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Unequal abundance as a result of unequal vulnerability of species to the gears deployed by Artisanal Fishers in South-western Marine Waters of Côte d'Ivoire, West Africa

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Abstract

Catch data derived from artisanal fishery and collected from October 2017 to December 2018 have been used to estimate sixty-four fish and other fishery resources abundance in connection with the fishing gears with which they had been caught. These gears deployed in continental shelf waters of Côte d'Ivoire by the fishers included the drifting gillnet, stationary gillnet, bottom gillnet, beach seine, purse seine and longline. The results indicated differences in the abundance of each species relating to the gear type. Some species were caught with one fishing gear while others were vulnerable to at least two gears. Additionally, some pelagic species, of which the Sardinellas (e.g. *Sardinella aurita* Valenciennes, 1847 and *S. maderensis* (Lowe, 1839)), accounted for the principal species with higher abundance. The drifting gillnet and purse seine proved to be the fishing gears that caught the most specimens, cumulating 43.24% and 34.54% of total number of species landed, respectively. Catches with longline were however more diversified, spanning the pelagic to bottom species. The study also described the environmental conditions of these species through the change in temperature and phytoplankton abundance due to the change in season, which indirectly contributed significantly to varying abundance of species.

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Introduction

With its practice date back to ancient times and role as a way to supply people's needs for aquatic living resources suitable for human consumption, fishing has shaped to some extent mankind's history. True, in former times, fishing gears were not as much sophisticated as the ones fishers use today and yet efficacious enough to help fishers take good catches, fitting for their time. Truly, worldwide, there have been reports on stocks declines and collapses (Garcia *et al.*, 2003; Srinivasan *et al.*, 2012) as well as on commercially exploited fish (Hutchings, 2000). Instead, aquatic environments undoubtedly are still populated by the living organisms, mainly because over time the target species have developed strategies to ensure their own survival in an effort to escape the devastating effects of some gear types. Those strategies may involve the species' behaviour (e.g. escapement of fish of certain size, avoidance response to fishing gears), the swimming speed, the detection of movement, the hearing capability and the visual sensitivity of species, to name a few.

Those strategies may vary across species, but the final result leads to a change in the abundance of the species that are fished for, following unequal vulnerability of such organisms to the fishing gears. There are many definitions for the term vulnerability, depending on the field addressed. However, we will shift from the broader concept of vulnerability to the specific area of fishing and say that a given species is considered as vulnerable to a gear type when that species can be caught in such a gear. Yet, things do not always turn out to working fine this way because the efficiency of the gear has much more to do with selectivity. And selectivity itself, which is the quantitative expression of selection (Hamley, 1975), is viewed by Huse *et al.* (2000) as a key factor (among many others such as effort, catchability, fishermen's choice of time and fishing area) on which exploitation of fish stocks is dependent. The main objective of the current study was therefore to address the efficiency of the fishing gears deployed by the artisanal fishers. A specific goal was to evaluate the abundance of each species in relation to the gear types. The environmental conditions of species are described to determine whether or not there was any relationship between these conditions and species variation in abundance.

Materials and methods

Sampling procedure

Samples were collected from October 2017 to December 2018 from the artisanal fishery. Actually, artisanal fishers played a key role in this study. They were the ones who went fishing aboard dugout canoes powered by 40-hp motors. As members of a multispecies artisanal fishery, fishers would target various species using at least six gears (e.g. the drifting gillnet, stationary gillnet, bottom gillnet, beach seine, purse seine and longline). Fishing operations occurred in continental shelf waters. Fishers would set most of the gears at night and retrieve them the following day. Fishers preferably would spend a 3-day stay at sea (weather permitting), as iceboxes were kept aboard the canoes to ensure the quality of the landed product. Landings generally occurred in the morning on the fishers' return, though some other casual landings would take place in the afternoon.

Using satellite data obtained from MODIS-Aqua to describe environmental conditions

According to Njoku *et al.* (1985), ocean temperature measurements made by satellite remote sensing can be extremely useful in defining the distribution of marine fish habitat conditions. Therefore, we used satellite techniques for measurement of sea surface temperature (SST) and chlorophyll-A (Chl-A), as they bear scientifically-based accuracy. The term SST has typically been used to describe the mean temperature of the upper few meters of the ocean, as Kent *et al.* (2017) did. The SST and Chl-A data were obtained from the NASA's Ocean Biology Processing Group Webpage, freely downloading them as mean values of level 3 Network Common Data Format. In addition, these data were transferred into the SeaDAS software package, making it possible for them to be adjusted to the geographic coordinates of the continental shelf of Côte d'Ivoire. The SST and Chl-A variations were described with regard to a broader place to facilitate readers' understanding.

Fishery data processing

Several samples were taken first from the landings. And, then, sub-samples that were species-specific were constituted according to their kinds. The later samples were weighed, as we did for the former, and the specimens within them were counted and the result was extrapolated to the whole landings. Field data were recorded on sheets of paper and then taken to office for final registration on an Excel file of a computer. The abundance of each species was expressed as a percentage of the number of such a species to the total number of all species landed, taking into consideration the gear type with which that species was caught. Species were finally ranked according to their total percentages.

Results

Table 1 shows the list of species landed and the relative abundance of each of them in connection with the gear in which they had been caught. Some species like the southern pink shrimp *Farfantepenaeus notialis* (Pérez-Farfante, 1967) or the Atlantic chub mackerel *Scomber colias* Gmelin, 1789 were mainly caught with one gear, namely the beach seine and the drifting gillnet, respectively. Other species like largehead hairtail *Trichiurus lepturus* Linnaeus, 1758 or Senegal needlefish *Strongylura senegalensis* (Valenciennes, 1846), were caught with more than two fishing gears. Moreover, species listed in Table 1 can be assigned four zoological groups. Some species are fish (example: the round Sardinella known as *Sardinella aurita*; West African goatfish *Pseudupeneus prayensis* (Cuvier, 1829)) while others are crustaceans (example *Farfantepenaeus notialis*; mantis shrimps *Scyllarides herklotsii* (Herklots, 1851)). In addition, some other species are cephalopods (example: the elegant cuttlefish *Sepia elegans* Blainville, 1827) whereas others are gastropods (example: sea snails). Regarding the way species are distributed within the water column, they can be associated with different habitats. For example, some species are pelagic (e.g. the sardinellas *Sardinella aurita* and *S. maderensis*, West African Ilisha *Ilisha africana*, *Farfantepenaeus notialis*) while others are semi pelagic (e.g. Alexandria pompano *Alectis alexandrinus* (Geoffroy Saint-Hilaire, 1817), Cunene horse mackerel *Trachurus trecae* Cadenat, 1949). Still other species like Senegal needlefish *Strongylura senegalensis* and Bobo croaker *Pseudotolithus elongatus* (Bowdich, 1825) are demersal whereas others are either benthic or benthopelagic (e.g. Daisy stingray *Dasyatis margarita* (Gunther, 1870), Largehead hairtail *Trichiurus lepturus*). Though present in the landings, not all species were that abundant. Overall, two fish species known as the Sardinellas prominently occurred in the catches, since their cumulative percentages were 39.54% (for *Sardinella aurita*) and 32.64% (for *Sardinella maderensis*), far exceeding the percentages of the other species (Table 1).

Table 1. Relative abundance of species (%) regarding their vulnerability to the fishing gears deployed by the artisanal fishery in marine waters of Sassandra, a southwestern locality of Côte d'Ivoire.

Species	Abundance in connection with fishing gear types*						Total (%)	Rank
	DGN	SGN	BGN	BS	PS	LL		
Sardinella aurita	20.72	0.00	0.00	0.00	18.81	0.00	39.54	1
Sardinella maderensis	20.04	0.00	5.94	0.00	6.64	0.00	32.64	2
Ilisha africana	0.25	0.00	1.48	0.60	5.02	0.00	7.35	3
Chloroscombrus chrysurus	0.00	0.00	0.86	3.14	1.73	0.00	5.73	4
Farfantepenaeus notialis	0.00	0.00	0.00	4.63	0.00	0.00	4.63	5
Strongylura senegalensis	0.33	0.00	0.19	0.44	0.52	0.34	1.83	6
Pseudotolithus elongatus	0.00	0.31	0.03	0.18	0.55	0.02	1.09	7
Trichiurus lepturus	0.00	0.00	0.28	0.31	0.17	0.30	1.07	8
Ethmalosa fimbriata	0.00	0.00	0.00	0.48	0.48	0.00	0.97	9
Scomber colias	0.60	0.00	0.00	0.00	0.00	0.00	0.60	10
Pentanemus quinquarius	0.00	0.00	0.24	0.32	0.00	0.00	0.56	11
Trachurus trecae	0.10	0.00	0.09	0.11	0.11	0.01	0.42	12
Exocoetus volitans	0.40	0.00	0.00	0.00	0.00	0.00	0.40	13
Brachydeuterus auritus	0.03	0.00	0.25	0.00	0.00	0.07	0.35	14
Euthynnus alletteratus	0.14	0.00	0.00	0.00	0.07	0.03	0.24	15

Species	Abundance in connection with fishing gear types*						Total	Rank
	DGN	SGN	BGN	BS	PS	LL	(%)	
Galeoides decadactylus	0.00	0.00	0.10	0.08	0.03	0.01	0.21	16
Eucinostomus melanopterus	0.00	0.00	0.00	0.00	0.18	0.00	0.18	17
Auxis thazard	0.18	0.00	0.00	0.00	0.00	0.00	0.18	17
Umbrina canariensis	0.00	0.05	0.00	0.08	0.02	0.02	0.18	17
Priacanthus arenatus	0.18	0.00	0.00	0.00	0.00	0.00	0.18	17
Cynoglossus canariensis	0.00	0.18	0.00	0.00	0.00	0.00	0.18	17
Brotula barbata	0.00	0.00	0.00	0.00	0.00	0.18	0.18	17
Arius parkii	0.00	0.03	0.00	0.06	0.01	0.05	0.15	23
Promethichthys prometheus	0.03	0.00	0.01	0.00	0.05	0.03	0.12	24
Others	0.07	0.00	0.00	0.02	0.03	‡	0.12	24
Sarda sarda	0.11	0.00	0.00	0.00	0.00	0.00	0.11	26
Pagellus bellottii	0.00	0.00	0.01	0.00	‡	0.08	0.10	27
Pomadasys jubelini	0.00	0.01	‡	0.03	0.02	0.02	0.09	28
Ophisurus serpens	0.00	0.00	0.00	0.00	0.00	0.08	0.08	29
Callinectes amnicola	0.00	0.05	0.02	0.00	0.00	0.00	0.07	30
Selene dorsalis	0.00	0.00	0.00	0.04	0.00	0.02	0.06	31
Polydactylus quadrifilis	0.00	0.01	0.00	0.01	0.02	0.01	0.05	32
Branchiostegus semifasciatus	0.00	0.00	0.00	0.00	0.00	0.05	0.05	32
Lethrinus atlanticus	0.00	0.01	‡	0.01	0.00	0.01	0.04	34
Katsuwonus pelamis	0.04	0.00	0.00	0.00	0.00	0.00	0.04	34
Tarpon atlanticus	0.00	0.00	0.00	0.00	‡	0.02	0.03	36
Sphyraena afra	0.00	0.00	0.00	0.00	0.00	0.03	0.03	36
Sepia elegans	0.00	0.00	0.00	0.00	0.03	0.00	0.03	36
Cynoponticus ferox	0.00	0.00	0.00	0.00	0.00	0.03	0.03	36
Lutjanus goreensis	0.00	0.01	0.00	0.00	0.00	0.01	0.02	40
Campogramma glaycos	0.00	0.00	0.00	0.00	0.01	0.00	0.01	41
Stromateus fiatola	0.00	0.00	0.00	0.00	0.01	0.00	0.01	41
Alectis alexandrinus	0.00	‡	0.00	0.00	0.01	‡	0.01	41
Rhinobatos rhinobatos	0.00	‡	0.00	0.00	0.00	0.01	0.01	41
Coryphaena hippurus	‡	0.00	0.00	0.00	0.00	0.01	0.01	41
Panulirus regius	0.00	0.01	0.00	0.00	0.00	0.00	0.01	41
Scyllarides herklotsii	0.00	0.01	0.00	0.00	0.00	0.00	0.01	41
Scomberomorus tritor	‡	0.00	0.00	0.00	‡	‡	0.00	48
Prionace glauca	0.00	‡	0.00	0.00	0.00	‡	0.00	49
Xiphias gladius	0.00	‡	0.00	0.00	0.00	‡	0.00	50
Istiophorus platypterus	0.00	‡	0.00	0.00	0.00	‡	0.00	51
Dasyatis margarita	0.00	‡	0.00	0.00	0.00	0.00	0.00	52
Thunnus albacares	0.00	0.00	0.00	0.00	‡	‡	0.00	53
Drepane africana	0.00	0.00	0.00	0.00	‡	0.00	0.00	54
Liza falcipinnis	0.00	‡	0.00	0.00	0.00	0.00	0.00	55
Manta birostris	‡	0.00	0.00	0.00	‡	0.00	0.00	56
Lichia amia	0.00	‡	0.00	0.00	‡	‡	0.00	57
Elagatis bipinnulata	0.00	0.00	0.00	0.00	0.00	‡	0.00	58
Muraena sp.	0.00	0.00	0.00	0.00	0.00	‡	0.00	59
Rachycentron canadum	0.00	0.00	0.00	0.00	0.00	‡	0.00	60
Epinephelus aeneus	0.00	0.00	0.00	0.00	0.00	‡	0.00	61
Chaetodipterus goreensis	0.00	0.00	0.00	0.00	0.00	‡	0.00	62
Pseudupeneus prayensis	0.00	0.00	0.00	0.00	0.00	‡	0.00	63
Sea snails	0.00	‡	0.00	0.00	0.00	0.00	0.00	64

*DGN = drifting gillnet ; SGN = stationary gillnet ; BGN = bottom gillnet ; BS = beach seine ; PS = purse seine ; LL = longline. ‡ = Caught with this type of gear, but is so scarce that its percentage is poor.

Fig. 1 shows the contribution of each gear type to total number of specimens caught (Fig. 1A) and to the yield (Fig. 1B). In either case, the drifting gillnet and purse seine proved to be the most effective as they contributed 43.24% and 34.54% to total number of specimens caught and 48.48% and 33.36% to the yield, respectively. However, catch derived from longline was made up of species spanning the pelagic to bottom component, making it the most diversified. Fig. 2 shows satellite-derived SST measurements of general temperature conditions in the upper mixed layer on continental shelf of Côte d'Ivoire within the study period. In each image the land was indicated with black colour whereas marine waters appeared in various colours shown on the accompanied colour chart below (Fig. 2).

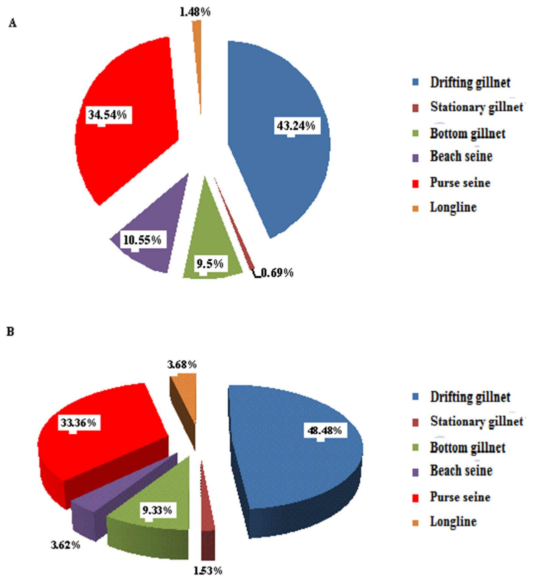

Fig. 1. Each fishing gear's contribution in total catch in terms of number of specimens caught (**A**) and in terms of yield (**B**) at Sassandra, a southwestern locality of Côte d'Ivoire.

Overall, water masses on continental shelf of Côte d'Ivoire were relatively hot, with temperature varying between 21 and 29°C annually, on average. For example, in October 2017 the shelf was covered by waters that were slightly less hot (□25-26 °C) compared with those in November and December 2017 (□27-28 °C), illustrated by mixture of green and yellow colours versus orange colour, respectively. However, a change occurred from January to March 2018, as waters near the coast were the only ones to be less hot (□27 °C), prior to the conflicting situation from April to June 2018 (□28-27.39 °C) and the one from July to September (□26.18-25.45 °C) where cold waters (illustrated by blue colour) amidst relatively hot waters (symbolized by yellow and orange colours) occurred. From October (27.03 °C) onward, the shelf was covered by very hot waters of □28 °C (illustrated by orange colour) in November and December 2018.

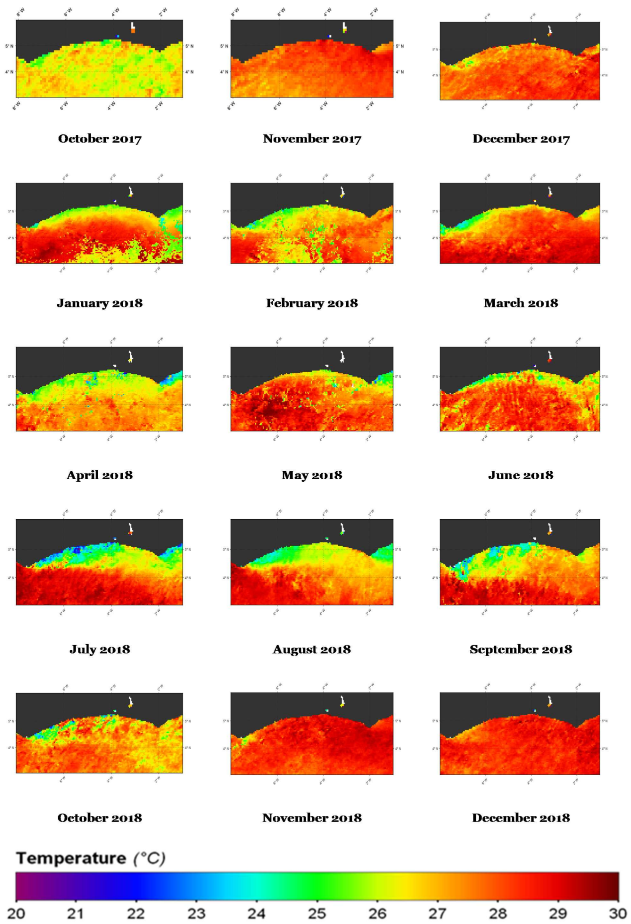

Fig. 2. Spatial distribution of Sea Surface Temperature (SST) within the Ivorian shelf derived from Satellite observations by MODIS-Aqua from October 2017 to December 2018.

Fig. 3 shows sea surface chlorophyll-A concentrations in continental shelf waters of Côte d'Ivoire. Each image shows the land in black, with marine waters illustrated by different colours that are shown in the accompanied colour chart below (Fig. 3). In addition, by dense cloud-cover atmosphere, no records were obtained, which were illustrated by white colour. Overall, water masses were characterized by low chlorophyll-A concentrations, though some short phases of presence of chlorophyll-A were observed in coastal waters in October 2017 (1.25mg/m3) and May 2018 (0.55mg/m3). However, richness in chlorophyll-A was particularly noticeable in coastal waters from June 2018 (2.45mg/m3) to November 2018 (0.84mg/m3), even attaining high values in July (6.58mg/m3) and August (4.4mg/m3).

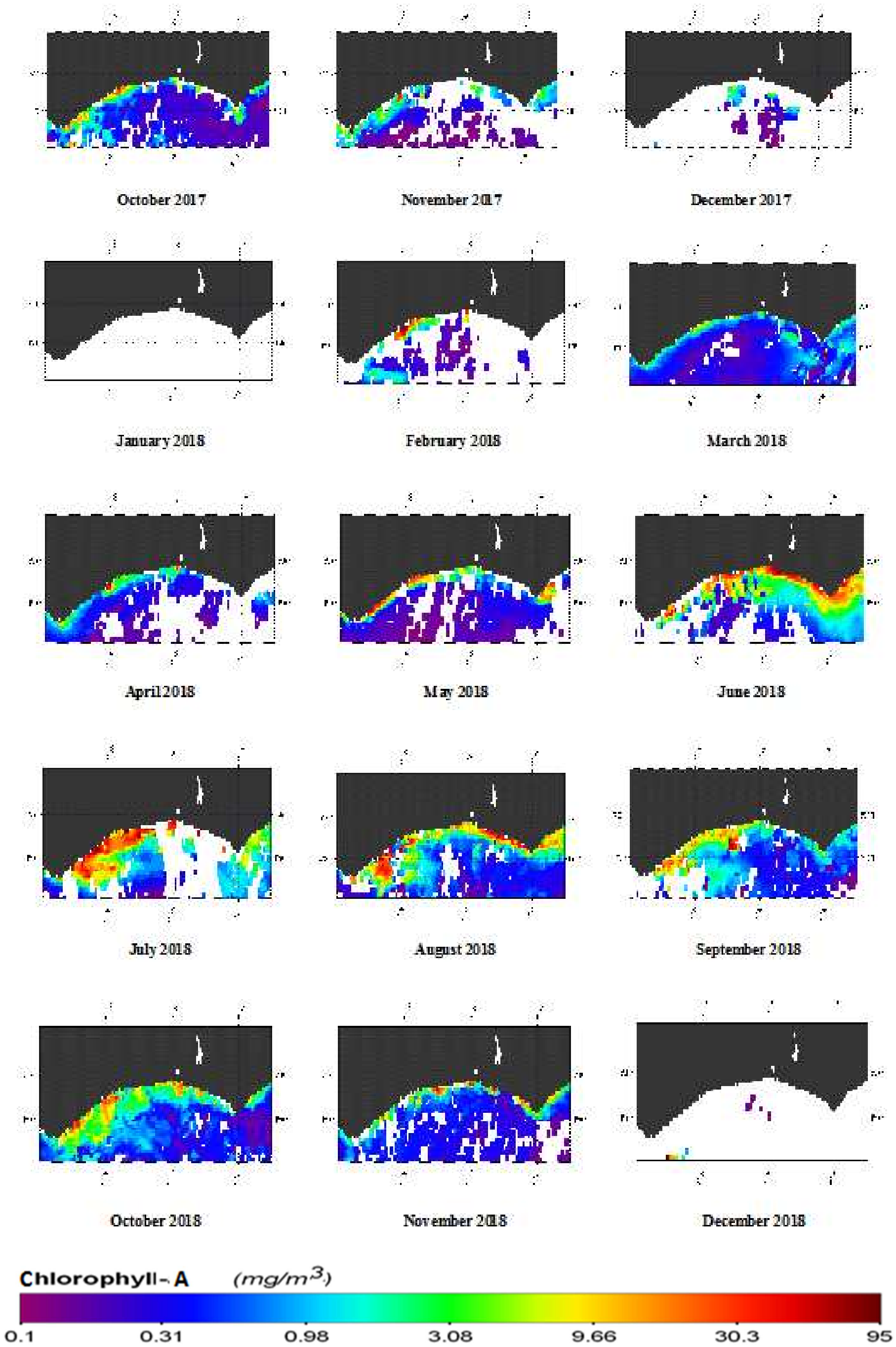

Fig. 3. Spatial distribution of surface Chlorophyll-A (Chl-A) concentration within the Ivorian shelf derived from Satellite observations by MODIS-Aqua from October 2017 to December 2018.

Discussion

Fish and other aquatic living resources naturally display unequal abundance, which is exacerbated when it comes to using various gears that have different selectivity to catch them. In fact, among the species listed in the present study (see Table 1) are the pelagic, semi pelagic, demersal, bentic or bentopelagic species named after the different realms from which they are in the water column. Catches obtained through the use of the gears are a perfect illustration of what it stands for species distribution within a shared ecosystem as their dwelling place and whose equilibrium they partake in. That really shows they do have similar compliance with existing ecological requirements inherent to local environmental conditions (Root, 1967; Allan, 1995). Although the study does not specifically address this aspect, we may infer that some of those species could likely be related to one another, at least regarding feeding. For, within a given ecosystem, some species are prone to serve for food for others. In this connection, feeding can be viewed as a driving force to maintaining the ecosystems function, as long as such ecosystems remain under full equilibrium state. For example, Bahou *et al.* (2007) found that little tuny *Euthynnus alletteratus* (Rafinesque, 1810) heavily feed on *Farfantepenaeus notialis*, *Trichiurus lepturus* and Atlantic bigeye *Priacanthus arenatus* Cuvier, 1829. Another study by Bahou *et al.* (2018) showed that *Sardinella aurita*, *Euthynnus alletteratus*, frigate tuna *Auxis thazard* (Lacepède, 1800) and West African Spanish mackerel *Scomberomorus tritor* (Cuvier, 1831) occurred in the diet of the Atlantic sailfish *Istiphorus platypterus* (Shaw and Nodder, 1792). The round sardinella *Sardinella aurita* are known for their opportunistic behaviour and feeding on planktonic organisms (Fréon, 1988).

The phytoplankton is the primary production within an aquatic ecosystem, and the higher the quantity of chlorophyll-A, the higher the abundance of phytoplankton (Morales, 2014; Bahou, 2020). The phytoplankton has some periods for showing greater abundance, which generally coincide with cooling conditions. Several authors (Binet, 1993; Reyssac, 1993) noted that the main upwelling season that occurs seasonally on continental shelf of Côte d'Ivoire was crucial for the priming of the ecosystem productivity. For during such an event, there is a plankton (both phytoplankton and zooplankton) bloom following the enrichment of the environment by nutrient-rich waters reaching the euphotic layer from the bottom, boosting the planktonic food web (Binet, 1995). Coastal waters seem to be highly favoured by upwelling occurrence because in addition to being rich in phytoplankton and zooplankton, they benefit from the low sea surface temperature that comes along with it. Surface water temperatures fall below 25°C, according to Koranteng (1995). Therefore, coastal waters were generally less hot compared with waters that were relatively far from the coast. In the current study, sea water was the most low in temperature and rich in chlorophyll-A (thereby in phytoplankton) during the main upwelling season. Most of the species listed in Table 1 generally increase in abundance during that season. Especially the ones known as the small pelagics (namely *Sardinella aurita*, *S. maderensis*, *Ilisha africana*, etc) make up the majority of the fishers' catch during such a period. When commenting on those species' abundance and occurrence in the catches, FAO (2008) noted that the small pelagics generally account for 80% of the landings. Bahou (2020) found three reasons which act in the Sardinellas' favour in terms of greater abundance. These are, as follows: the Sardinellas' schooling behaviour, their key role as prey for many predatory species within the ecosystem, and the Sardinellas' tendency to select upwelling areas for preferential habitat due to those places being characterized by permanent cool-water-layer (Fréon, 1988).

To some extent, fishing gears' efficacy to capture more individuals may depend greatly on the species' behaviour, though the gears through their selectivity would also play a part. For example, species moving about in shoals are generally subject to massive catch by encircling and large drifting gillnets (Bahou, 2020). Additionally, species that are known as the small pelagics are the most vulnerable to surface gears (namely the drifting gillnet and beach seine), which were the main fishing gears used by the artisanal fishers. Such gears will be more efficient for catching pelagically distributed fish than they would for the bottom-dwelling component. Yet, Heins and Godø (2002) warn of the danger that may arise from the utilization of those types of gear, stating that it can over time result in an unbalanced exploitation, thereby creating a stock with different distributional characteristics. In fact, the abundance of fish and other aquatic animals in commercial catches made by artisanal fishers is affected by fishing strategy (namely choice of fishing area) and gear characteristics (e.g. mesh size, how deep the gear can go). In any event, choice of fishing gear is based on the fishers' experience of when and where to operate the gear in order to obtain the most profitable catches in terms of abundance of the desired species. In fact, species known as the small pelagics, of which the Sardinellas, benefit from a comparative advantage due to their naturally high abundance. Pézennec *et al.* (1993) rightly found that coastal pelagic species account for the principal fish resources on Ivorian shelf. Finally, another factor to take into account in the species' unequal abundance is climate change. For variations in species abundance are generally admitted to be largely tributary of climatic fluctuations (Belvèze, 1984; Garcia, 1984; Cury and Roy, 1987). For instance, according to Binet (1982), variations in the yield of *Sardinella aurita* reflect the stock availability, which in turn is related to hydroclimatic conditions.

Conclusion

The current study provides information on the abundance of various commercially important species caught in the gears used by the artisanal fishers in a southwestern locality of Côte d'Ivoire. Such species abundance in connection with gear type obviously reflects the gears' efficacy but also the species' response. The study may also serve as a warning against the threat that could result from the fishers' tendency to continuously use surface gears for the main fishing gears within the fishing areas. For, in so doing, they will unwillingly introduce disturbance in the ecosystem functioning rather than working at keeping it function in a stable state for the viability of the fishing activity.

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