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ARTICLE

Detecting Multispecific Patterns in the Catch Composition of a Fisheries-Independent Longline Survey

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Abstract
Understanding the main factors that regulate species composition in fisheries is of utmost importance for developing efficient management strategies, particularly under the scope of ecosystem-based conservation approaches. This study used multivariate statistics to analyze catch data collected during a ~10-year, fishery-independent, standardized longline survey conducted in coastal waters (<20-m isobaths) off Recife, northeastern Brazil. A redundancy analysis (RDA) was performed to assess the influence of spatiotemporal, environmental, and bioecological variables on the variability in longline catch composition and to identify similarly distributed groups of species. Additionally, an analysis of similarities (ANOSIM) was conducted to investigate the likeness among the multispecific groups and identify the most influential variables. A total of 1,295 specimens representing 29 species of teleosts, elasmobranchs, and sea turtles were caught, but most species (62.0%) were little represented (<1%) in the catch composition. The RDA model indicated that the catch composition was significantly influenced by habitat type, behavior, trophic level, year, site, water transparency, month, and sea surface temperature; bioecological variables provided the greatest contribution to explain the variability in catch composition. The ANOSIM revealed that marine catfishes, moray eels, and Nurse Shark *Ginglymostoma cirratum* were the most similar in their relation to several spatiotemporal and environmental variables. The patterns reported herein might be useful to improve coastal fisheries management because they present the species that are influenced by similar drivers and the main factors underlying their respective catch rates. Therefore, this approach could be a potentially useful tool for lessening the number of biological dimensions, which frequently limit the capacity to implement effective management strategies in multispecies fisheries.

Coastal ecosystems comprise extremely dynamic habitats and exhibit a considerably greater biodiversity than that found in oceanic areas (Norse 1993; Mann 2000). Also, coastal habitats frequently encompass important nursery and foraging grounds for several marine species (Seminoff et al. 2002; Hajisamae et al. 2003; Heupel et al. 2007). The utilization of nearshore environments by marine taxa is influenced by species-specific bioecological traits such as site fidelity, migratory patterns, foraging

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behavior, and reproductive cycles (Stoneburner 1982; Carlson et al. 2010; Espinoza et al. 2016). Species that exhibit some level of niche overlap, therefore, will be more prone to be simultaneously harvested by a specific fishery (Magnusson 1995; Jennings et al. 2001). Therefore, taking an ecosystem-based approach into account, there is a need to better understand the factors influencing habitat usage by marine coastal species and to include multispecific information on management planning in order to design more efficient conservation strategies (Polunin and Roberts 1996; Lucena et al. 2002; Cetra and Petrere 2014).

In the last decades, the concern about fisheries sustainability has been growing worldwide, particularly in regard to coastal areas, which have been historically subject to diverse forms of fishing pressure (McGoodwin 1990; Jackson et al. 2001; Stewart et al. 2010). Consequently, the awareness towards the biological components underlying the structure and dynamics of coastal fisheries has been increasing (Hoggarth et al. 2006) and providing important aids for the development of efficient management policies that could yield long-term sustainable catches (Ludwig et al. 1993). However, an insufficient amount of available fisheries data, either due to inadequate monitoring or recent implementation (Beddington et al. 2002), often limits this type of research. The development of management policies has thus been widely focused on the industrialized sector, probably as a consequence of easier access to the data (Stewart et al. 2010; Pennino et al. 2016) and because small-scale fisheries are considerably less subsidized and have a much reduced political power compared with industrial fisheries (Jacquet and Pauly 2008).

In this context, multivariate statistical methods have been effectively applied to fisheries data in order to understand the factors underlying the patterns in catch composition (Pelletier and Ferraris 2000; Frédou et al. 2006; Cetra and Petrere 2014; Pennino et al. 2016). Such an approach enables the identification of groups of species with similar characteristics, thus allowing multispecific rather than species-specific management strategies, which could be more useful for an ecosystem-based management of fisheries (Polunin and Roberts 1996). Therefore, the multivariate analysis of fisheries data may provide an important tool for promoting the efficiency of fisheries resources management by allowing researchers and managers to deal with considerable number of different taxa in an effective way.

This study aims to identify multispecific groups in the catch composition of a long-term, fisheries-independent, coastal longline survey, which could be interpreted as management units to simplify complex, multispecies fishery management. We hypothesize that species sharing similar ecological traits, e.g., in habitat usage and movement behavior, will be more closely related to each other. By addressing how different biotic and abiotic variables influence the species distribution and by identifying the most similar groups of species caught in this region, a better understanding of the dynamics in equatorial coastal ecosystems is expected to be achieved. Furthermore, the information reported herein will be potentially useful to improve the readiness and adequacy of conservation policies and to assess the possible effects of management strategies upon the different species that comprise catch composition in longline fisheries.

METHODS

Study area and fishing procedure.—This study used data collected in a long-term, fishery-independent, longline survey conducted in coastal waters off Recife, northeastern Brazil (8.10°S, 34.87°W). The survey spanned from September 2005 through December 2014, but the operations were interrupted between September and October 2008, between February and June 2009, and between January and June 2013 due to funding constraints. The study area was divided into two contiguous nearshore sampling sites, Boa Viagem (BV) and Paiva (PA) (Figure 1). Despite the short distance between the two sites, they differed considerably at the level of anthropic interference and seafloor composition. The BV site is a densely populated area and comprises hard-bottom, topographically complex substrate, whereas PA is comparatively unpopulated and comprises mostly soft substrate. The northernmost section of PA encompasses the Jaboatão Estuary (Figure 1), although the estuarine plume frequently extends across BV and even farther north, depending on the direction and intensity of coastal currents.

The fishing gear and procedures were rigorously standardized throughout the survey in order to minimize the number of factors that could have had an influence on species catchability, such as hook type and size, soak time, fishing depth, and bait type. Fishing operations were scheduled on a weekly basis (mean duration of 5 d/week) and each fishing trip encompassed eight bottom longline sets (effort = 100 hooks per set) equally distributed between fishing sites, i.e., two longlines operating simultaneously at each site during four consecutive nights. The longlines were equipped with 17/0 circle hooks baited with moray eel *Gymnothorax* sp., deployed alongshore during the late afternoon between the 11- and 15-m isobaths, and allowed to fish overnight (mean soak time ± SD = 15.5 ± 2.4 h). At dawn, upon gear retrieval, all specimens were identified to the lowest possible taxonomic level. A thorough description of the study area and fishing methods can be found in Afonso et al. (2011) and in Hazin and Afonso (2013).

Analytical approach.—The CPUE of each species was determined as the number of specimens caught per 1,000 hooks. The analysis included (1) spatiotemporal predictors, i.e., year (from 2005 to 2014), month (from January to December), fishing site (BV and PA), and fishing set (four longline sets performed on each site); (2) environmental predictors, i.e., lunar phase (new moon, first quarter, full moon, and last quarter), water transparency (m), sea surface temperature (SST; °C), and pluviosity (mm); and (3) bioecological predictors, i.e., trophic level (ascending order: herbivores, zooplankters, sessile invertebrate predators, mobile invertebrate predators, and generalist carnivores), behavior (demersal or pelagic), and type of habitat (rocky, soft bottom, and both when no clear preference has been described in the literature). The water transparency and SST were measured onboard during

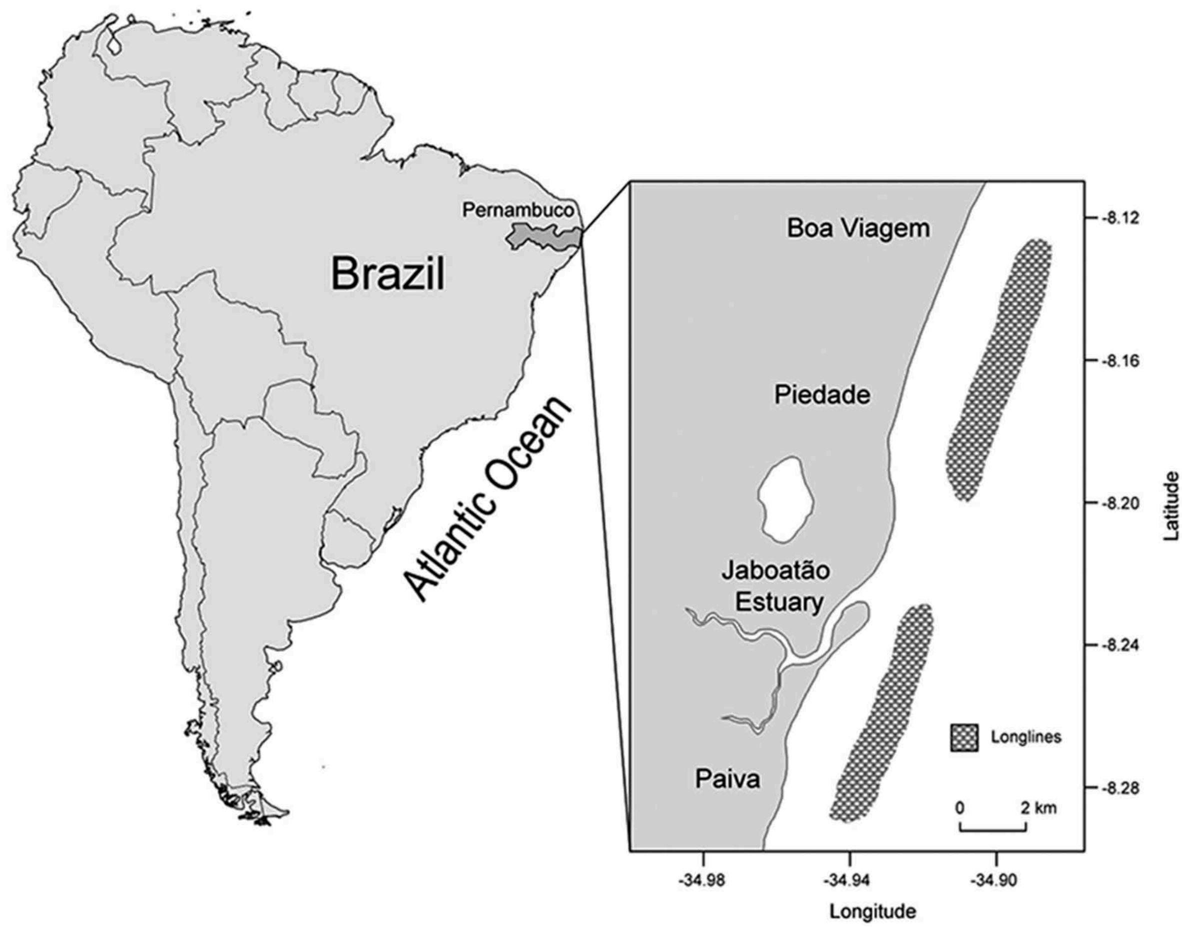

FIGURE 1. The study area depicting the location of the Pernambuco State within the northeastern coast of Brazil and the study site off Recife.

gear deployment with a Secchi disk and a FURUNO echosounder, respectively, whereas daily mean pluviosity data were downloaded from the Instituto Nacional de Meteorologia (INMET 2016) database. Background information about the bioecological traits of each species were retrieved from Compagno (1984), Allen (1985a, 1985b), Robins and Ray (1986), Heemstra and Randall (1993), Last and Stevens (1994), Nelson (1994), McEachran and Notarbartolo (1995), and Bjorndal (1996). To normalize the final data set of predictor variables, each continuous variable was subtracted from the corresponding mean and divided by its standard deviation.

All analyzes were conducted in R version 3.3.1 (R Development Core Team 2016) and the statistical significance level was set at 0.05. The taxa with relative abundance < 1% were considered as rare. A Kolmogorov–Smirnov test was performed to compare the spatial distribution of the environmental continuous predictors, i.e., water transparency and SST, between the two fishing sites. A redundancy analysis (RDA) performed with the vegan package (Oksanen et al. 2015) was used to assess the statistical significance of the predictor variables upon species abundance. The initial model included year, month, fishing set, water transparency, SST, pluviosity, and trophic level as quantitative, discrete, candidate variables, and fishing site, lunar phase, behavior, and type of habitat as factorial variables. The ordistep function was applied to identify the best final model based on the Akaike information criterion (AIC) values of the significant variables, and the total variation explained by the final RDA model was partitioned by the corresponding groups of significant variables, i.e., spatiotemporal, environmental, and bioecological, using the varpart function. The groups of species were identified according to their similar abundance distributions and likewise influence posed by the significant variables.

Additionally, an analysis of similarities (ANOSIM) was performed to further assess the similarities among the previously identified groups of species. For this purpose, Bray–Curtis dissimilarity indices were computed for the respective matrices of abundance of each group of species using the vegdist function. The ANOSIM was independently performed for each matrix of dissimilarities, considering the significant variables detected by the RDA approach as the grouping factors. Strong significant similarities were identified when significance was reached and the ANOSIM statistic (R) was lower than 0.1, whereas strong dissimilarities were considered when $R > 0.9$.

RESULTS

Catch Composition

A total of 1,295 specimens representing 29 taxa and 17 families of teleosts (11), elasmobranchs (5), and quelonids (1) were caught during the survey span. Rare taxa accounted for 62.0% of species (Table 1). Most of the catch was composed of teleosts (CPUE = 2.45 specimens/1,000 hooks, 54.3% of total catch) followed by sharks (CPUE = 1.56 specimens/1,000 hooks, 34.6%), rays (CPUE = 0.45 specimens/1,000 hooks, 9.9%), and sea turtles (CPUE = 0.05 specimens/1,000 hooks, 1.2%) (Table 1). Among the teleost catch ariid catfishes were by far the most abundant (78.4%), followed by Muraenidae (11.1%). Among the elasmobranchs, Nurse Shark *Ginglymostoma cirratum* (47.4%) was the most abundant shark species, followed by Blacknose Shark *Carcharhinus acronotus* (28.1%), and Tiger Shark *Galeocerdo cuvier* (17.3%), whereas Dasyatidae were the most abundant ray (74.1%).

Distribution of Environmental Variables

Clear seasonal patterns were evident for water transparency, SST, and pluviosity. Water transparency and SST decreased between May and August (Figure 2a, b) while pluviosity increased during this same period (Figure 2c). A slight reduction in mean water transparency was noted over the years (Figure 2a), and the lowest SSTs (24°C) were registered in 2008 and 2010 (Figure 2b), whereas no clear annual variation was noted for pluviosity (Figure 2c). Also, the two sampling sites exhibited

TABLE 1. Details of the taxonomic groups caught off Recife during the survey. Included are the corresponding CPUE, expressed as the number of specimens caught per 1,000 hooks, and the relative abundances in percentage.

Family	Species	CPUE (number/1,000 hooks)	Relative abundance (%)
	Sharks		
Carcharhinidae	*Carcharhinus acronotus*	0.438	9.67
	Carcharhinus leucas	0.052	1.14
	Carcharhinus perezi	0.003	0.07
	Carcharhinus limbatus	0.031	0.68
	Carcharhinus brevipinna	0.007	0.15
	Carcharhinus falciformis	0.007	0.15
	Sphyrna mokarran	0.007	0.15
	Sphyrna lewini	0.003	0.07
	Galeocerdo cuvier	0.270	5.96
	Rhizoprionodon lalandii	0.003	0.07
Ginglymostomatidae	*Ginglymostoma cirratum*	0.740	16.34
	Rays		
Dasyatidae		0.333	7.35
Mobulidae		0.091	2.01
Myliobatidae	*Aetobatus narinari*	0.024	0.55
	Teleosts		
Lutjanidae	*Lutjanus griseus*	0.087	1.92
	Lutjanus cyanopterus	0.010	0.22
	Lutjanus jocu	0.028	0.65
	Lutjanus analis	0.024	0.53
Ariidae		1.934	42.73
Serranidae	*Epinephelus itajara*	0.049	1.08
Haemulidae	*Conodon nobilis*	0.010	0.22
Megalopidae	*Megalops atlanticus*	0.021	0.46
Echeneidae		0.010	0.22
Ephippidae	*Chaetodipterus faber*	0.003	0.07
Pomacanthidae	*Pomacantus paru*	0.003	0.07
Sphyraenidae		0.003	0.07
Tetraodontidae		0.003	0.07
Muraenidae		0.273	6.03
	Sea turtles		
Cheloniidae		0.059	1.30

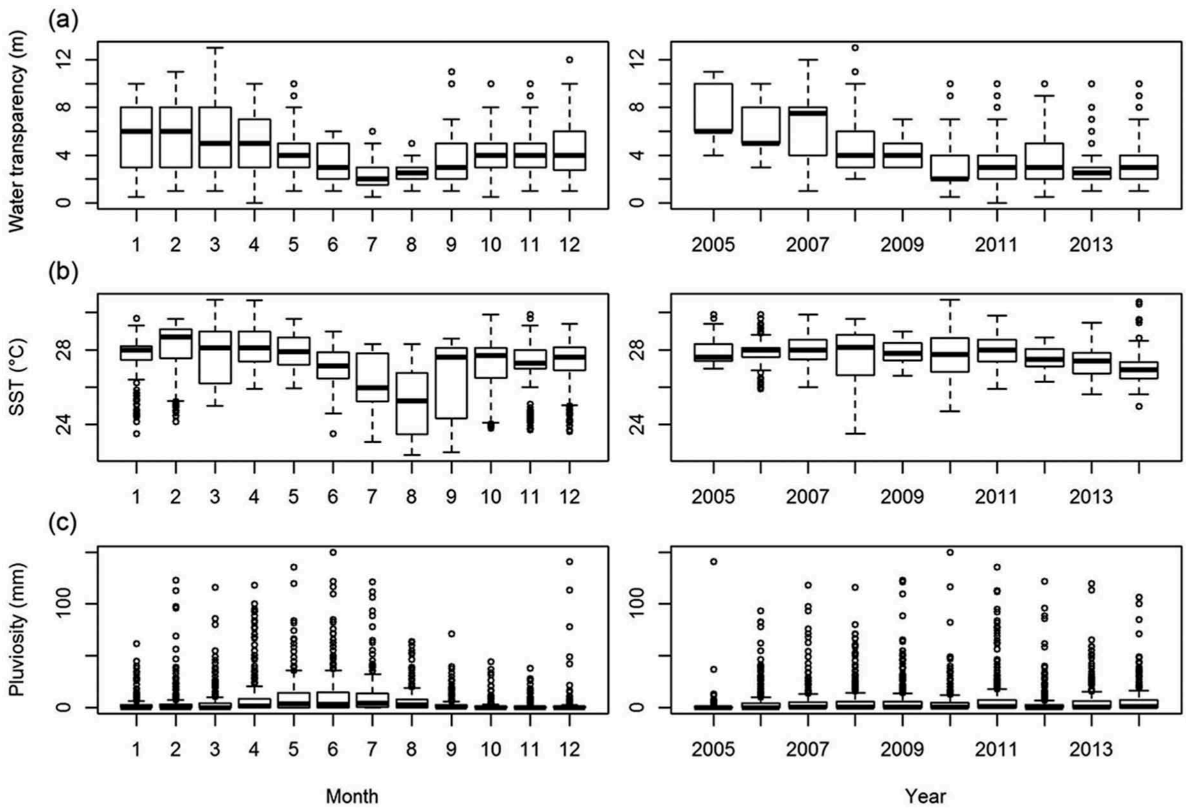

FIGURE 2. Monthly (left panels) and yearly (right panels) distributions of the environmental variables (**a**) water transparency, (**b**) sea surface temperature (SST), and (**c**) pluviosity.

statistically similar water transparency (D = 0.016, P = 0.981) and SST (D = 0.041, P = 0.369) values.

Abundance Patterns

The RDA model showed that all sets of variables had a significant effect upon species CPUE. This model included habitat (F = 24.619, P = 0.005), behavior (F = 23.796, P = 0.005), trophic level (F = 14.649, P = 0.005), year (F = 6.812, P = 0.005), site (F = 3.048, P = 0.005), water transparency (F = 2.415, P = 0.005), month (F = 2.538, P = 0.005), and SST (F = 2.334, P = 0.005) as predictor variables, which altogether explained 19.9% of the total variance of the data. The bioecological variables were the most important predictors influencing species abundance (variance = 15.8%), followed by the spatiotemporal (variance = 3.8%) and environmental (variance = 0.4%) predictors.

The RDA model allowed the identification of three groups of species or which abundance patterns differed considerably from the remainder of the taxa caught, i.e., (1) Tiger Shark, Blacknose Shark, Bull Shark *C. leucas*, Blacktip Shark *C. limbatus*, and dasyatid rays (G1); (2) ariid catfishes, Nurse Shark, and moray eels (Muraenidae) (G2); and (3) mobulid rays and sea turtles (Cheloniidae) (G3) (Figure 3). The grouping of G1 species was associated with generalist habitat preferences, higher trophic levels, and pelagic behavior. These species were more frequent at the beginning of the survey, and were caught more often in BV and during the first months of the year, when lower SST and greater water transparency are more common (Figure 3). The grouping of G2 species was associated with a demersal behavior and a preference for rocky habitats. These species were also more frequent at the beginning of the survey and during the first few months of the year, but they were more related during periods of warmer SST and lower water transparency (Figure 3). The grouping of G3 species was influenced by their pelagic behavior. These species tended to occur mostly at BV and were apparently more frequently found during the final years of the survey and during the last few months of the year, as they were associated with lower water turbidity and lower SST values (Figure 3).

The ANOSIM indicated that the similarities among the three groups of species were significantly influenced by all sets of variables, and G2 exhibited a greater number of strong similarities (four) than did G1 (one) and G3 (none) (Table 2). The G3 species differed considerably regarding trophic level, and the similarities within this group were only significantly influenced by their spatial occurrence (Table 2). The similarities among G1 species were mostly regulated by their coinciding seasonality, followed by a lower contribution of their yearly distributions, trophic levels, and behavior (Table 2).

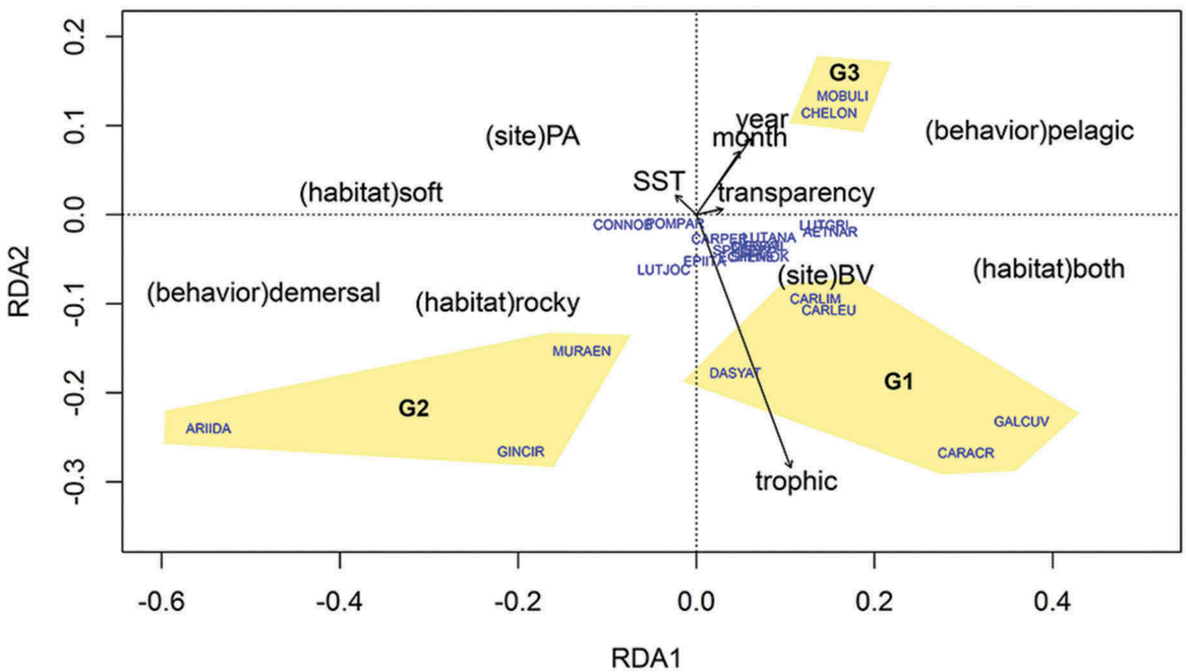

FIGURE 3. RDA triplots of the abundance data of the species most frequently caught constrained by the corresponding significant variables. The polygons depict the corresponding groups of similar species, i.e., G1, G2, and G3.

TABLE 2. Analysis of similarity performed between the groups of species caught by longline off Recife and the significant variables influencing their abundance patterns. Included are the corresponding groups of species (Group), the group of variables (Variable group), the significant variables (Variable), and corresponding *R*-statistics (*R*) and *P*-values (*P*). Strong significant similarities (*) and dissimilarities (†) are also represented.

Variable group	Variable	*R*	*P*
	Group 1		
Bioecological	Behavior	0.439	0.001
	Trophic level	0.435	0.001
Spatiotemporal	Year	0.149	0.001
	Month*	0.052	0.002
	Group 2		
Bioecological	Habitat type†	0.908	0.001
Spatiotemporal	Year	0.105	0.001
	Month*	0.013	0.024
	Site*	0.050	0.001
Environmental	Water transparency*	0.037	0.006
	SST*	0.060	0.022
	Group 3		
Bioecological	Trophic level†	0.989	0.001
Spatiotemporal	Site	0.213	0.004

Despite the dissimilarities of G2 species regarding habitat type, this group of species had considerable similar spatiotemporal distributions and was strongly influenced by two environmental variables, water transparency and SST (Table 2).

DISCUSSION

The suitability of management policies in multispecies fisheries is often hindered by different species-specific traits that altogether determine how marine communities make use of their habitats. The use of multispecific information, therefore, may be of utmost importance for developing efficient management strategies focused on the factors that influence different species in a similar way (Polunin and Roberts 1996; Lucena et al. 2002; Cetra and Petrere 2014). This study provides important information in this regard because it examines data collected during a fisheries-independent, long-term survey, routinely conducted in the same coastal area, following a thoroughly standardized procedure (Hazin and Afonso 2013). Consequently, some factors that commonly influence catch rates and catch composition such as trip duration, crew size, configuration of the fishing gear, and type of boat (Pelletier and Ferraris 2000; Frédou et al. 2006; Cetra and Petrere 2014; Pennino et al. 2016) did not change throughout the sampling process.

The analyses presented herein followed methods previously used in multivariate marine studies (Clarke and Warwick 1994; Pennino et al. 2016), but the ANOSIM was also introduced, as a complementary approach, to further examine the level of similarity between different groups of species. This was helpful in assisting with the identification of the more similar species and the variables responsible for their similarities. The bioecological traits were the most important variables responsible for species grouping since they posed a greater influence upon their abundance variability. Yet, the similarities among the different groups of species were also influenced by spatiotemporal and environmental variables.

Although G1 included only elasmobranchs and could thus be easily misinterpreted as the most similar group of species, the interspecific similarities within this group were comparatively lower than that for G2 and they were mainly regulated by species seasonal distribution, which tended to be more abundant at the beginning of the year. On the other hand, the ecological patterns of marine catfishes, Nurse Sharks, and moray eels (G2), all of which are demersal species with relatively sedentary behavior, might have contributed to these species exhibiting an analogous spatiotemporal distribution and the highest value of similarity among all groups of species. Although G2 species differed regarding habitat type, probably because of the preference of marine catfishes for soft-bottom regions, the spatial similarities within this group might be associated with the greater occurrence of both Nurse Sharks and moray eels at BV (rocky habitat). The greater occurrences of G2 species at the beginning of the year was related to warmer temperatures and greater water turbidity, supported by strong similarities in this regard. Hence, a greater presence of G2 species is expected for the period from January to July, when the highest SSTs (from January to April) and lowest water transparencies (from May to July) are recorded in this region. Even though G3 species exhibited some similarities regarding their spatial distribution, this was the most differing group of species because they occupy distinctly different trophic levels, e.g., the mostly herbivorous sea turtles and filter-feeding mobulids.

The SST and water transparency did not differ significantly between the two fishing sites, probably due to their proximity to each other. Indeed, although PA is located closer to the Jaboatão Estuary, freshwater outflow is also present at BV due to the effect of coastal currents on the local hydrodynamics (Rollnic and Medeiros 2013). Despite the relevant closeness between both sites, a significant spatial effect was observed in longline catch composition. Such a trend could be partially explained by the differences in the substrate composition among sites, since species with a preference for soft-bottom habitats, e.g., marine catfishes (Robins and Ray 1986), were more frequently caught at PA. Also, other uncontrolled factors such as anthropogenic interference might also influence the species' distributions in this region.

In general terms, it was possible to identify some levels of overlap in the temporal abundance patterns of G1 and G2 species; both groups usually became less frequent over the years and were captured more often in the first months of the year. Fisheries bycatch has been one among several contributors for a significant reduction in sea turtle populations (Hays et al. 2003; Peckham et al. 2007). Notwithstanding, the mortality of sea turtles in the present study was nonexistent (Hazin and Afonso 2013), and their catch rates have increased in more recent years. Marcovaldi and Chaloupka (2007) have reported an increase in sea turtle nesting abundance along the Brazilian coast following the prohibition of turtle harvesting in the 1980s. Therefore, the increase in turtle catch could be related to an increase in turtle abundance derived from local conservation programs.

This study provides an insight into the most influential factors likely to have an impact on the catch composition in longline coastal fisheries and, possibly, a way to better describe the similarities within multispecific groups of species, which could allow the development of more specific and efficient conservation and fisheries management measures. The Nurse Shark, for example, is listed as an endangered species in Brazil (Rosa et al. 2006), and its capture has been prohibited by the Brazilian Ministry of the Environment (ICMBio 2015). The period between January and July, therefore, when the local relative abundance of Nurse Sharks off Recife increases, should be considered more carefully when designing protective measures for this endangered species. Additionally, future management strategies towards this species might also positively influence the conservation of ariid catfishes and moray eels in this region, due to the considerable similarities among these taxa. Nevertheless, other biological factors such as species migration patterns, spawning aggregations, and reproductive cycles might also contribute to different species being harvested together and should be considered in future studies in order to describe the factors underlying the variability in multispecific fisheries catches more thoroughly. Since it was not possible to accurately identify all taxa caught at the species level, some of the trends described in this study were assessed at the family level and should thus be interpreted carefully. The inclusion of detailed species-specific information on future research might help to better identify the linkages and differences between the distinct species caught in multispecies fisheries. Therefore, a better understanding of the spatiotemporal, environmental, and biological variables responsible for the overlapping distributions of coastal fishery resources is needed to develop efficient multispecific management strategies.

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