



Scientific Note

Feeding and trophic relationships of two highly migratory sharks in the eastern south Pacific Ocean

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Abstract. A total of 433 stomachs of *Prionace glauca* and *Isurus oxyrinchus*. The results showed a high dietary overlapping (PSI = 0.69) in both sharks, whereas the most important preys were bony fishes (72.21 % and 86.95 % IRI, *P. glauca* and *I. oxyrinchus*, respectively).

Key words: trophic ecology, ontogenetic changes, feeding strategy, sharks

Resumen. Alimentación y relación trófica de dos tiburones altamente migratorios en el Océano Pacífico Sur-oriental. Se analizó un total de 433 estómagos de *Prionace glauca* e *Isurus oxyrinchus*. Los resultados mostraron que existe una alta sobreposición dietaria (PSI=0.69), en tanto las mayores presas correspondieron a peces óseos (72.21% y 86.95 % IRI; *P. glauca* e *I. oxyrinchus*, respectivamente).

Palabras clave: ecología trófica, cambios ontogenéticos, estrategia de alimentación, tiburones

To understand the biological interactions of any organism in their ecosystem is necessary to study the relationships and differences related to diet, food consumption and ontogenetic changes (Lopez *et al.* 2009). Thus, qualitative analyses, including stomach contents can help to infer the trophic level occupied by any species in their habitat (Movillo & Bahamonde 1971). Whereas, quantitative studies using the same approach can estimate the predation and consequently reflect the importance and dependence on the predators diet (Ricklefs 1979, Wootton 1990, Abrams 2000, Lopez 2008). On the other hand, studies in dietary overlap are useful to understand how two species use the same food resource and thus identify the connections between predators and preys; which is

important information for the fisheries management based on ecosystem relationships. In most marine ecosystems, sharks and other cartilaginous fish species play a fundamental role occupying high trophic levels (Cortes 1999) and subsequently are important in regulating the ecosystem structure through feeding (Stevens *et al.* 2000, Bascompte *et al.* 2005, Heithaus 2005, Shepherd & Myers 2005, Myers *et al.* 2007). So far, knowledge of trophic interactions among highly migratory predators is poorly understood (Dobson & Frid 2009). Most of the highly migratory oceanic sharks exhibit a generalist feeding strategy with a wide variety of preys. This suggests that the dietary overlap is potentially greater. Nevertheless, the competition between them can be avoided, either by spatial

segregation or migration between oceanic and coastal waters (Lopez 2008, Dobson & Frid 2009). The blue shark *Prionace glauca* (Linnaeus, 1758) and the mako short fin *Isurus oxyrinchus*, Rafinesque, 1810, are large epipelagic highly migratory species (Lopez 2008, Lopez *et al.* 2009, Lopez *et al.* 2010) and mostly inhabit waters between 7° to 25° C (Compagno *et al.* 2005). Blue shark and mako short fin feeding studies have been done generally in the north Pacific and Atlantic Ocean waters. These species have showed a wide trophic spectrum, including cephalopods and epipelagic fishes as their most important preys (Stiwell & Kohler 1982, Cliff *et al.* 1990, Vaske-Junior & Rincon-Filho 1998). In the southeastern Pacific, diet of *P. glauca* and *I. oxyrinchus* has been studied only in the last five years (Pardo-Gandarillas *et al.* 2007, Lopez *et al.* 2009, Lopez *et al.* 2010); on the other hand, trophic relationships of these and other oceanic fishes (e.g., swordfish, mako shark, etc.) have not been studied. Hence, quantify the feeding ecology of these epipelagic highly migratory sharks is essential for modelling their trophic relationships (e.g. ontogenetic differences), and their potential regulatory effects (top-down regulation) in the structure and function of oceanic marine ecosystems (Lopez *et al.* 2009). Therefore, the purpose of the present study was to analyse the dietary overlap of *P. glauca* and *I. oxyrinchus* off Chile during 2005 and 2006.

A total of 433 specimens (n= 228 *P. glauca* and n= 205 *I. oxyrinchus*) were obtained between March 2005 and December 2006 as by-catch from industrial long-line swordfish fisheries off Chile, in a geographic range between 21°-35°S/78°-118°W. Common indexes were used to describe the diet of the predator, following Cortes (1997) percent frequency of occurrence (%F), percent number (%N) and percent per weight (%W). Indexes were calculated for higher groups (i.e. Osteichthyes) and specific prey categories. Index of relative importance (IRI) was calculated (Pinkas *et al.* 1971): $IRI = (\%N + \%W) \times \%F$. IRI percent was also calculated for both broad and specific taxonomic categories of prey group following Cortes (1997). Specimens of *P. glauca* and *I. oxyrinchus* were separated in three groups: small size (Ss), middle size (Ms) and large size (Ls). Hence, individuals of blue shark, which had a total length less than 170 cm, were considered as Ss. Meanwhile, lengths ranged from 170 - 195 cm were considered Ms and when exceeded 195 cm in length were treated as Ls. In the same way, individuals of mako shark less than 180 cm

were considered Ss. Lengths ranged from 180 - 285 cm were considered as Ms and specimens above 285 cm were treated as Ls. The percentage similarity index (PSI): $1 - 0.5 \times (\sum a_i - b_i)$ (according to Whittaker 1952, following Hallacher & Roberts 1985) was used, where 'a' and 'b' are the proportions of IRI of the *i*th category of prey in the diet of the different groups. The range of PSI goes from 0 (no prey in common) to 1 (complete overlap). PSI values were tested using the Wilcoxon Test (*W*) (Lopez 2008) based on the contribution of each prey expressed as %IRI. In order to verify if the number of studied stomachs was adequate, a trophic diversity curve was generated following Ferry & Caillet (1996) and Gelsleichter *et al.* (1999). All statistical analyses were made with R project software (R Development Core Team 2011).

The diversity trophic curve for both sharks showed that the number of analysed stomachs nearly reached the asymptote (Fig. 1), indicating that the number of stomachs was apparently sufficient to study the dietary overlap. On the other hand, stomach with contents was 186 (81.5%) for blue sharks and 129 (62.9%) for mako sharks. The prey list of both sharks can be found in Lopez *et al.* (2009) and Lopez *et al.* (2010). In general terms, the diet of blue sharks and mako sharks was dominated by osteichthyes fishes (72.21% and 86.32% IRI, respectively) following by cephalopods (27.06 and 12.32% IRI) (Table I). The tridimensional representation of the diet (Fig. 2) revealed a specialist feeding strategy on osteichthyes fishes. The remainder preys can be considered rare or accidental food. Similar situation occurred with feeding by sexes (Table I) in which bony fishes and cephalopods were the most important prey. On the other hand, the blue sharks and mako sharks showed similar feeding (PSI = 0.69); furthermore the *W* test corroborated that similarity ($W = 22.5$; $p = 0.8497$). Comparing the diet between sexes of blue sharks, no differences were found (PSI= 0.92; $W=25.0$; $p=1.000$) as well as males and females of mako shark, with a PSI value of 0.98 ($W=30.0$; $p=0.5135$). Table II shows the values of PSI when diets by sex were compared for the two shark species, they presented ranges above 60 % (PSI=0.60) of similarity.

Feeding by size in blue sharks was dominated by osteichthyes (Table III), with 64.48% IRI in Ss; 74.75% IRI in Ms and 73.15% IRI Ls. Cephalopods were the second group in relative importance, with 35.28% IRI in Ss; 20.17% IRI in Ms and 26.40% IRI in Ls. All individuals (Ss, Ms and Ls) of mako short

fin shark showed a feeding dominated by osteichthyes, with 85.43% IRI, 88.98% IRI and 56.23% IRI, respectively. Related with blue sharks, cephalopods were secondary in terms of relative importance, with 13.51% Ss, 10.02% Ms and 43.22% Ls. Marine birds, crustaceans and marine mammals were considered occasional food due the low percentage in relative importance (0.02% IRI, 0.05% IRI and 0.25% IRI,

respectively). Comparing the diet, in blue sharks it was found that all stages were similar in terms of PSI range (Table IV). Similarly, mako shark individuals presented a higher similarity in the diets by stages, as well. Comparing the stages of both shark species, there were no differences in diets, with PSI values above to 0.5.

Table I. Feeding by major group in sexes of *Prionace glauca* and *Isurus oxyrinchus* off Chile, in 2005 and 2006.

| Item | <i>Prionace glauca</i> | | | <i>Isurus oxyrinchus</i> | | |
|----------------|------------------------|------------|------------|--------------------------|------------|------------|
| | Females | Males | General | Females | Males | General |
| | | | %IRI | | | |
| Cephalopods | 25.74 | 22.18 | 27.06 | 6.60 | 7.39 | 12.32 |
| Crustacea | - | 0.01 | >0.01 | 0.02 | - | >0.01 |
| Chondrichthyes | 0.35 | 0.10 | 0.17 | 0.61 | .84 | 0.67 |
| Osteichthyes | 73.69 | 76.63 | 72.21 | 92.62 | 91.77 | 86.95 |
| Reptiles | 0.06 | - | >0.01 | - | - | - |
| Marine Birds | - | - | - | 0.05 | - | 0.01 |
| Marine Mammals | 0.15 | 1.09 | 0.53 | 0.11 | - | 0.02 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 |

Table II. Diet overlap between sexes of blue shark and mako short fin shark off Chile, in 2005 and 2006. Bsh: Blue Shark (*Prionace glauca*) and Msf: Mako short-fin (*Isurus oxyrinchus*). Below diagonal PSI values and above diagonal *p* values from Wilcoxon test.

| | Male Bsh | Female Bsh | Male Msf | Female Msf |
|-------------------|----------|------------|----------|------------|
| Male Bsh | - | 1 | 0.5947 | 0.7974 |
| Female Bsh | 0.9236 | - | 0.7974 | 1 |
| Male Msf | 0.6860 | 0.6310 | - | 0.5135 |
| Female Msf | 0.6714 | 0.6162 | 0.9807 | - |

According to the number of stomachs analyzed, the diversity trophic curve (Fig. 1) closely approaches an asymptote for both sharks. However, addition of new stomachs in futures stomach content analysis should help to a better description of diet and trophic interaction of these sharks. In fact, Ferry & Cailliet (1996) indicate that the number of stomachs analyzed conditioned the asymptote reached in the diversity trophic curve of any predator. Respect to feeding strategy and according to Cortés (1997), both

graphical methods (Fig. 2) for the two shark species show a homogeneous diet and specialized feeding strategy at higher-level groups of preys. Therefore, *P. glauca* and *I. oxyrinchus* could be considered as specialist predators on osteichthyes in this area of the Pacific Ocean. Nevertheless, the feeding strategy of these migratory pelagic sharks might depend on the environmental availability of their prey. Because of migrations and habitat shifts, their food spectrum might increase and/or change (Wootton 1990, Lopez

2008, Lopez *et al.* 2009, Lopez *et al.* 2010). Thus, a predator could be specialized in major food categories without distinguishing between species, particularly if their consuming rate is being influenced by the environment Cortés 1997, Lopez *et al.* 2010). In this study, the blue shark appears as a specialist on osteichthyes (>70 %), which is consistent with studies in different latitudes and years (Tricas 1977, 1979,

Stiwell & Kohler 1982, Kubodera *et al.* 2007, Pardo-Gandarillas *et al.* 2007, Markaida & Sosa-Nishizaki 2010). The mako short fin shark also shows a higher specialization on osteichthyes (>85% IRI), which is similar with other studies on feeding of mako short fin sharks (Stiwell & Kohler 1982, Maia *et al.* 2006, Lopez *et al.* 2009).

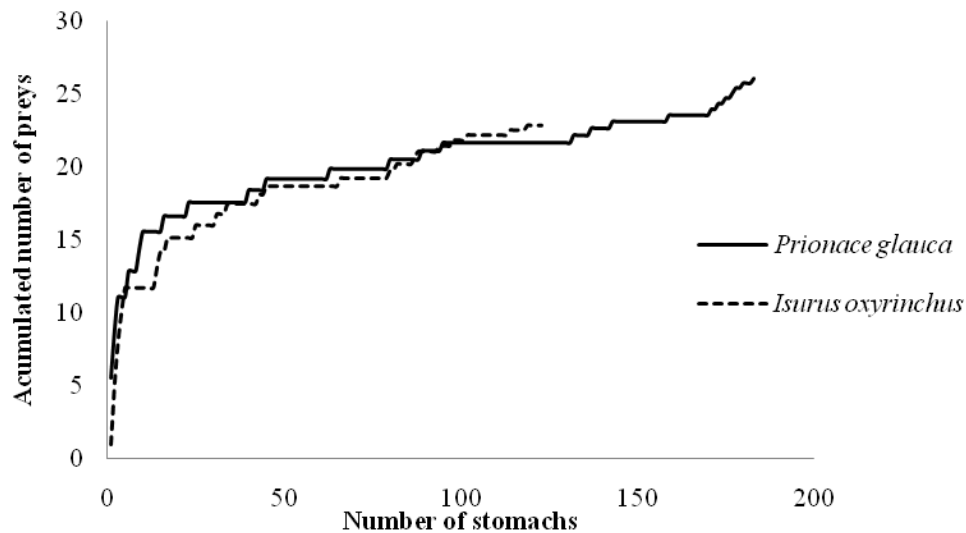


Figure 1. Diversity trophic prey curve for blue shark (*Prionace glauca*) and mako shark (*Isurus oxyrinchus*) off Chile, in 2005 and 2006.

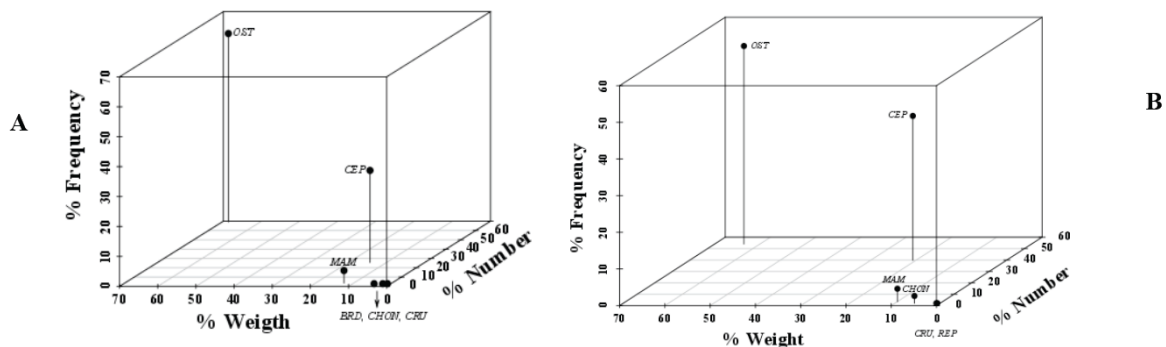


Figure 2. Tridimensional diet representation of *Isurus oxyrinchus* (A) and *Prionace glauca* (B), off Chile, during 2005 and 2006. (OST: Osteichthyes, CEP: Cephalopoda; CHON: Chondrichthyes; CRU: Crustacea; BRD: Marine birds and MAM: Mammalia)

In relation to feeding by intraspecific relationships (sexes and sizes), no differences were found between females and males in the studied species, as well as among sexes of the different species of sharks studied. Previous knowledge on feeding by sexes in blue sharks (Markaida & Sosa-Nishizaki 2010, Lopez 2008, Lopez *et al.* 2010) found no feeding overlap among females and males of *P. glauca*. Studies on feeding by sexes of mako short fin sharks such as Lopez (2008) and Lopez *et al.* (2009) indicate no differences in feeding of females and males. It was

found a high similarity when comparing sexes by species (e.g., male blue sharks vs female mako short fin sharks). This may occur since both shark species present similar feeding strategies on major groups of food. Furthermore, the trophic similarity may occur because of habitat and time-space scale that sharks occupy, expecting some degree of competition. Also, fisheries can affect the trophic interactions of top predators like blue and mako short fin sharks, and change the feeding strategy or producing dietary shifts (Stevens *et al.* 2000).

Table III. Feeding by major group considering maturity stages of *Prionace glauca* and *Isurus oxyrinchus* off Chile, during 2005 and 2006. (Ss: small size, Ms: middle size and Ls: large size)

| Item | <i>Prionace glauca</i> | | | <i>Isurus oxyrinchus</i> | | |
|----------------|------------------------|------------|------------|--------------------------|------------|------------|
| | Ss | Ms | Ls | Ss | Ms | Ls |
| | %IRI | | | | | |
| Cephalopoda | 35.28 | 20.17 | 26.40 | 13.51 | 10.02 | 43.22 |
| Chondrichthyes | 0.16 | - | 0.04 | 0.99 | 0.75 | 0.55 |
| Crustacea | - | 0.63 | - | 0.02 | - | - |
| Marine Birds | - | - | - | 0.05 | - | - |
| Marine Mammals | 0.05 | 3.97 | 0.40 | - | 0.25 | - |
| Osteichthyes | 64.48 | 74.75 | 73.15 | 85.43 | 88.98 | 56.23 |
| Reptiles | 0.03 | - | - | - | - | - |
| Total | 100 | 100 | 100 | 100 | 100 | 100 |

Table IV. Diet overlap between maturity stages of *Prionace glauca* (Bsh) and *Isurus oxyrinchus* (Msf) off Chile, during 2005 and 2006. Below diagonal PSI values and above diagonal *p* values from Wilcoxon test.

| | Ss Bsh | Ms Bsh | Ls Bsh | Ss Msf | Ms Msf | Ls Msf |
|---------------|--------|--------|--------|--------|--------|--------|
| Ss Bsh | - | 0.5211 | 1 | 1 | 0.7874 | 1 |
| Ms Bsh | 0.7761 | - | 0.4206 | 1 | 1 | 0.7874 |
| Ls Bsh | 0.8639 | 0.9066 | - | 1 | 1 | 1 |
| Ss Msf | 0.6719 | 0.6719 | 0.7986 | - | 0.9357 | 0.6752 |
| Ms Msf | 0.6205 | 0.7608 | 0.7512 | 0.9415 | - | 1 |
| Ls Msf | 0.8730 | 0.6529 | 0.7375 | 0.5544 | 0.5020 | - |

On the other hand, relationships among different size showed no differences in the diet of sharks studied. The individuals of blue sharks and mako short fin sharks presented a high similarity between Ss, Ms and Ls, sharing the same proportion of food. Ontogenetic changes through diet are a common pattern in fishes (Wootton 1990). Moreover, most of these ontogenetic changes probably reflect morphological and maturational changes, particularly the increase in mouth size and improvements in locomotive and

sensory abilities (Wootton 1990, Cortés 1997, Abrams 2000, Lopez 2008), and also include age-specific changes in the use of habitat (Lopez 2008).

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