Abstract
We describe for the first time the trophic spectrum and diet breadth instead width of the Pacific sierra \textit{Scomberomorus sierra}, in two areas of north-west Mexico. We analyzed a total of 178 stomachs, 131 from Mazatlan, Sinaloa, Mexico, and 47 from Bahia Almejas, Baja California Sur. The index of relative importance (IRI) was used to rank the main food components. The results determined that in these two areas that \textit{S. sierra} is an opportunistic ichthyophagous predator, consuming mainly fish species that form dense schools (families Clupeidae and Engraulidae), as well as cephalopods as a smaller proportion of the food items for this important sport and commercial fish along the north-west Mexico coast.

Zusammenfassung
Zum ersten Mal beschreiben wir hier das Nahrungsspektrum der pazifischen Sierra-Makrele \textit{Scomberomorus sierra} von zwei Gebieten im Nordwesten Mexikos. Wir haben insgesamt 178 Mägen untersucht, 131 aus Mazatlan, Sinaloa, und 47 aus Bahia Almejas, Baja California Sur. Der Index der relativen Bedeutung (IRI) wurde verwendet, um die Hauptnahrungsmittel zu klassieren. Die Ergebnisse zeigten, dass \textit{S. sierra} in diesen beiden Gebieten als Opportunistischer Fischfresser auftritt, der hauptsächlich Fische, die dichte Schwärme bilden (Familien Clupeidae und Engraulidae), zu einem geringeren Anteil aber auch Cefalopoden als Hauptnahrungsmittel für diesen wichtigen Sport- und Handelsfisch im Nordwesten Mexikos konsumiert.

Résumé
Nous décrivons pour la première fois le spectre trophique et la diversité du régime de \textit{Scomberomorus sierra} dans deux zones du nord-ouest du Mexique. Nous avons ausculté un total de 178 estomacs, 131 à Mazatlan, Sinaloa, et 47 à Bahia Almejas, Baja California Sur. L’indice d’importance relative (IRI) a été utilisé pour classer les principaux composants de la nourriture. Les résultats ont démontré que, dans ces deux zones, \textit{S. sierra} est un prédateur ichthyophage opportuniste, consommant de préférence les espèces de poissons qui forment des bancs serrés (familles des Clupeidae et des Engraulidae), ainsi que des céphalopodes dans une proportion moindre du régime de ce poisson, important pour le sport et pour le commerce, le long de la côte nord-ouest du Mexique.

INTRODUCTION
Scombrids (tuna, mackerel, bonito, and sierra) are fish that constitute the base of artisanal fisheries in many tropical and subtropical regions (Allen and Robertson 1994; Fischer et al. 1995). The genus \textit{Scomberomorus} is one of the most important and includes 18 species, of which two can be found in the eastern Pacific Ocean and the Gulf of California: \textit{Scomberomorus sierra} and \textit{Scomberomorus concolor} (Collette and Nauen 1983). The Pacific sierra, \textit{S. sierra}, is a vagile neritic epipelagic species, which forms large schools and migrates seasonally...
for feeding and spawning. On the Pacific Mexican coast the fishing season is from October to June and the average catch of this resource is 4500 annual tons (Fischer et al. 1995). The catch size structure varies between 250 to 780 mm fork length (FL), by fish between 350 to 500 mm LF supports the fishery (Aguirre-Villaseñor et al. 2006). Over 75% of catch comes from the Gulf of California (Montemayor-López and Cisneros-Mata 2000).

Despite its economic importance, there is limited knowledge on the basic biology of the species. There have been studies on taxonomic aspects (Fitch and Flechsig 1949), on distribution and juvenile description (Klawe 1966), monographs on the Scomberomorus genus (Collette and Russo 1984), on the importance of S. sierra in the coastal fishery in the southern Baja California peninsula (Ramírez-Rodríguez 1985; Aguirre-Villaseñor et al. 2006) and on age, growth and stocks differentiation (Medina-Gómez 2006; Ramírez-Pérez et al. 2010). Even fewer are studies referring to food habits; there are only brief reports where it is established that it is a carnivorous species of the pelagic zone that consumes fish species of the families Engraulidae and Clupeidae (Artunduaga 1972; Pérez-Ramos 1994; Montemayor-López and Cisneros-Mata 2000).

Studies focused on increasing knowledge of trophic ecology (prey consumed, diet breadth, and relative importance of each prey species), are useful to understand the functional role of fish in ecosystems (Wootton 1990; Cruz-Escalona et al. 2000). In the present study we characterize the diet of S. sierra on the north-west Mexico coast, in order to provide new and basic knowledge of its feeding ecology.

MATERIALS AND METHODS

Scomberomorus sierra is a fishing resource caught seasonally in the artisanal fishery of the north-west Mexico coast, mainly between October and July (Montemayor-López and Cisneros-Mata 2000). In this fishery, gill nets 160 m long and 3 m deep are used, with a mesh size between 6.98 and 7.62 cm,

![Fig. 1. Study area where specimens of Pacific sierra Scomberomorus sierra were caught, showing locations of Bahía Almejas (BA) and Mazatlán (MZ).](image-url)
which are placed perpendicularly to the coastline at sunset (18:00) and checked regularly.

The data analyzed in this study come from two important fishing places of *S. sierra*. The two localities are separated by the Baja California Sur peninsula (Fig. 1) and are known to contain different fish stocks (Ramírez-Pérez et al. 2010). The sampling period at Mazatlan, Sinaloa (MZ) (23°13' N and 106°26' W) was from November 2001 to June 2002, and at Bahía Almejas, B.C.S. (BA) (24°28' N and 111°41' W), at March 1998 and February 1999. Organisms were collected directly at the landing site and for each individual we recorded fork length (FL), and extracted the stomach (Figs 2-3). The stomach contents were kept in labelled plastic bags, and frozen until analysis.

In the laboratory, the stomach contents were rinsed with water through a 500 µm steel sieve to remove fluid and fine material and the wet weight of empty stomachs were recorded to the nearest 0.1 g. For the qualitative analysis, prey species were separated and identified to the lowest taxonomic level possible, depending on the degree of digestion. Separation and identification were done using a stereoscopic microscope and specific taxonomic keys. Vertebral characteristics (e.g. counts, number, and position) were used to identify fish remains using keys by Clothier (1950), Monod (1968) and Miller and Jorgensen (1973) (Arizmendi-Rodríguez et al. 2006). For cephalopods, due to rapid digestion of soft body parts, we used the mandibular apparatus (beak) for identification; for this particular group we followed the work by Wolff (1984). Laboratory reference collections at CICIMAR-IPN provided additional support in the identification of fish and cephalopods.

Cumulative prey curves were used to determine if an adequate number of stomachs had been sampled to characterize the diet, according to the methodology proposed by Jiménez-Valderde and Hortal (2003). We randomized (100 times) the observed data matrix of the stomach number (unit effort) versus accumulated prey items to obtain a curve of species (using the EstimateS program). The sample size was considered adequate when the curve was asymptotic.

Diet was analyzed using three methods for each prey taxon following Hyslop (1980): The percentage frequency of occurrence (%OF), referred as the frequency of occurrence of prey items within the total number of stomachs with food:

\[
\text{OF} (%) = \frac{\text{No. of stomachs including a prey item}}{\text{No. of stomachs with food}} \times 100
\]

The numerical percentage of abundance (%N), referred as the prey item abundance within the total number of prey items identified in the total number of stomachs with food:

\[
\text{N} (%) = \frac{\text{No. of prey items}}{\text{Total No. of prey items}} \times 100
\]

The gravimetric percentage (%W) is the wet

<table>
<thead>
<tr>
<th>Prey species</th>
<th>OF</th>
<th>%OF</th>
<th>N</th>
<th>%N</th>
<th>W</th>
<th>%W</th>
<th>IRI</th>
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<td>2</td>
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<td>4</td>
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<td>14.81</td>
<td>13.63</td>
<td>68.53</td>
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<tr>
<td>Anchoa spp.</td>
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<td>38</td>
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<td>40.67</td>
<td>37.42</td>
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<td>0</td>
<td>14.25</td>
<td>13.11</td>
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<tr>
<td>TOTAL</td>
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<td>64</td>
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<td>108.69</td>
<td>100.00</td>
<td>5820.90</td>
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weight of prey items found within the total wet weight of stomachs with food:

\[ W(\%) = \left( \frac{\text{Weight of prey items}}{\text{Total weight of prey items}} \right) \times 100 \]

The hierarchization of food items was established using the Index of Relative Importance (IRI) of Pinkas et al. (1971), which provided an optimal balance of the three methods:

\[ \text{IRI} = \% \text{OF} \times (\% \text{N} + \% \text{W}) \]

The values of IRI were expressed in percentage to facilitate the comparison with others studies (Cortés et al. 1996):

\[ \text{IRI} (\%) = \left( \frac{\text{IRI}}{\sum \text{IRI}} \right) \times 100 \]

By using the absolute values of the numeric method, the diet breadth was calculated using the standardized Levin's index (Hurlbert 1978; Krebs 1989).

\[ B_i = \frac{1}{n-1} \left( \frac{1}{\sum} \frac{p_{ii}^2}{p_{ii}} - 1 \right) \]

Where \( B_i \) is Levin's index for the predator \( i \); \( p_{ii} \) is the proportion of the diet of predator \( i \) that is made up of prey \( j \); and \( n \) is the number of prey categories.

The index values range from 0 to 1. Low values (< 0.6) indicate a specialist predator that uses few prey items and prefers certain prey; high values (≥ 0.6) indicate a generalist predator that uses all resources without preference (Labropoulou and Eleftheriou 1997).

RESULTS

We analyzed a total of 178 stomachs, 131 from MZ, and 47 from BA. The mean length of organisms sampled from MZ was 386±90 mm FL (255-620 mm interval size) and from BA was 473±104 mm FL (330-690 mm interval size). The percentage of stomachs containing food was 44% for MZ, and 68% for BA.

The prey species accumulation curve showed enough samples to characterize the diet of \( S. \sierra \), in the two sampling sites (Figs 4-5). For the MZ zone the trophic spectrum of \( S. \sierra \) included a total of five prey items. According to the \( \%N \), the most important prey were \( \text{Anchoa spp.} \) comprising 59.3%, followed by \( \text{Opisthonema spp.} \) and \( \text{Etrumeus teres} \), both species comprising 15.6% of stomachs. Using \( \%W \), \( \text{Anchoa spp.} \) and \( \text{Opisthonema spp.} \) represented over 50% of the total weight (108.69 g). According to the \( \%\text{OF} \), \( \text{Anchoa} \) were present in 46.5% of stomachs, followed by \( \text{Opisthonema} \) and \( \text{E. teres} \) with 15.5%. According to IRI values, \( \text{Anchoa} \) was the most important prey with 77.4%, followed by \( \text{Opisthonema} \) (9.9%) and \( \text{E. teres} \) (7.7%) (Table I; Fig. 6). The diet breadth value was low (\( \text{Bi} = 0.37 \)), which suggests that the trophic behaviour of \( S. \sierra \) in this zone is as a specialist.

For BA we counted a total of five prey species.

Fig. 2. From the beach to consumer. Fresh \( Scomberomorus \) \( \text{sierra} \), on ice, together with other species, waiting for local consumers to buy them. Photo by X. G. Moreno-Sanchez.

Fig. 3. \( Scomberomorus \) \( \text{sierra} \) from the market, undergoing dissection for stomach contents. Photo by X. G. Moreno-Sanchez.
According to %N, the most important prey items were Loligo spp. (29.79%), Anchoa nasus (27.66%) and Anchoa ischana (25.53%), while using the %W, Anchovia macrolepidota and Loligo spp. represented >50% of consumed biomass. According to the %OF, the most frequent prey was A. ischana (37.5%), followed by A. nasus (31.2%). The IRI indicated that A. ischana was the most important prey (31.05%), followed by Loligo spp. (29.9%) and A. nasus (24.3%) (Table II; Fig. 6). The diet breadth of S. sierra in this zone also indicated a specialist behaviour (Bi = 0.50).

**DISCUSSION**

In a summary of studies on the diet of S. sierra in the eastern tropical Pacific, Fischer et al. (1995) reported that adult S. sierra fed on small pelagic fish, especially anchovies (Anchoa and Centregaulis) and sardines (Opisthonema). In the Colombian Pacific, Artunduaga (1972) reported that S. sierra is a carnivorous fish located on the higher levels of the food chain, whose existence depends mainly on planktophagous fish. For the Mexican Pacific, Pérez-Ramos (1984) and Lizárraga-Rodríguez (1984) reported that off the coasts of Mazatlan and Nayarit, Mexico, S. sierra fed on anchovies (Anchovia macrolepidota, Anchoa spp., Ctenogaulis mysticus) and sardines (Opisthonema spp.). In the present study, results show that S. sierra is a carnivorous ichthyophagous predator in the coastal pelagic zone, consuming mainly species from the families Clupeidae and Engraulidae, and a lower proportion of cephalopods (squid).

Related species as Scomberomorus cavalla and Scomberomorus regalis from the western coast of India fed on fish of the families Carangidae (Caranx) and Engraulidae (Harengula), prey species inhabiting the coastal pelagic zone (Randall 1967). On the Florida coast, S. cavalla and S. maculates fed mainly on clupeiform fish (anchovies and sardines), and less so on invertebrate species (shrimp and squid) (Naughton and Saloman 1981).

Off the eastern coast of the Malaysian peninsula, S. commerson fed on carangid fishes (Decapterus), scombrids (Rastrelliger) and barracuda (Sphyraena) (Bachok et al. 2004). This same species fed on engraulids (Engraulis encrasicolus) and clupeids (Sardina pilchardus) off the Mediterranean coast of Egypt (Bakhoum 2007). According reports, it is evident that the diet of species of the genus Scomberomorus is very similar and is directly related to the prey species that inhabit the coastal pelagic zone.

Results in this study are very similar to those reported for other species the same genus, which suggests that their main prey items are species of the families Engraulidae and Clupeidae. Their importance in the diet is due to those species being in the same habitat as their predator, forming dense schools, presenting small sizes and being easy to ingest (Naughton and Saloman 1981). A good representative example of this is A. macrolepidota, an anchovy that is considered abundant in the Mexican Pacific coast (Yáñez-Arancibia 1978; Fischer et al. 1995).

According to Levin’s index, S. sierra was categorized in the two sampled zones as a predator with a specialist trophic behaviour, since its diet breadth was

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**Table II.** Summary and methods used to analyze S. sierra diet in Bahía Almejas (BA), Baja California Sur. OF occurrence frequency method, N numeric method, W gravimetric method, and IRI index of relative importance.

<table>
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<tr>
<th>Prey species</th>
<th>OF</th>
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<th>%W</th>
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<tr>
<td>Loligo spp.</td>
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<td>31.25</td>
<td>14</td>
<td>29.79</td>
<td>101</td>
<td>23.17</td>
<td>1654.76</td>
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<td>15.62</td>
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Xchel G. Moreno-Sánchez, Casimiro Quiñonez-Velázquez, Leonardo A. Abitia-Cárdenas, and Jesús Rodríguez-Romero
narrow and its food spectrum included few species. In the two sampled zones there was a marked preference for one or two prey species. Also, a specialist trophic behaviour has been reported for *S. commerson* off the eastern coast of the Malaysian peninsula and the Egyptian Mediterranean coast (Bachok et al. 2004; Bakhoum 2007). Off Malaysia there were eight food components of which only three represented over 75% of the diet, while for Egypt there were five food components, of which one species, *Engraulis encrasicolus*, represented 95% of the diet.

The *Bi* values in the present study suggest that on the Mexican north-west Pacific coast, *S. sierra* shows an opportunistic behaviour (plastic predator), consuming a small number of prey species - the most available and abundant epipelagic prey. This trophic behaviour coincides with the definition of an opportunistic predator by Gerking (1994): a species that has the capacity to feed on prey that are unusually abundant in the environment.

Other predators present in the study area showing a similar diet to *S. sierra* are the roosterfish *Nematistius pectoralis*, sailfish *Istiophorus platypterus*, sea lion *Zalophus californianus*; all predators located on a similar

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**Fig. 4.** Randomized cumulative prey curve for *S. sierra* in MZ. *H'*, Shannon–Wiener diversity; Max, maximum diversity; Min, minimum diversity; CV, coefficient of variation.

**Fig. 5.** Randomized cumulative prey curve for *S. sierra* in BA. *H*', Shannon–Wiener diversity; Max, maximum diversity; Min, minimum diversity; CV, coefficient of variation.
trophic level (Fischer et al. 1995; Rosas-Alayola et al. 2002; Espinosa de los Reyes-Ayala 2007; Rodríguez-Romero et al. 2009). This could imply a possible interspecific competition, for food resource distribution. In most cases where similar diets are reported, there is a high abundance of food. When the resource is not abundant, other factors come into play, such as spatial and temporal segregation, as well as trophic plasticity of the species (Cruz-Escalona et al. 2000). In the present case the species fed on prey that presented a high availability and abundance on the north-west Mexico coast. We conclude that the Pacific sierra S. sierra is an opportunistic ichthyophagous predator in the coastal epipelagic zone, which has an impact on species that form dense schools (Anchoa and Eudinostomus species).

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