ORIGINAL ARTICLE

Fishing effects on elasmobranchs from the Pacific Coast of Colombia

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Abstract

During 1995, 2001, 2003, 2004 and 2007; we studied the temporal variation in the structure of the elasmobranch assemblage along the Colombian Pacific coast using: the community index of diversity, heterogeneity, equitability, species composition, average catch sizes, and mean trophic levels. A total of 1711 specimens from 19 species (7 sharks and 12 rays) were collected during the 90 trawling operations. The number of species captured varied between 7 (1995) and 12 (2007) demonstrating a trend towards an imbalance in the assemblage attributes. In 1995, the mean trophic level (TL_m) of the assemblage was 3.60, but in 2007 it decreased to 3.55 when the functional level of large predators was absent ($TL \geq 4$). These results suggest changes in species composition, structural attributes, and a reduction of the highest functional level. Alterations to the catch proportions were also found: i.e. a greater abundance of rays of lower trophic levels. This study suggests an effect of trawling on the stability of this tropical coastal ecosystem.

Keywords: sharks; rays; fisheries; trophic levels; community structure

Introduction

Over the last 50 years, sustained fishing activity worldwide and the steady degradation of habitats have had a wide range of impacts on ecosystems; reflecting in changes of abundance, spatial distribution, productivity, and structure of those communities under exploitation (Hall 1999, Jackson et al. 2001, Myers & Worm 2005, Lotze et al. 2006, Navia et al. 2012). This impact on the structure and function of communities has been widely documented, quantified, and found to impair the maintenance of goods and services that ecosystems provide to humans (Worm et al. 2006, Branch et al. 2010, Lotze et al. 2011).

There are ecological limits (especially related to the energetic balance within food webs) that explain the low number of top predators that may be extracted from a marine environment (Pérez-España et al. 2006). Regardless of known implications, most fisheries tend to focus on these top predators (Branch et al. 2010). Pauly et al. (1998) documented the results of such extractive activities as "fishing down marine

food webs": a gradual change in landings from long-lived, upper trophic level species to short-lived, lower trophic species. This phenomenon was observed at both a global (Pauly et al. 1998) and local scale in Thailand (Christensen 1998), Canada (Pauly et al. 2001), the Mediterranean Sea (Pinnegar et al. 2003), Chile (Arancibia & Neira 2005), Uruguay and Argentina (Jaureguizar & Milessi, 2008), India (Bhathal & Pauly 2008), and Brazil (Freire & Pauly 2010). Conversely, some authors suggest that the decline in mean trophic levels of fisheries landings is due to increased exploitation of the lower trophic levels of marine food webs (Essington et al. 2006). This effect, called "fishing through the food web", has been recorded in North Pacific fisheries (Litzow & Urban 2009).

Sharks and rays are associated with many fisheries worldwide and more than half of the annual catch is through by-catch (Bonfil 1994, Stevens et al. 2000). Consequently, these species are listed as highly vulnerable to exploitation (Holden 1974, Walker 1998) and considered to be among the most endangered vertebrate groups in the world (Stevens et al. 2000, Dulvy & Reynolds 2002, Dulvy et al. 2014). Numerous studies have recorded high reduction rates of elasmobranchs over the past 50 years in many fisheries (e.g. Graham et al. 2001, Coelho et al. 2003, Baum et al. 2003, Myers & Worm 2005). Moreover, it has been proposed that the reduction or disappearance of sharks considered as top predators may have strong effects on the function and structure of the marine food webs (Stevens et al. 2000, Myers et al. 2005, Navia et al. 2010, Navia 2013).

The central and southern Pacific coast of Colombia have been key areas to the domestic shrimp industry since 1960 (de la Pava & Mosquera 2001). Several species of sharks and rays are caught as by-catch and some are commercially exploited (Mejía-Falla & Navia 2011). Despite the history of the shrimp industry in this area, official records of catch efforts and landings are poor (Rueda et al. 2006, Mejía-Falla & Navia 2011). As a result, data required for the design of an appropriate fishery management plan is lacking. Furthermore, trawling impacts and changes to the fish assemblages over time in this area have not been assessed. Based on industrial shrimp trawling fleet data, the goal of our research is to evaluate the changes in the elasmobranch assemblage structure between 1995 and 2007 and determine possible effects of trawling on the assemblage.

Materials and methods

Monitoring of onboard shrimp vessels trawling between Golfo de Tortugas and Ensenada de Guapi (Colombian Pacific coast) was conducted every October in 1995, 2001, 2003, 2004 and 2007 (**Figure 1**). To standardize efforts, all fishing operations were carried out by the same vessel (M/N Arraiján) using the same fishing gear (trawl nets; each 27 m in length, mesh size 2 ¼"); between 11.6 and 31.0 m deep (**Table 1**), in the same area (Figure 1), and under procedures traditionally used by commercial fishing vessels: i.e. trawling three hours during the day and six hours at night. Following each haul, sharks and rays were identified and recorded to species level; sex, size (total length, L_T in cm), weight (g), and number of specimens per species.

Relative abundance (catch per unit effort) was calculated by dividing the total number of specimens of each species by the total number of hours per haul in
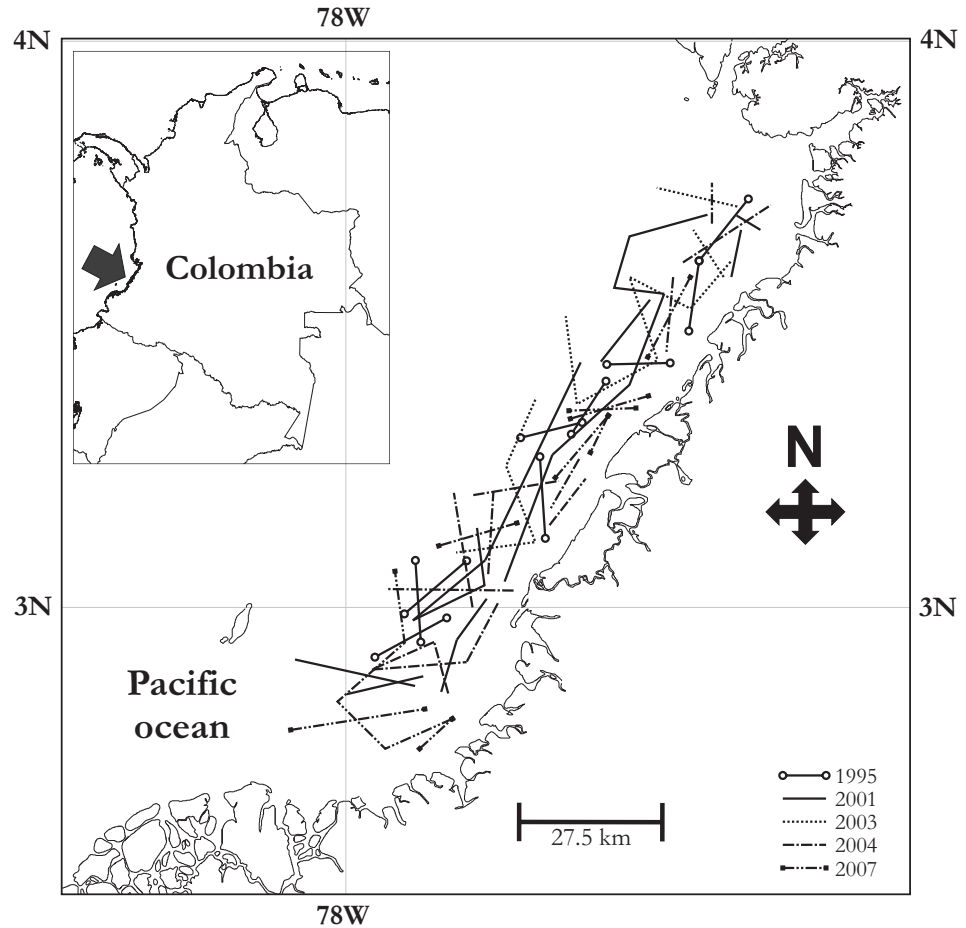
Fig. 1. Study area, Colombian south Pacific coast. Lines indicate approximate tracks of fishing trips during sampling years.

the sampling year. Temporal variations in these relative abundances were analyzed using ANOVA (Kruskal-Wallis test, Zar 1999) and differences in species richness over time were evaluated using Cochran's Q test (Zar 1999). Differences in species catch size (L_T) between sampling years were evaluated with a nonparametric ANOVA (Zar 1999).

Table 1. Number of trips and trawling depths per year carried out onboard the vessel M/N Arraiján.

Year	Number	Depth		
		Minimum	Maximun	Average
1995	18	5.5	35.0	18.0
2001	24	8.5	59.4	31.3
2003	16	4.9	25.2	11.6
2004	18	3.6	52.2	20.0
2007	19	10.8	27.0	19.2

To analyze changes in the elasmobranch assemblage attributed over time, we calculated the indices of heterogeneity, diversity, and equitability (Krebs 1999); using the software Ecological Methodology (Krebs 2001). The nonparametric Simpson's index (D) was used to compare heterogeneity, and respectively, the complement index (1-D) towards diversity ranging from 0 (low diversity) to 1 (maximum diversity). Shannon diversity index (H') was also used to measure diversity. Equitability was quantified using Simpson's measure ($E_{1/D}$), which ranges from 0 to 1 and is not affected by rare species (Krebs 1999). These indices accurately describe the structural and functional attributes of fish communities (Piet & Jennings 2005) and there is available theoretical and empirical evidence that they can measure the impact of fishing (Rochet & Trenkel 2003).

Significant differences ($\alpha = 0.05$) between the attributes of the assemblage were evaluated by applying the Hutchenson's t test (1970) to the Shannon diversity index values, under the null hypothesis that the diversity of the samples were not different. This test was calculated as $t = (H'_1 - H'_2) \times (\text{Var } H'_1 + \text{Var } H'_2)^{-0.5}$, where H'_1 and H'_2 are the Shannon diversity indices of samples 1 and 2, respectively, and Var H'_1 and Var H'_2 are the variances of each of the indices (Magurran 1988).

To evaluate the effects of trawling on the trophic structure of the ecosystem in question, the historical changes of the mean trophic level (TL_m) of the elasmobranch assemblage were analyzed. To quantify the trophic level of the species, studies on feeding habits carried out in the same studied area were used (Gómez et al. 2003, Mejía-Falla et al. 2006, Navia et al. 2006, 2007, 2011, López-García et al. 2012, Navia 2013). For those species whose diet has not been studied in this area, we used studies conducted in the Eastern Tropical Pacific (ETP) (Valadez-González 2007). Literature on the diet of *Carcharhinus leucas* and *C. porosus* in the ETP was not available. Thus, we used trophic level values calculated by Cortés (1999): TL = 4.3 for *C. leucas* and TL = 4.1 for *C. porosus*. Trophic levels (TL_k) were quantified by applying the formula proposed by Cortés (1999) and reviewed by Ebert & Bizarro (2007).

$$TL_k = 1 + \left[\sum_{j=1}^{n} P_j \times TL_j \right] \qquad (1)$$

where P_j is the fraction of prey i in the diet of predator j; TL_j is the trophic level of prey i in the diet of predator j. We used the reference values of trophic levels for prey suggested by Cortés (1999), Ebert & Bizarro (2007) and López-García et al. (2012).

The mean trophic level (TL_m) of the assemblage for each sampling year was calculated according to Pauly & Palomares (2005):

$$TL_m = \frac{\sum TL_k \, Y_{ij}}{\sum Y_{ij}} \qquad (2)$$

Where TL_k is the mean trophic level of the species or group k, and Y_{ij} is the catch of species or group i in year j.

Results

A total of 90 net hauls and 396 hours of fishing were monitored; a total of 1711 specimens of 19 species (7 sharks and 12 rays) were captured (**Table 2**).

Table 2. Trophic level (TL), catch per unit effort (CPUE, used as relative abundance synonymously) and average catch sizes (L$_T$ in cm) of elasmobranchs caught during sampled years. Number of effective sampling hours per year is indicated in brackets.

		1995 (76)			2001 (87)			2003 (63)			2004 (60)			2007 (110)		
	TL	n	CPUE	LT	n	CPUE	LT	n	CPUE	LT	n	CPUE	LT	n	CPUE	LT
SHARKS																
Family Triakidae																
Mustelus lunulatus	3.8	3	0.04	36.0	42	0.48	67.6	3	0.05	53.3	0	-	-	1	0.01	55.0
Family Carcharhinidae																
Carcharhinus porosus	4.1	18	0.24	41.0	1	0.01	40.0	11	0.17	37.6	1	0.02	38.0	0	-	-
Family Sphyrnidae																
Sphyrna corona	4.1	0	-	-	0	-	-	7	0.11	52.8	0	-	-	0	-	-
Sphyrna lewini	4.4	3	0.04	42.5	6	0.07	53.0	0	-	-	1	0.02	88.0	0	-	-
Sphyrna media	3.9	0	-	-	3	0.03	58.9	0	-	-	0	-	-	0	-	-
Sphyrna tiburo	3.2	2	0.03	37.0	3	0.03	83.2	4	0.06	40.5	3	0.05	97.5	2	0.02	-
RAYS AND SKATES																
Family Narcinidae																
Narcine entemedor	3.7	0	-	-	12	0.14	58.3	1	0.02	60.0	2	0.03	37.4	95	0.86	37.8
Narcine leoparda	3.6	0	-	-	0	-	-	4	0.06	25.7	3	0.05	-	196	1.78	21.9
Family Rhinobatidae																
Rhinobatos leucorhynchus	3.5	16	0.21	32.5	28	0.32	55.4	10	0.16	49.1	16	0.27	59.0	67	0.61	38.9
Zapteryx xyster	3.5	0	-	-	54	0.62	55.4	0	-	-	0	-	-	0	-	-
Family Rajidae																
Raja velezi	3.6	0	-	-	14	0.16	69.0	0	-	-	0	-	-	1	0.01	-
Family Urotrygonidae																
Urotrygon aspidura	3.7	61	0.79	34.5	38	0.44	32.9	66	1.04	30.9	13	0.22	23.9	145	1.32	28.5
Urotrygon rogersi	3.5	40	0.54	22.9	0	-	-	0	-	-	0	-	-	47	0.43	24.8
Urotrygon spp.	3.6	0	-	-	0	-	-	0	-	-	3	0.05	24.1	607	5.52	42.5
Family Dasyatidae																
Dasyatis longa	3.8	0	-	-	24	0.27	150.6	3	0.05	127.7	10	0.17	125.3	10	0.09	129.7
Dasyatis spp.	3.8	0	-	-	0	-	-	1	0.02	149.0		-	-		-	-
Family Gymnuridae																
Gymnura marmorata	3.7	0	-	-	0	-	-	4	0.06	39.4	2	0.03	26.9	2	0.02	55.5
Family Myliobatidae																
Aetobatus narinari	3.9	0	-	-	0	-	-	1	0.02	185.3	0	-	-	1	0.01	124.5
Species richness		7			11			12			10			12		
Total number captured		143			225			115			54			1174		

The number of species varied between 7 (1995) and 12 (2003, 2007). No significant differences were found in occurrence (Cochran, Q = 4.30, df = 4, p = 0.367) but there were significant differences in relative abundance (CPUE) between studied years (Kruskal-Wallis test, H = 3.01, df = 4, p = 0.045). For example, in sharks, the relative abundance of *C. porosus* changed from 0.24 in 1995 to 0.01 in 2001, and *Mustelus lunulatus* changed from 0.48 in 2001 to 0.01 in 2007. Average catch size decreased during these years from 67.6 to 55.0 cm L_T. Regarding batoids, *Dasyatis longa* changed from a relative abundance of 0.27 and average catch size of 150.6 cm L_T in 2001 to 0.09 and 129.7 cm L_T, respectively, in 2007. On the other hand, the index of relative abundance of some small sized rays with no commercial value, such as *Narcine entemedor*, *N. leoparda* and *Urotrygon aspidura* increased; while the catch sizes declined (Table 2).

There was no clear trend in equitability and heterogeneity over time. Between 1995 and 2001, these attributes increased, whereas between 2001 and 2007, they decreased. Either way, this suggests an alteration of the species richness and abundance during the research period. Species richness of elasmobranchs differed significantly between all sampled years (**Table 3**), indicating considerable variation in the assemblage composition during the studied period.

Table 3. Comparison of Shannon diversity index values (H'₁ and H'₂) between sampling years and statistical significance (α = 0.05) using the Hutchenson's t test. d.f = degree freedom, p = probability.

Years	H′₁	H′₂	d.f	t_{table}	t_{cal}	p
1995 vs 2001	1.17	2.02	210	1.97	17.80	< 0.05
1995 vs 2003	1.17	1.59	241	1.97	6.21	< 0.05
1995 vs 2004	1.17	1.89	142	1.97	11.05	< 0.05
1995 vs 2007	1.17	1.72	168	1.97	12.33	< 0.05
2001 vs 2003	2.02	1.59	149	1.98	7.75	< 0.05
2001 vs 2004	2.02	1.89	73	2.00	2.48	< 0.05
2001 vs 2007	2.02	1.72	381	1.96	13.12	< 0.05
2003 vs 2004	1.59	1.89	154	1.96	4.21	< 0.05
2003 vs 2007	1.59	1.72	126	1.96	2.49	< 0.05
2004 vs 2007	1.89	1.72	60	2.00	3.35	< 0.05

Over the years studied, the number of species increased (7 to 12) while the TL_m decreased slightly (**Figure 2**). As an exception to this trend, 11 species were collected in 2001 and the TL_m was the second highest of all sampled years. This was due to the catch of *Zapteryx xyster* and *Raja velezi*, resulting in a TL higher than the other rays in the study, and only occurred in that year. The TL_m of the assemblage ranged from 3.61 in 1995 to 3.55 in 2007. Species from the top predator functional level (TL ≥ 4.0), such as those from the Sphyrnidae and Carcharhinidae families, were not recorded during any of the fishing trips in 2007.
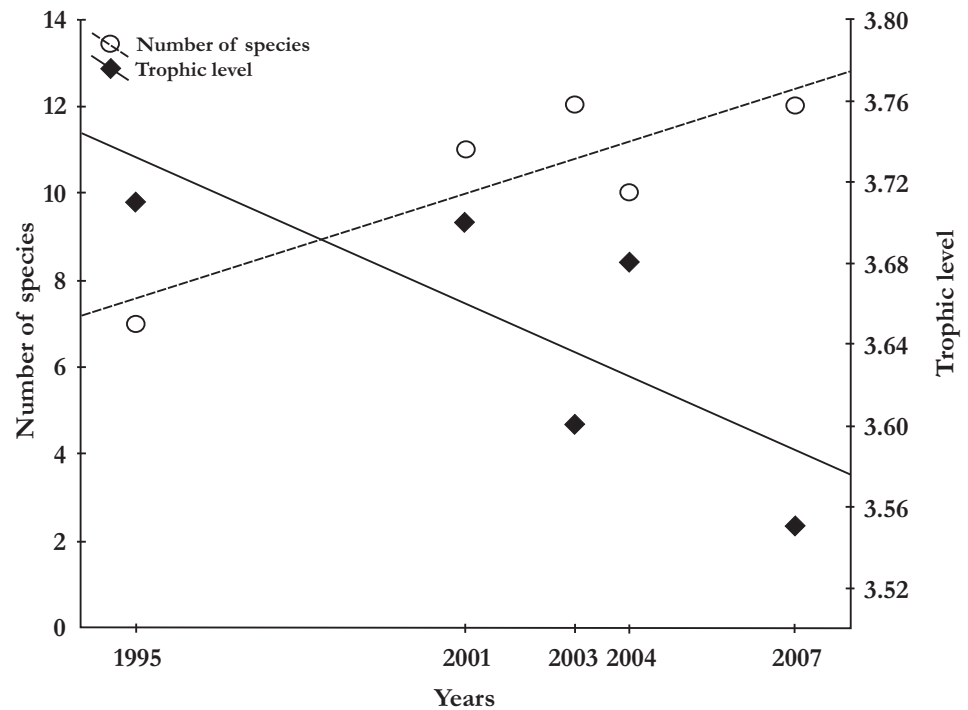
Fig. 2. Study area, Colombian south Pacific coast. Lines indicate approximate tracks of fishing trips during sampling years.

Discussion

Changes in the elasmobranch assemblage detected during this study included alteration of assemblage attributes (heterogeneity, diversity, and equitability), modification of the relative abundance of most species, a slight reduction in mean trophic level, reduction in average catch size, and a substantial reduction in upper trophic level predators. For example, *M. lunulatus* and *D. longa*, considered the most important commercial elasmobranch species in the late 1990s on the Pacific coast (Zapata et al. 1999), showed a significant downward trend in abundance and average catch size. According to Piet & Jennings (2005), this effect on average catch size and species composition is directly linked to changes in the trophic structure of the community.

Thirty of the 48 largest marine ecosystems on the planet have shown reductions in trophic levels (Essington et al. 2006). Although the results of this study do not demonstrate the removal of top predators from the studied area, they do show that species with TL ≥ 4 decreased significantly. In contrast, the intermediate trophic level species increased in abundance over the same period. These results are consistent with fisheries statistics for the Colombian Pacific coast (Mejía-Falla & Navia, 2011), which showed a reduction in average catch sizes and an increase in abundance of juvenile and intermediate TL species. This suggests a significant reduction or even possible loss of the ecological function of top predators, especially those at the adult stage, which could impact, in the short or medium term, the structure of the food web in the study area. This is especially important considering top predators were identified as the most important species in keeping the balance of an ecosystem's structure (Navia et al. 2010, 2012, Navia 2013).

The rate of decline of trophic levels in this assemblage (0.0035 year^{-1}) is lower than those reported in other studies (e.g. Pauly et al. 1998, Pinnegar et al. 2003, Milessi et al. 2005; Jaureguizar & Milessi 2008). However, it is worth noting that in just 5 years of sampling, the TL$_m$ of the assemblage showed a reduction. This might reflect the significant impact that trawling has had on the species within the studied area even though this fishery does not catch high trophic level shark species on a regular basis.

The increase of species richness and evenness between 1995 and 2007 suggests the occurrence of additional elasmobranchs species that were not associated with the shrimp trawl fishery in earlier years. This change in the assemblage composition is the result of increased catch frequency of intermediate or lower trophic level species including *N. leoparda*, *N. entemedor*, *Rhinobatos leucorhynchus*, and *U. aspidura* (TL < 3.7).

According to Piet & Jennings (2005), the assumption that assemblages have had an integrated response to fishing pressures implies that all fish community indicators should decrease. This has been observed in shallow water fisheries of the North Sea (Piet & Jennings 2005) and coastal shrimp fisheries along the Pacific coast of Colombia in the latter years of this study. It has been argued that community indices and trophic levels calculated from landings in some countries are biased by economic interests towards targeted species (Bianchi et al. 2000, Essington et al. 2006). Consequently, changes in community indices and trophic levels are not reliable indicators of the impact on fisheries. This work, however, was based on direct monitoring onboard fishing vessels and assessed all the elasmobranch species captured (regardless of their economic value). Therefore, this study provides accurate and reliable information on the performance of both indicators and assemblage attributes.

The changes in the assemblage found in this study; i.e. reduction in mean trophic level, increased richness of small species, and changes in their abundance; suggests fishing effects some of the structural and functional parameters of the trophic networks: proportion of top predators, links density, and predatory function. If this trend continues and extends to other functional groups, the upper trophic levels of the food web within the study area will experience overexploitation. Consequently, the network structure will be simplified and the productivity and biomass will decrease, as has been recorded within many other ecosystems highly impacted by fishing (Coll et al. 2008, 2009a, Barausse et al. 2009, Morissette et al. 2009, Navia et al. 2012). Essington et al. (2006) suggests that the reduction observed in trophic levels of an ecosystem can be influenced by the depletion of upper trophic levels (e.g. fish) and the creation of alternative fisheries of lower trophic levels (e.g. invertebrates). However, this is not the case in Colombian Pacific fisheries because despite the reduction in yields from traditional fisheries, no new alternative fisheries have been developed.

In the Pacific Region, the shrimp fishery began in the 1960s and peaked in 1974 when there were 138 boats in this fishery (de la Pava & Mosquera, 2001). In the mid-1980s, the shrimp crisis began, which led to the continuous reduction of vessels until 2007 when there were only 29 active (Navia et al. 2008). Despite this drastic reduction in fishing activity, the proportion of by-catch (including elasmobranchs) versus shrimp in the Colombian Pacific Ocean between 2004 and 2005 was around 14:1 kg (Rueda et al. 2006), which was well above the overall average of 10:1 kg in other world tropical fisheries (Hall et al. 2000, Lewinson et al. 2004).

Conclusion

Our results suggest that trawling has possibly impacted the structure and composition of the elasmobranch assemblage in the Colombian Pacific coastal waters. This has led to the reduction of individuals in upper trophic levels, potentially contributing to instability of the food web and/or alteration of ecosystem control mechanisms. Impacts on the elasmobranch assemblage may also trigger gradual changes that could lead to a new organization of the food web as has been suggested for various marine ecosystems (Chen et al. 2008, Coll et al. 2009a, 2009b, Duan et al. 2009, Andersen & Pedersen 2010, Scheffer 2010, Lotze et al. 2011). These changes to the Colombian Pacific ecosystems could make this food web particularly sensitive to the loss of top predators, as suggested by Navia et al. (2012).

Acknowledgements

Conflicts of interest

The authors declare that there are no conflicts of interest.

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Efectos de pesca sobre elasmobranquios en el Pacífico colombiano

Resumen. Durante 1995, 2001, 2003, 2004 y 2007 estudiamos la variación temporal en la estructura de un ensamblaje de elasmobranquios a lo largo de la costa pacífica colombiana. Para ello utilizamos los índices de diversidad, heterogeneidad, equitatividad y composición de especies, así como el tamaño promedio de capturas y los niveles tróficos promedio. Se colectó un total de 1711 especímenes de 19 especies (7 tiburones y 12 rayas) durante 90 operaciones de pesca de arrastre. El número de especies capturadas varió entre 7 (1995) y 12 (2007), lo cual demuestra una tendencia hacia un desbalance en los atributos del ensamblaje. En 1995 el nivel trófico promedio (TL_m) del ensamblaje fue de 3.60, pero en 2001 disminuyó a 3.55, cuando estuvo ausente el nivel funcional de grandes predadores ($TL \geq 4$). Estos resultados sugieren cambios en la composición de especies y en los atributos estructurales, y una reducción del nivel funcional superior. Se encontraron también alteraciones en las proporciones de captura, como una mayor abundancia de rayas de niveles tróficos inferiores. Este estudio sugiere un efecto de la pesca de arrastre en la estabilidad de este ecosistema tropical costero.

Palabras clave: tiburones; rayas; pesquerías; niveles tróficos; estructura comunitaria

Efeitos sobre a pesca nos elasmobrânquios no Pacífico colombiano

Resumo. Durante 1995, 2001, 2003, 2004 e 2007 estudamos a variação temporal na estrutura da comunidade de elasmobrânquios ao longo da costa pacífica colombiana usando o índice comunitário de diversidade, heterogeneidade, equidade, composição de espécies, tamanho médio das capturas e níveis tróficos médios. Um total de 1711 espécimes de 19 espécies (7 tubarões e 12 raias) foram coletadas durante as 90 operações de pescas de arrasto. O número de espécies capturadas variou entre 7 (1995) e 12 (2007), demonstrando uma tendência ao desequilíbrio nos atributos da comunidade. Em 1995, o nível trófico médio (TL_m) da comunidade era de 3,60, mas em 2007 decresceu para 3,55 quando o nível funcional de grandes predadores estava ausente ($TL \geq 4$). Estes resultados sugerem alterações na composição das espécies, em atributos estruturais e uma redução do mais alto nível funcional. Também foram encontradas alterações na proporção de capturas, ou seja, uma maior abundancia de raias de níveis tróficos mais baixos. Este estudo sugere um efeito da pesca de arrasto na estabilidade de este ecossistema costeiro tropical.

Palavras-chave: tubarões; raias; pesca; níveis tróficos; estrutura da comunidade

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His main research interest is directed to the evaluation of the ecological function of elasmobranchs in marine ecosystems, and the determination of the relationship between life history characteristics of these species and their vulnerability, with emphasis on reproduction and age. He recently initiated studies on the essential habitats of elasmobranchs and ecological processes that determine their richness and distribution.

Paola Andrea Mejía-Falla

Her research focused on the life history strategies and demographics of elasmobranchs, as well as to assess the effect of fishing on such population parameters. She has conducted research on reproduction, age and growth of various species of elasmobranchs, both marine and freshwater. She has initiated studies on essential habitats of elasmobranches and on the macro-ecological processes that determine the distribution of these species.