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ARTICLE

Investigating Fishing Impacts in Nigerian Coastal Waters Using Marine Trophic Index Analyses

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Abstract

In Nigerian coastal waters (NCW), fishing has increased steadily over the last seven decades. Artisanal fisheries cover the entire 850-km length of the coast, where over 1 million fishermen exploit estuarine and oceanic resources up to 40 m deep, and approximately 250 industrial trawlers target fish resources in deeper waters beyond the first 9.26 km (5 nautical miles) from shore. We investigated the hypothesis that growth in fishing effort will increase impacts on coastal fish stocks, as reflected by significant reductions in the mean trophic level (MTL) and maximum mean length of the catch and an increase in the fishing-in-balance index. Our analyses are based on a 60-year time series from 1950 to 2010 (obtained from the Sea Around Us Project; www.seaaroundus.org). Results showed that the impacts of fishing in NCW are high. The sustained increases in landings from the 1970s to the 2000s have resulted in less productive coastal fisheries, a reduction in the MTL of the catch (which might mean reduced biodiversity), a reduction of average size in the fisheries, and the need to expand further into deeper waters to maintain catch levels. This research contributes to fisheries ecology by furthering our understanding of coastal fisheries and their impacts on marine biodiversity.

Fisheries research has shifted toward ecosystem-based approaches that utilize biological indicators and multivariate analyses to measure the status of global fisheries (Branch et al. 2010; Swartz et al. 2010; Froese et al. 2012; Lietao 2015). Recent studies have focused on ecosystem approaches to fisheries management (Jackson et al. 2001; Coll et al. 2008), with the use of landings data to calculate marine indicators (Pauly et al. 1998; Morato et al. 2006; Bhathal and Pauly 2008) in order to measure the impacts of fishing on global marine ecosystems.

On a global scale, studies have revealed an increasing loss of marine biodiversity, with growing numbers of unsustainable, collapsed, and fully exploited fisheries. This has been accompanied by a decrease in the number of underexploited or moderately exploited stocks and a decline in the mean trophic level (MTL) of global fisheries catches (FAO 2014; Lietao 2015). An early example is a study conducted by Pauly et al. (1998), who showed that the global trophic level of catch data from the Food and Agriculture Organization of the United Nations database of fisheries landings appeared to have declined at a rate of 0.1 every decade between the late 1940s and the 1990s.

The MTL of catch data is a metric chosen by the Convention on Biological Diversity that allows for the detection of shifts in catch composition data from high-trophic-level predators to low-tropic-level organisms, thus providing an indication of overfishing at higher trophic levels. The fishing-in-balance (FIB) index is a measure of balance between

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catch and trophic level that is often used in conjunction with the MTL because more biomass should be available in the ecosystem as fishing effort moves down to capture organisms at lower trophic levels (Pauly et al. 2000).

Although criticism has been leveled against the adequacy of using catch-based methods in fisheries research, particularly in regard to the marine trophic index (MTI; de Mutsert et al. 2008; Branch et al. 2010; Daan et al. 2011; Froese et al. 2012), the availability of long-term series of fisheries catch data and the lack of alternative data in data-poor regions incentivize the continued use of catch-based methods for determining the impacts of fishing on marine ecosystems. This is especially true for studying fishing impacts in the marine ecosystems of developing countries with limited resources for science and research.

In the 1970s and 1980s, fishing effort and fishing power increased rapidly in Nigerian coastal waters (NCW; Figure 1), and the coastal fisheries began to industrialize. Over the last three decades, artisanal fisheries have grown in number due to the increasing population in Nigeria (Nigeria is the most populous country in Africa, with a population very close to 200 million people). As a result of these changes, Nigerian coastal fisheries landings have increased more than 3.5-fold from 150,000 metric tons in 1980 to approximately 500,000 metric tons in 2010 (Sea Around Us Project; www.seaaroundus.org).

The most important fishing gear in NCW is the bottom trawl, reflecting the growth in fishing power, fishing effort, and the preference for benthic coastal fish resources in the industrial fishing subsector. Artisanal fishers use various fishing gears that target a variety of organisms, including reef-associated species, such as snappers *Lutjanus* spp., Sompat Grunt *Pomadasys jubelini*, and mullets *Mugil* spp. They also target pelagic species, such as Bonga *Ethmalosa fimbriata* and sardinellas, along with other benthic species like croakers *Pseudotholithus* spp. Fishermen in this sector use a variety of fishing gears, including pots, traps, gill nets, seine nets, longlines, cast nets, encircling nets, pole and lines, and harpoons.

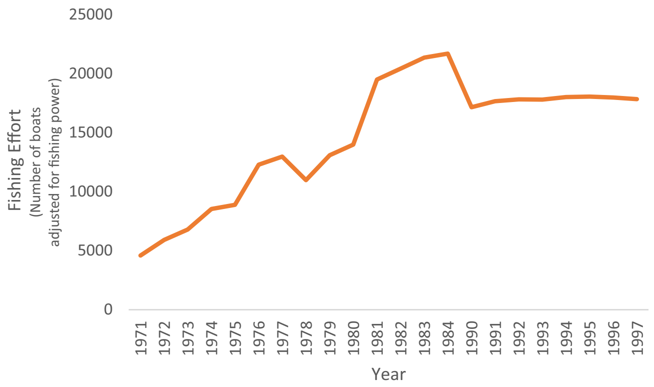

FIGURE 1. Time series of fishing effort for Nigerian coastal waters (based on data from Ssentongo et al. 1986 and Ogbona 2001).

Currently, fisheries resources in NCW are being exploited almost at full capacity, with 80% of fisheries collapsed (catch is less than 10% of historical peak catch), overexploited (catch is between 10% and 50% of historical peak catch, and the year in question is postpeak), or fully exploited (catch is greater than 50% of historical peak catch; www.seaaroundus.org). This scenario shows that fisheries management in NCW has been largely inefficient, perhaps due to a weak fisheries regulatory landscape, particularly in the artisanal fishing subsector (Kaitriko and Macusi 2012; Lewerenz and Vorrath 2015; Bailey et al. 2018).

The more regulated industrial fishing subsector has been managed through various measures put in place to minimize the impacts of fishing; such measures include the enforcement of mesh size restrictions and area closures (as stipulated in the Sea Fisheries and Sea Licensing decrees of 1972 and 1992 [Federation of Nigeria 1992]). However, overfishing in NCW remains a problem that is far from being resolved.

The goal of our research is to use statistical approaches to investigate and document trends in the MTI for coastal fisheries of Nigeria in order to understand past and present trends and to provide context for future management of these valuable but rapidly declining coastal fisheries resources. The MTI measures the MTL for marine ecosystems and indicates the extent of “fishing down the food webs” (Biodiversity Indicators Partnership; https://www.bipindicators.net/indicators/marine-trophic-index). We reviewed the last seven decades of catch data from the Sea Around Us database, with a particular focus on the MTI of fisheries landings during this period. We analyzed the fishing data from NCW to test the hypothesis that fishing has resulted in impacts on coastal fish stocks, as reflected in significant reductions in the MTL and maximum mean length (MML) of the catch and an increase in the FIB index over the period of interest (1950–2010).

METHODS

Data acquisition and treatment.— Nigeria is situated in the Gulf of Guinea Central ecoregion (www.seaaroundus.org). Here, fisheries are made up of a multispecies, multigear artisanal fishing subsector (that operates in the coastal lagoons, creeks, and marine areas up to 40 m) and an industrial fleet of trawlers that target fish, shrimp, and other invertebrates in waters beyond 9.26 km (5 nautical miles) from the shoreline (Amire 2003; Nwafili and Gao 2007).

A systematic countrywide collection of fisheries data began in the early 1970s, but Etim et al. (2015) recently reconstructed fishing data from 1950 to 2014 via the method of Zeller and Pauly (2007). We obtained this fishing data from the Sea Around Us Project Web site for use in our study to gain insights into the pattern of resource use and its ecosystem consequences.

Catch was reported in metric tons per year along with the MTL, FIB index, and MML of landings. We treated data by removing taxonomic records that were not clear or specific enough (e.g., data specified as “marine pelagic fish,” “marine benthic invertebrates,” etc., were removed). We log-transformed the MTL index, FIB index, and MML of the catch data before using multivariate statistical approaches to analyze and categorize the data in XLSTAT 2018 (a statistics plug-in for Microsoft Excel 2016).

Data analyses.— After the data were log-transformed, a segmentation technique that allowed *K*-means clustering for the grouping of data into congruent classes was applied (Bouguettaya et al. 2015). We used agglomerative hierarchical clustering (AHC) to group years with similar MTI characteristics into similar clusters. Our goal was to partition observations of landings into *K* clusters, where individual observations were categorized into classes with the nearest mean.

We removed years that had negative MTI values based on our data transformation and gave similar weights to the variables (MTL, FIB index, and MML) used in our analyses by selecting the center and reduced options. The sum of squared Euclidean distances was used to determine distance by clusters to derive an index of oddity for each cluster. Each cluster had a central object or year that served as a class centroid, or a center point for observed data, around which years with similar MTI characteristics converged. Years with more similar MTI values were grouped within the same clusters, whereas dissimilar years were grouped further apart from each other based on observed MTI data.

As a follow-up to the AHC, we performed ANOVA on the data values from the clusters generated in the AHC, and we conducted a post hoc test (least-significant-difference test) to determine whether MTI values were significantly different among the AHC clusters generated in the first step of our analyses. We also carried out linear regressions on MTI time series of MTL index, FIB, and MML data for the three time periods identified by the cluster analysis and for the complete time series of these indicators. Significance for all statistical tests was set at an α of 0.05.

RESULTS

The most prominent features observed through analyses of fishing data for NCW were an overall decline in MTL

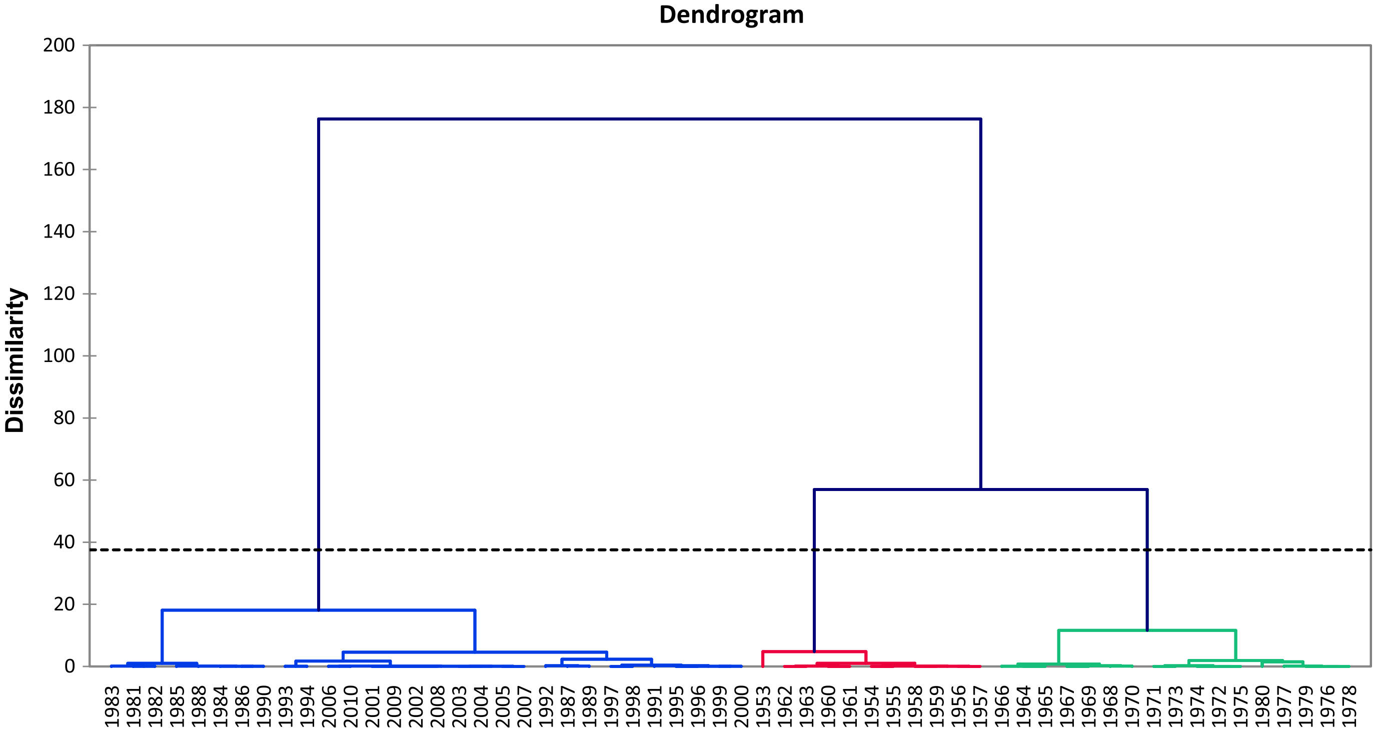

FIGURE 2. Dendrogram showing hierarchical clustering of marine trophic index data for Nigerian coastal waters for the years 1950–2010. The maximum number of clusters is indicated by the horizontal dashed line, which cuts through the dendrogram to produce three clusters.

index and MML and an increase in the FIB index over the study period.

Agglomerative Hierarchical Clustering Analysis

The AHC analysis allowed for the grouping of years with similar MTI profiles into the same clusters (Figure 2). Two main MTI profiles were evident in the dendrogram: one branch of the dendrogram attached to MTI profiles for the 1950s to early 1980s, and the other branch contained years from 1981 onward. The dendrogram contained three clusters representing the three major periods in the data set: 1953–1963 (period 1); 1964–1980 (period 2); and 1981–2010 (period 3). The central year for each cluster was as follows: 1957 for period 1; 1970 for period 2; and 1992 for period 3.

In the first branch of the dendrogram, there were three additional subgroups of years based on MTI profiles in the fisheries. The MTI data for the early 1980s appeared to be more similar to those for the early part of the 2000s but further apart from those for the 1990s.

Analysis of Mean Trophic Level

Mean trophic levels for landings from NCW were similar enough for periods 1 and 2 (which may be why they were categorized together in the second branch of the dendrogram), but the MTL for period 3 was further apart from those of the earlier two periods. The average MTL (±SD) was 3.71 ± 0.01 for the first cluster, 3.70 ± 0.05 for the second cluster, and 3.42 ± 0.06 for the third cluster.

There was a slight initial increase in the MTL for NCW in period 1, with a slope of 0.002 ($R^2 = 0.69$, $P = 0.0002$), which was followed by a declining MTL on average (Figure 3). Thereafter, a cyclical pattern of rise and fall in the MTL index was observed, but this cycle showed a decline from 3.75 beginning in the late 1970s to an MTL of 3.35 in the 1990s. The lowest MTL was recorded in 1998, when the MTL dipped to 3.29. For the entire data set (1950–2010), the MTL index declined at a rate of −0.007 ($R^2 = 0.74$, $P < 0.0001$).

The average values for the MTL were significantly different for the three periods of interest (ANOVA: $P < 0.001$). The least-significant-difference post hoc test revealed that the average MTL for period 1 was not different from that for period 2, but the average for period 1 was higher than the average MTL for period 3. The MTL for period 2 was also higher than that for period 3.

Analysis of the Fishing-in-Balance Index

During period 1, the FIB index for landings from NCW gradually increased, with a slope of 0.019 ($R^2 = 0.95$, $P < 0.0001$), to a value of 0.24 in 1963 (Figure 4). The average FIB index for this period was 0.10 ± 0.08. A cyclical pattern of rise and fall in the FIB index was observed during the 1970s and 1980s (period 2), and the FIB index values for the 1980s almost dipped back to 1970 values. During period 2, the average FIB index was 1.22 ± 0.42, with an increasing slope of 0.073 ($R^2 = 0.849$, $P < 0.001$). The highest FIB index values in the time series were observed during period 3, with an average index of 1.80 ± 0.32. There was an increasing trend in this last period as well, with a slope of 0.335 ($R^2 = 0.849$, $P < 0.001$). Over the whole time series, the FIB index increased at a rate of 0.039 ($R^2 = 0.88$, $P < 0.001$).

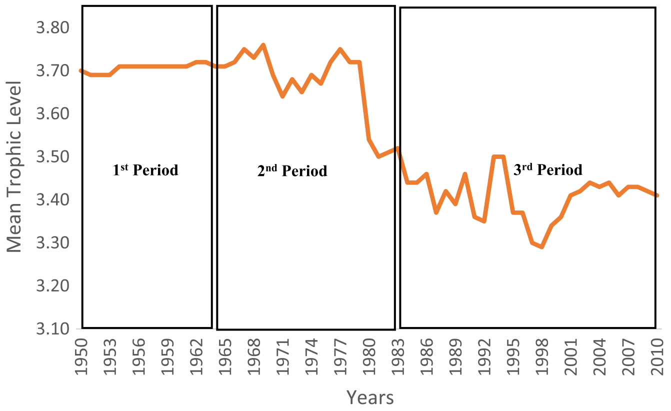

FIGURE 3. Time series of mean trophic level for Nigerian coastal waters for the years 1950–2010. Each rectangle indicates the length of time in each of the three periods identified by cluster analysis.

Average FIB index estimates were significantly different for the three periods we studied (ANOVA: $P = 8.6435 \times 10^{-24}$). The least-significant-difference post hoc test revealed that the average FIB index for period 1 was lower than those for periods 2 and 3, and the average FIB index for period 2 was also lower than that for period 3.

Analysis of Maximum Mean Length

Between 1950 and 1980, the MML of landings in NCW increased from 74.8 cm in 1950 to 91.8 cm in 1980 (Figure 5). By the 1990s, there was a major reduction in the average size of fish, with a 16-cm average reduction between periods 2 and 3. A continuous decline was observed from the early 1980s onward at a rate of −0.471 ($R^2 = 0.571$, $P < 0.001$), and the lowest recorded MML (60.60 cm) was observed in 1997. Afterwards, small increases in MML were realized between 1997 and 2010.

The average MML was 75.99 ± 1.15 cm for the first cluster of years, 83.72 ± 4.54 cm for the second cluster, and 67.94 ± 5.48 cm for the third cluster. The average values for the MML were significantly different among the three periods (ANOVA: $P < 0.001$), and the general trend in MML was a decline at a rate of −0.29 ($R^2 = 0.400$, $P < 0.001$) over the entire study period. The least-significant-difference post hoc test showed that the average MML in the fishery for period 1 was significantly lower than that for period 2. Furthermore, the MML from period 1 was significantly lower

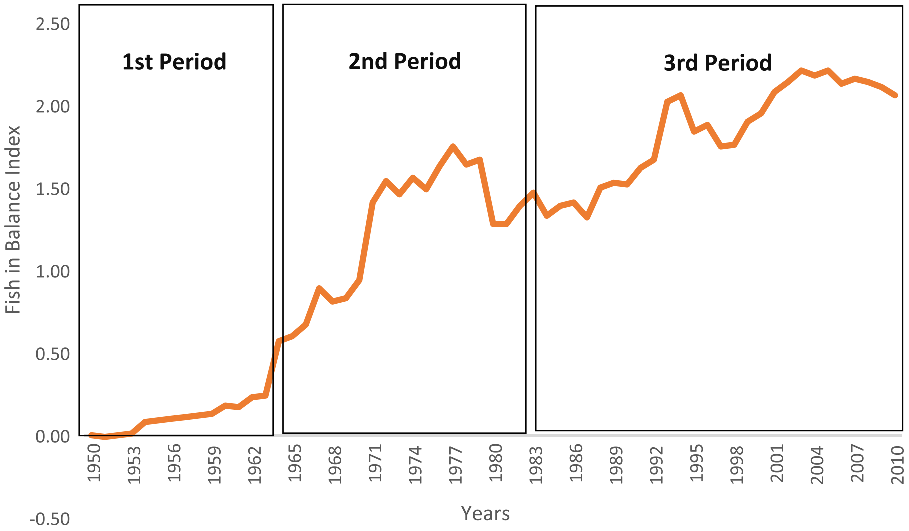

FIGURE 4. Time series of the fishing-in-balance index for Nigerian coastal waters for the years 1950–2010. Each rectangle indicates the length of time in each of the three periods identified by cluster analysis.

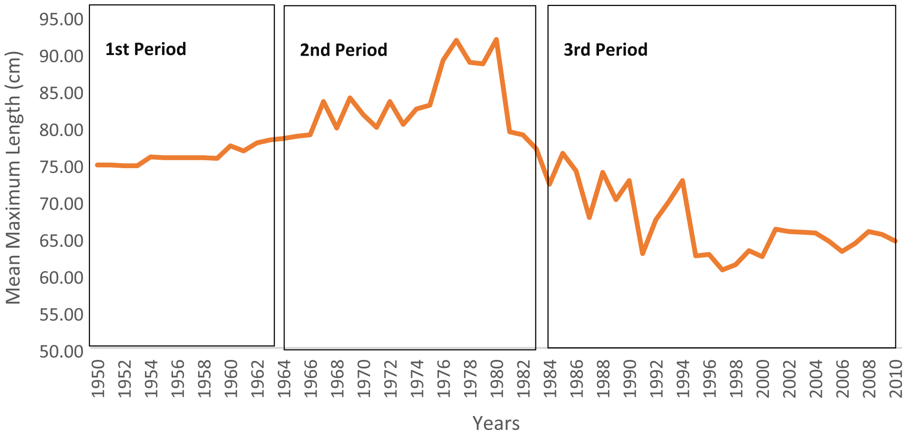

FIGURE 5. Time series of maximum mean length (cm) for Nigerian coastal waters for the years 1950–2010. Each rectangle indicates the length of time in each of the three periods identified by cluster analysis.

than the MML from period 3, and the MML from period 2 was significantly higher than that from period 3.

DISCUSSION

The MTI has been widely used to characterize global fisheries over the last decade. The use of catch data to analyze impacts of fishing on marine ecosystems has important limitations, especially when fishing disproportionately affects one part of the food web. When this is the case, the MTL of the catch may not accurately reflect ecosystem MTL, but when fishing affects the entire food web concurrently, fish landings data approximately represent the ecosystem (Branch et al. 2011; Carruther et al. 2012). In NCW, industrial fishing effort disproportionately affects bottom-dwelling organisms by mainly targeting coastal shrimp resources along with other bottom-dwelling species, such as croakers, threadfins *Pentanemus* spp., and reef-associated species. Artisanal fisheries utilize diverse gears and strategies that harvest resources in the entire water column up to 40-m depth (Amire 2003).

The fishing characteristics of fleets in NCW have changed with time, and rapid increases in fishing effort and fishing power have contributed to the overfishing of fish stocks in NCW. Several fish stocks are reported to have collapsed in the inshore waters of Nigeria (Sea Around Us Project), and a wider envelope of sea area is currently subjected to increasing exploitation as industrial fishing effort continues to push deeper into offshore waters such that 80% of stocks are now fully exploited, overexploited, or collapsed (Sea Around Us Project).

We applied cluster analysis to classify the MTI based on fisheries landings data collected in NCW during 1950–2010, and we were able to classify the time series into three distinct time periods. The MTL index and MML were statistically distinct between periods 1 and 3, but only the MML was statistically different between periods 1 and 2. Period 2 was a period of increased growth in MML and MTL index for NCW fisheries. During this period, fishing power grew almost 28-fold, with bottom trawl fisheries contributing about 14.5% (1970s) of fish total landings (80,173 metric tons) compared to 0.45% of total landings (33,029 metric tons) in the 1950s. Fishing power grew even more in the ensuing years, and by the 1990s trawl fishing was contributing more than 40% of total landings (415,461 metric tons) in NCW (Sea Around Us Project).

Compared to 1950s baselines, fish landings more than doubled in the 1970s and increased about tenfold in the 1990s, signifying increasing anthropogenic impacts in the coastal ecosystem of Nigeria. To maintain the increasing catch from the continental shelf, fishers had to fish at increasing depths, perhaps because resources in nearshore waters had largely been depleted (Adebola and de Mutsert 2019).

Mean Trophic Level

The MTL index is the most widely used marine index for monitoring global marine biodiversity, but its usefulness as an indicator has been criticized mainly because it can change based on factors influencing fisheries in specific geographical locations, including economics, fishing technology, targeting patterns, and management strategies (Branch et al. 2010). This indicator works well for explaining changes in the marine ecosystem in combination with known changes in fishing practices, and we describe these in conjunction here.

In our analysis of fish landings data for NCW, we found that the MTL index of the catch was highest during period 1 of our study (1953–1963), with an average MTL of 3.71 ± 0.01. Both fishing effort and fishing power were at a minimum during this time period, and fishing effort seems to have been spread evenly among taxa in the ecosystem.

Fishing mostly occurred in nearshore waters during period 1 because most vessels used for fishing during this period were paddle canoes, which were restricted to fishing in nearshore areas of the continental shelf. Pots and traps were by far the most prominent gears used, accounting for about 33% of gears in 1957. The most important species in the catch were Boe Drum *Pteroscion peli*, Bonga, large African croakers *Pseudotolithus* spp., snappers, mullets, barracudas *Sphyraena* spp., and threadfins.

The average MTL for period 2 (1964–1980) was not significantly different from that for period 1 because fishing power at this stage was still comparable to that of the first period and also perhaps because top predators had not been depleted from the ecosystem at that point in the fishing history of NCW. Pots and traps remained the most prominent gears used throughout period 2, followed by gill nets (17%) and trawls (14.5%). Landings mostly consisted of barracudas, Sompat Grunt, threadfins, African croakers, Bonga, common stingray *Dasyatis pastinaca*, Senegal Jack *Caranx senegallus*, and Guinean Pompano *Trachinotus maxillosus*.

The MTL in period 3 (1981–2010) was significantly different from the MTLs in periods 1 and 2. This reflects the greater contribution of lower trophic levels and the important role that economics played in the contribution of species to landings data. Due to the economic value of shrimp, fishers began to concentrate effort on the shrimp fishery in the mid-1980s (i.e., at the beginning of period 3). As a result, shrimp contributed up to 7% of the landings in NCW for the first time. At the same time, medium pelagic fishes (e.g., Bonga) and small pelagic fishes (e.g., *Sardinella* spp.) were contributing more to landings data during this period. In addition to these, the contribution of top predators, including sharks, large rays, and other large pelagic scombroids, declined from 30% of the 1950s landings to 17% of the 1990s landings.

The biomass of top predators in NCW has been reduced by almost half during the last 70 years even though fishing has expanded into deeper areas of the Exclusive Economic Zone, and fishing is now occurring at an increasing depth in comparison with areas fished during the 1950s.

Top predators are late-maturing, long-lived species that are not easily replaced when their populations become depleted. Moreover, fishing in deeper and less productive areas of the continental shelf may be an unsustainable strategy for long-term fish production in Nigeria. Expansion into deeper water may mean that less productive fish stocks are currently being targeted—a sign that the present fishing strategy of expansion into more pristine fishing grounds offshore is most likely unsustainable.

Fishing-in-Balance Index

Bathal and Pauly (2008) showed that the expansion of coastal fisheries is positively correlated with the FIB index. They recorded a fourfold increase in the FIB index for coastal fisheries in India between 1970 and 2000. Over the same time period in NCW, the FIB index only increased approximately twofold from 0.94 (in 1970) to 1.95 (in 2000). Similarly, the increase in the FIB index for NCW confirms theoretically the observed expansion of fishing into deeper areas of the continental shelf (often talked about by fishers) because over the years, fishers continued to deploy fishing effort across a wider range of sea surface and depth to meet the growing demand for fish products.

For the most part, the FIB index showed continuous expansion in NCW through the three periods examined (1953–1963, 1964–1980, and 1981–2010). The FIB index was generally steeper between 1964 and 1980, a sign that period 2 was one of rapid expansion. This period was a time of increasing industrialization and growth in fishing power that allowed fisheries to access deeper and relatively more pristine fishing grounds over the continental shelf. The additional growth in fishing power resulting from the growth in the shrimp industry during the mid-1980s to mid-1990s did not produce the same precipitous rise in the FIB index as was observed in the early 1970s. This is perhaps because shrimp trawlers mainly operated between the 50- and 80-m isobaths, thus restricting their fishing effort to the shallow to mid-depth sections of the continental shelf.

Maximum Mean Length

The contribution of trawl fisheries increased from 0.45% of total landings in the 1950s to 14.5% in the 1970s. Trawlers mainly landed large demersal and pelagic predators, such as barracudas, African croakers, and elasmobranchs, and during this period the MML increased from an average of 75.99 ± 1.15 cm in the 1950s to 83.72 ± 4.54 cm in the 1970s.

The increase in average MML of the catch between these periods may have been due not only to an increased contribution of higher-trophic-level species, such as sharks and barracudas, but also to density-dependent increases in growth rates as fishing pressure reduced competition for resources among fish in the ecosystem. Moreover, the observed rise in MML could have resulted from growth in fishing power, which might have provided access to more productive fishing grounds while enabling fishers to capture more mobile, large species that were less likely to have been caught in the less efficient fishing gears used by artisanal fishers in the 1950s.

Beginning in the 1980s, the MML of fisheries catch in NCW began a rapid and precipitous decline that extended through 2010. The decline in MML for period 3 might have occurred because the largest fish were targeted and first harvested either for economic reasons or in some cases as the result of a need to comply with fishing policy that imposed size limits based on mesh sizes.

The reduction in overall MTL index in the coastal fisheries of Nigeria due to the loss of top predators and the deliberate targeting of the shrimp resource beginning in the mid-1980s, along with the higher contribution of small pelagic species (especially sardinellas, whose populations vary with environmental factors) to landings, might have contributed to the observed steady decline of MML in the fisheries of NCW beginning in the early 1980s and the continuing abatement of MML currently observed in the fisheries.

Conclusions

The AHC analysis provided insights into the main characteristics of fisheries in NCW. We classified fishing periods based on ecological attributes (i.e., MTI) measured for fish landings data from the three time periods. We conclude that fishing impacts in NCW appear to be very high.

Our analyses support the hypothesis of declines in MTI metrics (MTL index and MML) and an increase in the FIB index, with significant linear trends as fishing effort increased over the period for which data were analyzed. Given the evidence, a reduction in fishing effort coupled with investments in sustainable aquaculture and stronger governance of ocean resources is necessary to attain sustainable fisheries in Nigeria.

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