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Cephalopod species in the diet of large pelagic fish (sharks and billfishes) in Ecuadorian waters

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ABSTRACT

Large pelagic fish species are apex predators in the ecosystem of the Pacific Ocean, and they represent important economic resources for fisheries. In Ecuador there is a fishery for billfish such as *Istophorus platypterus*, *Xiphias gladius*, *Makaira nigricans*, and *Kajikia audax*, in which sharks such as *Prionace glauca* and *Isurus oxyrinchus* are also caught. Their prey includes small fish and cephalopods. We studied the trophic ecology of sharks and billfish captured in Santa Rosa (Salinas) and Playita Mía (Manta) Ecuador during 2013 and 2014, in order to evaluate their trophic relationship with different cephalopod species. Our results show that cephalopods are the most important prey in the diet of sharks (%IRI = 61.6) and billfishes (%IRI = 77.5). Twenty two species of cephalopods of the Orders Octopoda, Vampyromorphida and Teuthida were identified in the stomach contents, with *Dosidicus gigas*, *Ancistrocheirus lesueurii* and *Histioteuthis dofleini* being the most important. We also demonstrated that squid are abundant in waters off Ecuador. The ommastrephid *D. gigas* was the main prey for billfish (%IRI = 93.7 for *X. gladius*) and the second most important for sharks (%IRI = 44.9 for *I. oxyrinchus*). Cephalopods are key prey items for predatory pelagic fish in the Pacific Ocean off the coast of Ecuador. Further studies on the diet of these fish species are needed to better understand their role as top-level predators in the marine food web and to improve knowledge of the diversity of cephalopods in the region.

1. Introduction

Large pelagic fishes—sharks, billfish, and other large bony-fish—are top predators in ocean ecosystems. Sharks and billfishes are widely distributed in the Pacific Ocean (Strasburg, 1958; Joseph et al., 1988; Walsh and Brodziak, 2014). Their distribution overlaps in the case of *Prionace glauca*, *Isurus oxyrinchus*, *Xiphias gladius*, *Istiophorus platypterus*, *Makaira nigricans* and *Kajikia audax*. *Alopias* spp. and is closely related to the equatorial region (Compagno, 1984), while other species such as *Sphyrna* spp. are more related to the continental shelf (Compagno, 1984; Bassuno et al., 2011). These sharks and billfishes are broadly carnivorous. Their diet is mainly composed of fish and squid, and to a lesser extent crustaceans. Both groups are opportunistic feeders (Abitía-Cárdenas et al., 2002; Arizmendi-Rodríguez et al., 2006; Maia et al., 2006; Torres-Rojas et al., 2006; Castillo et al., 2007; Abitía-Cárdenas et al., 2010).

Oceanic cephalopods include the Oegopsida, Vampiromorpha, and Cirrata, and a few species of incirrate octopodas (Nesis, 2003). These cephalopods are an important food resource as they rapidly convert and concentrate slow and fast-growing oceanic resources into high energy food for sharks, billfishes, and other large predators (Clarke, 1996). Squid are the most important and diverse group among the oceanic cephalopods, and the family Ommastrephidae include some of the most abundant nektonic epipelagic organisms in terms of both number and biomass (Cherel et al., 2007). This is reflected in the feeding habits of large predators, for whom ommastrephid squid are the most important prey in terms of biomass, representing 70–95.9% in the diet of billfishes (Peristeraki et al., 2005; Markaida and Hochberg, 2005; Cherel et al., 2007), 5–20% for sharks *I. oxyrinchus* (Maia et al., 2006), and 20–40% in *Sphyrna lewini* (Estupiñan-Montaño et al., 2009).

Opportunistic predators such as sharks and billfishes play an important role in the predator/prey relationship in marine ecosystems, and the study of their feeding habits is useful in understanding the trophic chain, mainly because we can identify prey species previously unrecorded in a given locality after studying their stomach contents (Salman, 2004). Thus, the description of the

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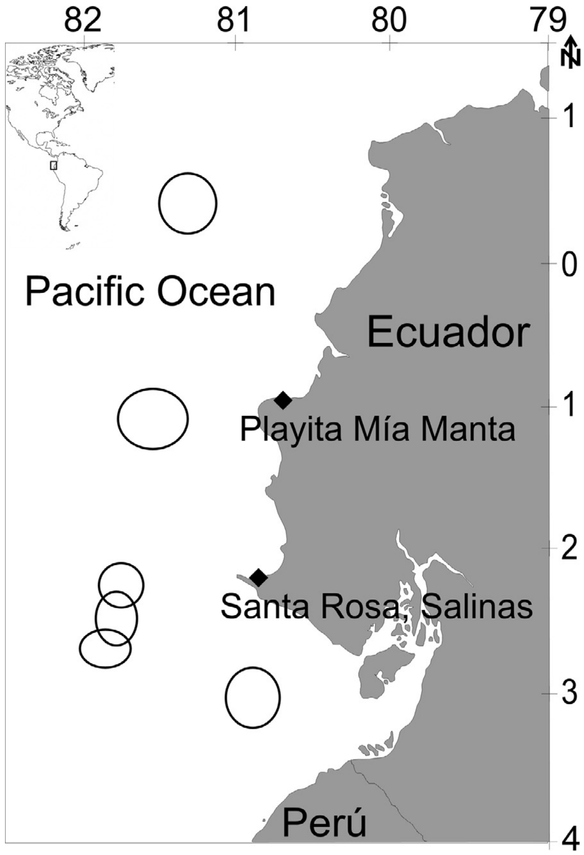

Fig. 1. Fishing Ports of Santa Rosa Salinas and Playita Mía Manta Ecuador where samples were collected. Circles represent the area where artisanal fisheries work.

feeding habits of cephalopod predators is important for the study of cephalopod populations where there is little other information (Clarke, 1966). Billfishes and sharks also prey on fish, but this study was focused on the incidence and abundance of cephalopod species in their stomach contents.

2. Methods

2.1. Samples

Sharks (*P. glauca*, *I. oxyrinchus* and *Alopias* spp.) and billfishes (*K. audax*, *X. gladius*, *I. platypterus* and *M. nigricans*) were sampled from the artisanal longline fisheries in the fishing ports of Santa Rosa, Salinas (02°13′0″S, 80°58′0″W), and Playita Mía, Manta (0°56′59″S, 80°42′34″W), Ecuador from June 2013–November 2014 (Fig. 1). Artisanal longline fisheries work between 20 and 70 nautical miles from the coast, on board small vessels. We measured and examined the stomachs of all sharks and billfishes received at the fishing port twice a month in Santa Rosa and eight times a month in Playita Mía. All samples were pooled to provide an overall view. Sample size of sharks and billfishes from Playita Mia were smaller than from Santa Rosa. We measured precaudal length in sharks and fork length of billfishes to the nearest 10 mm. Stomach contents were collected, frozen and transported to the marine resources laboratory of the Universidad Laica Eloy Alfaro de Manabí, Manta, Ecuador for analysis.

2.2. Stomach contents analysis and index of relative importance

A subjective, visual stomach fullness index was assigned to every stomach: 0, empty; 1, scarce remains; 2, half full; 3, almost full; 4, completely full (Breiby and Jobling, 1985). Only stomachs with fullness index of between 1 and 4 were analyzed. Stomach contents were separated and identified using several publications: complete fish and cephalopods were identified from Fischer et al. (1995a,b) and Jereb and Roper (2010). Bones were identified with the help of Clothier (1950), Barrera-García (2008), and by comparison with the fish and skeleton collection of the project "Trophic Ecology of Large Pelagic Species of Ecuador". Cephalopod beaks were identified using Clarke (1962); Iverson and Pinkas (1971); Wolff (1982, 1984); Clarke (1986); Lu and Ickeringill (2002); Chen et al. (2012).

Frequency of occurrence, numeric and gravimetric methods were used to quantify the diet. Frequency of occurrence (%FO) was calculated according to the percentage of predators that fed on a certain prey. Number (%N) was the number of individuals of a certain prey relative to the total number of individual prey. And percentage weight (%W) was the weight of a certain prey relative to the total weight of all prey (Cailliet, 1976). Graphs of the index of relative importance, IRI = (%N + %W) × (%FO) were plotted to illustrate the diet of each predator following Pinkas et al. (1971). Only the most important prey were included in the plots. The IRI was expressed as:

$$\%\mathrm{IRI} = \left(\frac{\mathrm{IRI}}{\Sigma \mathrm{IRI}}\right) \times 100$$

The percentage of IRI for *Alopias* spp. was calculated based on the %FO, %N, and %W reported by Polo-Silva et al. (2007), Polo-Silva et al. (2009) and for *Spyrna* spp. they were taken from Estupiñan-Montaño et al. (2009).

2.3. Consumption of cephalopods and D. gigas by predators

Estimates of consumption of cephalopods by each predator species were based solely on the available data from each catch and assuming there is no variation in the feeding habits of predators through time. Therefore they do not represent total consumption by the whole predator population. The results are limited estimations and must be carefully interpreted, but nevertheless they are useful approximations providing insight into the cephalopod population's diet.

The percentage of cephalopods in the total stomach contents of each predator captured during 2007–2011 was calculated and plotted to show the trophic connections. To estimate cephalopod consumption (Q_i) by each predator, three parameters are needed (Table 1): (1) the catches of the eight predator species (F_j) (we used the total value of the catches from each specific predator 2007–2011 reported by the Ministerio de Agricultura, Ganadería, Acuacultura y Pesca (MAGAP, 2014); (2) the consumption-biomass relationship to each group of predators $(Q/B)_j$ [taken from Rosas-Luis et al. (2008)]; and (3) the diet composition (DC_{ij}) of the prey (i) in the stomach contents of the predator (*j*) (%IRI calculated in this work). The expression to calculate the consumption is:

$$Q_i = \sum_{i=1}^{n} F_j \times \left(\frac{Q}{B}\right)_j \times DC_{ij}$$

The value was calculated for each predator and summarized in the graphs.

3. Results

A total of 175 *P. glauca*, 143 *I. oxyrinchus*, 55 *Alopias* spp., 108 *X. gladius*, 64 *I. platypterus*, 76 *K. audax* and 59 *M. nigricans* individuals were measured in the present study. Fig. 2 shows the size distribution of these predators.