

Preliminary diet analysis of the blue shark *Prionace glauca* in the eastern South Pacific

Análisis preliminar de la dieta del azulejo *Prionace glauca* en el Pacífico suroriental

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Abstract. - The diet of the blue shark *Prionace glauca* off central and northern Chile in the eastern South Pacific, during 2005 and 2006 were dominated by teleost fishes (72.21 %IRI) and cephalopods (27.07 %IRI). The seasonal feeding of blue shark showed as the most important prey diverse teleost fish species. Our findings would confirm that blue shark is a predator with wide trophic spectrum in the eastern south Pacific, although a higher number of stomachs need to be studied.

Key words: Seasonal diets, food habits, Chondrichthyes, Chile

INTRODUCTION

Sharks are believed to have played an important role in aquatic food webs throughout their evolutionary history (Cortes 1999). Although it is widely recognized that many extant shark species are top or apex predators in marine communities, little quantitative information is available on their diets (*e.g.*, Wetherbee & Cortes 2004). The blue shark *Prionace glauca* (Linnaeus, 1758) is an epipelagic highly migratory species that belongs to the family Carcharhinidae (with 12 genus and 53 species) and preferably inhabits waters between 7°-25°C (Compagno *et al.* 2005). Blue shark feeding studies have been done mainly in the north Pacific and Atlantic waters, where the species has presented a wide trophic spectrum (Cortes 1997, 1999), including cephalopods and epipelagic fishes as their most important preys (Cortes 1999). In the south eastern Pacific, the trophic relationships of oceanic fishes (*e.g.*, swordfish, mako shark, etc.) have not been studied, even though, dietary studies have been done for some species (Ibañez *et al.* 2004, Castillo *et al.* 2007, Pardo-Gandarillas *et al.* 2007, Letelier *et al.* 2009). In fact, the research regarding feeding habits in Chilean and the south-eastern Pacific oceanic ichthyofauna have been focused mainly on neritic fishes. This zone is characterized by high production areas as a result of interception of ocean currents or water masses, which in turn created turbulences and noticeable temperature and salinity gradients (Espíndola & Vega 2009). The purpose of the present study was to analyse the diet

of *P. glauca* off the central and northern Chilean coasts during 2005 and 2006.

MATERIAL AND METHODS

A total of 228 (n= 54 females, 118 males) specimens were obtained between March 2005 and December 2006 from industrial long-line swordfish fisheries off Chile as bycatch, in a geographic range between 21°-35°S; 78°-118°W. The total length (TL) and sex of each specimen was registered on board prior to the removal of the stomach, which was stored under freezing conditions after removal. The samples were analysed at the National Museum of Natural History (MNHNC), Santiago, Chile, following Letelier *et al.* (2009).

The prey items in each stomach were identified to the lowest possible taxonomic level, weighted and counted. The prey items cephalopods, fishes, crustaceans, among others, were identified according to Iverson & Pinkas (1971), Mead (1972), Retamal (1981), Roper *et al.* (1984), Wolff (1984), Clarke (1986), Nakamura (1986), Nesis (1987), Roper *et al.* (1988), Voss *et al.* (1998), Jefferson *et al.* (1993) y Márquez (1990) and compared with the MNHNC references collections. Common indices 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) indices were

calculated for broad and specific prey categories. The index of relative importance (IRI) was calculated (Pinkas *et al.* 1971): $IRI = (\%N + \%W) \%F$. Percent IRI was also calculated for both broad and specific taxonomic categories of prey group following Cortés (1997).

Seasonal changes in the diet of blue shark were studied with the percentage similarity index (PSI), proposed by Whittaker (1952) according to Hallacher & Roberts (1985): $PSI = 100 \sum_{i=1}^s \min(a_i, b_i)$, where a and b are the proportions of IRI of the i th category of prey in the diet of *P. glauca* by seasonal differences, and s is the total number of prey categories, in common, of the diet that is being compared. The range of PSI goes from 0 (no prey in common) to 100 (completely overlapping). The dietary overlap between groups was calculated using the Spearman rank correlation coefficient (r_s) (Cortés 1997; González & Oyarzún 2003; López 2008) as described by Fritz (1974). It is based on the contribution of each prey in the diet expressed as %IRI. The null hypotheses, for r_s , indicated a different diet for the compared groups. If r_s were significant, the null hypothesis was rejected, indicating that the diet was similar (Zar 1999). In order to verify if the studied stomach number was adequate, a trophic diversity curve was generated following Ferry & Caillet (1996), Cortes (1997) and Gelsleichter *et al.* (1999).

RESULTS

Of the 228 stomachs of blue shark studied, 172 (75.4 %) contained prey items and 56 (24.6 %) were empty. The lengths ranged from 75 to 491 cm TL. Fifty four stomachs were from females and 118 from males. Eighty six stomachs were collected in 2005 and 142 stomachs in 2006. The diversity trophic curve showed a clear asymptote was not completely reached (Fig. 1), indicating that the number of

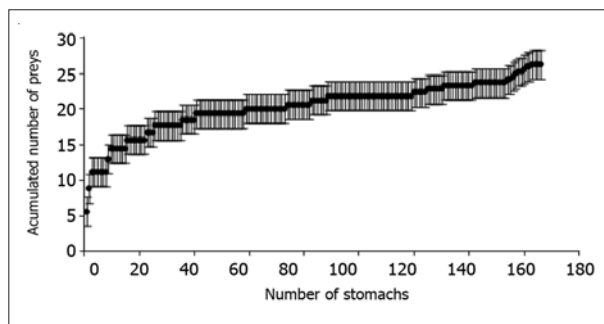


Figure 1. Trophic diversity curve for *Prionace glauca* in the eastern South Pacific off Chile, between March 2005 and December 2006 (bars= standard error) / Curva de diversidad trófica para *Prionace glauca* en el Pacífico suroriental frente a Chile entre marzo de 2005 y diciembre de 2006 (barras= error estándar)

stomachs was not sufficient for the characterized the diet of blue shark, then a higher number of stomach with contents should be analyzed. In the whole seasonal and geographical range, a total of 19 prey items were identified (Table 1). Bony fishes, cephalopods, cartilaginous fishes, crustaceans, marine mammals and marine reptiles were the major categories of prey identified in the diet of *P. glauca*, with fishes and cephalopods being the most important groups (Fig. 2, Table 1). Overall, the most important prey item was the jumbo squid *Dosidicus gigas* (Orbigny) (27.4 %IRI), followed by the butterflyfish *Cubiceps pauciradiatus* (Günther) (21.5 %IRI) and longnose lancetfish *Alepisaurus ferox* Lowe (19.6 %IRI). Less important preys were squid *Todarodes filippovae* Adam, swordfish *Xiphias gladius* L., skipjack tuna *Katsuwonus pelamis* L. and the bottlenose dolphin *Tursiops truncatus* (Montagu) (6.9 %; 6.2 %; 2.8 %; 2.5 %IRI, respectively).

The presence of a marine turtle (*Dermochelys coriacea* (Vandelli)), in one female shark, make the only difference in prey diversity between sexes. Through the different seasons of the year, *P. glauca* showed a diet dominated by bony fishes (> 65 %IRI) followed by cephalopods (< 20 %IRI). The other prey represented less than 5% of the diet (Fig. 3). In austral winter, the butterflyfish *C. pauciradiatus* was the most important item (40.5%IRI), while *D. gigas* (21.6 %IRI) and *K. pelamis* (12.4 %IRI) were secondary in importance. In fall, *A. ferox* (34.2 %IRI) was the most important prey, *D. gigas* (27.7 %IRI) and *X. gladius* (16.1

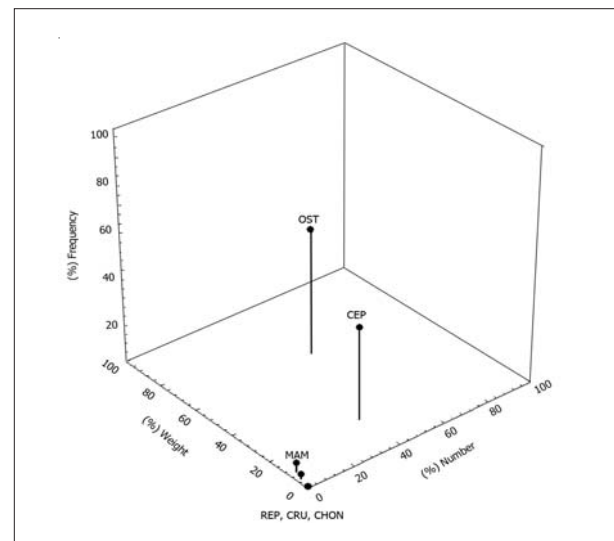


Figure 2. Three dimensional graph of diet composition of *P. glauca* in the eastern South Pacific off Chile, between March 2005 and December / Gráfico tridimensional de la composición de la dieta de *P. glauca* en el Pacífico suroriental frente a Chile, entre marzo de 2005 y diciembre de 2005

Table 1. Diet composition of the blue shark, *Prionace glauca*, in eastern South Pacific off Chile during 2005 and 2006, expressed as percents by number (%N), frequency of occurrence (%F) and weight (%W), and the percent index of relative importance (%IRI) (sample size =172 stomach with contents) / Composición de la dieta del azulejo, *Prionace glauca*, en el Pacífico suroriental frente a Chile durante 2005 y 2006, expresado como porcentajes en número (%N), en frecuencia de ocurrencia (%F) y en peso (%W), y el porcentaje del índice de importancia relativa (%IRI) (tamaño de la muestra=172 estómagos con contenidos)

Item	%N	%F	%W	IRI	%IRI
FISHES					
Chondrichthyes					
Carcharhinidae					
<i>Prionace glauca</i>	0.49	0.51	0.55	0.52	0.03
Lamnidae					
<i>Lamna nasus</i>	0.98	1.01	4.88	5.92	0.32
Chondrichthyes remains*	0.49	0.51	0.21	0.35	0.02
Osteichthyes					
Alepisauridae					
<i>Alepisaurus ferox</i>	11.76	12.12	18.62	368.29	19.64
Bramidae					
<i>Brama australis</i>	2.94	2.53	2.51	13.77	0.73
<i>Taractichthys cf. steindachneri</i>	0.49	0.51	0.25	0.37	0.02
Carangidae					
<i>Trachurus murphyi</i>	1.96	1.52	1.99	5.99	0.32
Gempylidae					
<i>Ruvettus pretiosus</i>	0.98	1.01	2.99	4.01	0.21
Nomeidae					
<i>Cubiceps pauciradiatus</i>	16.18	16.67	8.06	403.97	21.54
Cubiceps remains*	2.94	3.03	0.77	11.24	0.60
Scombridae					
<i>Katsuwonus pelamis</i>	3.92	3.54	10.25	50.11	2.67
<i>Scomber japonicus</i>	0.49	0.51	0.16	0.33	0.02
Scombridae remains*	0.49	0.51	1.14	0.82	0.04
Tetraodontidae					
<i>Arothron sp.</i>	0.49	0.51	0.27	0.39	0.02
Xiphiidae					
<i>Xiphias gladius</i>	5.39	5.56	15.59	116.57	6.22
Fish remains	5.88	6.06	0.90	41.09	2.19
CEPHALOPODS					
Cirroteuthidae					
<i>Cirrothauma sp.</i>	0.49	0.51	0.72	0.61	0.03
Ommastrephidae					
<i>Dosidicus gigas</i>	21.08	20.71	3.78	514.76	27.44
<i>Todarodes filippovae</i>	9.80	10.10	2.94	128.75	6.86
Vampyroteuthidae					
<i>Vampyroteuthis infernalis</i>	0.49	0.51	0.01	0.25	0.01
Cephalopods remains*	7.84	7.58	13.22	159.56	8.51
CRUSTACEAN					
Solenoceridae					
<i>Haliporoides cf. diomedea</i>	0.49	0.51	0.01	0.25	0.01
MAMMALS					
Delphinidae					
<i>Tursiops truncatus</i>	3.43	3.54	9.96	47.34	2.52
REPTILE					
Derموchelyidae					
<i>Derموchelys coriacea</i>	0.49	0.51	0.22	0.36	0.02
Total	100	100	100	1876	100
Total Chondrichthyes	1.96	2.02	5.64	15.35	0.17
Total Osteichthyes	53.92	54.04	63.51	6345.84	72.21
Total Cephalopods	39.71	39.39	20.67	2378.38	27.07
Total Crustaceans	0.49	0.51	0.01	0.25	<0.01
Total Mammals	3.43	3.54	9.96	47.34	0.54
Total Reptiles	0.49	0.51	0.22	0.36	<0.01
Total	100	100	100	8788	100

Table 2. Comparison of the seasonal *P. glauca* diet composition off Chile during 2005 and 2006 using values of diet overlap obtained with the Spearman rank correlation coefficient (r_s) (above diagonal) and level significance (P) (below the diagonal), calculated from the index of relative importance expressed as a percent (%IRI). Samples sizes are given in parenthesis / Comparación de la composición dietaria estacional de *P. glauca* frente a Chile durante 2005 y 2006, utilizando los valores de sobreposición de la dieta obtenida a partir del coeficiente de correlación del rango de Spearman (r_s) (sobre la diagonal) y el nivel de significancia (P) (debajo de la diagonal) calculado del índice de importancia relativa expresado como porcentaje (%IRI). Los tamaños de las muestras están entre paréntesis

Season	Winter (N=50)	Fall (N=60)	Spring (N=56)
Winter		-0.5	0.5
Fall	0.6667		-1.0
Spring	0.6667	0.6667	

%IRI) were the secondary prey items. In spring, the cephalopod *D. gigas* (39.8 %IRI) and the fish *C. pauciradiatus* (37.8 %IRI) dominated as prey, leaving *A. ferox* (10.9 %IRI) as a tertiary food item. According to r_s , the feeding of blue shark varied throughout the three seasons in this study (Table 2). Nonetheless the relative importance of food was more similar in winter and spring (PSI=70%) than in the other seasons.

DISCUSSION

The stomach contents analyses clearly reflect the importance of teleost fishes as an important food item in the diet of blue sharks. Within these fishes, the more important species were *C. pauciradiatus* and *A. ferox*. It is important to note the blue shark predated on other shark species such as juveniles of *Lamna nasus* (Bonnaterre) and also showed cannibalism, but in a lesser degree; however, the presence of juvenile sharks in the stomach contents of *P. glauca* could be due to discard of *L. nasus* and *P. glauca* gravid females which are sending back to the sea, allowing the juveniles became available as a prey. The cephalopods were an important food item for blue shark, mainly jumbo squid *D. gigas*, which was the most significant single item in the diet of this shark. Marine mammals, as well as turtles and crustaceans, were rare or accidental food. The diet of the blue shark represented in this study did not differ from previous studies in other areas, such as Cortes (1999) and Tricas (1977, 1979), the exception is the presence of marine reptiles as a rare food item.

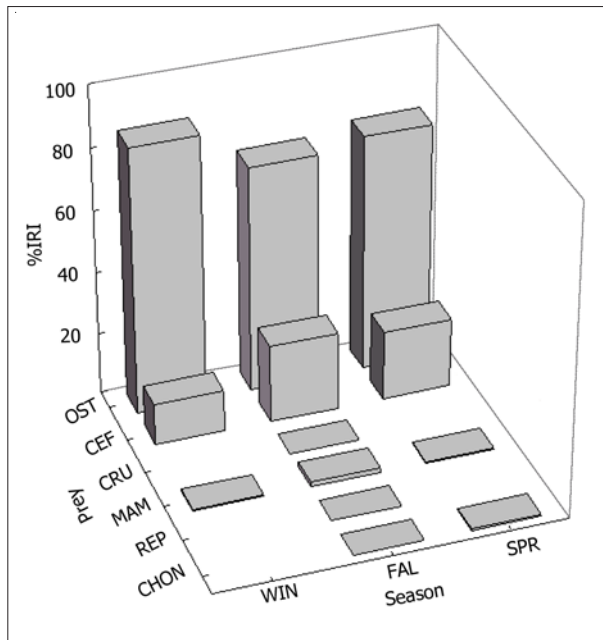


Figure 3. Seasonal variation of food items in the diet of *P. glauca* off Chile, in 2005 and 2006. (OST: teleost fishes, CHON: cartilaginous fishes, CEF: cephalopods, CRU: crustaceans, MAM: marine mammals and REP: marine reptiles. WIN: winter, FAL: fall and SPR: spring) / Variación estacional de las presas en la dieta de *P. glauca* frente a Chile en 2005 y 2006. (OST: peces teleosteos, CHON: peces cartilaginosos, CEF: cefalópodos, CRU: crustáceos, MAM: mamíferos marinos y REP: reptiles marinos. WIN: invierno, FAL: otoño y SPR: primavera)

Although the trophic diversity curve did not reach the asymptote this study represents the first effort to report the feeding of the blue shark off the south eastern Pacific. In the future, more than 172 stomachs should be tested to analyze the diet of blue shark in this area of the South Pacific Ocean.

Following the Cortes (1997) and Wetherbee & Cortes (2004) method, the blue shark has a heterogeneous diet as showed in the great variety of taxa found as food, then *P. glauca* could be considered having a wide trophic spectrum strategy in this area of the Pacific Ocean. Nevertheless, the feeding strategy of these migratory pelagic fishes might depends on the environmental availability of their prey as they have great movements and habitat shifts, so they might have a wide food spectrum (Wootton 1990, Cortes 1997, 1999, Stevens 2008). A predator could be specialized in major food categories without distinguishing between species, particularly if their consuming rate is being influenced (Cortes 1997). The diet of any generalist predator or fish in this case reflects the food that is available in the environment (Ricklefs 1979; Wootton 1990), this means

that feeding of this fishes could be used to infer the relative abundance of the preys found in their stomachs (Smale 1996).

The blue shark diet showed temporal variation. These variations are closely linked to the predator-prey dynamics (Ricklefs 1979, Wootton 1990, Abrams 2000), especially when dealing with highly migratory fishes.

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