominance continued into the 2000s, with landings from this sector comprising up 70-75 % of the total marine fisheries landings (Kay *et al.* 2014). The biomass of coastal demersal stocks has been impacted by a robust artisanal fishing sector composed of domestic and foreign fishers, with little or no governance. Thus, in 2008, the relative biomass of Liberia's stocks, including cassava croaker, would most likely have decreased to about 50 % of the original biomass.

Trawling was introduced to Liberia in 1938 (Kay *et al.* 2014). However, industrial fisheries (shrimp trawling) only began in 1955. By the late 1970s, this fishery involved up to 30 vessels, but it went bankrupt in the 1980s (Haakonsen 1991). Trawling continued to the 2000s with foreign, distant water fleets given access to fishing areas outside of the inshore waters (Mallory 2013). This suggests that the industrial fisheries have exploited coastal resources since the 1950s. In the absence of governance for trawling vessels, they would have substantially impacted the demersal resources, thus justifying the assumption that the relative biomass of demersal stocks, including cassava croaker, would be reduced to about 50 % of the original biomass.

Finally, two studies provide evidence of biomass decline of the cassava croaker stock in Liberia, i.e., 1) an estimated 37 % decline of biomass from 2000 to the 2006 levels (Nunoo and Nascimento 2015); and 2) CPUE data showing a decline from 9 tonnes per boat per day in 1998 to 2 tonnes per boat per day in 2010 (Mees *et al.* 2011).

Based on this qualitative and partially quantitative evidence, we set the relative biomass in 2009 at 30-70 % of the original biomass, i.e., with a mid-point of 50 % (see Table 4). This was used as a prior to constrain the Monte Carlo fitting of the CMSY analysis such that the initial relative biomass used in the fitting will not exceed 70 %.

A similar deductive process was used to justify the relative biomass assumption at the end of the time series. Given that the cassava croaker is now listed in the IUCN Red List as Endangered (Nunoo and Nascimento 2015), the current biomass is assumed not to exceed 50 % of the unexploited, original biomass. Also, the LBB results in Table 3 suggest that the 2019 relative biomass is at about 20 %. Thus, the final relative biomass used in the CMSY analysis was set to 0.01-0.4, with the mid-point at 0.2.

A preliminary CMSY run of the catch and CPUE data in Table 3 and the priors in Table 4 suggests that the stock is overexploited with $B_{2018}/k = 0.43$. (CPUE and catch data with the Bayesian Schaefer method, BSM; see Table 5). The r-k pairs identified in the catch only (CMSY: $r = 0.669$, $k = 4.03 \cdot 10^3$) and catch and CPUE (BSM: $r = 0.605$, $k = 4.62 \cdot 10^3$) runs were very similar and thus led to very similar MSY estimates (CMSY = 0.674, BSM = 0.699). However, neither estimate reflects the drastic declines in biomass signaled by Nunoo and Nascimento (2015), which resulted in the inclusion of this species in the IUCN Red List. This is most likely due to the short catch time series masking the decline of the biomass from higher levels in the 1950s when industrial fisheries started (Haakonsen 1991), an example of the shifting baseline syndrome (Pauly 1995). Moreover, the catch data in Table 3 most likely does not account for the prevalent IUU catches described in Sherif (2014).

To account for this shifting baseline syndrome, reconstructed catch data (which includes subsistence and recreational fishing, and some other forms of IUU catches) for cassava croaker caught in Liberia for 1993-2014 were downloaded from the *Sea Around Us* (www.seaaroundus.org) website. A second analysis was run with this dataset (see Appendix B) and the priors in Table 4 without using the CPUE values in Table 1. Figure 3b shows a stronger relative biomass decline reflecting Nunoo and Nascimento (2015) findings. Thus, to account for the evolution of relative biomass in earlier decades (and possibly to reduce the variability of the 2009-2018 dataset), the results of this second analysis were used to set the priors for the initial relative biomass. That is, B/k_{2009} at 40 % of the original biomass as suggested in Figure 3b) and for the intermediate relative biomass (B/k_{2014} at 28 % of the original biomass, see Table 5) in a final CMSY analysis.

Assuming that the catch data in Table 1 represent the cassava croaker stock in this region, then the final results suggest that cassava croaker has an MSY at 744 t, a B_{MSY} at 2,230 t and an F_{MSY} at $0.334 \cdot \text{year}^{-1}$ (Table 5 and Figure 4), leading to a 2018 relative biomass level at 34% of the original biomass and an annual exploitation rate of 2.4, which places this stock in the overexploited category (i.e., the red zone of the Kobe plot in Figure 4). These results are in line with the findings of Nunoo and Nascimento (2015). Note that this final analysis results with almost overlapping r-k estimates (Figure 4a, Panel C; red and blue crosses), signifying a reduction in the variability compared with the preliminary analysis (Figure 3a, Panel C). These results translate to an almost identical estimate of MSY (Table 5; see Figure 4b, Panel A).

These results lead to the conclusion that the current fishing effort of the small-scale fisheries and the total allowable catch (TAC) of industrial vessels applied to this stock are outside of sustainable levels. Thus, it is recommended to reduce fishing effort and the TAC to sustainable levels, i.e., at or below MSY, to let the stock recover. Also, suspending fishing licenses to industrial vessels and setting closed seasons for small-scale fishing might further encourage the stock's recovery. Finally, existing and emerging policies against, e.g., the use of illegal mesh sizes and other destructive fishing methods, must be strictly enforced. Without these measures, the endangered cassava croaker stock might be pushed to the brink of extinction, putting Liberians at risk of losing a resource on which they depend for food.

Table 4. Relative biomass (B/k), resilience (r), carrying capacity (k) and catchability (q) priors used for the assessment of the catch time series of the cassava croaker (*Pseudotolithus senegalensis*) stock in Liberia using the Monte Carlo method of Froese *et al.* (2016). Priors used for three consecutive analyses using catch and CPUE data in Table 3, and *Sea Around Us* reconstructed catch data in Appendix B.

Parameter	Estimates	Comments
Initial relative biomass	0.3 - 0.7	B/k_{2009} assumed at 0.5 based on historical data (see text). Catch and CPUE data from Table 1.
	0.8-1.0	B/k_{1993} default setting. Catch data from Appendix B.
	0.2-0.6	B/k_{2009} assumed at 0.4 based on results in Figure 3b. Catch and CPUE data from Table 1.
Intermediate relative biomass	0.5 - 0.9	Default setting (for 2014). Catch and CPUE data from Table 3.
	0.3-0.7	B/k_{2009} assumed at 0.5 based on historical data (see text). Catch data from Appendix B.
	0.01-0.4	B/k_{2014} assumed at 0.28 based on results in Table 5. Catch and CPUE data from Table 1.
Final relative biomass	0.01 - 0.4	B/k_{2018} assumed as B/B_{02019} at 0.2 (confidence interval of +/-0.2; Table 3). Catch and CPUE data from Table 1.
	0.01-0.4	B/k_{2014} assumed B/B_{02019} at 0.20 based on results in Table 3. Catch data from Appendix B.
	0.01-0.4	B/k_{2018} assumed as B/B_{02019} at 0.2 (confidence interval of +/-0.2; Table 3). Catch and CPUE data from Table 1.
Range for r	0.36 - 0.82	From FishBase (www.fishbase.org) version of August 2019.

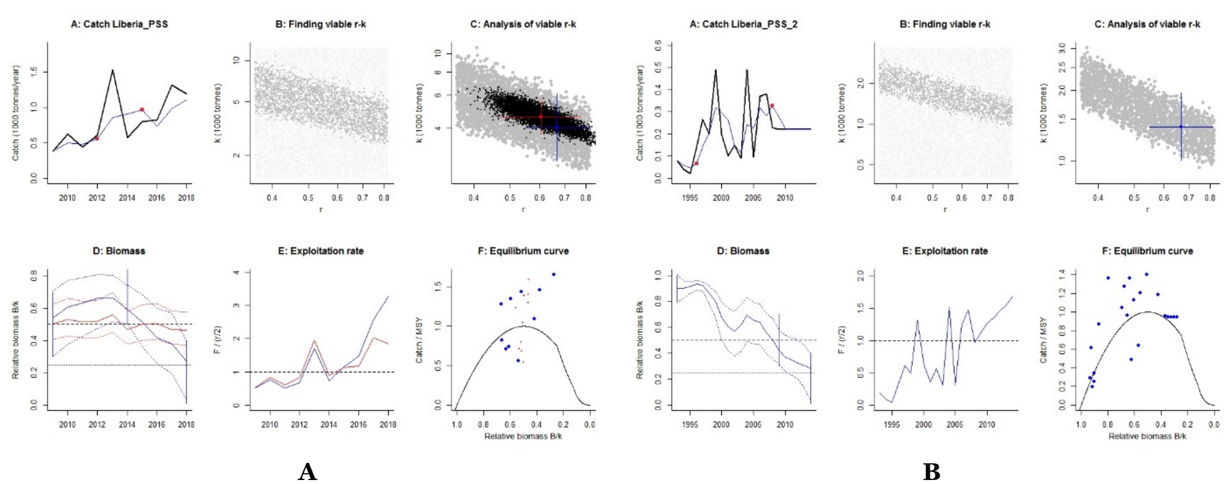
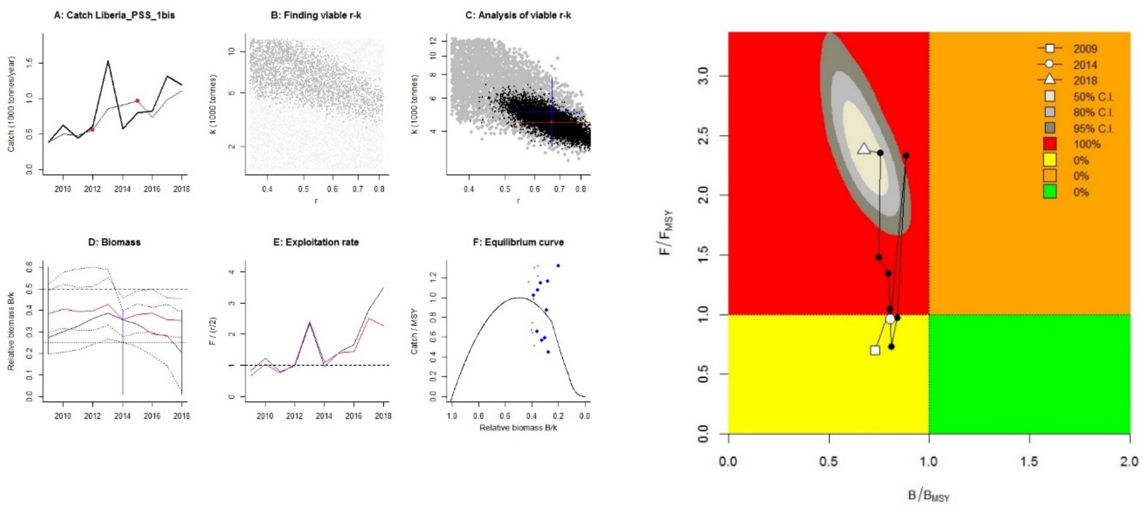


Figure 3. Results of the preliminary and secondary analysis using the Monte Carlo approach (CMSY) to estimating stock status references (Froese *et al.* 2016) applied to the cassava croaker, *Pseudotolithus senegalensis* in Liberian waters. A: Preliminary analysis of the 2009-2018 landings data from Table 1. Note the slight difference of the r-k pairs (panel C) between catch (blue) and CPUE (red) data sets and the slight misfit of the exploitation rate from catch (blue) and CPUE (red) data sets. B: Secondary analysis of the 1993-2014 reconstructed catch data from the *Sea Around Us* database (Appendix B). Note that the relative biomass for 2009 (Panel D, blue solid line) is around 0.4 and the resulting 2014 value is around 0.3.

Table 5. Results of the Monte Carlo method of stock reference points estimation by Froese *et al.* (2016) applied to the catch and CPUE data in Table 1 (2009-2018) using the priors in Table 4 for the cassava croaker, *Pseudotolithus senegalensis*, stock in Liberia. CMSY: catch data; BSM: catch with CPUE data. Preliminary and final runs based on catch and CPUE data in Table 1 and priors in Table 4. Secondary run based on reconstructed catch data from the *Sea Around Us* (www.seaaroundus.org) in Appendix B and priors in Table 4 (CPUE data in Table 1 was not used, thus no BSM results are available).

Parameter	CMSY	BSM	Run
r	0.669 (0.549-0.814)	0.605 (0.47-0.78)	Preliminary
	0.669 (0.549-0.814)	—	Secondary
	0.669 (0.549-0.814)	0.667 (0.522-0.854)	Final
k	4.03 (2.67-6.06)	4.62 (3.71-5.74)	Preliminary
	1.40 (1.00-1.95)	—	Secondary
	5.06 (3.30-7.76)	4.46 (3.47-5.73)	Final
MSY (t•10^3)	0.674 (0.443-1.03)	0.699 (0.605-0.807)	Preliminary
	0.233 (0.179-0.304)	—	Secondary
	0.845 (0.538-1.33)	0.744 (0.630-0.879)	Final
q	-	0.00147 (0.00121-0.00179)	Preliminary
	-	0.00199 (0.00164-0.00242)	Final
Relative biomass (B/k) in last year	0.271	0.427	Preliminary
	0.280	—	Secondary
	0.203	0.337	Final
Exploitation rate, F/(r/2) in last year	3.27	2.00	Preliminary
	1.68	—	Secondary
	3.49	2.38	Final
F_{MSY}	--	0.303 (0.235-0.390)	Preliminary
	--	0.334 (0.275-0.407)	Secondary
	-	0.334 (0.261-0.427)	Final
B_{MSY} (t•10^3)	-	2.31 (1.86-2.87)	Preliminary
	-	0.698 (0.501-0.973)	Secondary
	-	2.23 (1.73-2.87)	Final
Biomass in the last year (t•10^3)	-	1.97	Preliminary
	-	0.391	Secondary
	-	1.50	Final
B/B_{MSY} in the last year	-	0.855	Preliminary
	--	0.560	Secondary
	-	0.674	Final
F in the last year	--	0.605	Preliminary
	-	0.563	Secondary
		0.794	Final
F/F_{MSY}	-	2.00	Preliminary
	--	1.68	Secondary
		2.38	Final



A-F **G**

Figure 4. Results of the final analysis using the CMSY/BSM methods (Froese *et al.* 2016) to assess the status of cassava croaker, *Pseudotolithus senegalensis* in Liberian waters using data in Table 1 and priors in Table 4. A: Catch data; B-C: the CMSY analysis of catch data identified 5,096 viable trajectories for 2,991 r-k pairs. Note congruence of the catch-based (blue cross) and CPUE-based (red cross). The CPUE data improved the fit of the exploitation rate in Panel E. Note congruence between and concentration of blue and red dots at the right side of the peak of the equilibrium curve (Panel F) indicating the overexploited status of this stock. The exploitation rate reached above MSY levels, which reduced the biomass (B/B_{MSY}) below 1. G: Kobe plot presenting F/F_{MSY} vs. B/B_{MSY} from the initial year of the time series (2009, white square) via the intermediate year (2014, white circle) and the final year (2018, white triangle), which places the stock in the red critical zone of overexploitation.

Acknowledgments

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Appendix A: Summary of data on the marine fisheries of Liberia, 1950-2010.

LIBERIA[1]

Dyhia Belhabib,[a] Yevewuo Subah,[b] Nasi T. Broh,[b] Alvin S. Jueseah,[b] J. Nicolas Nipey,[b] William Y. Boeh,[b] Duncan Copeland,[c] Dirk Zeller,[a] and Daniel Pauly[a]

[a]*Sea Around Us*, University of British Columbia, Vancouver, Canada [b]Bureau of National Fisheries, Monrovia, Liberia [c]West Africa Regional Fisheries Project, Monrovia, Liberia

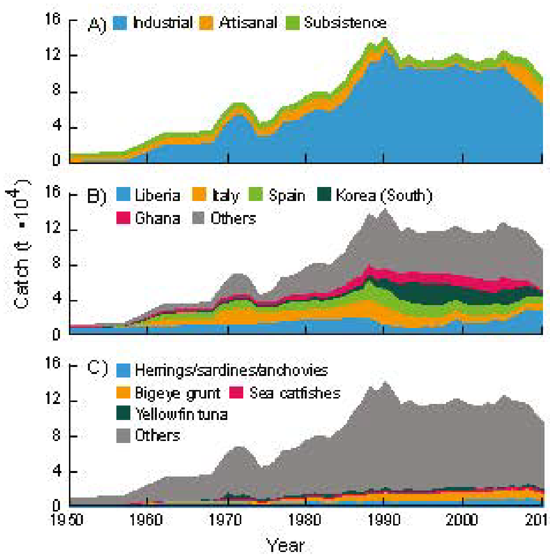

Figure 1. Liberia (EEZ: 246,000 km²) has a continental shelf of 18,500 km². Figure 2. Domestic and foreign catches taken in the EEZ of Liberia: (A) by sector (domestic scores: Ind. –, –, 4; Art. 3, 3, 3; Sub. 1, 3, 3; Dis. –, –, 4); (B) by fishing country (foreign catches are very uncertain); (C) by taxon.

Liberia, the only country in Africa that was never colonized, is located in Sub-Saharan West Africa (figure 1). The marine fisheries of Liberia could generate a sustainable catch sufficient to meet the animal protein needs of its people (Haakonson 1992), contrary to what the low official estimates suggest. Only part of the artisanal sector is covered by official statistics, and the industrial sector, consisting of foreign and "Liberian" vessels mostly owned by foreign companies, remains largely invisible in the data. Overall, catches in the EEZ are taken by industrial fleets (figure 2A), most of which are foreign fleets (figure 2B). Domestic catches were estimated by Belhabib et al. (2013) at 8,000 t in the 1950s, increased to 19,000 t/year in the late 1980s, and declined during the civil war period (1989 to mid-late 2000s), when catches consisted overwhelmingly of foreign-controlled industrial interests. Catches peaked at 29,000 t in 2009 and declined slightly to 28,000 t in 2010. Domestic catches were 2.5 times the data supplied to the FAO, almost 30% of which originated from coastal lagoons. Total allocated catches were dominated by small pelagic species: various clupeoids such as herrings, sardines and anchovies, and bigeye grunt (*Brachydeuterus auritus*). Thus, Liberian fishers should benefit from the fact that illegal fishing, which previously made up to half the foreign catch, has declined because of improved monitoring and surveillance.

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Stock assessment of European anchovy, round sardinella, bonga shad and common octopus exploited in Mauritania[1]

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Abstract

Stock assessment using CMSY/BMS methods were performed for four species exploited in Mauritania: European anchovy (*Engraulis encrasicolus*), round sardinella (*Sardinella aurita*), bonga shad (*Ethmalosa fimbriata*), and common octopus (*Octopus vulgaris*), which the LBB model also applied to European anchovy and bonga shad. The CMSY model is applied to all species using CPUE data for some and only catch data for others (when CPUE data were unavailable). Abundance is obtained either from the CPUE of commercial fisheries or from biomass estimates via acoustic surveys. Our assessments of the three small pelagic species shared between several countries of Northwest Africa corroborates assessed earlier studies suggesting that these species are overfished. More complete spatial data could narrow down the imprecision of these.

Introduction

This report presents the work completed during the workshop on LBB and CMSY methods in September 2019 in Dakar, Senegal (see Palomares *et al.* 2020 for the LBB and CMSY methods). Four of the five species we studied are here; the fifth (lobster) produced results too uncertain to present. We present these four species, the data available on them, and the methods used to assess their fisheries status.

European anchovy (Engraulis encrasicolus)

The European anchovy (*Engraulis encrasicolus*) is a coastal pelagic species that can form very large schools and is mainly present in the eastern Atlantic, from the North Sea to South Africa and the Mediterranean (see FishBase; www.fishbase.org).

European anchovy is a planktivorous species that performs low-amplitude seasonal migrations conditioned mainly by water temperature. Despite its socio-economic importance for the coastal communities of West Africa, the biology and population dynamics of the European anchovy are poorly understood in this region. The FAO working group on assessing small pelagic fish off Northwest Africa considers the stock of European anchovy to be panmixic and straddling from Morocco to Senegal). However, this is contradicted by survey data in the sub-region suggesting that this species has two distinct stocks in Northwest Africa. This was confirmed by a recent analysis of anchovy otolith shapes, which also suggests the existence of two separate stocks: one around the Cap Blanc (21°N), the other south of Casablanca (32°N) (Jemaa *et al.* 2015).

Round sardinella (Sardinella aurita)

Round sardinella (*Sardinella aurita*) is a small pelagic species of the family Clupeidae and is widely distributed along the African coast, from the Mediterranean to South Africa. The round sardinella occurring in Mauritania waters appears to be part of a large stock ranging from Senegal and The Gambia in the South to Morocco in the North, and whose center of gravity oscillates seasonally as a function of temperature (Pauly 1994; Samb and Pauly 2000). Round sardinella has been fished since well before the 1980s by Senegalese wooden *pirogues* deploying mainly purse seines. This species was also targeted by large industrial pelagic trawlers (e.g., Russian and Romanian trawlers) operating under fisheries agreements

[1] Cite as: Jeyid, M.A., S. Abdelkerim, B. Tfeil and E. Beibou. 2020 Stock assessment of European anchovy, round sardinella, bonga shad and common octopus exploited in Mauritania, p. 50-58 *In:* M.L.D. Palomares, M. Khalfallah J. Woroniak and D. Pauly (eds.) *Assessments of marine fisheries resources in West Africa with emphasis on small pelagics*. Fisheries Centre Research Report 28(4), UBC, Vancouver, Canada.

with Mauritania. Since 2013, this species has been the target of coastal purse seiners working for fishmeal plants.

Sardinella aurita is a fast-growing species, especially during its larvae stage when it is driven northward and toward the coast by surface currents, and its length increases rapidly. At the age of 1 year, it reaches about 20 cm (Ghéno 1975).

Bonga shad (Ethmalosa fimbriata)

The bonga shad (*Ethmalosa fimbriata*; Family Clupeidae) is widespread in West Africa (Gourène and Teugels 2003; Marcus 1984; Moses 1988; Scheffers *et al.* 1972; Longhurst and Pauly 1987, p. 189-192, and see other contributions in this volume)

Common octopus (Octopus vulgaris)

Common octopus (*Octopus vulgaris*) is characterized by fast growth, allowing the population to double in less than 15 months (see SeaLifeBase; www.sealifebase.org). Octopus catches generated by the industrial fishery off Mauritania decreased for a while, until reaching relative stability from 2013 to 2016, followed by improvement from 2017 and 2018. For a long time, the deep-sea fishery dominated octopus landings. From 2012, following the departure of European vessels from the Mauritanian EEZ, the situation was reversed, with landings from artisanal fishing far exceeding those from deep-sea industrial fishing.

Material and Methods

The Fishery Committee for the Eastern Central Atlantic (CECAF) provided the data used here to assess European anchovy. The length frequencies data covered the period from 2014 to 2018 and was used for the LBB analysis. These data were obtained from sampling the industrial fishery targeting European anchovy and operating in the Northwestern African region. The catch data (also from the industrial fishery) covered a more extended period, from 2004 to 2018, and were used to apply the CMSY method. We obtained priors for the LBB and CMSY/BSM models from FishBase and local knowledge about this species. The LBB analysis was performed first, and its results were used as priors for the CMSY/BSM analysis.

Catch statistics for round sardinella were available for the northwest African region (Morocco, Mauritania, Senegal, and The Gambia) mainly from fishing logs (industrial and artisanal fishing) and records from fishmeal plants and freezer factories. These data, covering the years 1990 to 2018, were used as input along with CPUE data from a Dutch fleet that fished in Mauritanian waters from 1995 to 2012. We also used the range 0.46 to 1.16 year^{-1} in FishBase (see www.fishbase.org) for the intrinsic population growth rate of *Sardinella aurita*.

For bonga shad, catch data were available covering the years 2001 to 2018. In addition, CPUE data were available for the years 2001 to 2017. Based on a time catch series for 1991to 2018 for *O. vulgaris,* two different CMSY analyses were performed; the first used CPUE data as an abundance index, second did not. The CPUE data were based on a scientific survey by IMROP, and estimated via a General Linear Model. However, both analyses showed the common octopus stock in Mauritania to have been overexploited for over two decades. For both analyses, the following prior (from SeaLifeBase; www.sealifebase.org) was applied when running the CMSY analysis: r = 0.81 year^{-1} (0.53 to 1.21 year^{-1}). Table 1 summarizes the priors that were used for our CMSY/BMS analyses.

Table 1. Priors used in this study for the CMSY/BSM stock assessments of European anchovy, round sardinella, bonga shad, and octopus

Item	Anchovy	Sardinella	Bonga	Octopus
B_{start}/k	0.1 – 0.5[a)]	0.5 – 0.8	0.1 – 0.5	0.2 -0.6
B_{int}/k	0.01 - 0.4	--	0.5 – 0.9	0.1 – 0.4
B_{end}/k	0.2 – 0.49	0.4 - 08	0.2 – 0.6	0.01 – 0.4
r ($year^{-1}$)	0.39 – 0.91	0.46 – 1.16	0.61 – 1.39	0.53 – 1.2
k (10^3 t)	158 - 1145	Default	Default-	30.9 - 282

a) Expert judgement

Results and Discussion

According to the LBB analysis the European anchovy stock is overfished, with very high fishing mortality (F) relative to natural mortality (F/M = 2.45. This resulted in a well-fitted LBB plot (Figure 1). L_c and L_{opt} were than L_{mean}, which confirms the overexploited state of the stock. The CMSY/BSM analyses of European anchovy are summarized in the different panels of Figure 2, while those for round sardinella are summarized in Figure 3 (see also Table 2 and Figure 6).

The available catch time series for *Ethmalosa fimbriata,* which covered the years 2001 to 2018 (Figure 4, Panel A) was probably not reliable and long enough to provide results that could be interpreted straightforwardly, at least not with the priors in Table 1. Notably, our analysis suggests that the stock's biomass, which was assumed to have been strongly reduced below carrying capacity before 2001 (Figure 4, Panel D), massively increased in the decade starting in 2001, until higher catches brought it down. The scenario suggests, according to the CMSY and the BSM models, that the MSY estimates for bonga shad is about 78,600 and 69,400 tonnes·$year^{-1}$, respectively, and that the biomass by BSM was 96,700 tonnes in 2017 (see Table 2 and Figure 6).

However, these results are unreliable, as the massive increase in biomass in the early 2000 is unlikely to have occurred. We assume that is was due to B_{start}/k being set too low (see Table 1).

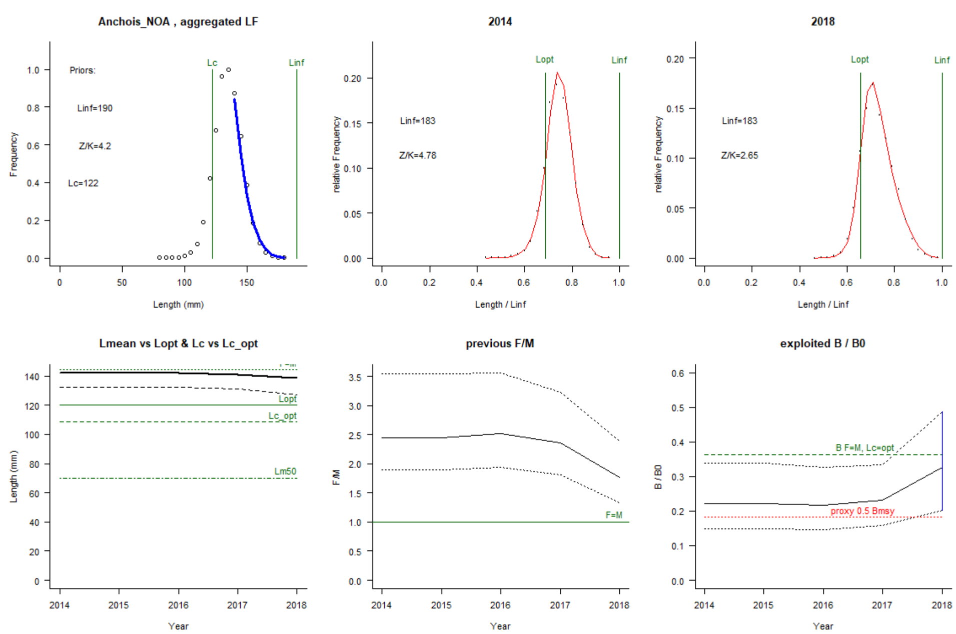

Figure 1. Application of the LBB method to L/F samples of European anchovy caught off Mauritania. This application generated the following results: L_{inf} = 18.3 cm (for a prior of 19 cm), L_{opt} = 12 cm; L_{c_opt} = 10.8 cm; M/K = 1.57; F/M = 2.45; and B/B_o = 0.22 (0.15-0.34).

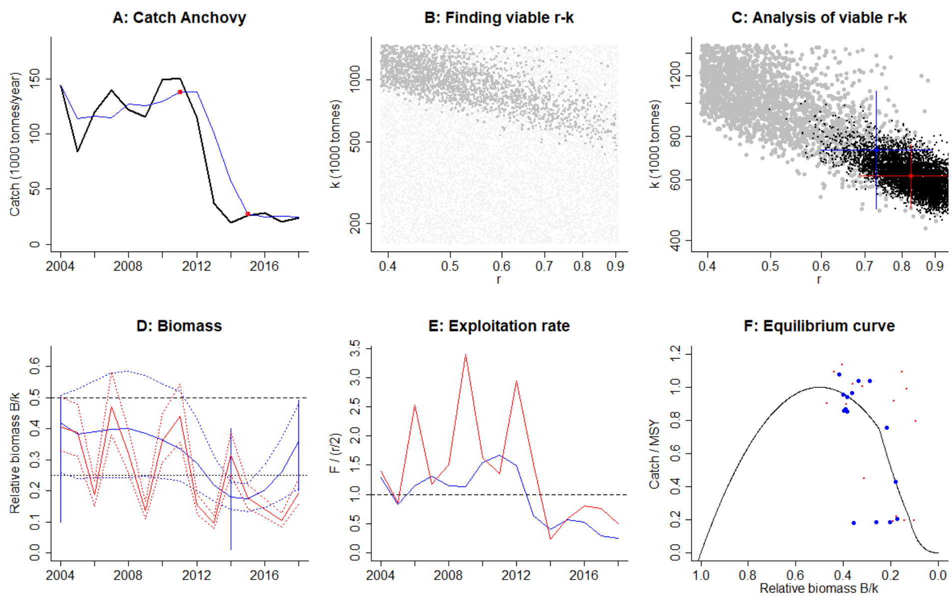

Figure 2. Application of the CMSY and BSM methods to a catch time series of European anchovy from Mauritania (see also Table 1).

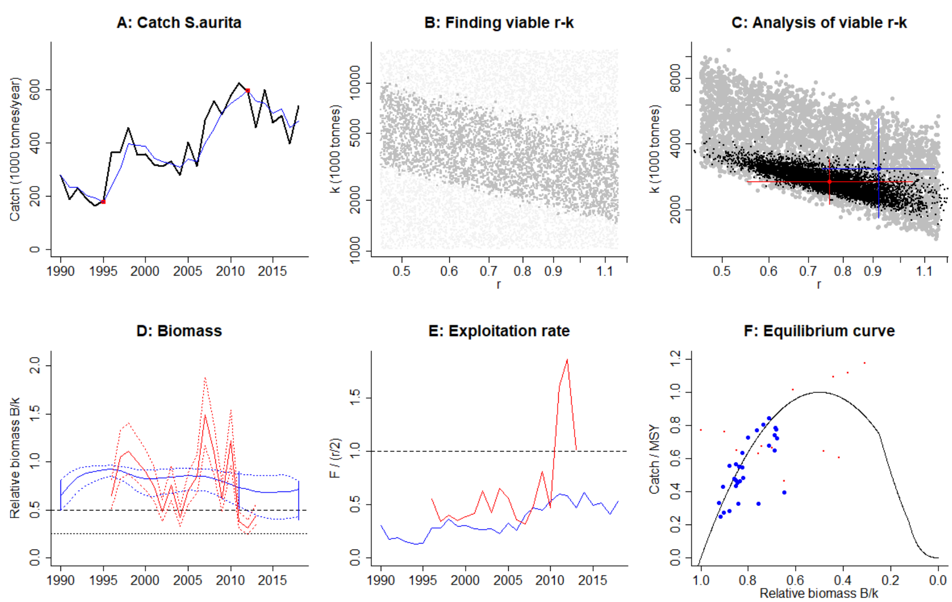

Figure 3. Graphical summary of the stock assessment of the stock of round sardinella ranging from Senegal and Gambia to Mauritania and Morocco; the CPUE data (red in in Panel D originate from a Dutch fishery off Mauritania (see also Table 1).

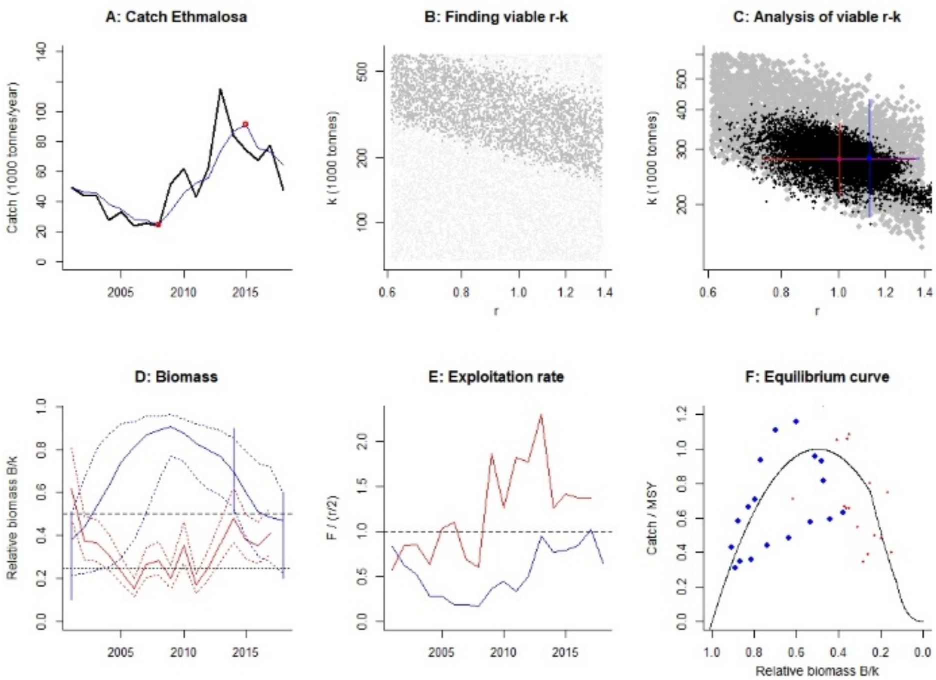

Figure 4. Graphical summary of the stock assessment of the stock of bonga shad exploited in Mauritanian waters (see also Table 1).

According to the BSM model, i.e., using the CPUE from scientific surveys, the stock of common octopus in Mauritanian waters was overfished throughout the study period. Without CPUE, the CMSY analysis suggests that overexploitation started a few years later. The CMSY estimates an MSY of 29,400 t close to that obtained by the BSM model (MSY = 28,000 t); however, the carrying capacity estimated by CMSY, 122,000 t, is much greater than that estimated by the BSM model (k = 80,000 t). The estimated biomass in 2018 reached 48,000 tonnes (Figure 5, Panel D; see Table 2 and Figure 6). Despite the gradual increase in catches and the exploitation rate since 2012, the biomass continues to increase but at levels below BMSY. The CMSY model estimates a high exploitation rate in relation to the biomass production model. Given the results of other stock assessments for other species and previous work done by IMROP staff, who assessed the stock a 'fully exploited' (but not overexploited), this model appears to provide pessimistic assessments. Thus, it may appropriate to apply the CMSY model to a more extended series of catch data (1981 to 2018) combined with an index of abundance from the industrial, commercial fleet.

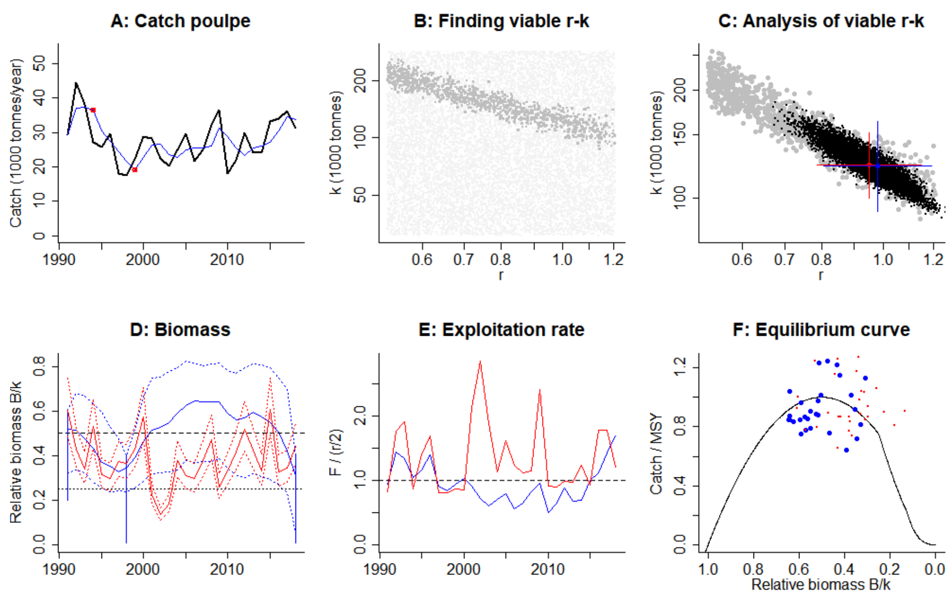

Figure 5. Results of the CMSY/BSM analyses of the status of the octopus fishery in Mauritania (see also Table 1).

Table 2. Results (w/ 95 % confidence intervals) of this study of the CMSY/BSM stock assessments of European anchovy, round sardinella, bonga shad and common octopus.

Item	Anchovy	Sardinella	Bonga shad	Octopus
r ($year^{-1}$)	0.73 (0.59-0.9)	0.76 (0.51-1.11)	0.93 (0.61-1.39)	0.95 (0.79-1.15)
k (10^3 t)	689 (474-1001)	2771 (2176-3529)	277 (212-361)	123 (100-152)
MSY (10^3t·year)	123 (105-144)	524 (399-689)	69.4	294 (269-320)
B_{end}/B_{MSY}	0.346	1.11 (0.735-1.57)	0.70 (0.48-1.15)	0.78 (0.59-0.96)
B_{end}/k	0.173	0.55 (0.37-0.78)	0.35 (0.24- 0.58)	0.39

The first recommendation for this fishery is to reduce fishing effort, particularly by the artisanal fishery, that has continued to increase in the last 8 years. To ensure the sustainability of this resource, the TAC must be respected. In the literature, it is well documented that overfishing removes large predators of cephalopods, which leads to an increase in their carrying capacity. The CMSY model is more suitable for fisheries characterized by stable carrying capacity. A previous stock assessment of the same octopus stock by IMROP using the Schaefer model showed that the stock's status improved from 'overexploited to 'fully exploited.'

Overall, these results suggest that the CMSY and BSM methods are suitable to assess the status of fisheries such as those of Mauritania, especially if they can be complemented with priors from other methods such as LBB. The 4 stocks whose status is documented here would all benefit, if to a variable extent, from reducing the fishing effort applied to them. This is in line with the results of Meissa and Gascuel (2015), working on demersal stocks.

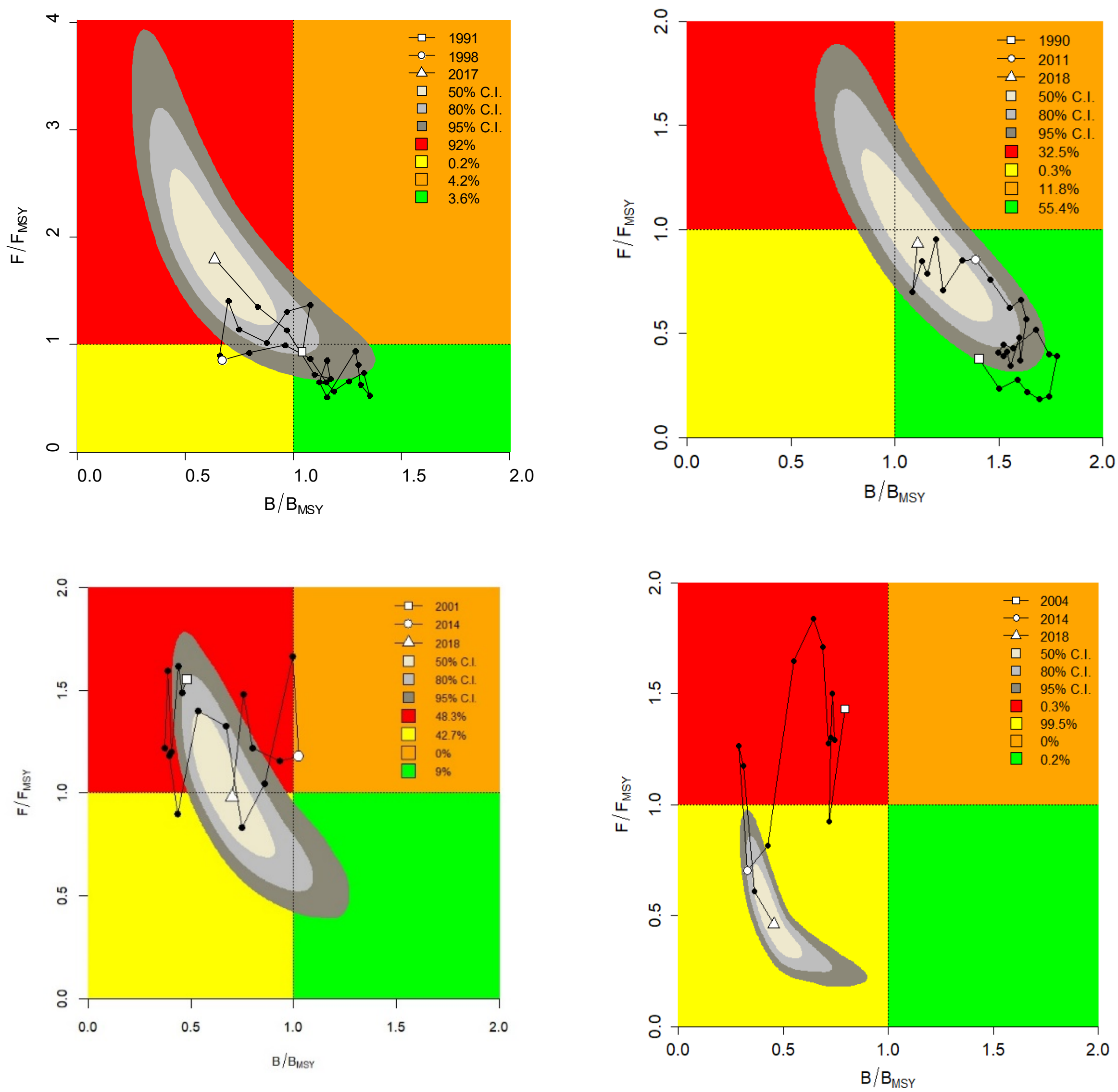

Figure 6. Kobe plot with results of CMSY or BSM for European anchovy (upper left), round sardinella (upper right), bonga shad (lower left), and octopus (lower right); (see text).

Acknowledgments

Our thanks go to the team who contributed to the collection of data in the various countries of Northwest Africa and various scientific institutions in the sub-region. A big thank you to the CSRP for organizing this training course and to the MAVA Foundation for funding it. Also, a very big thank you to the *Sea Around Us* team.

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Appendix A: Summary of data on the marine fisheries of Mauritania, 1950-2010.

MAURITANIA[1]

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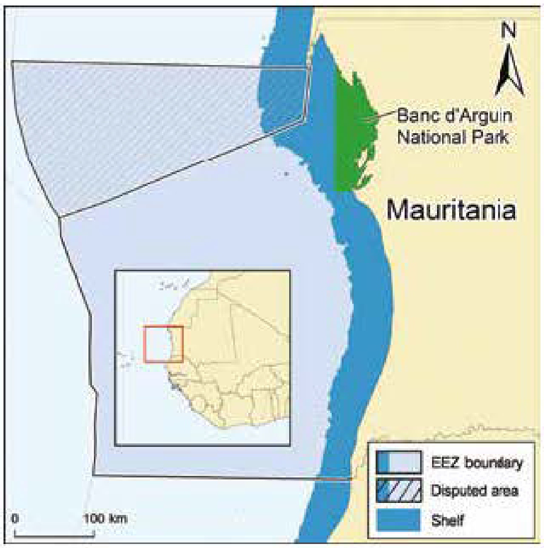

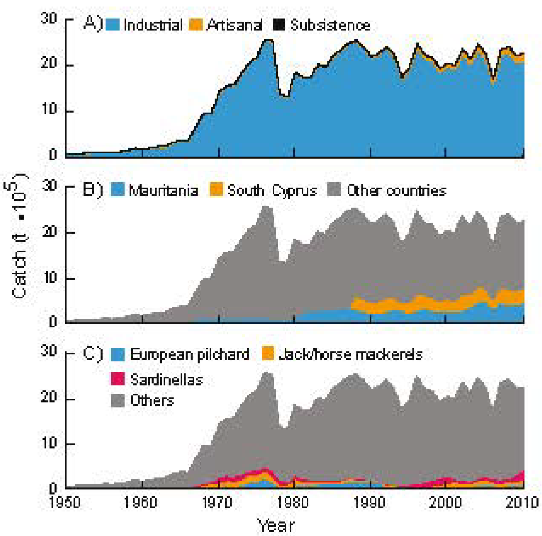

Figure 1. The Mauritanian EEZ (204,600 km²), of which 36,260 km² is shelf. Figure 2. Domestic and foreign catches taken in the EEZ of Mauritania: (A) by sector (domestic scores: Ind. 2, 2, 4; Art. 2, 3, 4; Sub. 2, 2, 2; Rec. –, 4, 4; Dis. 4, 4, 4); (B) by fishing country (foreign catches are very uncertain); (C) by taxon.

Mauritania, which boasts the largest marine protected area in West Africa, the Parc National du Banc d'Arguin (PNBA; figure 1), has productive fisheries because of its wide continental shelf and a seasonal upwelling. The domestic catch, as reconstructed by Belhabib et al. (2012), was 20,000 t/year in the 1950s, increased in 2 stages to more than 300,000 t/year in the late 1990s, and was about 440,000 t/year in the late 2000s. Overall, this is 3 times the data FAO reports on behalf of Mauritania. The majority of catches in this EEZ is industrial (figure 2A), exclusively by foreign fleets (figure 2B). The industrial sector is plagued by uncertainty about actual beneficial ownership; for example, about 60% of the "domestic" catch (and 40% of the discards) is generated by Mauritanian-flagged Chinese vessels. Foreign fishing is widespread in Mauritania, with 38% of foreign catch taken by Eastern European, 27% by Chinese, and 20% by European Union vessels. Part of the foreign catch was taken without authorization from Mauritania. Figure 2C presents top taxa, which include European pilchard (*Sardina pilchardus*), horse mackerels (*Trachurus* spp.), and sardinella (*Sardinella* spp.), which fluctuate less in Mauritania than further south in Senegal or north in Morocco (Samb and Pauly 2000). The only legal fishery inside the PNBA is conducted by the Imraguen people, whose traditional ways contrast the massive industrial vessels operating outside (Picon 2002).

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Stock assessment of round sardinella (*Sardinella aurita*) caught along the coast of Senegal[1]

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Abstract

The LBB and CMSY/BMS methods were used to evaluate the state of the stock of round sardinella (*Sardinella aurita*) based on national data from the Exclusive Economic Zone (EEZ) of Senegal. However, this migratory stock is shared between Morocco, Mauritania, Senegal, and The Gambia. Still, the results strongly suggest that the round sardinella stock is overfished, confirming the results of previous studies of this stock. Measures need to be taken to reduce the fishing effort targeting this resource to allow its biomass to rebuild.

Introduction

The marine catch from Senegalese waters is divided almost equally between industrial and artisanal fisheries (Appendix A). Small pelagic fish, consisting mainly of round sardinella (*Sardinella aurita*), make up about 70 % of landings by artisanal canoes or 'pirogues' (Ndiaye et Kébé 2017). Small pelagics contribute the bulk of the fish caught and subjected to traditional onshore processing and marketing. Thus, small pelagics provide livelihoods for coastal communities and represent a major source of protein for the Senegalese population (Ba *et al.* 2017).

The increasing demand for round sardinella by both a growing population and the production of fishmeal for export (Pauly 2019) has led to a massive increase in the artisanal fishing effort. It is necessary to evaluate the status of this stock to take the appropriate measures for its management.

Round sardinella (*Sardinella aurita*; Family Clupeidae), which reproduces in April and October (Baldé *et al.* 2019), migrates seasonally between the Exclusive Economic Zones (EEZ) of Morocco, Mauritania, Senegal, and The Gambia (FAO 2014; Samb and Pauly 2000; Thiaw *et al.* 2017). Ideally, it should be studied on a regional basis. However, this study is based solely on Senegal's data, with the results being used in part as priors for the regional study of Palomares *et al.* (this volume).

Material and Methods

Collection operations of catch and effort statistics for the artisanal fishery occur daily in landing sites along the Senegalese coast. Catch data are obtained via random sampling of fisheries units when the fish are landed. The weight of the catch is obtained via actual weighing or estimated visually. Information on catch

[1] Cite as: Thiaw, M. I. Ndour1, M. Thiam, O. Sadio, B.S. Baldé, E.H. Sow, A. Sall and J.H. Sène. 2020. Stock assessment of round sardinella (Sardinella aurita) caught along the coast of Senegal, p. 59-63 *In:* M.L.D. Palomares, M. Khalfallah, J. Woroniak and D. Pauly (eds.) Assessments of marine fisheries resources in West Africa with emphasis on small pelagics. Fisheries Centre Research Report 28(4), UBC, Vancouver, Canada.

weight is obtained from skippers or persons involved in fish processing or marketing (Thiao *et al.* 2016). The discarding of fish common in industrial fisheries is rare to non-existent in the Senegalese artisanal fishery. Data collected from the different landing sites is extrapolated to unmonitored areas and regions.

The CRODT provided catch and CPUE data covering 1982 to 2017 and length-frequency (L/F) data covering 2004 to 2017. These data refer only to Senegalese waters and are thus incomplete, given that this stock is shared between many countries.

We used the Bayesian LBB method of Froese *et al.* (2018) to analyse the L/F data for *S. aurita,* given a prior of L_{inf} = 42 cm (Postel 1955); the defaults provided by the software were used for the other priors.

The application of the CMSY method and the related BSM method (Froese *et al.* 2016) required an estimation of the 'resilience' of *S. aurita*. This estimate was obtained from FishBase (www.fishbase.org), which assessed its resilience as 'high,' i.e., with an intrinsic rate of population growth r of 0.74 year^{-1}, with 95 % confidence limits ranging from 0.46 to 1.15 year^{-1}. For the ratio of starting biomass (in 1982) relative to carrying capacity (k), we assumed B_{start}/k = 0.9 -1.0; all other priors were defaults provided by the software (see Palomares *et al.* 2020, this vol.).

Results and Discussion

The LBB model (Figure 1) suggests that the relative biomass of *S. aurita*, which had been hovering between B/k = 0.2 and 0.4 in the early 2010s, recovered in the latter part of the decade. However, in the early 2010s, most individuals were caught at a size > L_{opt}, while the 2017 catches were made up mainly of juveniles (see also Ndour *et al.* 2013). Thus, the apparent recovery came at the cost of growth overfishing. The CMSY/BSM results (Figures 2 and 3) show an increase in *S. aurita* catch from 1982 to 2009, followed by increases to 2017. Otherwise, the biomass gradually decreased to 2010 while remaining higher than B_{MSY}. From 2011, the biomass decreased below that required for MSY.

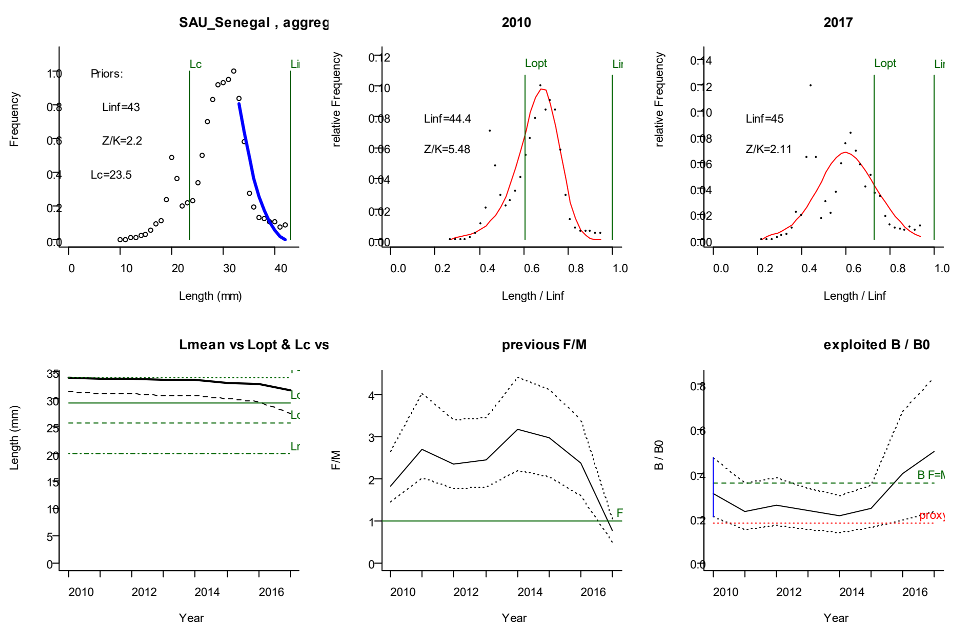

Figure 1. Application of the LBB model to round sardinella caught in Senegalese waters (see text).

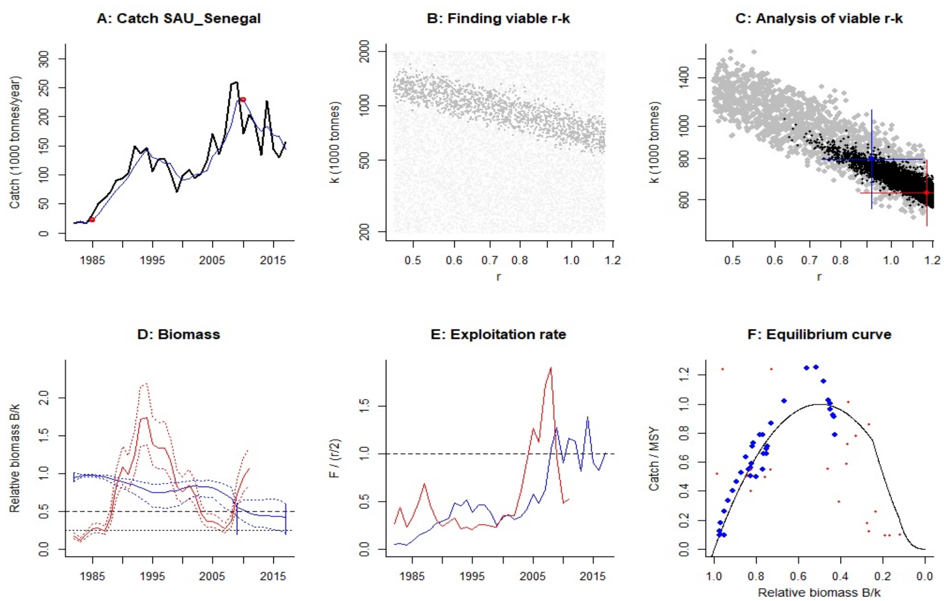

Figure 2. Stock assessment of *Sardinella aurita* in Senegal using the CMSY/BSM methodology. MSY = 184,000 t·year^{-1}, r = 1.17 (0.872-1.57) and B_{end}/k = 0.48 (0.26-0.68).

Our results suggest that round sardinella is overexploited. While this analysis is based on partial data covering only Senegalese waters, it confirms earlier hypotheses regarding the stock's problematic state (FAO 2014).

Based on this study, we recommend that:

1. Given that the stock of round sardinella is shared between Senegal, Mauritania, and The Gambia, an analysis should be completed using all data from these 3 countries to provide more reliable results (see Palomares *et al.* 2020, this vol.);
2. Despite the uncertainty associated with (1), fishing effort targeting sardinella should be reduced to rebuild its population.

Acknowledgements

We acknowledge the contribution of the CRODT staff for collecting and providing the catch data, and the MAVA Foundation and the Sub-Regional Fisheries Commission (CSRP) for funding and hosting, respectively, the workshop during which most of the work toward completion of this contribution was performed.

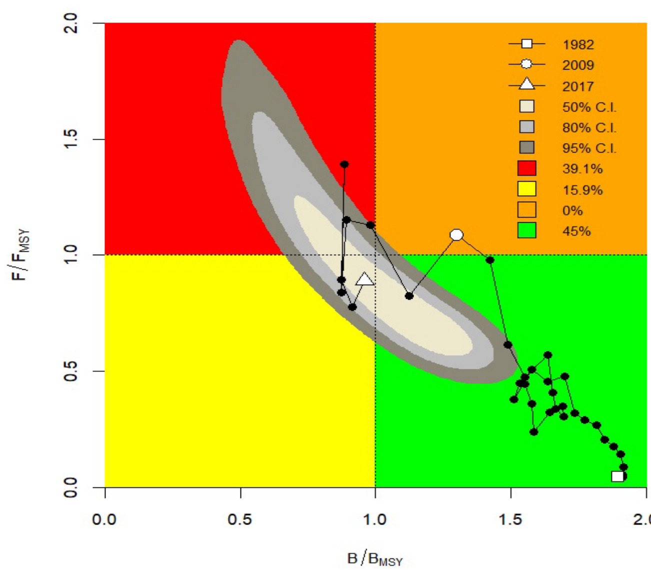

Figure 3. Kobe plot summarizing the results in the different panels of Figure 2.

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Appendix A: Summary of data on the marine fisheries of Senegal, 1950-2010.

SENEGAL[1]

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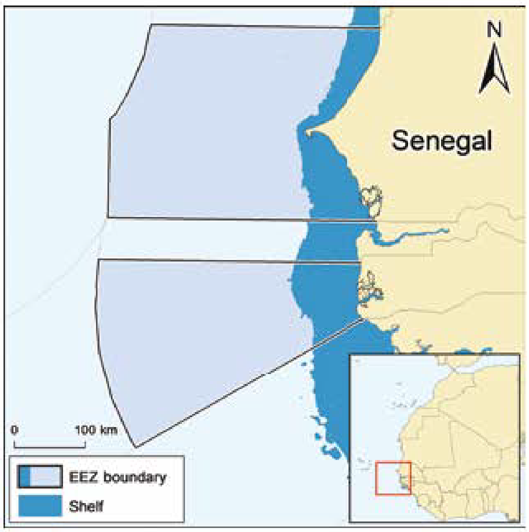

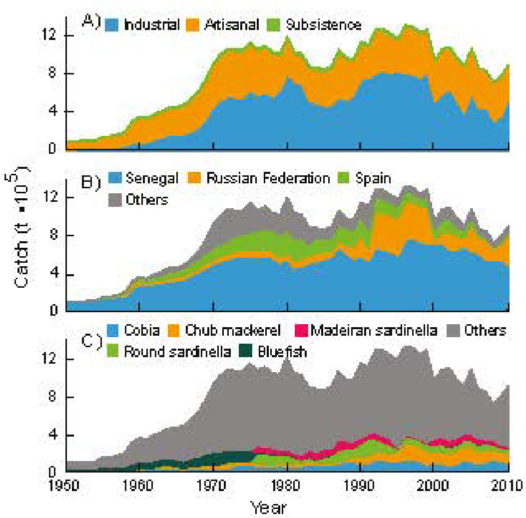

Figure 1. Senegal (EEZ: 158,000 km²) has a continental shelf of 23,900 km². Figure 2. Domestic and foreign catches taken in the EEZ of Senegal: (A) by sector (domestic scores: Ind. 3, 3, 4; Art. 2, 2, 3; Sub. 3, 3, 3; Rec 2, 2, 4; Dis. 4, 4, 4); (B) by fishing country (foreign catches are very uncertain); (C) by taxon.

Senegal is located at the edge of 2 highly productive fishing zones: the Canary Current Large Marine Ecosystem and the Gulf of Guinea Large Marine Ecosystem (figure 1). Its colonial history contributed toward enriching fisheries data through surveys and analyses of the artisanal and industrial sectors. Official catches are lower than estimated maximum sustainable yield (MSY), but the pervasiveness of overexploitation (Cormier-Salem 1994; Thiao et al. 2013) suggests that this MSY will remain unattainable. Total catches are dominated by the industrial sector (figure 2A), although much of this is by foreign fleets (figure 2B). Reconstructed domestic catches were estimated by Belhabib et al. (2013, 2014) at 100,000 t in 1950, increasing to more than 700,000 t/year in the late 1990s before declining to about 500,000 t in 2010 (figure 2B). Domestic catches in the Senegalese EEZ were 2 times the data supplied to the FAO, once adjusted for its EEZ. Illegal foreign fishing appears to have peaked in the late 2000s, and legal foreign catches have continued to decline as Senegal reduces fishing opportunities by foreign fleets. Senegalese catches taken outside the Senegalese EEZ increased from low levels in the mid-1970s to about 250,000 t in 2010, much of which is taken from the Mauritanian EEZ but landed and reported in Senegal. Senegalese catches cover a multitude of taxa (figure 2C), but recently, the dominance of chub mackerel (*Scomber japonicus*) has increased.

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Estimating biological reference points for bonefish (*Albula vulpes*) in Sierra Leone fisheries through CMSY and LBB analyses[1]

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Abstract

The intensity of industrial fishing is currently high in the Exclusive Economic Zone (EEZ) of Sierra Leone, requiring an evaluation of exploited stocks' status. This study focuses on the bonefish (*Albula vulpes*), which is both abundant and sought after. The CMSY and LBB/BSM methods were applied to length-frequency, catch time series, and CPUE data from the national fisheries statistical database to provide relevant reference points on the stocks. The results indicate that bonefish are currently being overexploited, i.e., that their biomass is below that which would generate maximum sustainable yield (MSY).

Introduction

The industrial fisheries operating in Sierra Leone's Exclusive Economic Zone (EEZ; Figure 1, and see Appendix A) comprises bottom trawlers, midwater trawlers, pelagic trawlers, shrimpers, and tuna vessels (Shower 1999). The finfish and shrimp targeted by these fisheries suffered very high exploitation in the 1980s and 1990s, with occasional 'peak catches' followed by strong declines in demersal landings in the succeeding years (see Showers 1999 and www.searoundus.org). The finfish trawlers target mid-water and demersal stocks.

There have been worrying signs about the status of the stocks exploited by these fisheries. The availability of the newly-developed LBB (Froese *et al.* 2018) and CMSY/BSM methods (Froese *et al.* 2016) makes it possible to analyse accumulated data on the stocks exploited by these fisheries (see Palomares *et al.* 2020, this vol.).

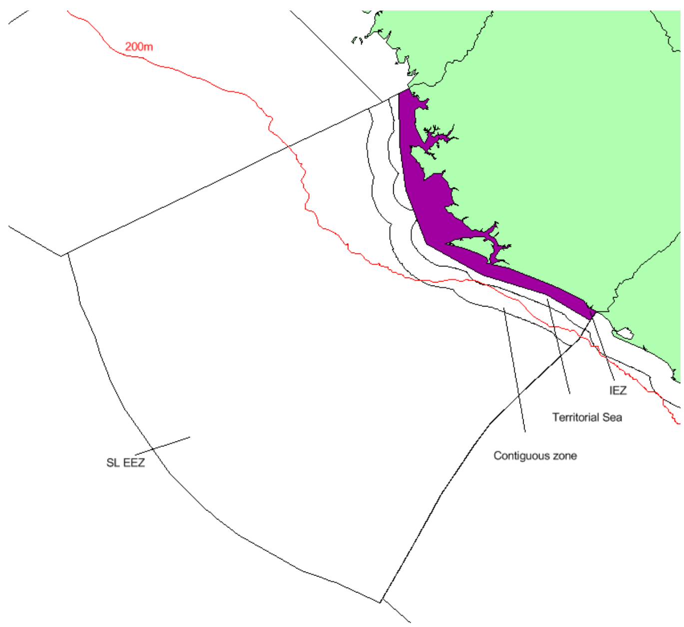

Figure 1. Features of Sierra Leone's Exclusive Economic Zone, of 159,000 km² (see also Appendix A).

The bonefish (*Albula vulpes*; Family Albulidae; Figure 2) is one of the most prominent commercial fish species in the demersal fisheries of Sierra Leone and the intense exploitation of the national fisheries over

[1] Cite as: Showers, P.A.T. and A.I. Turay. 2020. Estimating biological reference points for bonefish (*Albula vulpes*) in Sierra Leone fisheries through CMSY analysis, p. 64-68 *In:* M.L.D. Palomares, M. Khalfallah, J. Woroniak and D. Pauly (eds.) *Assessments of marine fisheries resources in West Africa with emphasis on small pelagics*. Fisheries Centre Research Report 28(4), UBC, Vancouver, Canada.

the 10 years warrants a close evaluation of its stocks. This species is exploited mainly by demersal trawlers and, to a lesser extent, by other gears

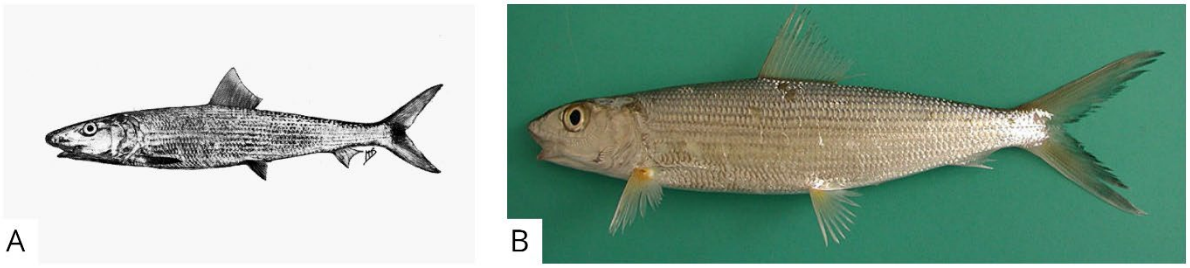

Figure 2. Images of *Albula vulpes*; A: drawing by P. Heemstra; and B: photo by R. Freitas (from www.fishbase.org).

Bonefish, commonly called 'ninebone fish' in Sierra Leone, is a marine species widely distributed in the tropical waters on both sides of the Central Atlantic, ranging from the Gulf of Mexico to Brazil in the West and from Mauritania to Angola in the East. The species inhabits shallow coastal waters, estuaries, and bays, spawns in open waters; the eggs are pelagic. Bonefish can reach about 1 m in length; they feed on a wide range of nekton and zoobenthos, including cephalopods and shrimps. Its trophic level is estimated at 3.7 ±0.3 (see FishBase; www.fishbase.org). Bonefish is amongst the most abundant species in the demersal trawl fisheries of West Africa, and it usually fetches a high price. In Sierra Leone, bonefish occur in the shelf's upper and central areas (Figure 3), where the industrial and artisanal fisheries intensely exploit it.

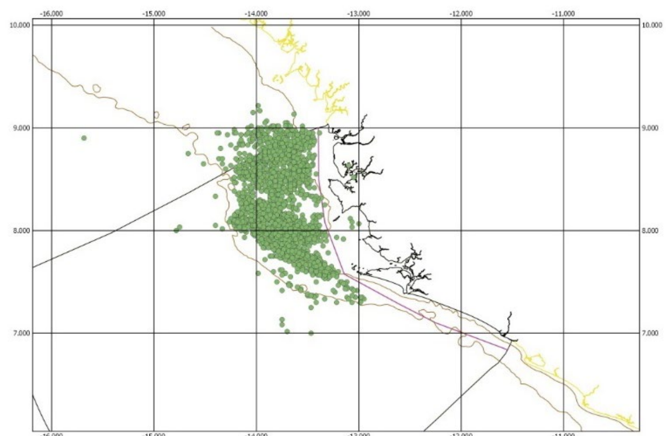

Figure 3. Spatial distribution of bonefish (*Albula vulpes*) catches in 2018, as reported by vessels reporting to the Sierra Leone's authorities.

Materials and Methods

The LBB and CMSY/BSM methods are relatively new developments, designed to analyze data widely available from port sampling and fisheries observer programmes. Amongst the most outstanding advantages of these methods is that they require a minimum of data input to estimate the current biomass of exploited species relative to unexploited biomass (B/B_0) as one of its key outputs. Details of the methods and their routines are discussed in Froese *et al.* (2017), Froese *et al.* (2018), and other contributions of this report.

The data employed in this analysis were obtained from the Sierra Leone fisheries database (IFDAS), which contains commercial fisheries data obtained from 2008 to 2018 by fisheries observers, trained in fish taxonomy, statistics, and biological sampling, on board fishing trawlers (Table 1). Other relevant information on bonefish was obtained from the scientific literature and FishBase (www.fishbase.org).

The priors used for the LBB analysis were L_{inf} = 52.3 cm; Z/K = 1.9; F/K = 0.371 and L_c = 32.6 cm (each prior was provided as a range; only the midpoints are given here). The priors used for the CMSY/BSM analysis were: B_{start}/k = 0.1-0.5 (because the stock was already heavily impacted in the early 2000s); B_{int}/k = 0.5-0.9 (default, for 2014); B_{end}/k = 0.4-0.8 (default); r = 0.05-0.5 year^{-1} (from FishBase) and k = 7.53-244 10^3 t·year^{-1} (default). The technology creep of the fishing effort was set at 4 % year^{-1} (see Palomares and Pauly 2019).

Table 1. Catch of bonefish in Sierra Leone, with CPUE (arbitrary units)

Year	Catch (t)	CPUE
2008	784	0.68
2009	666	0.58
2010	846	0.63
2011	727	0.75
2012	95	0.29
2013	375	0.32
2014	1714	0.60
2015	2025	0.59
2016	1911	0.55
2017	1507	0.62
2018	1347	0.63

Results and Discussion

The available length frequency data did not generate a particularly good fit when analyzed with the LBB method (Figure 4); nevertheless, the main numerical results, i.e., L_{inf} = 53.7 cm (95 % C.I. = 53.0-54.2); L_{opt} = 37 cm; M/K = 1.34 (1.05-1.65); F/M = 1.77 (1.19-1.74) and B/B_0 = 0.29 (0.16-0.48), seem reasonable. These results informed the CMSY/BSM analyses which followed. The graphical results from the CMSY/BSM analysis are presented in Figure 5.

In numerical terms, our results were as follows for the CMSY analysis (i.e., without CPUE data): MSY = 3,810 t·year^{-1} and B_{end}/B_0 = 0.71. When the CPUE data are used in conjunction with the BSM method, these parameters become MSY = 810 t·year^{-1} and B_{end}/B_0 = 0.42, i.e., the result are far more conservative. However, the time series analyzed here is too short to generate reliable results (note the wide confidence intervals in grey in Figure 5 (left panel). This contribution must be considered tentative.

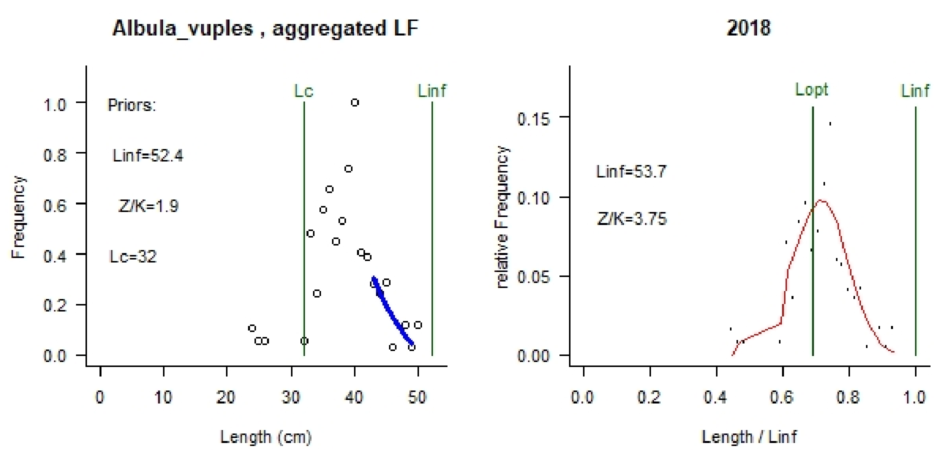

Figure 5. Graphical output of LLB analysis for bonefish (*Albula vulpes*) in Sierra Leone (see text).

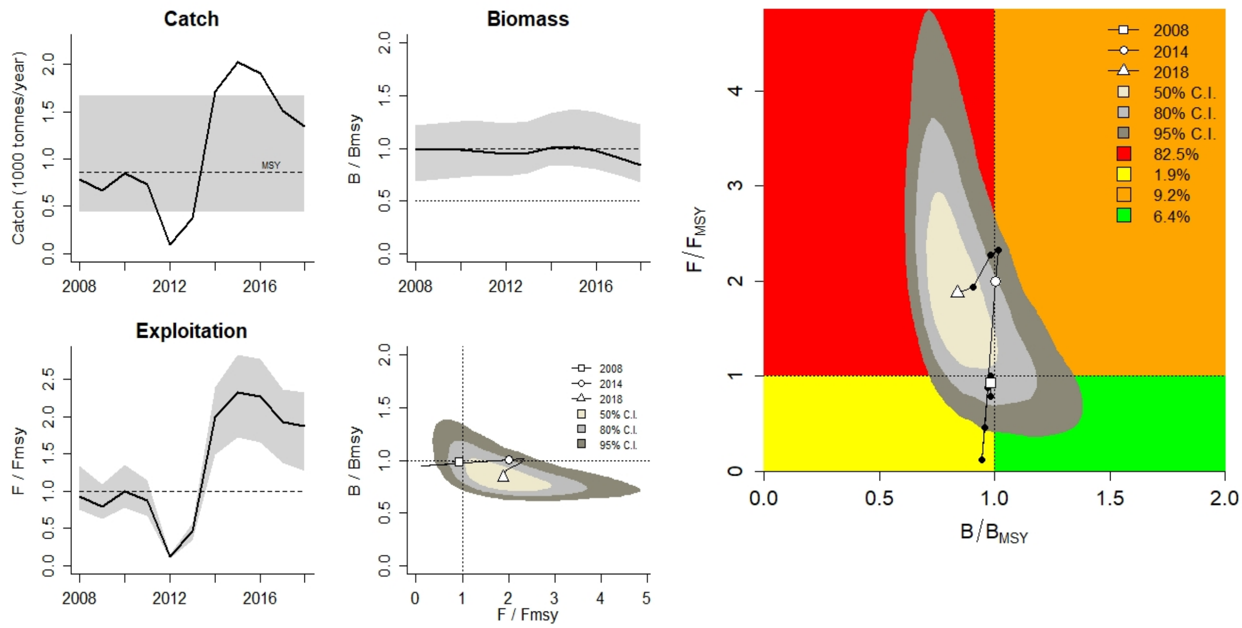

Figure 6. Graphical summary of the stack assessment of bonefish (*Albula vulpes*) exploited in Sierra Leone. Left: Trends in catch, biomass, and exploitation rate (2008-2018), with a small Kobe plot; Right: Enlarged version the Kobe plot (see text for the corresponding numerical results).

Acknowledgements

The authors wish to express their appreciation to all collaborators/enumerators of the Sierra Leone Fisheries Ministry for their hard work in obtaining fisheries data for the national database. We also express our gratitude to the Fisheries Ministry and the World Bank fisheries program officers, especially its consultant, Mr. Stephen Akester, for providing vital assistance to Sierra Leone fisheries research and management through all these years. Finally, we sincerely thank the sponsors of this workshop, the MAVA Foundation and the Sub-Regional Fisheries Commission, and the *Sea Around Us* team, for contributing toward improving fisheries research in data-poor countries, especially in West Africa.

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Appendix A: Summary of data on the marine fisheries of Sierra Leone, 1950-2010.

SIERRA LEONE[1]

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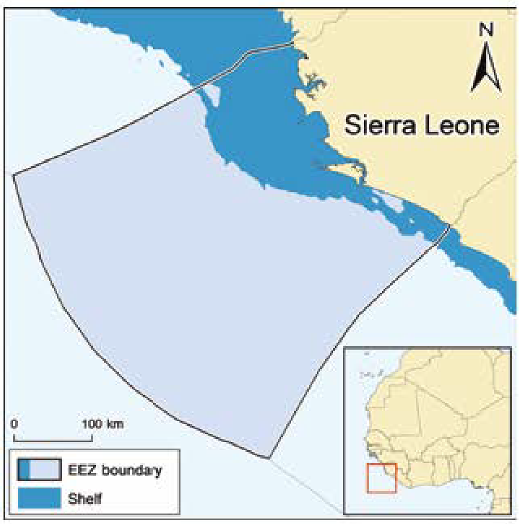

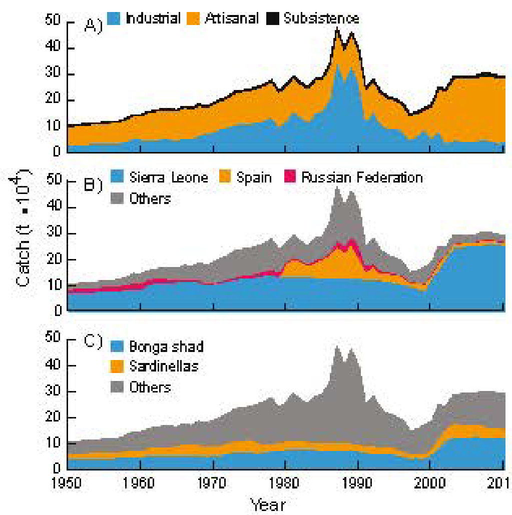

Figure 1. Sierra Leone has a continental shelf of 26,600 km² and an EEZ of 159,000 km². Figure 2. Domestic and foreign catches taken in the EEZ of Sierra Leone: (A) by sector (domestic scores: Ind. –, 4, 4; Art. 2, 3, 4; Sub. 1, 1, 1; Dis. –, 2, 4); (B) by fishing country (foreign catches are very uncertain); (C) by taxon.

Sierra Leone is located in northwest Africa (figure 1). After independence from British colonial rule in 1961, the country experienced nearly continuous strife over access to natural resources, culminating in a civil war (1991–2002) funded by blood diamonds. With deepening poverty, the people of Sierra Leone became increasingly dependent on marine fisheries as an alternative source of livelihood and food. But like blood diamonds, fisheries are usually dominated by large-scale operations and hard-to-monitor small-scale operations (Golley-Morgan 2012). The reconstruction by Seto et al. (2015) estimated domestic catches of 70,000 t in 1950, which peaked at 140,000 t in the late 1970s, declined to 80,000 t in 2000, and then increased again since the end of the civil war to 250,000 t in 2010. Domestic catches were about 30% higher than the data supplied to the FAO and were dominated by the artisanal sector (figure 2A). Although foreign fleets dominated in the 1980s, this has declined in recent years (figure 2B). Bonga shad (*Ethmalosa fimbriata*) had the largest contribution to catches, followed by sardinella (*Sardinella* spp.; figure 2C). Illegal foreign fisheries were ubiquitous during the civil war. Their recent decrease illustrates the significant improvement in monitoring and enforcement efforts by the country. The artisanal fisheries increased strongly in response to development aid and the opportunity to act as near-shore extensions of the remaining foreign industrial fleets.

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Assessment of 14 species of small pelagic fish caught along the coast of Northwest African countries[1]

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Abstract

The major stocks of small pelagic fishes in Northwest Africa move seasonally across the boundaries of the Exclusive Economic Zones of this sub-region's countries and, thus, must be assessed by pooling the catch and related data generated by national entities. Therefore, small pelagic catch data 'reconstructed' by the *Sea Around Us* from 8 Northwest African countries (Cape Verde, The Gambia, Guinea, Guinea Bissau, Liberia, Mauritania, Senegal, and Sierra Leone) was combined by 'marine ecoregions.' The assessment of 14 species was performed using the CMSY and BSM methods, complemented with 'priors' from the LBB methods and previous applications of the CMSY/BSM methods to national data. The CMSY and BSM methods, which are presented in some detail, generated time series of the biomass of these small pelagics, documenting serious depletions. There is an urgent need to rebuild the populations of small pelagic fish in the sub-region, particularly because their contribution to local food security is increasingly undermined by their use as raw material for fishmeal exports.

Introduction

Since the 1990s, evidence has been mounting that fisheries, almost everywhere, are in serious trouble due to huge increases in fishing effort and a declining global resource base (Tremblay-Boyer *et al.* 2011; Watson *et al.* 2013). Detailed stock assessments are available in many economically developed countries (e.g., the EU, Norway, the US, Canada, or Australia). They confirm large-scale resource depletion and provide a baseline for rebuilding efforts. Unfortunately, similar stock assessments are lacking for developing countries, in general, and Northwest Africa, in particular.

There are many reasons for this, notably: (a) lack of expertise, only slowly alleviated through various training workshops such as the one documented in this report, (b) the frequently cited "lack of data," and (c) the absence of methods to generate at least preliminary assessments with the limited data that are available. While (a) remains a real problem, (b) and (c) have been recently mitigated, through the development of computer-intensive methods relying mainly on fisheries catch time series.

A comprehensive global set of fisheries catch data now exists – the reconstructed catches of the *Sea Around Us*. These catches correct many of the worst problems associated with the database of landings (not catches!) disseminated by the Food and Agriculture Organization of the United Nations (FAO), which is largely based on unmodified submissions by its member countries (see Pauly and Zeller 2016a and www.seaaroundus.org).

The assessments presented here should provide an impression of the status of 14 stocks of small pelagic fishes caught in the Exclusive Economic Zones (EEZ) of 8 Northwest African countries (Cape Verde, The Gambia, Guinea, Guinea Bissau, Liberia, Mauritania, Senegal, and Sierra Leone). However, contrary to these reports and other contributions, we account for the stocks (except those caught in the EEZ of Cape Verde) 'straddling' the EEZ of 2 or more countries during seasonal migrations. Also, we use the

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'reconstructed' catch data of the *Sea Around Us* for these assessments, covering a longer time series (usually 1950 to 2016; see www.seaaroundus.org), i.e., longer than most national data sets.

Finally, we present the full set of equations derived for the Length-based Bayesian Biomass (LBB) method (Froese *et al.* 2018a, 2019) and by Froese *et al.* (2017) for the CMS/BMS method, to serve as reference, because none of the other contributions in this report included these equations.

Material and Methods

The LBB method

The Length-based Bayesian Biomass (LBB) estimation method (Froese *et al.* 2018) relies heavily on the von Bertalanffy growth function (VBGF; Bertalanffy 1938; Pauly 1998), used to depict the growth in body length.

$$L_t = L_{inf}\left[1\text{-}e^{-K(t-t_0)}\right] \quad ...1)$$

where L_t is the length at age t, L_{inf} is the mean length that the individuals of the species and stock in question would reach if they were to grow indefinitely (i.e., the 'asymptotic' length), K expresses the rate at which L_{inf} is approached (of dimension time^{-1}, usually year^{-1}), and t_o is the age the fish would have at a length of zero if their growth always conformed to the VBGF even at younger ages (which it doesn't, but this does not matter for the LBB method, see below).

The majority of fish and invertebrate species grow throughout their lives and approach L_{inf} if there were no natural (M) or fishing (F) mortality. This is expressed by:

$$N_{t2} = N_{t1} \cdot exp\text{-}(Z\,(t_2\text{-}t_1) \quad ...2)$$

where N_{t1} and N_{t2} are the numbers of a given cohort or a population at time 1 and 2, and Z is the instantaneous rate of total mortality, consisting of natural and fishing mortality, i.e., $Z = M + F$ (Beverton and Holt 1957; Pauly 1998).

Fishing gears have distinct selection curves; the curve assumed in LBB is sigmoid, i.e., very small individuals ($<L_x$) are not caught, all individuals past a certain size ($>L_{start}$) are caught. In contrast, the faction caught between L_x and L_{start} is an increasing, *S*-shaped function of length. This can be expressed by

$$S_L = \frac{1}{1+e^{-\alpha\,(L-L_c)}} \quad ...3)$$

where S_L is the fraction of individuals retained by the gear at length L. In Equation (3), is the steepness of the S-shaped curve describing the gear's selectivity. Mean length at first capture (L_c) is the length at which half of the individuals encounter the gear will be retained by it.

Combining Equations (1) to (3) leads to:

$$N_{L_i} = N_{L_{i-1}} \left(\frac{L_{inf} - L_i}{L_{inf} - L_{i-1}}\right)^{\frac{M}{K}+\frac{F}{K}S_{L_i}} \quad ...4)$$

and

$$C_{L_i} = N_{L_i}\,S_{L_i} \quad ...5)$$

where N_{Li} is the number at length L_i, N_{Li-1} is the number at the previous length L_{i-1}, C is the number vulnerable to the gear, and all other parameters are as defined above. To reduce the parameter requirements, the ratios M/K and F/M are output - along with an estimate of L_{inf} - instead of the absolute values of F, M, and K. Note that F/M =(F/K)/(M/K).

LBB, while referring to 'L_c', considers Equation (3), i.e., accounts for the fish caught at small sizes (larger than L_x, but less than L_c) that are not compensated for by the larger fish not caught above L_c, but below L_{start} (Silvestre *et al.* 1991).

When more than one year's worth of L/F data is available, catch in numbers are made comparable between years through the division of both sides of Equation (5) by their sums:

$$\frac{C_{L_i}}{\sum C_{L_i}} = \frac{N_{L_i}\,S_{L_i}}{\sum N_{S_i}\,S_{L_i}} \quad ...6)$$

The ratios M/K and F/K can be computed by fitting Equation (4) to LF data (Figure 1).

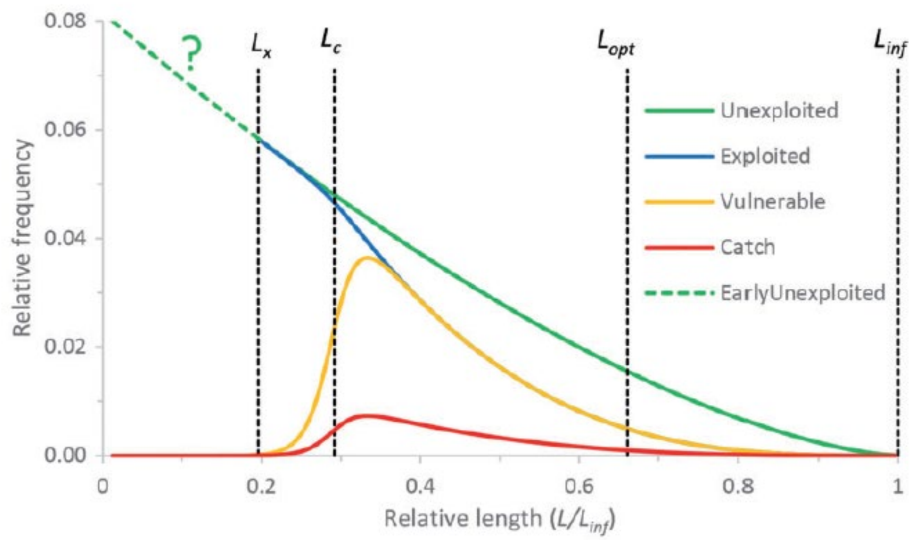

Figure 1. Illustrating the main features of the Length-based Bayesian Biomass (LBB) estimation method of Froese *et al.* (2018a). The red line is the part we can see, as derived from length-frequency samples. When fitted to L/F data (red), the LBB method allows inferences on the selection, growth and mortality processes which generated the underlying orange, blue, and green curves (see text).

Relative yield-per-recruit (Y'/R), as defined by Beverton and Holt (1966) can be computed, as presented by Froese *et al.* (2018a), from:

$$\frac{Y'}{R} = \frac{F/M}{1+F/M}\left(1-\frac{L_c}{L_{inf}}\right)^{\frac{M}{K}}\left(1-\frac{3(1-L_c/L_{inf})}{1+\frac{1}{M/K+F/K}}+\frac{3(1-L_c/L_{inf})^2}{1+\frac{2}{M/K+F/K}}-\frac{(1-L_c/L_{inf})^3}{1+\frac{3}{M/K+F/K}}\right) \quad ...7)$$

If CPUE is assumed proportional to biomass, dividing equation (7) by F/M leads to:

$$\frac{CPUE'}{R} = \left(\frac{Y'}{R}\right)/\left(\frac{F}{M}\right) = \left(\frac{1}{1+\frac{F}{M}}\right)\left(1-\frac{L_c}{L_{inf}}\right)^{\frac{M}{K}}\left(1-\frac{3(1-L_c/L_{inf})}{1+\frac{1}{M/K+F/K}}+\frac{3(1-L_c/L_{inf})^2}{1+\frac{2}{M/K+F/K}}-\frac{(1-L_c/L_{inf})^3}{1+\frac{3}{M/K+F/K}}\right) \quad ...8)$$

Thus, the relative biomass of a stock whose individuals are $>L_c$ is then given, if F = 0, by

$$\frac{B_0 > L_c}{R} = \left(1-\frac{L_c}{L_{inf}}\right)^{\frac{M}{K}}\left(1-\frac{3(1-L_c/L_{inf})}{1+\frac{1}{M/K}}+\frac{3(1-L_c/L_{inf})^2}{1+\frac{2}{M/K}}-\frac{(1-L_c/L_{inf})^3}{1+\frac{3}{M/K}}\right) \quad ...9)$$

where B_o is the unfished biomass. Thus, the ratio of fished to unfished biomass is:

$$B/B_0 = \left(\frac{CPUE'}{R}\right)/\left(\frac{B_0' > L_c}{R}\right) \quad ...10)$$

(Froese *et al.* 2018a). Also, we have:

$$L_{opt} = L_{inf} \cdot 3/(3+M/K) \quad ...11)$$

where L_{opt} is the length when the biomass of a cohort of fish or invertebrates reaches its maximum (Holt 1958). This allows defining:

$$L_{c\_opt} = \frac{L_{inf}(2+3\frac{F}{M})}{\left(1+\frac{F}{M}\right)\left(3+\frac{M}{K}\right)} \quad ...12)$$

that defines the mean length at first capture, which maximizes both the catch and the underlying biomass for a given set of F/M and M/K ratios.

The LBB method has been applied successfully to numerous data-sparse stocks, notably in China (Liang *et al.* 2020a). It was applied in several contributions in this report and one of the stocks analyzed in this contribution.

The CMSY and BSM methods

The CMSY, as documented in Froese *et al.* (2016), is, like the Maximum Sustainable Yield (MSY) concept from which it gets its name, based on an approach to fish population dynamics formulated by Schaefer (1954, 1957; see Figure 2). This approach, also known as 'surplus-production' modeling, assumes that a given ecosystem has, for any animal population, a specific carrying capacity (k). If this population is reduced through an external event (e.g., fishing), the population will tend to grow back toward its carrying capacity. Such growth will depend on the intrinsic growth rate of a population (r; of dimension: time^{-1}), which is determined by the attributes of the individuals of the population in question (individual growth rate, age at first maturity, natural mortality, fecundity, etc.), and by the current abundance (B) of the population.

Thus, the abundance of a very small population cannot grow by a large amount, even if its r is relatively high because r·B is close to zero. Conversely, population growth is also low near carrying capacity because r·B is multiplied by 1-B/k, which expresses density-dependant effects. This results in high population growth occurring at intermediate abundance levels. The maximum occurs at k/2.

Thus, a fishery can maintain a given population at any given biomass level by removing, each year, an amount of biomass equivalent to the natural growth of that population. Because new biomass production is maximized at half-carrying capacity (k/2), MSY is obtained when the unfished biomass (B_o) is halved, assuming

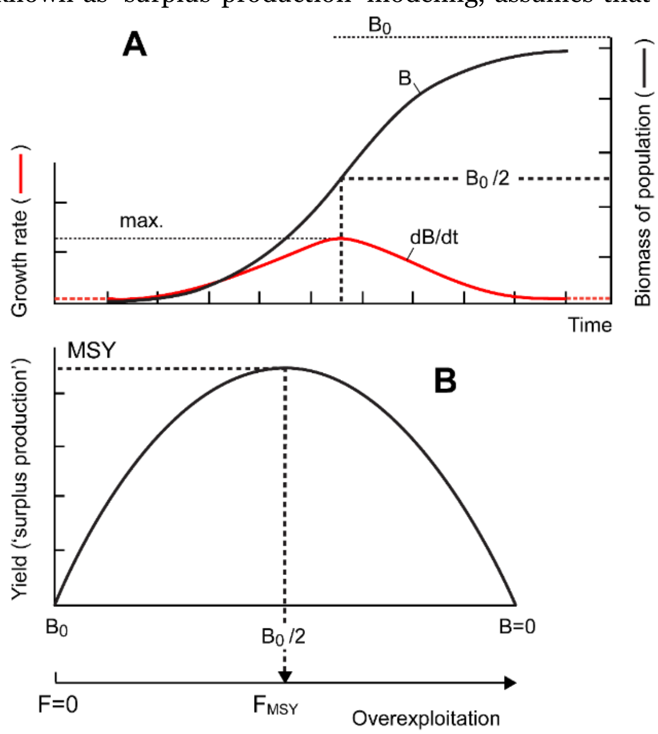

Figure 2. Basic principles behind (Schaefer-type) surplus-production models**. A**: the population size (i.e., biomass; B) of any living organisms (incl. small pelagic fish) will, if released into a new ecosystem, increase slowly, then rapidly, then again slowly as the carrying capacity of the ecosystem (B_o) is approached. **B:** The growth of that population (dB/dt), when plotted against biomass, generates a parabola, with low values of dB/dt (i.e., 'surplus production') both near carrying capacity and near B = 0. Surplus production has a maximum value at $B_o/2$, corresponding to Maximum Sustainable Yield. Surplus-yield predictions, and the CMSY method thus rest on a sound theoretical basis, since density-dependent limitation of carrying capacity is known to occur in all ecosystems (see text and Figure 3).

B_0~k. The CMSY method is built on this conceptual framework, essentially consisting of tracing random trajectories of its likely biomass for a given exploited stock and identifying the trajectories that remain viable while accommodating the catches taken from this population and a few other constraints (Figure 3). Here, 'remaining viable' means not going extinct. The constraints (or 'priors') are assumed biomass reductions caused by fishing, a range for the carrying capacity (k) of the species in the ecosystem in question, and a range of likely values of r, i.e., its maximum intrinsic rate of population growth. Qualitative measures of r, i.e., resilience (as defined in Musick 1999 and refined in Musick *et al.* 2000), are taken from FishBase (www.fishbase.org), which computes ranges of likely r values from biological parameters, especially the von Bertalanffy growth parameter L_{inf} and K, maximum age, and fecundity.

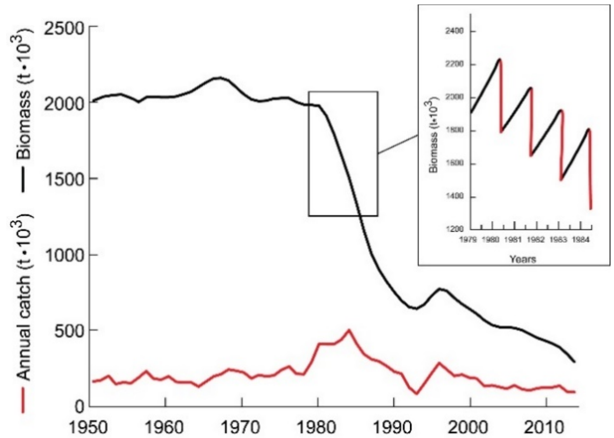

Figure 3. Illustrating the basic principle of the CMSY method: population biomass trajectories are projected from a start year (here 1950) where the biomass is assumed to be a (generally high) fraction of carrying capacity (k, or B_0) which increases via annual growth increments (as a function of population growth rate, r, and B/B_0) and decreases due to catches (in red, see insert). The trajectories that are retained are those that do not crash the population and conform to various constraints (see text).

In practice, given a catch time series and a wide range of r and k estimates, thousands of biomass trajectories can be generated, of which few are viable. Constraints refer specifically to independent prior knowledge of biomass levels. Thus, the reduction of biomass from carrying capacity by fishing at the start of the time series (e.g., 1950) is expressed as a fraction (B_{start}/k). Then, the likely fractions of biomass at some intermediate year (B_{int}/k) and at the end (B_{end}/k) of the catch time series are also obtained, e.g., from general knowledge about the fishery. Here, information from some of the national assessments in this report was used as priors (see Table 2).

Finally, the CMSY model was complemented by a Bayesian version of the full Schaefer model (BSM), which uses relative biomass time-series (e.g., catch per unit of effort or CPUE) from other stock assessments. This typically results in narrower estimates of fisheries reference points and good agreement with the age-based more-data-demanding assessments (see Froese *et al.* 2016, 2018b). This report presents the resulting B/B_{MSY} estimates of the CMSY analyses as an average of the last five years (2012-2016).

Another way of presenting the CMSY approach is to assume that from one year (t) to the next (t+1), the biomass (B_t) follows the equation:

$$B_{t+1} = B_t + r(1 - B_t/k)B_t - C_t \quad ...1)$$

where r is the intrinsic rate of population growth, k is the carrying capacity (≈B_0), and C_t is the catch in year t.

When the biomass (B_t) falls below 0.25k, Equation (1) is modified to allow for 'depensation' (≈reduced recruitment):

$$B_{t+1} = B_t + (4\text{r}\,B_t/k)(1 - B_t/k)B_t - C_t \mid B_t/k < 0.25 \quad ...2)$$

where $4rB_t/k$ creates a linear decline of population growth below B_{MSY}, i.e., half of the biomass capable of generating maximum sustainable yield (MSY).

The R software implementing the CMSY method includes a routine that produces wide (uniform) priors for k (Froese *et al.* 2017), whose output were accepted as defaults (as they were in the other contributions in this report):

$$k_{low} = \max(C)/r_{high}\,;\; k_{high} = 4\max(C)/r_{low} \quad ...3)$$

where k_{low} and k_{high} are the default lower and upper limits of k, max(C) is the maximum catch in the time series, and r_{low} and r_{high} are the lower and upper limits of r-range, which is explored by the CMSY. Thus, we have:

$$k_{low} = 2max(C)/r_{high}\,;\; k_{high} = 12max(C)/r_{low} \quad ...4)$$

with variables as in Equation (3).

Froese *et al.* (2017) formulated the BSM method such that the standard deviation of r in log-space is described by a uniform distribution (ranging between 0.001 irf and 0.02 irf), i.e.,

$$irf = 3/\left(r_{high} - r_{low}\right) \quad ...5)$$

where irf is an inverse range factor to infer the r-range, with r_{high} and r_{low} usually provided by FishBase (www.fishbase.org) for fishes (Table 1), and SeaLifeBase (www.sealifebase.org) for invertebrates.

Table 1. Ranges suggested by FishBase (www.fishbase.org) for population growth rate (in year^{-1}) of the 11 West African species analysed in this study.

Resilience (r)	Suggested prior	Species
High	0.6-1.5	*Decapterus macarellus, Ethmalosa fimbriata, Ilisha africana, Sardinella aurita, Trachurus trecae*
Medium	0.2-0.8	*Caranx rhonchus, Engraulis encrasicolus, Mugil cephalus, Sardinella maderensis, Sardina pilchardus, Trachurus trachurus*
Low	0.05-0.5	–
Very low	0.015-0.1	–

The k estimation by BSM also assumes that k has a log-normal distribution, with the mean of k providing a credible estimate.

The BSM method allows the estimation of a catchability coefficient (q) that relates CPUE (when available) to biomass. Here, priors are given by:

$$q_{low} = 0.25 r_{pgm} CPUE_{mean}/C_{mean};\; q_{high} = 0.5 r_{high}/CPUE_{mean} \quad ...6)$$

where q_{low} and q_{high} define a (uniform) range of prior for the catchability coefficient; r_{pgm} is the geometric mean of the prior range for r; $CPUE_{mean}$ is the mean CPUE over the last few years, and C_{mean} is the mean catch over the same few years.

Finally, gradual improvements of the fishing boats, and of their gear, rigging, and instrumentation, which can be substantial, can be (and was) considered in BSM analyses, particularly when using industrial CPUE data, by including a technological 'creep' factor of, e.g., 2 % per year (Palomares and Pauly 2019).

The CMSY/BSM method has been applied to hundreds of 'data-rich' stocks, which enabled comparisons with the results of models requiring more data (Froese *et al.* 2018b). It has also been applied successfully to multiple stocks in countries and regions with few 'classical assessments, notably Turkey (Demirel *et al.* 2019) and Northeast Asia (Liang *et al.* 2020b; Ju *et al.* 2020; Rena and Liu 2020), and globally (Palomares *et al.* 2020).

The catch and CPUE time series used for assessing small pelagics

The catch time-series data used for the present study are mainly based on FAO data, corrected and complemented through a procedure called 'catch reconstruction' documented in Zeller *et al.* (2007), Lam *et al.* (2016), Palomares *et al.* (2016), Zeller *et al.* (2016) and Pauly and Zeller (2016a). The actual reconstructions were largely performed on a per-country (or overseas territory) basis. Over 200 papers (*Fisheries Centre Working Papers*, chapters in *Fisheries Centre Research Reports*, book chapters and articles in peer-reviewed journals) document the time series reconstructions in 273 EEZs or parts thereof (see Pauly and Zeller 2016b).

The catch of industrial, artisanal, subsistence and recreational fisheries of each country was presented in these publications, based on landing and related data from FAO or the fisheries agency of the country in question, complemented with data (including discards) from each sector as required to obtain a complete time series, from 1950 to 2010 (now updated to 2016) of catches by the sectors mentioned above including estimates of illegal and previously unreported catches.

The difference between reconstructed *vs*. official catches can be considerable: for example, some countries that emphasize industrial tuna catches but neglect to document catches of nearshore reef fishes, which massively contribute to their food security (Zeller *et al.* 2015). Overall, the reconstructed catches for the 8 countries covered here amount to 256 million tonnes over the last 67 years, which is 4 % of the global total, and about 70 % higher than officially reported catches. Also, reconstructed catches are taxonomically disaggregated to a finer level than official catches. In some cases, this yielded a species-specific time series of dubious validity, depending on how the disaggregation was performed.

Tables 2 and 3 summarize the priors used in and results of the CMSY/BSM analyses of the stocks assessed in this report's various contributions, emphasizing on CPUE time series priors for relative biomass. Table 4 summarizes assessments published by FAO, which also informed our assessment of the 14 stocks belonging to 11 species of small pelagic fish presented in this contribution.

Marine ecoregions (MEs) vs EEZs

The EEZs that countries can claim since the United Nations Convention on the Law of the Sea (UNCLOS) was concluded in 1982 extend a maximum of 200 nautical miles from the coast of maritime countries and their territories. Over 90 % of the world's marine fisheries catch originates from EEZs. In some cases, e.g., around isolated islands, the inshore fauna belongs to a distinct ecosystem; hence their exploited fish populations can be treated as distinct 'stocks.' However, in most cases, the EEZs along countries' coasts encompass a range of different ecosystems. Therefore, to better address ecosystem issues in fisheries data and assessments, the more nuanced spatial system of marine ecoregions (MEs) is offered by the *Sea Around Us* in addition to EEZs and LMEs.

The Marine Ecoregions of the World (often referred to as MEOW, but here labelled MEs) are biogeographic entities along the world's shelves and coasts, as defined by Spalding *et al.* (2012). ME data and GIS shapefiles are available from a joint WWF/Nature Conservancy project. MEs have clearly defined boundaries and definitions and are generally smaller than LMEs (see Figure 4).

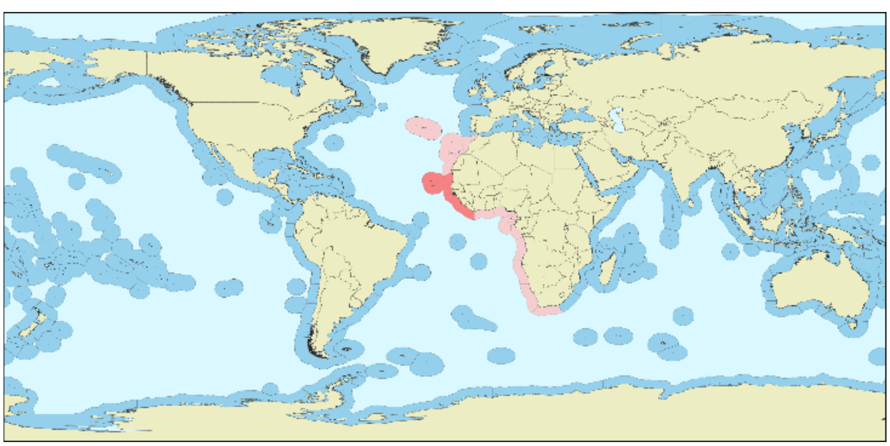

Figure 4. Map of the 232 Marine Ecoregions of the World (modified from Spalding *et al.* 2007). The 13 Marine Ecoregions overlapping with the Exclusive Economic Zones of West African countries are shown in pink. The MAVA Foundations operate operates in three of them (in red), i.e., the Cape Verde, Sahelian Upwelling, and Gulf of Guinea West.

Table 2. Priors used for the CMSY/BSM analyses by the authors of this report (**r** is in year^{-1}).

Countries	Species	Catch	CPUE	r	r range	k (10^3t)	B_{start}/k	B_{int}/k	B_{end}/k	Reference
Cape Verde	*Spicara melanurus*	1986-2015	-	-	1.4 - 4.4	Default	0.5-1.0	0.11-0.26	0.16-0.60	da Luz and Vieira (2020)
	Decapterus macarellus	1986-2015	-	1.08	0.71 - 1.62	Default	0.6-1.0	0.074-0.16	0.23-0.48	
The Gambia	*Ethmalosa fimbriata*	2005-2018	2005-2018	0.93	0.61 - 1.39	Default	Default	Default	Default	Sidibeh *et al.* (2020)
Guinea	*Ethmalosa fimbriata*	1995-2018	-	1.93	0.61 - 1.40	Default	Default	Default	Default	Soumah *et al.* (2020)
	Pseudotolithus elongatus	1995-2018	-	0.52	0.34 - 0.78	Default	Default	Default	Default	
Guinea-Bissau	*Galeoides decadactylus*	2000-2018	2000-2016	0.49	0.32 - 0.73	Default	0.2-0.6	0.01-0.5	0.01-0.3	Barri *et al.* (2020)
	Farfantepenaeus notialis	2000-2018	2000-2016	0.46	0.30 - 0.69	Default	Default	Default	Default	
Liberia	*P. senegalensis*	2009-2818	2009-2018	0.54	0.36 - 0.82	Default			0.01-0.4	Wehye & Palomares (2020)
Mauritania	*Engraulis encrasicolus*	2004-2018	-	0.59	0.39 - 0.91	158-1145	0.1-0.5	00.1-0.4	0.2-0.49	Jeyid *et al.* (2020)
	Sardinella aurita	1990-2018	1995-2012	0.74	0.46 - 1.16	Default	0.5-0.8	-	0.4-0.8	
	Ethmalosa fimbriata	2001-2018	2001-2017	0.93	0.61 - 1.39	Default	0.1-0.5	0.5-0.9	0.1-0.4	
	Octopus vulgaris	1991-2018	1991-2018	0.81	0.53 - 1.21	31-282	0.2-0.6	0.2-0.6	0.01-0.4	
Senegal	*Sardinella aurita*	1982-2017	1982-2017	0.74	0.46 - 1.16	Default	0.9-1	Default	Default	Thiaw (2020)
Sierra Leone	*Albula vulpes*	2008-2018	2008-2018	-	0.05 - 0.5	7.5–244	0.1-0.5	0.5-0.9	0.4-0.8	Showers and Turay (2020)

Table 3. Results of the CMSY/BSM analysis from the contributions in this report (k and MSY are in 10^3 tonnes). Only BSM results are shown for the stocks for which both BSM and CMSY were performed. CI=confidence interval.

Countries	Stock	Prior r (CI)	Prior k (CI)	MSY (10^3) (CI)	B_{end}/k	B_{end}/B_{MSY}	Exploitation (F_{end}/F_{MSY})	Reference
Cape Verde	*Spicara melanurus*	0.557 (0.395-0.785)	3.7 (2.37-5.77)	0.516 (0.406-0.654)	0.361	0.722	1.560	da Luz and Vieira (2020)
	Decapterus macarellus	1.2 (1.02-1.41)	7.120 (6.18-8.19)	2.13 (2,020-2.25)	0.401	0.802	0.609	
The Gambia	*Ethmalosa fimbriata*			15		0.892	1.32	Sidibeh et al. (2020)
Guinea	*Ethmalosa fimbriata*	1.13 (0.98-1.37)	199 (131-299)	55.7 (36.3-85.6)	0.37	0.739	1.76	Soumah et al. (2020)
	Pseudotolithus elongatus	0.73 (0.68-0.78)	44.5 (38-52)	8.1 (6.8-9.7)	0.29 (0.03-0.39)	0.593	1.52	
Guinea-Bisseau	*Galeoides decadactylus*	--	--	3189	--	--	--	Barri et al. (2020)
	Farfantepeneaus notialis	0.55 (0.449-0.674)	9.69 (6.93–13.55)		0.0872		0.705	
Liberia	*Pseudotolithus senegalensis*	0.667 (0.522-0.854)	4.46 (3.47-5.73)	0.744 (0.630-0.879)	0.337	0.674	2.38	Wehye & Palomares (2020)
Mauritania	*Engraulis encrasicolus*	0.73 (0.59-0.9)	689 (474-1001)	123 (105-144)	0.173	0.346	0.718	Jeyid et al. (2020)
	Sardinella aurita	0.76 (0.51-1.11)	2771 (2176-3529)	524 (399-689)	0.55 (0.37-0.78)	1.11	0.93	
	Ethmalosa fimbriata	0.93 (0.61-1.39)	277 (212-361)	69.4	0.35 (0.24-0.58)	0.70	0.982	
	Octopus vulgaris	0.95 (0.79-1.15)	123 (100-152)	294 (269-320)	0.39	0.78	1.37	
Senegal	*Sardinella aurita*	1.17 (0.872-1.57)	628 (500-790)	184 (165-205)	0.48	0.89		Thiaw *et al.* (2020)
Sierra Leone	*Albula vulpes*	0.13 (0.062-0.27)	26.3 (16.8-41.2)	0.810	0.48 (0.26-0.68	0.419	1.87	Showers and Turay (2020)

Table 4. Stock assessments of northwest African small pelagic stocks conducted by the Fishery Committee for the Eastern Central Atlantic working groups. Adapted from FAO (2019a, 2020a and 2020b); catches are in t per year, and their averages refer to the 2013-2018 period.

Species	**Catch in 2018**	**Average catch**	**$B_{2018}/B_{0.1}$**	**$F_{2018}/F_{0.1}$**	**Assessment[2]**	**Reference**
Caranx rhonchus South[1]	2,000	13,000[3]	–	–	–	FAO (2019a)
Caranx spp. South[1]	1,524[4]	2,116[4]	–	–	–	FAO (2019a)
Decapterus spp. South[1]	4,796[4]	6,070[4]	0.92[4]	0.95[4]	Fully exploited	FAO (2019a)
Engraulis encrasicolus	24,000	24,000[4]	–	0.69[5]	Fully exploited	FAO (2020a)
Ethmalosa fimbriata	48,000	70,000	–	1.56[5]	Overexploited	FAO (2020a)
Sardina pilchardus Zone A+B[1]	435,000	460,000	1.45	0.50	Not fully exploited	FAO (2020a)
Sardina pilchardus Zone C[1]	904,000	615,000	1.37	0.64	Not fully exploited	FAO (2020a)
Sardinella aurita	339,000	474,000	–	–	Overexploited	FAO (2020a)
Sardinella maderensis	80,000	190,000	–	–	Overexploited	FAO (2020a)
Sardinella spp. North[1]	419,000	665,000	–	–	Overexploited	FAO (2020a)
Sardinella spp. South[1]	60,047,000[4]	54,325,000[4]	1.29	0.49	Not fully exploited	FAO (2020b)
Scomber colias	419,000	379,000	1.23	0.84	Fully exploited	FAO (2020a)
Trachurus trachurus	99,000	118,000	0.83	1.19	Fully exploited	FAO (2020a)
Trachurus trecae North[1]	200,000	220,000	0.94	0.80	Fully exploited	FAO (2020a)
Trachurus trecae South[1]	31,487,000	22,032,000	0.75	1.25	Overexploited	FAO (2020b)

[1] The northwest African sardine stock is defined as three stocks, the northern stock (35°45'-32°N), the central (A+B) stock (32-26°N) and the southern stock (C) (26°N to the southern range of the species distribution; see FAO 2020). Note that here, we refer only with the central and southern stock overlapping with the region of the *Conseil Sous-Regional de la Pêche*. Note also that North refers to stocks in Mauritania, Senegal and The Gambia, while South refers to stocks in Guinea-Bissau, Guinea, Sierra Leone and Liberia.
[2] Equivalent CMSY B/k range: Not fully exploited > 0.6; fully exploited = 0.4-0.6; overexploited < 0.4.
[3] Average for 2014-2018.
[4] Refers to $Catch_{2017}$ (t), average catch for 2013-2017, $B_{2017}/B_{0.1}$ and $F_{2017}/F_{0.1}$.
[5] LCA-Y/R.

Adopting and presenting MEs as part of our spatial data system ensures that the stock assessments we performed for all maritime countries in the world, and to Northwest African countries in particular, are based on the well-established, data-poor CMSY/BMS methods (see above). The internal consistency in our global spatial data allocations is ensured in two steps: (1) we modified very slightly some ME boundaries to correspond to existing EEZ boundaries; and (2) we assigned the 232 MEs of Spalding *et al.* (2012) to our 273 EEZs (and parts thereof) as a function of the MEs' overlap with the EEZs

Results and Discussion

Based on the data in Tables 2, 3, and 4, we derived priors consistent with the biology of the 11 species studied here, and with the history of their exploitation, as presented below (see Table 5). Then, using these priors and the available ancillary data (see Table 5), we assessed 14 stocks of small pelagic fish; the results of these assessments are summarized in Table 6 and illustrated in Figures 6A and 6B. These results are detailed on a per-species bases in the following text, which concludes with a general overview of small pelagic fish's roles in Northwest Africa.

Caranx rhonchus

False scad (also known as *sareia-amarela* in Portuguese and as *diaî bou wekh* in Wolof), is a benthopelagic species found in marine and brackish water lagoons and estuaries, and which often forms schools near the bottom, usually at depths of 30-50 m (Bauchot 2003). False scad has been reported from a maximum depth of 200 m (Ly *et al.* 1996), and they range in the Eastern Atlantic from Morocco to Angola (Bauchot 2003), and possibly extending south to Namibia (Bianchi *et al.* 1999). The northern stock considered here straddles the Saharan Upwelling, Sahelian Upwelling, the Gulf of Guinea West, and Gulf of Guinea Upwelling marine ecoregions (see FAO 2002).

False scad is one of three major species of horse mackerels exploited by West African and European fleets, albeit as by-catch (FAO 2013, 2019b). The working group on assessing small-pelagic fishes off West Africa collects only catch data on this stock, i.e., there is no available CPUE data. The FishBase resilience category for this species (see Table 1) is based on 2 life-history parameters and the r-range from 1 stock assessment.[1] The B_{2016}/k range was assumed to be similar to that of horse mackerels (*Trachurus* spp.) in the region, i.e., 'overexploited' in Table 4 (equivalent range of 0.01-0.4; see Table 5).

False scad (*Caranx rhonchus*), occurring in Mauritania, Senegal, Gambia, Guinea-Bissau, Guinea, and Sierra Leone, was found to have a biomass corresponding to 0.59 of B/B_{MSY}, i.e., to be overfished (see Table 6).

[1] https://www.fishbase.ca/summary/Caranx-rhonchus.html.

Table 5. Priors used in the CMSY++ assessment of small-pelagic stocks in Northwest Africa.

Marine Ecoregion	Species	$Year_{start}$ catch	Relative biomass data	r-range	r_{BSM}	k_{BSM} (10^3t)	B_{start}/k	B_{int}/k	B_{end}/k
Northwest Africa[1]	*Caranx rhonchus*	1970	NA	0.21-0.48	NA	NA	NA	NA	0.01-0.40
Eastern Central Atlantic	*Decapterus macarellus*	1986	1986-2002[3]	0.71-1.62	0.872	23	0.2-0.6	NA	NA
West Africa[2]	*Engraulis encrasicolus*	1950	2000-2015[4]	0.39-0.91	0.618	1437	06.-1.0	0.2-0.6 2001	NA
Sahelian Upwelling	*Ethmalosa fimbriata*	1972	1995-2013[5]	0.61-1.39	1.01	257.6	0.4-0.8	NA	0.01-0.4
Gulf of Guinea West	*Ethmalosa fimbriata*	1950	1995-2016[6]	0.61-1.39	NA	NA	0.4-0.8	NA	0.01-0.4
Gulf of Guinea West	*Ilisha africana*	1992	NA	0.79-1.79	NA	NA	0.4-0.8[7]	NA	NA
Sahelian Upwelling	*Mugil cephalus*	1984	NA	0.34-0.77	NA	NA	NA	NA	02.-0.6[8]
Saharan Upwelling Sahelian Upwelling	*Sardinella aurita*	1976	1995-2009[9]	0.46-1.16	0.751	1134	0.2-0.6	0.1-0.5 1995	NA
Gulf of Guinea West	*Sardinella aurita*	1977	1995-2016[10]	0.46-1.16	0.675	196	0.1-0.5[11]	0.01-0.4 1995	NA
Saharan Upwelling Sahelian Upwelling	*Sardinella maderensis*	1967	1990-2014[6,9]	0.38-0.86	0.501	1023	0.6-1.0	NA	NA
Gulf of Guinea West	*Sardinella maderensis*	1970	1990-2012[10]	0.38-0.86	0.597	26	0.6-1.0	NA	NA
Saharan Upwelling Sahelian Upwelling	*Sardina pilchardus*	1966	1990-2016[9, 12, 13]	0.40-0.90	0.723	5126	0.6-1.0	NA	NA
Northwest Africa[1]	*Trachurus trachurus*	1990	1995-2015[9, 14]	0.31-0.72	0.606	649	0.4-0.8[15]	0.2-0.6 2000	NA
Northwest Africa[1]	*Trachurus trecae*	1990	1991-2015[9, 14]	0.73-1.65	0.764	1193	0.2-0.6	0.2-0.6[16] 2001	NA

[1] Mostly referring to marine ecoregions Saharan Upwelling, Sahelian Upwelling, Gulf of Guinea West, and may include Gulf of Guinea Upwelling.
[2] Includes marine ecoregions Saharan Upwelling, Sahelian Upwelling, Gulf of Guinea West, Gulf of Guinea Upwelling, Gulf of Guinea Central, Gulf of Guinea Islands, Gulf of Guinea South, Angolan, Namib, Namaqua and Agulhas Bank.
[3] CPUE based on the average of industrial and artisanal seine adapted from Table 1 of Stoberrup and Erzini (2006).
[4] Biomass estimates for Mauritania and Morocco by the R/V Dr Fridtjof Nansen and national vessels adapted from Table 6.3.2 of FAO (2019b).
[5] CPUE ($t \cdot trip^{-1}$) of encircling gillnets in Senegal adapted from Figure 7 of Ba *et al.* (2017).
[6] CPUE ($t \cdot trip^{-1}$) of industrial and artisanal fleets from Guinea-Bissau, Guinea, Sierra Leone and Liberia calculated from catch and fishing effort data presented in Tables 3.2.1 and 3.2.2 of FAO (2019a)
[7] LBB data from Stockholm and Isebor (1993) suggest B/B0=0.6 (see result of LBB analyses in Figure 5).
[8] There is no available assessment but exploited as by-catch in artisanal fisheries in Gulf of Guinea, and thus as a precautionary approach, setting B_{end}/k range as exploited.
[9] Biomass estimates for Mauritanian and Senegambian stocks by the R/V Dr Fridtjof Nansen adapted from Figure 7 of Lakhnigue *et al.* (2019).
[10] CPUE ($t \cdot trip^{-1}$) of pelagic trawl fleets from Guinea-Bissau and Guinea adapted from Table 2.3.1 of FAO (2019a).
[11] Mensah and Quaatey (2002) notes a near collapse of the Gulf of Guinea *S. aurita* stock in the 1970s.
[12] CPUE ($t \cdot trip^{-1}$) of Moroccan, European Gambian and Senegalese pelagic trawl fleets adapted from catch and effort data in Tables 2.2.1a and 2.2.1b of FAO (2016).
[13] CPUE ($t \cdot trip^{-1}$) of Moroccan purse seine fleets adapted from Figure 46 of INRH/DP (2017).
[14] Adapted from the Ram Legacy stock assessment database (RLSADB 2018).
[15] East European fishing fleets retracted from the region in 1990-1995 (see Bah and Sidibé, 2011 and Ould Taleb Sidi *et al.* 2011), which may be a reason for the low catches of horse mackerel at the start of the catch time series.
[16] $B_{2006}/B_{0.1}$ = 0.56 from Table 2 of Jalloh and Seisay (2011) used here as intermediate biomass range.

Table 6. List of small pelagic species considered in this study and which are found in the seven countries in which MAVA operates. All scientific names used here are currently valid and checked with FishBase. The catches (t; 1000^3) and B/B_{MSY} values are annual averages for the EEZ listed and the period 2012-2016.

Scientific name	English name	EEZ occurrence	Catch	B/B_{MSY}	Stock status
Caranx rhonchus	False scad	Mauritania, Senegal, Gambia, Guinea-Bissau, Guinea, and Sierra Leone	14.0	0.59	Overfished
Decapterus macarellus	Mackerel scad	Mauritania, Cape Verde Senegal, Gambia, G.-B, Guinea, Sierra Leone	2.92	0.41	Grossly overfished
Engraulis encrasicolus	European anchovy	Mauritania, Senegal, Gambia, Guinea-Bissau, Guinea, and Sierra Leone	139	0.46	Grossly overfished
Ethmalosa fimbriata	Bonga shad	Mauritania, Senegal, and Gambia	85	0.91	Slightly overfished
Ethmalosa fimbriata	Bonga shad	Guinea-Bissau, Guinea, and Sierra Leone	157	0.90	Slightly overfished
Ilisha africana	West African ilisha	Guinea-Bissau, Guinea, and Sierra Leone	9.21	1.5	Healthy
Mugil cephalus	Flathead grey mullet	Mauritania, Senegal, and Gambia	12.1	1.3	Healthy
Sardinella aurita	Round sardinella	Mauritania, Senegal, and Gambia	312	0.74	Overfished
Sardinella aurita	Round sardinella	Guinea-Bissau, Guinea, and Sierra Leone	87.2	0.38	Grossly overfished
Sardinella maderensis	Madeiran sardinella	Mauritania, Senegal, and Gambia	199	0.74	Overfished
Sardinella maderensis	Madeiran sardinella	Guinea-Bissau, Guinea, and Sierra Leone	53.3	0.79	Overfished
Sardina pilchardus	European pilchard	Mauritania, Senegal, and Gambia	1025	0.88	Slightly overfished
Trachurus trachurus	Atlantic horse mackerel	Mauritania, Senegal, Gambia, Guinea-Bissau, Guinea, and Sierra Leone	105	0.92	Slightly overfished
Trachurus trecae	Cunene horse mackerel	Mauritania, Senegal, Gambia, Guinea-Bissau, Guinea, and Sierra Leone	124	1.1	Healthy

Decapterus macarellus

Mackerel scad (also known as *cavala preta* in Kriolu) is a pelagic-oceanic species common at depths of 40-200 m (Smith-Vaniz 1986a) in most of the world's oceans. In the Eastern Atlantic, it occurs in St. Helena, Ascension, Cape Verde, and the Gulf of Guinea (Smith-Vaniz *et al*. 1990). Thus, it is considered a single straddling stock covering Mauritania, Cape Verde, Senegal, Gambia, Guinea-Bissau, Guinea, and Sierra Leone (see Table 5).

Catch data from the *Sea Around Us* is almost entirely from Cape Verde, reflecting the importance of the mackerel scad in Cape Verdean fisheries. It made up 40% of the marine fisheries catch at its peak in the late 1990s, decreasing to about 20% in the mid-2000s (Stobberup and Erzini 2006). The FishBase resilience category of mackerel scad (see Table 1) is based on one estimate of the K parameter of von Bertalanffy Growth Function (VBGF) and an r-range based on 3 stock assessments.[1] These priors for r were used, along with CPUE data for 1986 to 2004 from the trawl fleets adapted from Stobberup and Erzini (2006), with a 2% annual technology creep applied to the CPUE data (Palomares and Pauly 2020). The CMSY++ analysis was set to a start year of 1986 to use the first year of the CPUE time series as a starting biomass window to peg the analysis to that year's CPUE level, which is equivalent to the FAO category 'exploited,' i.e., B_{1986}/k range of 0.2-0.6 (see Table 5).

Our assessment of the stock of mackerel scad (*Decapterus macarellus*) occurring in Mauritania, Cape Verde Senegal, Gambia, Guinea-Bissau, Guinea, and Sierra Leone estimated its relative biomass to be 0.41 of B/B_{MSY}, i.e., to be grossly overfished (see Table 6).

[1] https://www.fishbase.ca/summary/Decapterus-macarellus.html

Engraulis encrasicolus

The European anchovy (also known as *youssou nokoum* in Wolof) is a pelagic-neritic species, i.e., it is found mostly in coastal waters (see Riede 2004 and Frimodt 1995), occurring from the surface to depths of 400 m (Schneider 1990). It is widespread in the Eastern Atlantic from Norway (Bergen) to South Africa (Durban) and also in the Mediterranean, Black, and Azov Seas (Whitehead 1990 and Whitehead *et al.* 1988). European anchovy performs extensive seasonal migrations along the northwest African coast, which corroborates the assumption that this species has only one stock in the region (FAO 2016).

As the bulk of the catches in this region are reported by Mauritania (and Morocco; see Jeyid *et al.* 2020), using the biomass estimates from acoustic sampling by the *R/V Fridtjof Nansen* in 2000-2015 from Mauritania and Morocco (FAO 2019b; see also Table 5) is justified. This species has a medium resilience (see Table 1), as estimated from 3 life-history parameters in FishBase and an r-range based on 21 stock assessments[1] (see Table 5). The stock was assessed as 'overexploited' in 2014 (FAO 2016; $B_{2014}/k<0.4$) and as fully exploited in 2018 (FAO 2019b; B_{2018}/k = 0.4-0.6, see Table 4). As the stock can be considered to have a high carrying capacity ($k_{BSM} = 1437 \cdot 10^3$ t; see Table 5), we assumed that it was healthy at the beginning of the time series (B_{1950}/k = 0.6-1.0). Finally, since the stock devolved to an overexploited state in the 2000s (as suggested by the CPUE trend), we assumed a B_{2001}/k range of 0.4-0.6.

The stock of European anchovy (*Engraulis encrasicolus*) occurring along the coasts of Mauritania, Senegal, Gambia, Guinea-Bissau, Guinea, and Sierra Leone was assessed to have a relative biomass (B/B_{MSY}) of 0.46, i.e., to be grossly overfished (see Table 6).

Ethmalosa fimbriata

The bonga shad (also known as *galucha* in Portuguese and *kobo* in Wolof) is a shallow (0-50 m depths) pelagic-neritic (brackishwater) species belonging to the Clupeidae Family that migrates from freshwaters (as far as 300 km up river; see Teugels 2007) to the coast to spawn (Riede 2004). It is found in the Eastern Central Atlantic, from Western Sahara (Dakhla) to Angola (Lobito Bay; see Gourène and Teugels 2003). Genetic studies divide the bonga shad into two stocks recognized in the region as the northern (Mauritania, Gambia, Senegal) and southern (Guinea, Guinea-Bissau, Sierra Leone, Liberia) stocks (Durand *et al.* 2012).

Important artisanal fisheries in northwest Africa exploit the northern stock of bonga shad (see Sidibeh *et al.* 2020). Using purse seines and encircling gillnets, their profits have declined due to the increasing costs of larger fleets exploiting a decreasing bonga shad biomass (Ba *et al.* 2017, Figure 7). Fishing effort and catch time series from this fishery were used in the CMSY++ analysis (1995-2013; see Table 5). Catch data heuristics suggested 1972 as the start year when the stock was not overexploited (B_{1972}/k = 0.6-1.0). Given an $F_{2017}/F_{0.1}$ = 1.45 estimated by FAO (2020a, b), we assumed an overexploited status ($B_{2016}/k<0.4$) in the final year of the time series.

The southern stock was assessed as locally intensively exploited in the mid-1970s (see Everett 1976), which provides a biomass window for the start of the time series (B_{1950}/k set at 0.4-0.8; see Table 5). The CMSY++ analysis was run with CPUE time series (1995-2016) from industrial and artisanal fleets of Guinea-Bissau, Guinea, Sierra Leone, and Liberia calculated from catch and fishing effort data presented in Tables 3.2.1 and 3.2.2 of FAO (2019a). The final year biomass window was based on the FAO (2020a) assessment of this stock being overexploited in 2018 in the whole sub-region ($B_{2016}/k<0.4$). The FishBase resilience category (see Table 1) used for both stocks was based on 3 life-history parameters and the r-range based on 5 stock assessments.[2]

The northern stock of Bonga shad (*Ethmalosa fimbriata*), occurring in Mauritania, Senegal, and The Gambia was found to be slightly overfished, with B/B_{MSY} = 0.91, like its southern stock, occurring off Guinea-Bissau, Guinea, and Sierra Leone, for which B/B_{MSY} = 0.90.

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[1] https://www.fishbase.ca/summary/Engraulis-encrasicolus.html.
[2] https://www.fishbase.ca/summary/Ethmalosa-fimbriata.html

Ilisha africana

The West African ilisha (also known as *capasseca* in Portuguese and *lati* in Susu and Krio) is a pelagic-neritic species found from the surface of the water column to depths of 35 m (Poll 1953). It inhabits coastal areas along beaches, brackish water lagoons and estuaries and may penetrate freshwaters (Fischer *et al.* 1981). This study assumes one stock for the Gulf of Guinea West marine ecoregion.

The West African ilisha is an important bycatch of the sardinella and shrimp trawl and purse seine fisheries in Ghana, Benin and Nigeria, i.e., the southern part of the Gulf of Guinea West marine ecoregion (Whitehead *et al.* 1988; Ajayi and Adetayo 1982). No official assessments are available; however, estimates of Z/K = 3.7 and F/Z = 0.44 from distinct coastal populations caught along with sardinella in Benin suggest an 'underexploited' stock (Edmond *et al.* 2017).

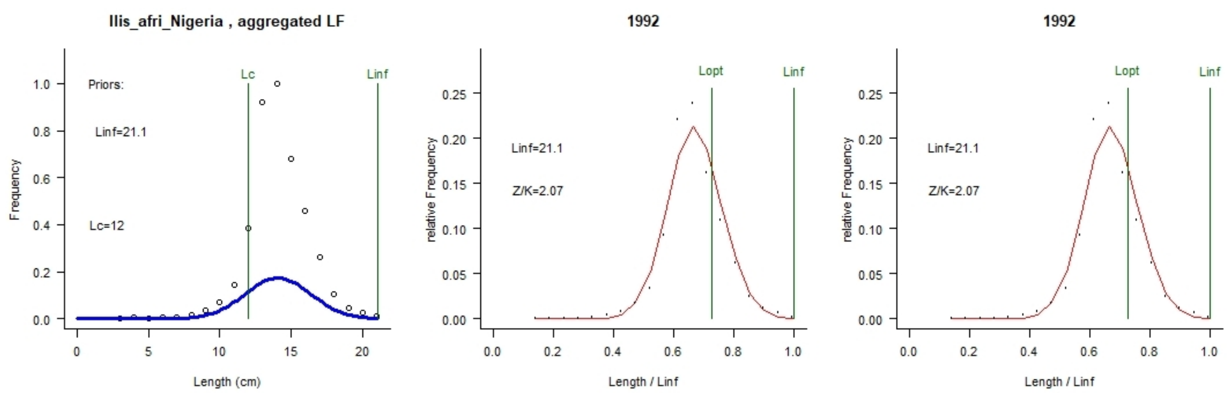

Figure 5. Result of the application of the LBB method to length-frequency data sampled from artisanal fleets in Benin and Nigeria primarily targeting *Ilisha africana* (Stockholm and Isebor 1993) suggesting a $B_{1992}/B_0 = 0.6$ used as prior in the CMSY analyses presented in this study (see Table 5).

The CMSY++ analysis was run from 1992 as suggested by catch data heuristics. A B_{1992}/k range of 0.4-0.8 (see Table 5) was used based on the results of the LBB model run on length-frequency data from Benin and Nigeria (Stokholm and Isebor 1993) suggesting a $B_{1992}/B_0 = 0.56$ (see Figure 5). The FishBase resilience category (see Table 1) of this species was based on a range of K values while the r-range was based on 3 stock assessments.[1]

Our CMSY assessment of West African ilisha (*Ilisha africana*), occurring of Guinea-Bissau, Guinea, and Sierra Leone, is that the stock currently exceeds the biomass required to generate MSY, i.e., $B/B_{MSY} = 1.5$ (Table 6), which is also corroborated by the LBB analysis in Figure 5.

Mugil cephalus

The flathead grey mullet (also known as *mulet grosse tête* in French) is found in all tropical, subtropical, and temperate coastal waters (common at depths of 0-10 m but reaches depths to 120 m; see Harrison 1995) often in brackish water lagoons and estuaries, and can reach up-river (Riede 2004). In the Eastern Atlantic, it spans from the Bay of Biscay to South Africa, including the Mediterranean and Black Seas (Thomson 1990). The stock considered in this study is that of the Sahelian Upwelling marine ecoregion as it is an important resource, e.g., in Senegal.

This stock is exploited as bycatch by the artisanal fisheries in the Gulf of Guinea (see Nunoo and Asiedu 2013). CPUE, biomass or length-frequency data could not be identified for this stock. The CMSY++ analysis was run with start year in 1982 based on catch data heuristics. The resilience category for this species from FishBase (see Table 1) was based on four life-history parameters and the r-range was based on 12 stock

[1] https://www.fishbase.ca/summary/Ilisha-africana.html

assessments (see Table 5).[1] A precautionary approach B_{2016}/k range of 0.2-0.6 was used, i.e., fully exploited, assuming continued exploitation of this stock since 1950.

Our results suggest that the stock of flathead grey mullet (*Mugil cephalus*) off Mauritania, Senegal, and The Gambia is healthy, with B/B_{MSY} = 1.3 (see Table 6).

Sardinella aurita

The round sardinella is also known as *tayit* (Arabic, Hassaniya), *sardinelle ronde* (French), *sardinella* or *sardinha* (Portuguese), *bonga séri* (Susu), and *yaboï maureug* (Wolof), to list a few of the many names used for this commercially critical pelagic species. It is oceanodromous (Riede 2004) in the Atlantic Ocean. In West Africa, it occurs from Gibraltar to South Africa (Saldanha Bay), notably in upwelling areas from Mauritania to Guinea (see Teugels 2007 and Cury and Fontana 1988). The round sardinella prefers clear saline coastal waters from the surface to depths of 350 m, preferring cold waters at 18-24°C (see Bianchi *et al*. 1999; Whitehead et *al*. 1988). Juveniles are found in shallow brackishwater nursery areas and migrate as adults to colder offshore waters (Whitehead 1985). Two stocks are recognized in our study area, the northern (Saharan and Sahelian Upwelling marine ecoregions) and southern (Gulf of Guinea West) stocks (FAO 2019a).

Biomass data used to inform the CMSY++ analysis for the northern stock were from the R/V Fridtjof Nansen acoustic surveys from Morocco, Mauritania and Senegal in 1995-2015 adapted from Lakhnigue *et al*. (2019, Figure 7). Heuristics of the catch data suggested a start year in 1976, and B_{1976}/k range of 0.2-0.6 (fully exploited) based on the importance of this stock in the region since the fishery began in 1967 (Lakhnigue *et al*. 2019). The intermediate biomass window used in the analysis was based on the 1995 biomass data from Lakhnigue *et al.* (2019), indicating a $B_{1995}/k \sim 0.3$ (see Table 5).

The southern stock was analyzed with CPUE data from Guinea and Guinea-Bissau's pelagic trawl fleets (FAO 2019a, Tables 2.3.1a). Catch data heuristics suggest a start year at 1977. Based on the southern stock's near collapse in the Gulf of Guinea in the early 1970s (Mensah and Quaatey 2002), a B_{1977}/k range of 0.1-0.5 was used. The intermediate biomass window was set at 1995 based on the CPUE data with a B_{1995}/k range of 0.01-0.4 based on an FAO (2019b) assessment of the stock's poor health (see Table 5).

The FishBase resilience category (see Table 1) for the species was obtained from three life-history traits, and the r-range was based on 12 stock assessments.[2]

The assessment of the round sardinella (*Sardinella aurita*) off Guinea-Bissau, Guinea, and Sierra Leone suggest that it is grossly overfished, B/B_{MSY} = 0.38 (see Table 6).

Sardinella maderensis

The Madeiran sardinella is also known as *grande allache* in French, *arenque* in Portuguese, or *yaboî tass* in Wolof. Despite what its name may suggest, it is found throughout the West African coast from Gibraltar to Angola (Gourène and Teugels 2003) and in the southern and eastern parts of the Mediterranean Sea and into the Suez Canal (Whitehead 1985). This species forms schools, preferring waters at 24°C and migrates from Gabon to Angola and from Sierra Leone to Mauritania, usually in association with upwelling seasons, with juveniles staying in shallow water nurseries in brackishwater lagoons and estuaries (Riede 2004). Two stocks are considered here, the northern (Saharan and Sahelian Upwelling marine ecoregions) and southern (Gulf of Guinea West) (FAO 2019a).

Several CPUE data sets were available for the northern stock: i.e., (1) biomass data from Fridtjof Nansen acoustic surveys from Morocco, Mauritania, and Senegal between 1995 and 2015 (Lakhnigue *et al*. 2019; Figure 7); and (2) catch data from industrial and artisanal fleets (Moroccan, Russian Federation, Ukrainian and others, European Union, Mauritanian, Senegalese, and Gambian) exploiting the stock in the region

[1] https://www.fishbase.ca/summary/Mugil-cephalus.html
[2] https://www.fishbase.ca/summary/Sardinella-aurita.html

(FAO 2016, Table 3.2.1b), and (3)fishing effort of these fleets on mixed sardinella fisheries (FAO 2016, Table 3.2.2). The average CPUE trend for the period 1990-2014 (Table 5) from these data was obtained using a software based on the method by Winker *et al.* (2020). The catch data suggested that an analysis for the period 1982-2016 could be performed, with a low depletion (B_{1982}/k=0.6-1.0) at the start of the time series being suggested by the CPUE trend.

There is no long-term time series of CPUE specific for the southern stock because it is caught with other sardinella in the Gulf of Guinea. However, FAO (2019a, Table 2.3.1c) presents CPUE data for *Sardinella* spp. from the Guinea-Bissau, Sierra Leone, and Liberian industrial and artisanal trawl fleets. The average CPUE trend for the period 1990-2012 (Table 5) was obtained using the method of Winker *et al.* (2020). Catch data heuristics suggested an analysis for the period 1970-2016, with the average CPUE trend used to set the intermediate biomass window B_{1996}/k at 0.1-0.4. The FishBase estimate of resilience (see Table 1) for this species was based on 3 life-history parameters and the r range was based on 6 stock assessments.[1]

Our assessment of the northern stock of Madeiran sardinella (*Sardinella maderensis*) off Mauritania, Senegal, and of the southern stock off Gambia Guinea-Bissau, Guinea, and Sierra Leone led us to conclude that they are overfished, with B/B_{MSY} = 0.74, and 0.79, respectively (see Table 6).

Sardina pilchardus

The European pilchard, also known as *sardina* in Arabic or *sardine* in French, is a coastal pelagic species forming schools commonly at depths of 25-55 m at daytime and 10-35 m at night and may extend to a maximum depth of 100 m (Whitehead 1985). It spans the Northeast Atlantic from the North Sea south to Senegal (Gorée) and is also present in the Mediterranean and the Sea of Marmara and the Black Sea (Whitehead 1985). There is one stock in the Saharan and Sahelian Upwelling marine ecoregion covering Mauritania, The Gambia, and Senegal.

Time series of relative abundance data were available for: (1) Moroccan, European, Gambian and Senegalese pelagic trawl fleets adapted from catch and effort data in Tables 2.2.1a and 2.2.1b of FAO (2016); (2) the CPUE of Moroccan purse seine fleets adapted from INRH/DP (2017; Figure 46 on p. 42); and (3) acoustic biomass estimates sampled by the R/V Dr. Fridtjof Nansen of Mauritanian and Senegambian stocks adapted from Lakhnigue *et al.* (2019; see Figure 7).

The average relative biomass trend expressed as CPUE was obtained using the method of Winker *et al.* (2020) and used here to inform the CMSY++ analysis. Catch data trend heuristics suggested an analysis for 1966-2016 with low depletion at the beginning of the time series (B_{1966}/k=0.6-1.0). An intermediate biomass window range of B_{2006}/k=0.2-0.6 was used following the CPUE trend. The FishBase resilience category (see Table 1) for this species was based on 3 life-history parameters, while the r-range was based on 18 stock assessments.[2]

FAO (2016) and Lakhnigue *et al.* (2019) assessed this stock as not fully exploited in the latter part of the time series. This assessment, diverging slightly, suggested that the European pilchard stock occurring off Mauritania, Senegal, and The Gambia is slightly overfished, with B/B_{MSY} = 0.88 (see Table 6).

Trachurus trachurus

The Atlantic horse mackerel is also known as *assatat* in Arabic (Hassaniya), *chinchard* in French, *chicharro* in Portuguese, *bologoui* in Susu, or *dîai* in Wolof. It is a coastal pelagic species forming large schools over sandy substrate found at the water column's surface to depths of over 1000 m but usually at depths of 100-200 m (FAO-FIGIS 2005). It is present in the Mediterranean Sea and the Eastern Atlantic from Norway to South Africa and along the coast to Maputo (Smith-Vaniz 1986b). Genetic evidence suggests one stock in the northeastern Atlantic up to Ghana (Healey *et al.* 2020), thus justifying the grouping in our analysis for

[1] https://www.fishbase.ca/summary/Sardinella-maderensis.html
[2] https://www.fishbase.ca/summary/Sardina-pilchardus.html

the Saharan Upwelling, Sahelian Upwelling and Gulf of Guinea West as one, i.e., for the whole Northwest African region.

The CMSY model does not seem to be applicable to the *Sea Around Us* reconstructed catch data from the three marine ecoregions covering our study area; therefore, the total catch data reported by Morocco, Mauritania, Senegal and the Gambia for 1990-2018 (adapted from FAO 2020a, Table 1.6.1) was used in this analysis. An average relative abundance trend for the period 1995-2015 was estimated using data from (1) acoustic biomass estimates sampled by the R/V Dr Fridtjof Nansen of Mauritanian and Senegambian stocks adapted from Lakhnigue *et al.* (2019, Figure 7); and (2) the Ram Legacy Stock Assessment Database (2018) and using the method of Winker *et al.* (2020). Although the catch data started in 1990, we opted to use catches for 1995-2018 to cover the same starting year as the relative biomass data. A low depletion was assumed at the start of the time series, i.e., B_{1995}/k range of 0.4-0.8. This was based on the decline in horse mackerel catches due to the temporary pull out, from 1990-1995, of East European fishing fleets mainly targeting horse mackerel in the region (Bah and Sidibé 2011; Ould Taleb Sidi *et al.* 2011). The intermediate B_{2006}/k range of 0.2-0.6 was based on the CPUE trend during that period (see Table 5). The FishBase resilience category (see Table 1) for this species was based on 4 life-history parameters, and the r-range was based on 11 stock assessments.[1]

The Atlantic horse mackerel (*Trachurus trachurus*) occurring off Mauritania, Senegal, The Gambia, Guinea-Bissau, Guinea, and Sierra Leone appears to be slightly overfished, B/B_{MSY} = 0.92 (see Table 6).

Trachurus trecae

The Cunene horse mackerel, also known as *carapau do Cunene* and *chicharro* in Portuguese, is benthopelagic, usually found at depths of 20-100 m (Schneider 1990). It occurs in the Eastern Atlantic from Morocco to Angola and sometimes to Namibia (Bianchi *et al.* 1999). We consider here one stock of the Cunene horse mackerel for the whole of Northwest Africa.

Similar to the Atlantic horse mackerel, the reconstructed catch data was not used for this analysis. Instead, the total catch data reported by Morocco, Mauritania, Senegal, and the Gambia for 1990-2018, adapted from FAO (2020a, Table 1.6.1), was used. We obtained an average relative abundance trend (1991-2015) for this stock from (1) acoustic biomass estimates sampled by the R/V Dr Fridtjof Nansen of Mauritanian and Senegambian stocks (adapted from Lakhnigue *et al.* 2019, Figure 7); and (2) the Ram Legacy Stock Assessment Database (2018), using the method of Winker *et al.* (2020). Similar to the Atlantic horse mackerel, East European fleets targeting this stock retracted from the subregion in 1990-1995 (see Bah and Sidibé 2011; Ould Taleb Sidi *et al.* 2011), which would have translated to a decrease in fishing pressure, resulting in a B_{1990}/k range of 0.2-0.6. In 2006, Jalloh and Seisay (2011, Table 2) estimated that the stock was at 56% of biomass at F = 0.1 with F/F_{MSY} = 0.98 (fully exploited; see Table 4), which translates to the B_{2006}/k range of 0.2-0.6 used as intermediate biomass prior in this analysis (see Table 5). The FishBase resilience category (see Table 1) was based on one value of the K parameter and the r-range was based on one stock assessment.[2]

Cunene horse mackerel (*Trachurus trecae*) occurring off Mauritania, Senegal, Gambia, Guinea-Bissau, Guinea, and Sierra Leone was assessed as healthy, with B/B_{MSY} = 1.1 (see Table 6); this result was unexpected and is discussed further below.

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[1] https://www.fishbase.ca/summary/Trachurus-trachurus.html
[2] https://www.fishbase.ca/summary/Trachurus-trecae.html

Overall assessment

Our key results (Table 6; Figures 6A and 6B), which summarize the status of the 14 small pelagic stocks assessed here, suggest that overfishing is widespread in Northwestern Africa. This result is not new. Indeed, our results largely confirm those of previous authors, particularly to the FAO-led stock assessments summarized in Table 4, whose stock status evaluation matches ours when one considers different status definitions and their wording (Table 7). Indeed, a substantial discrepancy occurs only in Cunene horse mackerel (*Trachurus trecae*), which we evaluated as 'healthy' (see Table 6); while the FAO-led assessment, perhaps based on better data, concluded that it was 'overexploited' (Table 4).

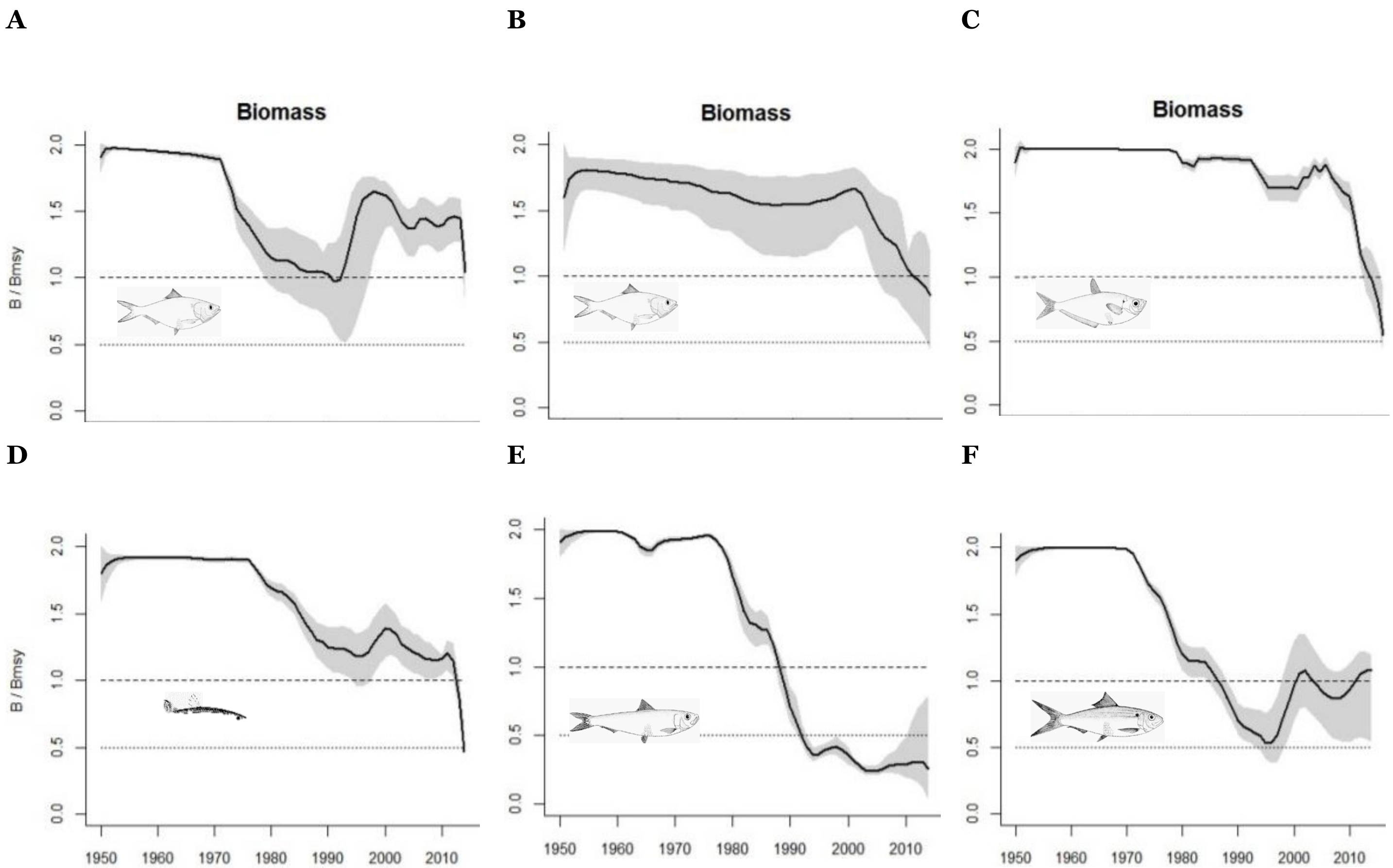

Figure 6A. Results of the CMSY analyses based on *Sea Around Us* reconstructed catch time series for 1950-2016 for non-straddling stocks in 3 marine ecoregions (see Table 6 for numerical results): (A) *Ethmalosa fimbriata* in the Sahelian Upwelling, (B) *Ethmalosa fimbriata* in the Gulf of Guinea West, (C) *Ilisha africana* in the Gulf of Guinea West, (D) *Mugil cephalus* in the Sahelian Upwelling, (E) *Sardinella aurita* in the Gulf of Guinea West, (F) *Sardinella maderensis* in the Gulf of Guinea West.

Table 7. Correspondence of terms used to assess the status of exploited fish stocks

FAO	***Sea Around Us***
Not fully exploited	$B \geq B_{MSY}$ (Healthy)
Fully exploited	$0.8*B_{MSY} \leq B < 1.0*B_{MSY}$ (Slightly overfished)
Fully exploited	$0.5*B_{MSY} \leq B < 0.8*B_{MSY}$ (Overfished)
Overexploited	$0.2*B_{MSY} \leq B < 0.5*B_{MSY}$ (Grossly overfished)
Overexploited	$B < 0.1*k$ or $B < 0.2*B_{MSY}$ (Collapsed)

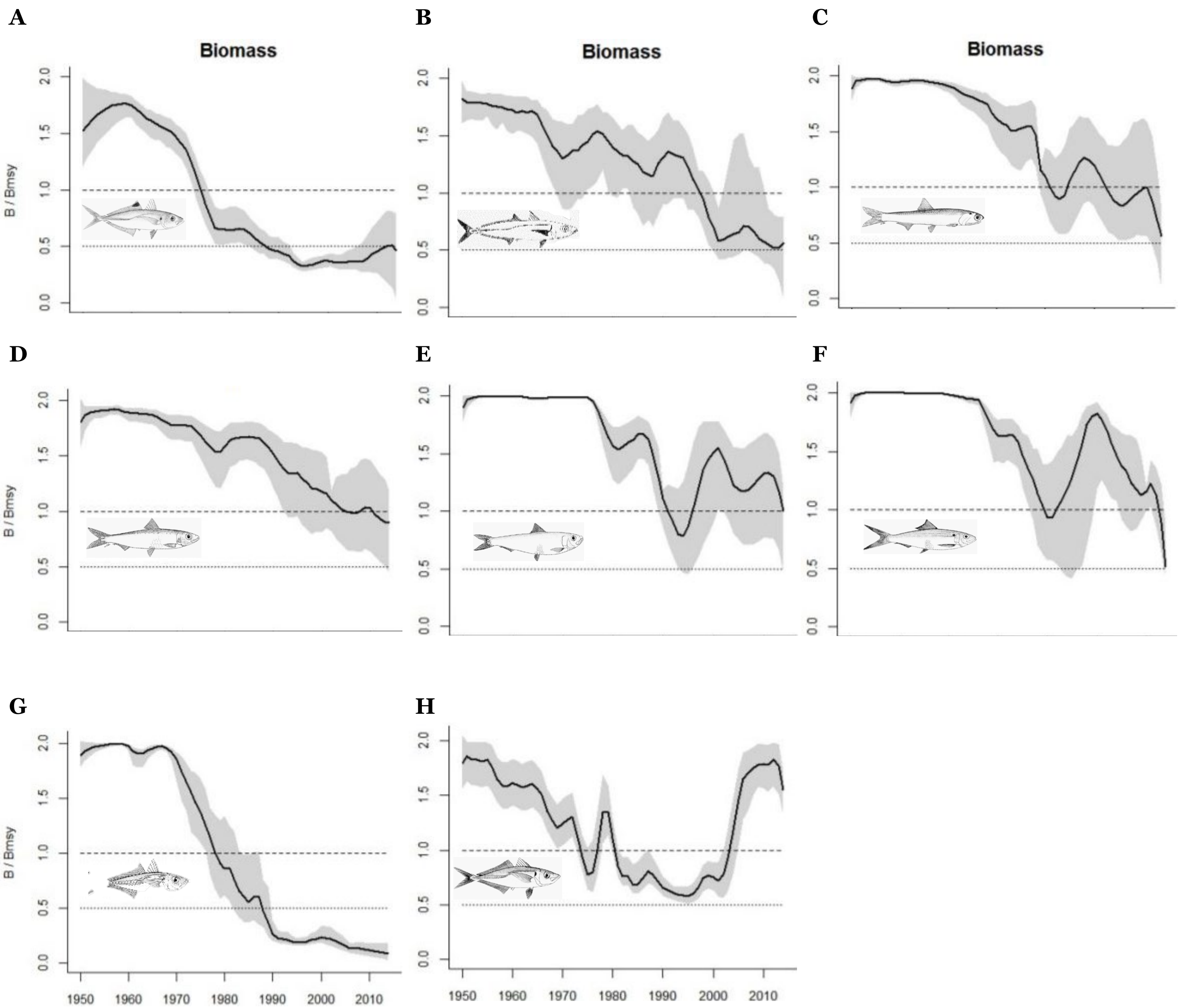

Figure 6B. Results of the CMSY analyses based on *Sea Around Us* reconstructed catch time series for 1950-2016 for straddling stocks in the 3 marine ecoregions (see Table 6 for numerical results): (A) *Caranx rhonchus* in North Western Africa, (B) *Decapterus macarellus* in the Eastern Central Atlantic, (C) *Engraulis encrasicolus* in Western Africa, (D) *Sardina pilchardus* in the Saharan Upwelling and the Sahelian Upwelling, (E) *Sardinella aurita* in the Saharan Upwelling and the Sahelian Upwelling, (F) *Sardinella maderensis*, (G) *Trachurus trachurus* in North Western Africa, (H) *Trachurus trecae* in Western Africa.

This confirms that the CMSY methods, when used with reliable catch time series, particularly when combined with CPUE and other ancillary data and priors from a length-based method, such as LBB, can quickly provide a credible stock assessment.

Thus, we encourage our colleagues in Northwest Africa and elsewhere to use the CMSY method, especially its latest versions (CMSY++), which resolve various issues noted by users.

Conclusions

We conclude this contribution with the slightly modified excerpts from the comments by Pauly (2019a, 2019b) on a major paper on fish in human nutrition by Hicks *et al.* (2019).

Eating fish is good for us. Fish are a source of micronutrients that help to prevent nutrient-deficiency diseases, which are a leading cause of infant deaths worldwide. Determining whether the consumption of locally caught fish could reduce the incidence of nutrient-deficiency diseases in countries particularly affected by this problem requires having access to the relevant data. Writing in *Nature*, Hicks *et al.* (2019) report their assessment of the nutritional content of 367 species of fish. For 43 countries, the authors mapped the relationship between the fish-derived nutrients available from fisheries' catches and the prevalence of nutrient-deficiency diseases in communities living within 100 kilometres of the coast. They found that most maritime countries, including developing countries would be sufficient to meet the key micronutrient needs of their populations.

For example, more than 75 % of the population in Namibia is at risk of calcium deficiency, even though enough fish is caught there to remedy this situation. In such cases, ensuring that even a fraction of a country's total fish catch is retained for local consumption could have a substantial impact on public health. This is particularly true for children under five years old, during a crucial stage of their development when micronutrient deficiencies have a severe effect. For 22 of the countries that Hicks *et al.* (2019) studied, 20 % or less of the fish caught could provide enough key micro- nutrients to meet the needs of all children under five years old.

Not only do nutrient shortages harm public health, but this problem has a knock-on effect of lowering gross domestic product. It might be supposed, then, that the governments of developing countries in the tropics – along with international development organizations or institutions such as the United Nations – would be doing everything possible to encourage the domestic consumption of fish caught in the EEZs of these countries. However, most economic-development policies, including those of these countries themselves, are geared towards promoting fish exports to match the insatiable demand for fish in the markets of high-income Western countries and East Asia (Swartz *et al.* 2010).

What are now the EEZs of economically developed countries were overfished long before overfishing began to occur in other countries. For example, the combined fisheries' catch in the North Atlantic peaked in 1975, and the world's catch peaked in 1996 (Pauly and Zeller 2016). The catch limits placed on overfished regions has led such economically developed countries on a quest to obtain their fish from other sources. These days, much of the haul in many parts of the developing world is either caught by local fishermen and exported, or taken by foreign fleets – which, by paying a nominal fee to access the EEZs of developing countries, catch fish for their own markets.

Such actions contribute to the scarcity of seafood and thus of micronutrients in many developing countries. This problem is perhaps greatest for countries in Northwest Africa. There, fishing by fleets from the European Union, Russia and China – and high fish exports to the EU – have led to resource decline and price increases that have made fish increasingly inaccessible to local consumers (Thiao *et al.* 2018). In Senegal, one of the countries studied by Hicks *et al.* (2019), sardinella is a staple food. A 2016 documentary film called *An Ocean Mystery: The Missing Catch* (see go.nature.com/2kyjv51) shows sardinella being smoked, dried and hand processed by Senegalese women and then trucked to the interior of the country, where these fish are the only affordable main source of micronutrients and animal protein. The leader of these workers emphasized in an interview in the documentary that it would be a catastrophe if the sardinella supply was interrupted, because they would have no fish to process.

Since then, this feared catastrophe has begun to happen. Despite much local consternation, more than 40 industrial fish- processing plants have been built, mainly by Chinese enterprises, along the coast of Senegal (see go.nature.com/2kva8bu) and neighbouring countries (see go.nature.com/2jtmcjq). These plants process sardinella and other small pelagic fish into fishmeal. Many of the local fisheries, which had traditionally supplied the regional markets with sardinella for human consumption, now instead supply the fishmeal plants, a process also noted in the Gambia by Sidibeh, *et al*. (2020, this vol.). These factories export their product mainly to China, which is the world's largest fishmeal importer, and it is commonly used there to feed farmed fish.

Thoughtful consumers in rich countries often insist that they eat fish certified as sustainably caught. This nebulous term often implies a hope that such fish are somehow being managed to ensure the continuation of an abundant supply. This contribution, and the report from which it is a part shows that this is not the case. These consumers also believe that farmed fish, e.g., salmon, contribute to sustainability, because it is widely thought that fish farming relieves pressure on capture fisheries. However, using sardinella to make fishmeal for farmed fish does not reduce the pressure on wild fish. Rather, it deprives people in the developing world, especially in Northwest Africa of previously affordable, nutritious local fish – to aid the production of costly farmed fish that is mainly consumed in high-income countries.

The above issues are not part of 'stock assessment; they are, however, part of what must be considered when managing fisheries.

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