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Article *in* Marine and Coastal Fisheries Dynamics Management and Ecosystem Science · March 2020

DOI: 10.1002/mcf2.10113

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Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 12:100–112, 2020
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ISSN: 1942-5120 online
DOI: 10.1002/mcf2.10113

ARTICLE

Spatial and Temporal Distribution of a Multiple Gear Fishing Fleet Exploiting the Caribbean Sea and North Brazil Shelf Large Marine Ecosystems

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Abstract

An industrial multigear fishing fleet from Venezuela emerged in 2009 as a governmental strategy to reduce the impact of industrial trawling on the Venezuelan coast of the North Brazil Shelf Large Marine Ecosystem. The current study aimed to examine the spatial–temporal distribution of fishing effort and the catch levels obtained by the Venezuelan industrial multigear fishing fleet during the period 2015–2018. Fishing gear types employed by this fleet in order of preference were as follows: bottom longline (target sea catfishes [family Ariidae]), trap (target snappers [family Lutjanidae]), pelagic longline (target tunas [family Scombridae]), hand line (target mackerels [family Scombridae]), and shark longline (target sea catfishes and sharks [families Carcharhinidae, Squalidae, Sphyrnidae, Ginglymostomatidae, Alopiidae, and Triakidae]). The kernel intensity estimator determined that the main fishing area was the North Brazil Shelf (comprising 95% of the total fishing sets). Fishing effort (fishing sets per trip) distribution may be associated with oceanic fronts present in the region. A change in the dynamics of the fleet were recorded, with an increase in the use of bottom longlines, along with a decrease in the use of traps, possibly due to overfishing of resources caught by traps. The analyses of covariance showed a linear and positive relationship between the catch and fishing effort but with significant changes over the study period for traps and bottom longlines, since in the years where the fishing effort of traps was lower there were greater catches by unit of effort, and vice versa for bottom longlines, where lower catches by unit effort were obtained in years with greater effort.

Subject editor: Patrick J. Sullivan, Cornell University, Ithaca, New York

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Received July 3, 2019; accepted January 25, 2020

The fisheries sector is economically important for most developing tropical countries. However, management of tropical fishery resource systems is difficult because these countries have limited financial resources for fisheries control and management (Castello et al. 2007). In addition, fisheries in these countries are characterized by being multispecies and multigear, where more than one species is caught simultaneously and one species can be caught by different fishing gear. This presents a major challenge to manage with respect to monospecific fisheries (Cardoso et al. 2015). Moreover, many governments tend to view fisheries as a growth sector and there may be limited awareness of the need to sustain the resources, resulting in overexploited and, eventually, collapsed fisheries (Padilla 1991).

For those fisheries based on several species and which use multiple gear types, successful management depends on knowing the fishing effort and catch trends (Anticamara et al. 2011) to understand how fishing operations take place and to identify potential impacts on exploited stocks given the interactions between assemblages of cooccurring species and types of gear (Monroy et al. 2010).

The failure of many fisheries has not been due to a lack of knowledge of the population dynamics of the target species but due to the lack of knowledge of other factors, such as the dynamics of the fishing fleets. This involves analysis of the area exploited for fishing, spatial and temporal variations in fishing intensity, and distribution of the boats. Combined, this provides information that is a key element in the understanding and management of the fisheries but that has received little research attention (Hilborn 1985). Knowledge of fishing fleet dynamics is essential to move from single species to fishery- or fleet-based advice (Duarte et al. 2009).

Another issue to consider on fishing management is the fishing area. Countries manage all fisheries within their Exclusive Economic Zones (EEZs) leading to derive indicators for marine fisheries and ecosystems at the national level, being that migrations of some exploited stocks are on a larger scale (Pauly et al. 2007). A better integration of fisheries could be achieved at the level of Large Marine Ecosystems (LMEs), which are oceanic coastal regions characterized by different bathymetry, hydrography, production, and trophic relations (Sherman and Duda 1999). However, no national or international jurisdiction reports at the LME level for catches and other quantities from which fisheries sustainability indicators could be derived were available (Pauly et al. 2007), but LMEs account for 80% of the world's annual fish catch (Pauly and Lamm 2016).

Two tropical LMEs are the Caribbean Sea and the North Brazil Shelf. Together these comprise a marine area of 4.4 million km^2, shared by 23 independent countries and overseas territories and with globally relevant biodiversity, which supports important ecological processes (Debels et al. 2017). However, this area is subject to serious threats from overfishing, pollution, and rising ocean temperatures, which may affect directly the principal source of income for an estimated 1 million people and indirectly could affect an additional 3 million (Debels et al. 2017; Isaac and Ferrari 2017).

In these two LMEs, the Venezuelan coast is one of the most important fishing areas in the Caribbean–Atlantic (FAO 2005). In 2004, Venezuelan catches reached 714,000 metric tons, followed by a steady decline that resulted in a total production of only 175,000 metric tons in 2010 (Mendoza 2015). Among the fisheries developed in Venezuela, one that had an important and controversial development since its beginning in the 1950s until its closure in March 2009, was the shrimp trawl fishery (Mendoza et al. 2010). In the beginning the fishing grounds were located on the western (Gulf de Venezuela) marine shelves of the country and later extended to the eastern region and Orinoco River delta (Alió et al. 2010; Mendoza et al. 2010). This fleet rapidly increased in numbers and by the late 1980s reached 450 vessels nationwide (Mendoza 2015), and the catch reached its peak in the early 1990s when more than 40,000 metric tons of fish, mollusks, and crustaceans were landed (Mendoza et al. 2010).

Due to the increase in the number of vessels, conflicts with the coastal artisanal sector, a bycatch discard of more than 50%, and overexploitation of fishery resources, management measures were taken to control fishing effort during the 1980s (Marcano et al. 2001; Pomares et al. 2010; Mendoza 2015), leading to a significant reduction in landings and number of vessels, and by 2006 there were around 260 trawlers operating in Venezuelan waters. Additionally, in 2008 a new fisheries and aquaculture law was enacted by presidential decree that prohibited industrial trawling in Venezuelan waters and became effective in March 2009 (Mendoza 2015).

At the same time, and in combination with these events, a new industrial fishing fleet, called the "Polivalente Costa Afuera (PCA-Ven)," emerged as former trawlers were converted to this new fishing gear form (Minpesca 2017). The industrial PCA-Ven fishing system is defined as the set of activities aimed at the extraction of demersal marine fish species with the simultaneous use of more than one fishing gear type, which may be longline, hand lines, and/or traps (Normas técnicas de ordenamiento que regula la pesquería industrial polivalente de costa afuera 2009). The simultaneous use of such gear by small-scale fishers has been traditional for many years (Mendoza 2015), but the simultaneous, industrial-scale use of such gear in this type of fishing is completely new to the country. In view of this, it is necessary to evaluate the fishing effort and catch levels of this new fleet on the demersal resources. There are many studies directed at pelagic species with high export potential, like Albacore *Thunnus alalunga* (Cabello et al. 2002; Arocha et al. 2013, 2019; Narváez et al. 2017), but demersal species, like Crucifix Sea Catfish *Sciades proops*, have been largely neglected since they have low export trade potential. They are, however, very important for the local market (Booth et al. 2001).

Accordingly, the objective of the current study was to examine the spatial and temporal dynamics of a multispecies and multigear fishing fleet, the PCA-Ven, to evaluate the role and importance of the various fishing gear forms for the exploitation of different species groups. To do so, we describe the fishery fleet and the catch composition by species group and by gear type. We also analyzed the relationship between catch and effort associated with each type of fishing gear employed and the possible changes in yield per effort per gear type across the 4 years of the study (2015–2018). This information based on the dynamics of the PCA-Ven fishing fleet can be used to regulate the capacity of the fleet and its fishing activity to adjust it to the level of a sustainable fishery.

METHODS

Study site.— In 2009, 248 industrial trawling vessels applied for incorporation into the multigear fishing fleet in the Sucre (northeastern area), Falcón (western area), and Anzoátegui (northern area) states, where the old trawler landing ports are located. The study was conducted within the fishing area of the multigear industrial fishing fleet that landed in the city of Cumaná, Sucre, Venezuela, considered one of the most productive fishing areas of the Venezuelan coast (FAO 2005).

Data source.— Data were obtained via the Logbook Program and the Observers Onboard Program of the Instituto Socialista de Pesca y Acuicultura of Venezuela provided by the Ministerio del Poder Popular de Pesca y Acuicultura, both institutions responsible for fisheries statistics in Venezuela.

The Logbook Program consists of the completion of forms by the boat captains, including data of weight measurements (in kg) per group of species, fishing gear, and geographic location of each fishing trip. The Observers Onboard Program consists of the completion of forms by observers onboard, who have previously taken a theoretical–practical course for species identification; these data were used to disaggregate the species composition. All information collected from logbooks and the Observers Onboard Program was reviewed and digitally stored. For this study, data collected between January 2015 and December 2018 were considered, with a monitoring of 100% of fishing trips for logbooks and a monitoring of 1.14% of fishing trips for the Observers Onboard Program. Physical characteristics of the vessels active during the study period were obtained from the fishing licenses available from records from the Instituto Socialista de Pesca y Acuicultura.

Data analysis.— Descriptive analyses were performed as mean and frequency estimates in R-Studio software version 3.4.4 (R Core Team 2018) to assay the spatial and temporal variation present in the fishery. The free software QGIS version 2.18.17 (QGI Development Team 2017) was used to generate a spatial distribution map of the fishing effort. The map was divided into two areas based on the classification of the LMEs (Sherman et al. 2017), the first being the Caribbean Sea area and the second the North Brazilian Shelf.

The number of fishing sets per trip was considered to represent the fishing effort for the industrial multigear fishing fleet (PCA-Ven); these were plotted based on the geographic coordinates where the sets were deployed. Records with incorrect geographical coordinates (e.g., landmarks, inverted signs) were identified and then excluded from analyses. Fishing effort intensity (fishing sets) in the two regions was determined by the kernel intensity estimator spatial statistics technique. For this, a statistical algorithm weighs each of the points with respect to distance from a central value (Beato 2008). The intensity of fishing effort per fishing area was identified as follows: very low intensity (number of sets from 1 to 199), low intensity (number of sets from 200 and 399), medium intensity (number of sets from 400 and 599), high intensity (number of sets from 600 to 799), and very high intensity (number of sets higher than 800 and equivalent to more than 25% of the fishing sets per year).

The distribution of number of trips, fishing effort, and total catch was determined by the number of types of fishing gear used per trip. For each year of study, the catch composition by species group (monophyletic group of closely related species; Nelson 1999), expressed in percentages, and the distribution by annual trimesters were analyzed, and the dominant species groups by region and fishing gear type were determined. Finally, analyses of covariance (ANCOVA) were performed to test the mean catch difference between the years, adjusted for fishing effort (Petrere et al. 2010) for each fishing gear type (traps, pelagic longline, bottom longline, and hand line). The assumptions of normality and homoscedasticity were graphically checked. The model was fitted without an intercept assuming that the catch would be zero in the absence of fishing effort and the observed data showed a tendency to pass the line through the origin. Shark longline data were not included in the analysis because there were just eight trips using this method.

RESULTS

Description of the Fishery

Between January 2015 and December 2018, 789 trips were recorded, with a total of 19,759 d at sea and 13,797 fishing sets (Table 1) at a depth between 25 and 100 m. These trips were carried out by 30 vessels in 2015, 36 in 2016, 37 in 2017, and 41 in 2018. The vessels involved were built between 1971 and 1993, measured between 15 and 29 m in length, had engines ranging from 300 to 1,140 hp, and had storage capacities that varied from 8 to 115 metric tons. On average eight fishermen crewed each vessel, and the average ± SD trip time was 25 ± 7 d. The fishery is carried on a year-round basis without seasonality.

Gear types employed by this fleet were traps, pelagic longline (PLL), bottom longline (BLL), shark longline (SLL), and hand line. All used dead sardines (Spanish Sardine *Sardinella aurita* or Brazilian Sardine *Sardinella brasiliensis*) as bait. The traps were of the Antillean type (arrowhead), with a wooden frame and covered with galvanized wire mesh, a form commonly used in Caribbean small-scale fisheries (Slack-Smith 2001). On average a crew will set 60 traps along a main line, separated by floats every 8–10 traps.

Generally, the three types of longlines (PLL, BLL, and SLL) used by this fleet were configured the same way, with a long main line (around 6 km) from which individual hooks are suspended at intervals of approximately 12 m. Every 600 m, floats are attached to the main line to keep it elevated horizontally in the water, and the hooks are attached to the main line vertically by monofilament branch lines. The major difference between PLLs and BLLs or SLLs is in the lengths of the branch lines. What makes SLLs different from BLLs is the design of the branch lines, with SLLs having a part made with steel. The hook of the longlines is commonly Japanese style size 6, with an average total setting of 650 hooks per longline. In the hand line fishing, normally six to seven fishermen constitute the crew of the vessel and each of them fish with one hand line (one hook at the end of the line).

For 71% of the trips, the industrial multigear fishing fleet used only one type of fishing gear. Bottom longlines were most commonly used (51% of all fishing sets), followed by traps (9% of all fishing sets), and then, to a far lesser extent, PLLs (1%) and SLLs (1%) (Table 1). Bottom longlines were responsible for more than 63% of the total catch during the study period. Trips using two types of fishing gear (26% of the trips) most often used a combination of BLLs and traps (19% of trips, 25% of fishing sets, and 17% of total catch). Fishing sets for each gear type are often thrown into the sea one after the other or in some cases are used separately throughout the day, one type during the day and other at night. Hand line fishing was performed during the time spent waiting to collect the longlines or traps.

The following groups of species occurred in the catches of the industrial multigear fishing fleet: sea catfishes (family Ariidae), snappers (family Lutjanidae), weakfishes (family Sciaenidae), grunts (family Haemulidae), tunas and mackerels (family Scombridae), jacks (family Carangidae), groupers (family Serranidae), marlins (family Istiophoridae), stingrays (families Myliobatidae, Dasyatidae, and Gymnuridae), and sharks (families Carcharhinidae, Squalidae, Sphyrnidae, Ginglymostomatidae, Alopiidae, and Triakidae), among other species of fish.

For fishing with traps, snappers were 71.2% of the total catch, whereas with PLLs tunas were 42.3% and marlins were 20.4% of the total catch. For BLLs, 60.5% of the catch was sea catfishes, while in the SLLs 46.3% were sea catfishes and 22.7% were sharks. For fishing with a hand line, mackerels comprised 86.8% of the catch (Figure 1).

Based on data from observers onboard the vessels, the top 10 most-captured species (Figure 2) were Crucifix Sea Catfish (29.4%), Vermilion Snapper *Rhomboplites aurorubens* (13.5%), Coco Sea Catfish *Bagre bagre* (12.5%), Gafftopsail Catfish *Bagre marinus* (6.8%), Thomas Sea Catfish *Notarius grandicassis* (3.2%), Green Weakfish *Cynoscion virescens* (3.1%), Kukwari Sea Catfish *Arius phrygiatus* (2.8%), King Mackerel *Scomberomorus cavalla* (2.7%), Gillbacker Sea Catfish *Sciades parkeri* (2.6%), and Acoupa Weakfish *Cynoscion acoupa* (2.3%). There were 71 other species that were captured, and these made up 21.1% of the catch. Considering that these data are the result of a 1.14% sample, this species identification must be taken with caution before being extrapolated to the entire fleet.

Spatial Distribution of Fishing Effort and Catch, per Gear Type

The spatial distribution of the fishing effort showed that fishing activities of the industrial multigear fishing fleet based in the city of Cumaná, Sucre, Venezuela, occurred mainly on the North Brazil Shelf, specifically in the EEZ of Venezuela and neighboring countries, such as Guyana, Suriname, and French Guiana (Figure 3). The highest fishing effort intensity occurred in the Orinoco Delta at the confluence of the Venezuelan and Guyana EEZs, and this was followed by the Caribbean Sea area of the Venezuelan EEZ, with a level of fishing effort between very low and medium. From 2015 to 2018, 93.5% of the total fishing sets occurred on the North Brazil Shelf, 73.2% of which were by BLLs, 23.1% from traps, and 1.5% from hand lines, followed in intensity by PLLs with 1.3%. The use of SLLs was exclusive to this region but occurred with low intensity at only 0.9%. The remainder of fishing sets (6.5%) were made in the Caribbean Sea area of the Venezuelan EEZ, with 33.7% from PLLs, 33.6% from traps, 31.6% from BLLs, and 1.1% from hand lines. In this area the distribution of effort between fishing gear types was more homogeneous.

Of the total catch, 95% was caught in the North Brazil Shelf, especially sea catfishes (51%), snappers (12%), sharks (11%), weakfishes (10%), and stingrays (10%). Tunas and marlins had larger catches in the Caribbean

TABLE 1. Distribution of the number of trips, fishing effort, and total catches according to the number of types of fishing gear used per trip as recorded by the Venezuelan industrial multigear fishing fleet from 2015 to 2018. Abbreviations are as follows: TR = traps, PLL = pelagic longline, BLL = bottom longline, SLL = shark longline, and HL = hand line.

Number of fishing gear types used, subtotals, and total	Number of trips	Number of fishing sets per gear type						Catch (kg) per gear type					
		TR	PLL	BLL	SLL	HL	%	TR	PLL	BLL	SLL	HL	%
Year 2015													
1	43	570					17	171,349					19
	5		57				2		14,292				2
	54			891			27			347,848			39
2	4	36	27				2	5,386	5,557				1
	51	587		624			37	96,757		150,408			28
	1	19				2	1	4,540				90	1
	3		22	25			1		6,836	12,341			2
	2			25		7	1			10,340		1,180	1
3	4	63	34	28			4	12,899	7,815	5,630			3
	1	11	3			11	1	470	2,270			1,800	1
	8	86		100		35	7	10,680		19,461		2,735	4
Subtotal	176	1,372	143	1,693		55	100	302,081	36,770	546,028		5,805	100
Year 2016													
1	30	445					12	166,326					13
	2		26				1		5,067				0
	90			1,391			38			585,515			47
2	50	516		572			30	95,462		158,542			21
	3	43				14	2	16,017				320	1
	10		80	84			5		32,984	40,045			6
	6			95		34	4			35,865		5,005	3
3	5	100	22	31			4	34,848	3,280	6,735			4
	1	17		3	3		1	5,700		380	60		0
	5	36		52		27	3	14,470		12,540		5,450	3
4	1	3	7	22		14	1	257	1,062	10,136		1,765	1
Subtotal	203	1,160	135	2,250	3	89	100	333,080	42,393	849,758	60	12,540	100
Year 2017													
1	13	190					5	88,412					5
	6		79				2		33,684				2
	144			2,232			62			1,214,153			69
	3				41		1				18,671		1
2	34	338		408			21	93,762		192,489			16
	5		53	58			3		15,350	23,301			2
	6			119		34	4			48,940		7,985	3
3	1	7	5	16			1	1,840	2,280	8,765			1
Subtotal	212	535	137	2,833	41	34	100	184,014	51,314	1,487,648	18,671	7,985	100
Year 2018													
1	3	46					1	17,892					1
	2		25				1		6,281				0
	161			2,540			77			1,244,623			82
	2				42		1				16,640		1
2	19	161		260			13	22,145		118,195			9
	1	14			15		1	433			4,675		0
	4		30	46			2		7,658	17,660			2
	1			14	14		1			11,100	2,690		1
	5			88		22	3			41,970		3,705	3
Subtotal	198	221	55	2,948	71	22	100	40,470	13,939	1,433,548	24,005	3,705	100
Total	789	3,288	470	9,724	115	200		859,645	144,416	4,316,982	42,736	30,035	

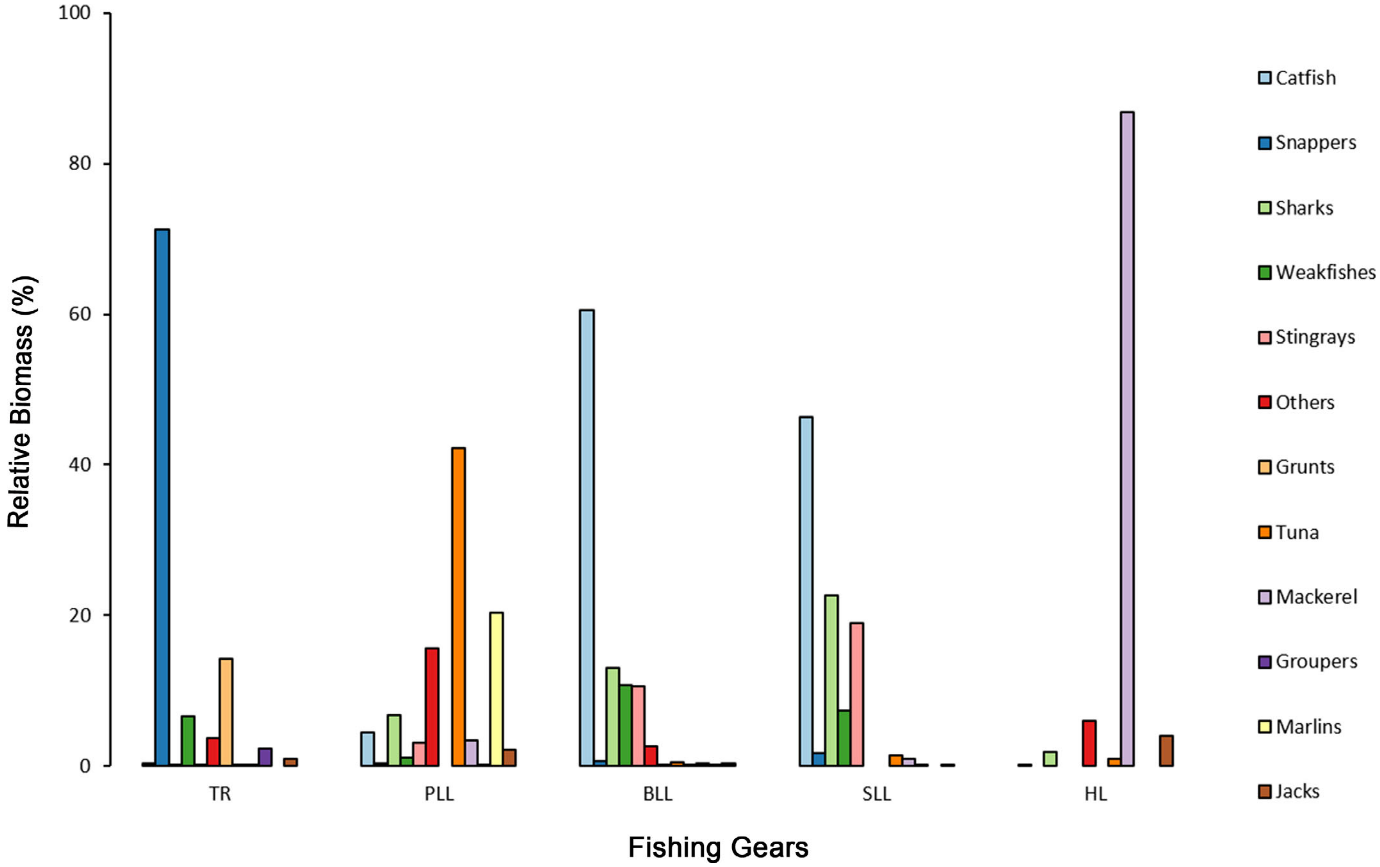

FIGURE 1. Composition of catches per group of species and type of gear (TR = traps, PLL = pelagic longline, BLL = bottom longline, SLL = shark longline, and HL = hand line) for the Venezuelan industrial multigear fishing fleet from 2015 to 2018.

zone of the EEZ of Venezuela (18% and 10%, respectively).

Temporal Variation in Catch and Fishing Effort Based on Gear Types

In the period from 2015 to 2017, trimesters 3 and 4 accounted for more than 60% of catches. More than 30% of the sea catfish, weakfish, stingray, and shark catch occurred in trimester 4. Likewise, more than 35% of the snappers were caught in trimester 3. In 2018, 55% of the total catch was obtained during trimesters 2 and 3, with the highest catches occurring in trimester 2 for sea catfishes, stingrays, snappers, grunts, and other species but in the third and fourth trimesters, respectively, for sharks and weakfishes (Figure 4).

Table 1 shows the dynamics of the Venezuelan industrial multigear fishing fleet, with a progressive increase of BLL fishing effort, together with a decrease in trap fishing effort, both having direct repercussions on catch composition. Considering total fishing effort, BLLs and traps were the dominate fishing gear contributing, respectively, 52% and 42% in 2015, 62% and 32% in 2016, 79% and 15% in 2017, and 89% and 7% for 2018.

The percentage catch composition per species group (Figure 4) showed that sea catfishes (captured by BLL) were the dominant group, increasing their contribution in total catches progressively from 2016 to 2018. The snappers (captured by trap) were the second largest catch group during 2015 and 2016 but declined to fifth place in 2017 and sixth place in 2018, surpassed by other groups of species such sharks, weakfishes, and stingrays. Grunts (captured by trap) were less important, but, like snappers, their catches decreased from 2015 to 2018.

According to the ANCOVA results, and the assumptions of the models fulfilled (see the Supplementary information available separately online), the relationship between catch and fishing effort was linear and positive for all gear types (Figure 5), indicating that as fishing effort increased the catch also increased proportionally. But in one case, that of the hand line gear, this relationship showed significant changes over the 4 years of this study.

Traps showed a significant change in the catch-per-effort ratio for the year 2017 (Table 2), with an increase in the effect of the fishing effort on catch (Figure 5). Pelagic longlines showed a constant catch–effort relationship

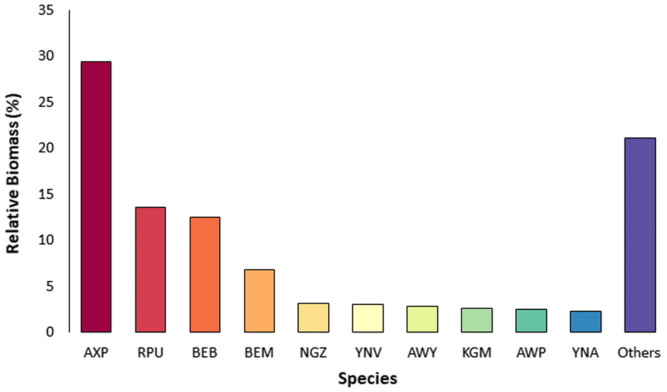

FIGURE 2. Composition of catches per species for the Venezuelan industrial multigear fishing fleet from 2015 to 2018 based on data from the Observers Onboard Program. Species abbreviations for the most-captured species are as follows: AXP = Crucifix Sea Catfish, RPU = Vermilion Snapper, BEB = Coco Sea Catfish, BEM = Gafftopsail Catfish, NGZ = Thomas Sea Catfish, YNV = Green Weakfish, AWY = Kukwari Sea Catfish, KGM = King Mackerel, AWP = Gillbacker Sea Catfish, and YNA = Acoupa Weakfish. There were also 71 other species captured in lesser amounts and these have been grouped together.

across the entire study period. In 2018, BLLs showed a significance decrease in the catch-per-effort ratio. On the other hand, hand lines showed a significant increase in the catch-per-effort ratio for all years, but in spite of the differences, these should be considered with caution due to the small volume of data available for this fishing gear type.

DISCUSSION

The industrial PCA-Ven fleet emerged as a fisheries management strategy against industrial trawling that was occurring on the Venezuelan coast, the fishery being characterized as multigear and multispecies and with similarities to other multigear fisheries around the world (e.g., the capture of many species but with a small group of them dominating the landings), such as the artisanal fisheries of the Kenyan coast (Tuda et al. 2016) and the semi-industrial fisheries of the Campeche Bank in Mexico (Monroy et al. 2010). An importance difference for the Venezuelan fleet is the simultaneous use of more than one fishing gear type. Despite the fleet being legally permitted to employ simultaneously more than one type of fishing gear, only one fishing gear was employed during most trips. The global fishing catch may involve gear types with different selectivities and, consequently, different fishing capacities (Hubert et al. 2012). We expected the simultaneous use of multiple fishing gears type since this could lead to an increase in overall catch as different gear types have the ability to catch different species. Nevertheless, a fishing gear with low selectivity and suitable to access the target fishery resources could drive them to use only one fishing gear type per trip. The BLL was the most commonly used fishing gear and had a greater apparent fishing effectiveness compared with other fishing gear types used by this fishery. This is expected since for commercial fishing it is generally desirable to use the most efficient fishing gear to save time and money (Hubert et al. 2012).

The species groups that comprise the multigear fishery catches on the North Brazil Shelf, such as sea catfishes, weakfishes, and snappers farther from the coast as well as pelagic species like mackerels and jacks, have already been reported (Cervigón et al. 1992; Mendoza 2015). These species are fished by longlines and traps (Isaac and Ferrari 2017). In the Caribbean Sea, many wide-ranging pelagic species, such as tunas and sharks, spend most of their life cycle in this ecosystem (Debels et al. 2017). The continental shelf ecosystem is the focus of the largest fisheries for shrimp and demersal fish (Debels et al. 2017; Isaac and Ferrari 2017). Thus, the industrial PCA-Ven fleet operates mainly in the LME of the North Brazil Shelf exploiting demersal fish. At the same time, the historical presence on this shelf of fishing fleets from countries like Brazil, Guyana, French Guiana, Suriname, and Trinidad-Tobago is well established (Booth et al. 2001).

The North Brazil Shelf (or Guianas–Brazil Shelf) houses a high diversity of fish (Cervigón et al. 1992) because this area is a class I ecosystem with high productivity ($>300\ \mathrm{g\ cm^{-2}\ year^{-1}}$) (Smith and Demaster 1996) due to the discharges of the Amazon River in Brazil (Heileman 2008) and the Orinoco River in Venezuela (Cervigón et al. 1992). Also, the area contains oceanic fronts, which generally coincide with the main biogeographic boundaries associated with zones of higher biological productivity, including fishing areas (Belkin and Cornillon 2007).

Venezuela's industrial multigear fishing fleet probably distributed its fishing effort, based on the presence of oceanic fronts that positively affected target species presence within this fishery, specifically in the Venezuelan EEZ in the Orinoco Delta and the Guyana EEZ. This pattern is similar to that found by Alemany et al. (2014), where the distribution of the demersal fishing fleets in the Argentine Sea and their fishing effort were positively associated with frontal areas, emphasizing the importance of marine fronts in demersal resource abundance and distribution.

The predominance of fishing gear types that target bottom-dwelling species, such as the BLL and trap, was expected because of the great abundance and high commercial value of demersal species (e.g., snappers) on the North Brazil Shelf (Booth et al. 2001; Debels et al. 2017). On the other hand, PLLs, traps, and BLLs were employed in similar proportions in the Caribbean Sea LME, and the catch reflected this diversity of fishing gear types (e.g., tunas, marlins, grunts, and sea catfishes).

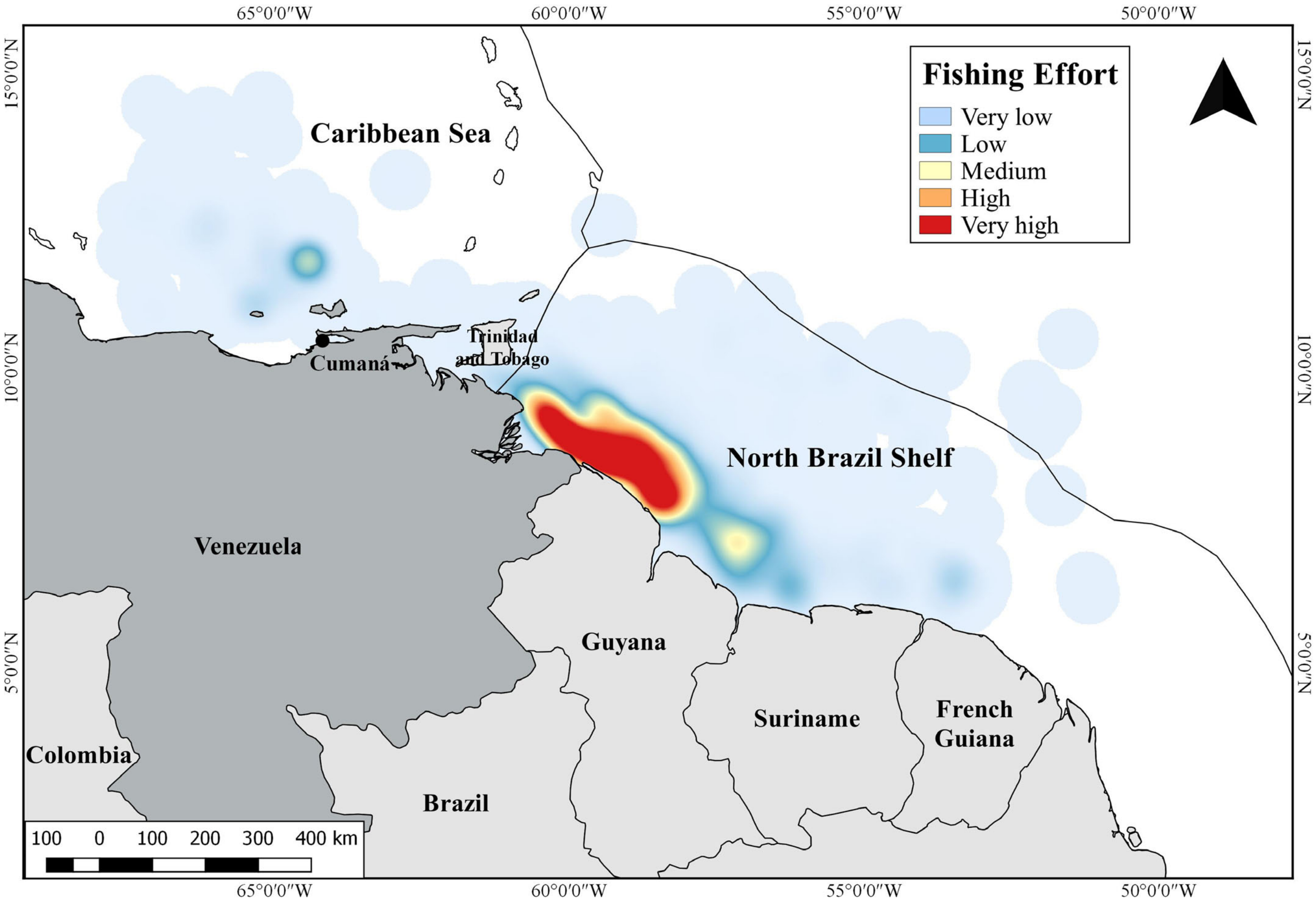

FIGURE 3. Spatial distribution of fishing effort (number of sets) recorded for the Venezuelan industrial multigear fishing fleet from 2015 to 2018. The intensity of fishing effort per fishing area was identified as follows: very low intensity (number of sets from 1 to 199; light blue), low intensity (number of sets from 200 and 399; blue), medium intensity (number of sets from 400 and 599; yellow), high intensity (number of sets from 600 to 799; orange), and very high intensity (number of sets higher than 800 and equivalent to more than 25% of the fishing sets per year; red).

The Caribbean Sea LME is considered an ecosystem with a great variety of marine species (Debels et al. 2017). The Venezuelan coastline occupies most of the southern margin of this LME and is characterized by a large coastal upwelling event and the influence of the Orinoco River plume (Mendoza 2015). Here, pelagic fish species such as tunas, mackerels, and jacks are dominant and in the demersal domain grunts, sea catfishes, snappers, and small sharks are abundant and diverse (Mendoza 2015).

The observed intra-annual second semester variations in highest quantity catches may be related to variations in the abundance of captured species due to environmental changes in the fishing area. Alió (2001), studying shrimp and bottom fisheries in the Orinoco Delta of Venezuela, found a seasonal trend in the CPUE with an increase associated with the rainy season in the second half of the year. In addition, the Orinoco Delta of Venezuela is under the influence of trade winds that blow most of the year to the east, but with greater continuity and intensity from January to June, which makes fishing operations difficult at this time. After June, the wind intensity decreases and the fishing operations become easier (Cervigón et al. 1992).

Interannual variations were also observed in values for catch and fishing effort. Sea Catfishes were the group of species with the highest catches from the overall total in this study and the main catch in the BLLs. The apparent progressive increase in fishing effort with this gear was accompanied by an increase in the proportion of sea catfishes in the total catch. However, the group of fish with the highest commercial value on the North Brazil Shelf is the snappers (Booth et al. 2001; Debels et al. 2017), and while sea catfishes increased, the proportion of snappers in the total catch progressively declined as trap-based fishing effort decreased.

As the situation above shows, it is important to understand the relationship between catch and fishing effort when attempting to identify the exploitation status of a

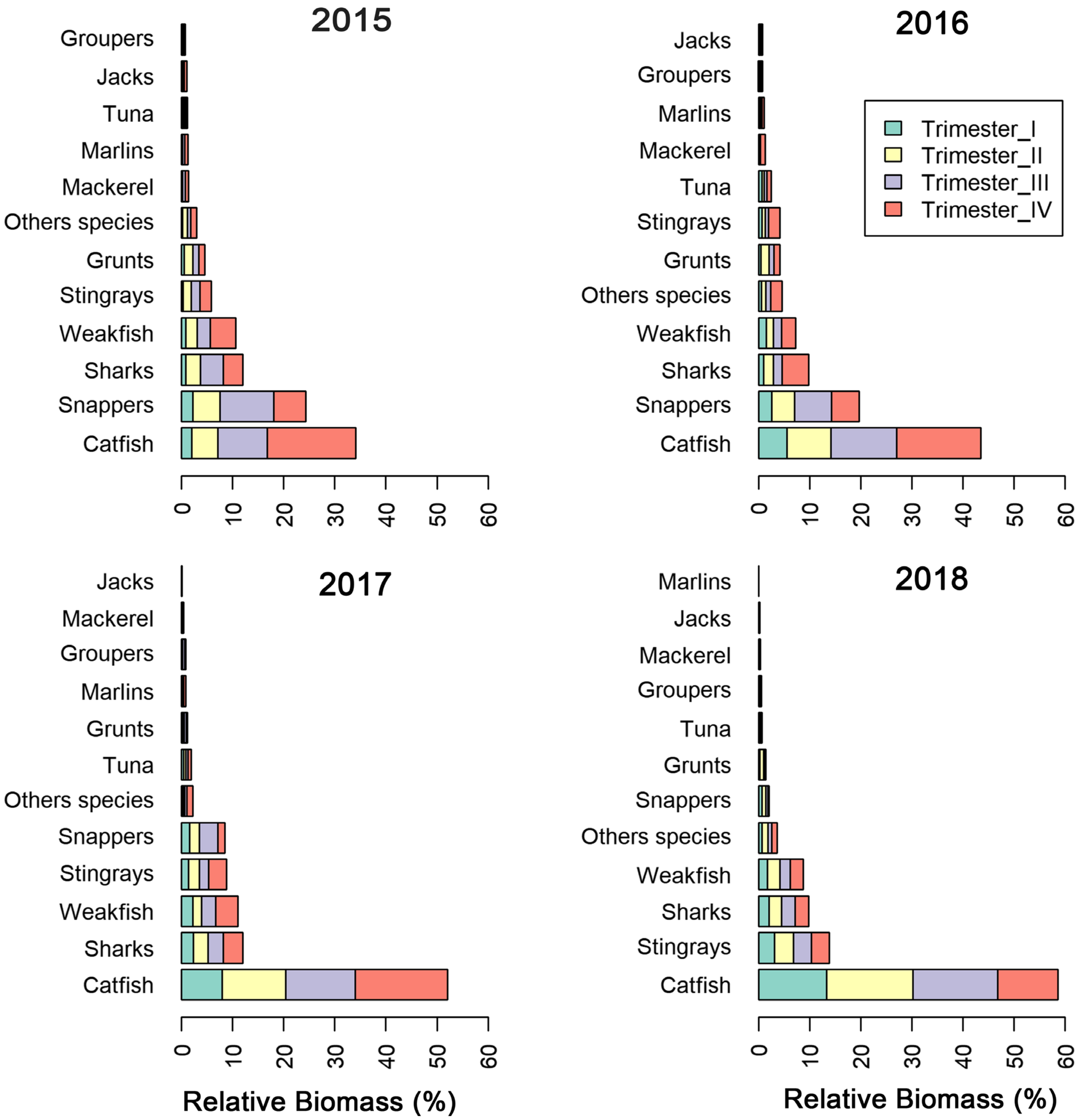

FIGURE 4. Composition of catches per group of species and trimesters for the Venezuelan industrial multigear fishing fleet from 2015 to 2018.

fishery and deciding on the type of strategy to employ for the management of the fishery in question (Halls et al. 2006; Lorenzen et al. 2006). In single-species fisheries, it is assumed that yield has a quadratic relationship with fishing effort (Schaefer surplus production models) until the maximum sustainable yield is reached. From this point on, CPUE shows a continuous decline, leading to an overexploited fishery and, eventually, to the collapse of the fishery (Hilborn and Walters 1992).

For multispecies fisheries this relationship between catch and fishing effort can be different. According to Welcomme (1999), the catch increases initially as effort

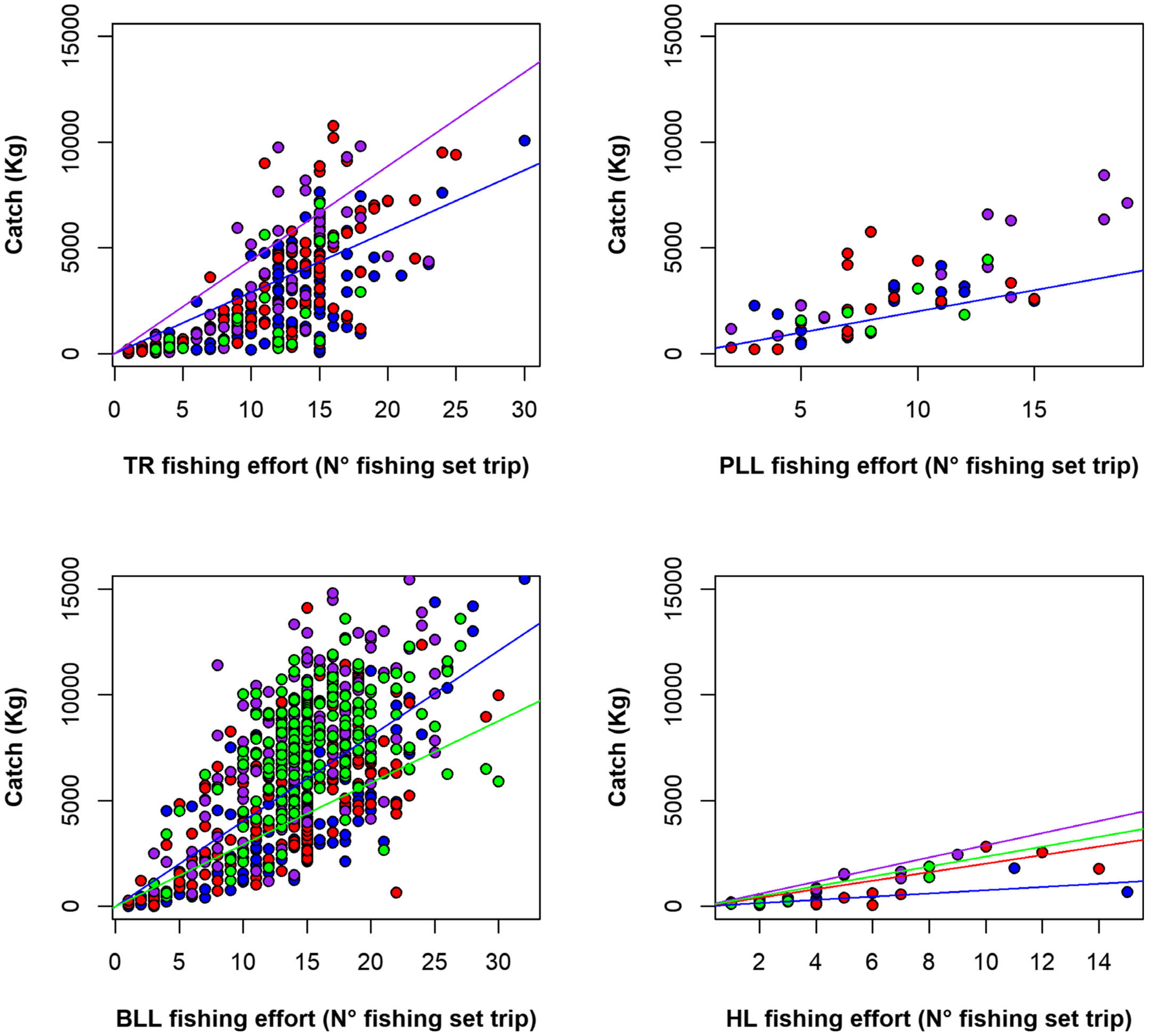

FIGURE 5. Seasonal variation of the catch per effort ratio recorded for the Venezuelan industrial multigear fishing fleet from 2015 to 2018. Years are distinguished by the following colors: 2015 = blue, 2016 = red, 2017 = purple, and 2018 = green ($P \geq 0.05$).

increases, but when the maximum sustainable yield is reached for the target species, its catch per effort ratio begins to decline. However, target species substitution could maintain high and stable yields. In this process, termed "fishing down" by Pauly et al. (1998), a multispecies fishery starts by capturing the largest fish, but once these are depleted other fish species, smaller but still abundant, are targeted to maintain the same yield levels, even though CPUE declines. Unless accompanied by recovery of formerly targeted species, such progressive species-hopping will eventually result in the complete collapse of the regional fishery concerned.

In the industrial PCA-Ven fishery, the process of target species replacement has economic roots (i.e., snappers have been replaced by sea catfishes). This could be because both Caribbean Red Snapper *Lutjanus purpureus* and Lane Snapper *L. synagris* on the North Brazil Shelf are considered to have been overfished (Heileman 2008). Since the industrial PCA-Ven fishery exploits several species with more the one fishing gear type, the masking of

TABLE 2. Results of the ANCOVA examining variation between fishing effort and catch between the years, for each type of fishing gear. The values marked with an asterisk indicate $P \leq 0.05$.

Effect	df	Estimate	Confidence limits	P
Traps				
Effort	1, 270	288.99	217.11; 360.88	6.42×10^{-14}*
Year 2015	4, 270	−843.03	−1,784.65; 98.60	0.0791
Year 2016	4, 270	−931.70	−1,815.76; −47.63	0.0389*
Year 2017	4, 270	−1,105.23	−2,375.06; 164.59	0.0878
Year 2018	4, 270	−771.73	−2,431.82; 888.36	0.3609
Effort: 2016	3, 270	74.45	−23.17; 172.08	0.1344
Effort: 2017	3, 270	154.12	27.40; 280.84	0.0173*
Effort: 2018	3, 270	−25.56	−196.29; 145.18	0.7684
Pelagic longline				
Effort	1, 45	200.13	19.97; 380.29	0.0303*
Year 2015	4, 45	479.51	−1,144.26; 2,103.28	0.5550
Year 2016	4, 45	582.01	−817.77; 1,981.80	0.4068
Year 2017	4, 45	−219.12	−1,794.21; 1,355.97	0.7806
Year 2018	4, 45	−188.21	−3,555.09; 3,178.68	0.9109
Effort: 2016	3, 45	36.29	−211.86; 284.45	0.7697
Effort: 2017	3, 45	193.62	−25.00; 412.24	0.0812
Effort: 2018	3, 45	73.84	−321.00; 468.68	0.7082
Bottom longline				
Effort	1, 662	402.25	333.72; 470.79	2×10^{-16}*
Year 2015	4, 662	−1,106.44	−2,140.08; −72.80	0.03594*
Year 2016	4, 662	634.51	−266.42; 1,535.44	0.16716
Year 2017	4, 662	1,598.84	467.92; 2,729.77	0.00566*
Year 2018	4, 662	3,010.33	1,831.73; 4,188.94	6.81×10^{-7}*
Effort: 2016	3, 662	−71.96	−164.47; 20.55	0.12716
Effort: 2017	3, 662	15.63	−84.25; 115.54	0.75871
Effort: 2018	3, 662	−109.99	−210.14; −9.84	0.03140*
Hand line				
Effort	1, 30	75.56	7.53; 143.58	0.0307*
Year 2015	4, 30	137.45	− 274.91; 549.81	0.5012
Year 2016	4, 30	−359.22	−845.24; 126.80	0.1416
Year 2017	4, 30	−305.27	−1,325.80; 715.26	0.5459
Year 2018	4, 30	−294.07	1,035.16; 447.02	0.4241
Effort: 2016	3, 30	125.89	27.49; 224.28	0.0139*
Effort: 2017	3, 30	213.17	32.82; 393.51	0.0221*
Effort: 2018	3, 30	159.69	4.88; 314.49	0.0436*

the species substitution process could be exacerbated and the final collapse, as proposed by Pauly et al. (1998), is therefore likely. The ANCOVA results given in Table 1 reinforce the idea that an overfished status exists in this fishery, not just for snappers, but also for sea catfishes. This conclusion is reached because for traps (that target snappers) an inverse relationship between the fishing effort and the catch during the year 2017 was evidenced, resulting in an increase of the effect of the fishing effort on the catch. Bottom longline (target sea catfishes) effort has been increasing progressively but by 2018 had begun to show a significant decrease in the effect of the fishing effort on the catch.

Such changes could be a reflection of the change in the population dynamics of the fish stocks exploited by this fleet and so underscores the great need to direct efforts to assess the stocks of the most heavily exploited species (sea catfishes and snappers), especially considering that the main fisheries in the North Brazil Shelf LME are overfished. International cooperation is required to better understand the biology and productivity of the fish stocks in this region and to help achieve the complicated task of managing the fishing resources of this LME. Although this fishery is more selective and less damaging for stocks than is industrial trawling, it also presents some weaknesses, such as economic viability. The industrial trawling fleet during its fall process in 2000 captured 11,200 metric tons that included 41 species, of which fish accounted for 78% by weight (Alió et al. 2010). The PCA-Ven fleet in the 4-year period of this study only captured approximately 5,000 metric tons including 81 species. Therefore, the economic sustainability of this fleet should be better studied in future research.

ACKNOWLEDGMENTS

The authors thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico for financial support and the Ministerio del Poder Popular de Pesca y Acuicultura and the Instituto Socialista de Pesca y Acuicultura for cooperation and making available the data used in this study. We also acknowledge the help provided by Xiomara Gutiérrez, Instituto Socialista de la Pesca y Acuicultura, Sucre, and the three anonymous reviewers whose comments and suggestions helped improve and clarify this manuscript. There is no conflict of interest declared in this article.

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