THE FOOD OF *SELENE PERUVIANA* (ACTINOPTERYGII: PERCIFORMES: CARANGIDAE) IN THE SOUTHERN GULF OF CALIFORNIA

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Tripp-Valdez A., Arreguín-Sánchez F., Zetina-Rejón M.J. 2012. The food of Selene peruviana (Actinopterygii: Perciformes: Carangidae) in the southern Gulf of California. Acta Ichthyol. Piscat. 42 (1): 1–7.

Background. The food and feeding habits of a fish are important for understanding not only the fish biology but also the role played by the species in the ecosystem. The Peruvian moonfish (known also as Pacific moonfish), *Selene peruviana* (Guichenot, 1866), is a relatively abundant species, with its biology poorly known along the Mexican Pacific zone. Therefore, the aim of this study was to determine the principal food items of the Peruvian moonfish by using stable isotopes and the stomach content analysis.
Materials and methods. We analyzed stomachs of 204 moonfish collected by a shrimp fishing boat along the coast of Nayarit and south of Sinaloa, Mexico from September to March, within 2006–2007. We also took 11 muscle samples of moonfish and some organisms being potential prey items for stable isotope analysis. Examining the stomach contents we determined the most important prey species using the geometric index of importance. We also determined the feeding strategy of this predator using Amundsen plots and Levin's index and finally we calculated the trophic position. We also determined the principal preys using stable isotopes analysis along with mixing models, and based on those values we calculated the trophic position.
Results. The stomachs of *Selene peruviana* contained chiefly engraulid fishes and crustaceans. The stable isotopes analysis (SIA) helped to identify partly digested material as representing crustaceans of the family Portunidae. The trophic position found by both methods was between 3.7 and 3.9 and we also determined that this fish tended to feed near the coast.
Conclusion. *Selene peruviana* is an opportunistic predator that consumes preys that are abundant in the zone. The stable isotopes analysis proved to be an efficient tool supplementing the stomach content analysis and helping to identify also partly digested items.

Keywords: *Selene peruviana*, feeding habits, stable isotopes, mixing models

INTRODUCTION

The fish family Carangidae includes a relatively large number of commercially important species. These species are used primarily for human consumption. They are exploited in commercial fisheries using several gear types, such as trawls, purse nets, traps, and lines. The Peruvian moonfish, (known also as Pacific moonfish), *Selene peruviana* (Guichenot, 1866), is a benthopelagic species that generally forms schools near the bottom and is found in coastal waters as deep as 50 m (Fischer et al. 1995). The species is found from southern California to Peru. In contrast with other carangids, such as the species of the genus *Caranx*, the Peruvian moonfish has little commercial value and is marketed as a third-class fish (Espino-Barr et al. 2004).

In Mexico, this species frequently appears as bycatch in the shrimp trawl fishery (Madrid-Vera et al. 2007), but its basic biology in the Mexican Pacific zone is not well understood. Its feeding habits in the Pacific from Colombian waters were described by López-Peralta and Arcila (2002). Feeding habits and prey–predator relations may help to characterize the role played by a fish species in the ecosystem. For this purpose, the analysis of the fish stomach contents is generally the most frequently used technique. This method can yield results of high level of taxonomic resolution, but only on recently ingested prey. It represents a snapshot of the food consumed by the predator. Moreover, soft-bodied organisms in the diet are difficult to identify, due to their rapid digestion (Hyslop 1980).

An alternative approach to the study of trophic relations is the use of stable isotope analysis (SIA) to examine the tissues of the predators and prey (Hobson 1999). The stable isotopes used in this analysis are nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) because both elements are

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derived exclusively from the diet (Gearing 1991). The $\delta^{13}C$ isotopes present a minimum amount of enrichment from the prey to the consumer (Deniro and Epstein 1981). This information serves to identify the original source of carbon in the trophic web. Using this approach, it is possible to determine whether two organisms share similar feeding areas. The $\delta^{15}N$ presents a major amount of enrichment. This information allows the estimation of the trophic position or trophic position of the predators and is useful for analyzing the structure of the food web (Minagawa and Wada 1984). Furthermore, SIA can be used along with mixing models that allow the determination of the prey-specific contribution to the diet of a predator (Phillips and Gregg 2003). However, these models require previous knowledge of the potential prey consumed by a predator. For this reason, the combined use of SIA and stomach content analysis is useful for achieving higher precision in identifying the diet of a species. The chief objective of this study is to determine the principal food sources of the Peruvian moonfish by using SIA and stomach content analysis.

MATERIALS AND METHODS

The study area was the coastal area of Nayarit and southern Sinaloa, Mexico between 21°54′N, 106º03′W and 21°09′N, 106°02′W (Fig. 1). In the shallow areas of this region, the sediments are sandy and coarse grained, whereas in deeper zones the sediments are composed of sandy-silt grains (De la Lanza-Espino 1991).
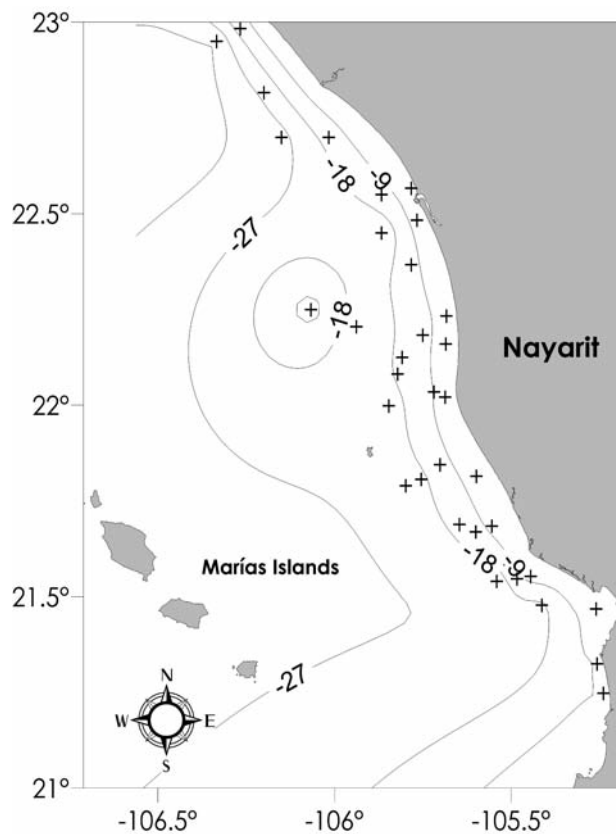

Fig. 1. Study area on the Southeastern Gulf of California, Mexico; + signs indicate sampling sites

The moonfish were collected within 2006–2007, during the shrimp fishing season, which ran from September through March. The specimens were measured (fork length) and the stomachs were extracted and preserved in formalin (10%) or frozen. For the SIA, a sample of muscle was taken from the dorsal region and immediately frozen. In addition, samples of fish and invertebrates that were considered to be potential prey were collected for SIA. We also obtained samples of the muscle of the prey found in the stomach contents of the moonfish. In all cases, the samples were frozen for further isotopic analysis.

Stomach content analysis. We analyzed the stomach contents by identifying the prey to the lowest possible taxonomic level. The wet weights, numbers, and frequencies of ocurrence of prey items were recorded. The preys were grouped depending on the amount of digestion that had occurred. The highly digested residues of organisms were pooled using categories of fish, crustaceans, and mollusks (Hyslop 1980). The importance of prey was determined with Amundsen plots (Amundsen 1996) and the geometric index of importance (GII) (Assis 1996). The GII is based on the weight (*W*), number (*N*) and frequency of ocurrence (FO) values, which are expressed as percentages of the total prey found in the stomachs (Stevens et al. 1982).

The geometric index of importance (GII) was calculated using the equation

$$GIIj = \left(\sum_{k=1}^{n} Vk \right) j / \sqrt{n}$$

where GII is the index of geometric importance, *Vi* is the sum of the *W*, *N*, and FO percentages per prey category *j* and *n* is the number of this values used (3).

To calculate the trophic position (TP) of the moonfish, we used the formula proposed by Christensen and Pauly (1992):

$$TP = 1 + \sum_{j=l}^{n} DC_{ij} \cdot TPj$$

In this equation, DC_{ij}, the diet composition, represents the proportion of prey type j in the diet of predator i. TP*j* is the trophic position of the prey, obtained from FishBase (Froese and Pauly 2011) and *n* is the number of groups in the diet of predator i. In this case, the proportions of prey types in the diet of *S. peruviana* were based on their relative weights.

The breadth of the trophic niche of the moonfish was estimated using the Levins index (Krebs 1999). The values of this index range from 0 to 1. Values close to 0 indicate a specialist predator, and values close to 1 indicate a generalist predator. The index is calculated using the equation

$$B_i = \frac{1}{n-1} \left(\frac{1}{\sum_j p_{ij}^2} - 1 \right)$$

where B_i is the breadth of the trophic niche, P_{ij} is the proportion of the diet of predator *j* represented by prey *i* and *n* is the total number of prey items.

Stable isotopes analysis. The muscle samples of the moonfish and its prey were dried at 50ºC for 24 h, the preys were obtained from the stomach contents and we

selected only those with very low levels of digestion. Prior to drying, the samples of prey were washed with distilled water to remove any gastric acid. After drying, the samples were ground to a fine powder using an agate mortar. The isotopic analysis was performed in the Xerais de Apoio á Investigación (SXAIN), Universidade da Coruña using a ThermoFinnigan FlashEA 1112 elemental analyzer connected to a Finnigan MAT Delta Plus isotopic-ratio mass spectrometer with a FLO II interface. The isotopic ratios were estimated using the following equations:

$$\delta X = \frac{R_{Sample} - R_{Standard}}{R_{Standard}} \cdot 1000$$

where δX is the difference in the isotopic composition between the sample and the standard in parts per thousand (‰) and R is the ratio of the heavier to the lighter isotope (i.e., $^{13}C/^{12}C$, $^{15}N/^{14}N$). The standard for $\delta^{13}C$ corresponds to PeeDee Belemnite (PDB), while the standard for $\delta^{15}N$ is atmospheric nitrogen.

The presence of lipids in samples can enrich values of $\delta^{12}C$ and affect the values of $\delta^{13}C$. For this reason, we used an arithmetic correction (Post et al. 2007):

$$\delta^{13}C_{corrected} = \delta^{13}C_{sample} - 3.32 + 0.99 \cdot C:N$$

where $\delta^{13}C_{sample}$ is the value obtained directly from the sample and $C:N$ is the carbon-nitrogen proportion found in the sample. These corrected values provide an estimate of normalized $\delta^{13}C$ without the effect of lipids and are comparable to values of $\delta^{13}C$ after a chemical extraction (Post et al. 2007, Logan et al. 2008).

To compare the isotopic results with those obtained from the stomach contents, we used the mixing model proposed by Erhardt (2009) with SISUS software to convert the isotopic values to values representing the relative contribution of the food type to the diet. The model applies a Bayesian approach that uses the values of the carbon and nitrogen isotopes to calculate the most probable contribution of the different sources (prey) to the mix (predator). The results of this analysis are presented as distributions of the percentage of importance in the diet, which ranges from 1% to 99%. Prior to the analysis, we corrected the isotopic fractionation (enrichment) value of the predator by subtracting 2.3‰ from the values of $\delta^{15}N$ (mean isotopic shift or fractionation value found by McCutchan et al. 2003) to eliminate the effect of the metabolic fractionation that occurs from one trophic position to another. The isotopic values of some potential prey types that appeared to be important in the stomach contents were also included in the model to determine the importance of these prey types at an assimilation level. For this purpose, we defined seven groups of prey items. Taxonomically related preys with similar isotopic values were placed in the same category. These groups, therefore, are formed by species with similar diets. This approach was taken because the use of many different prey items with similar isotopic values does not yield a feasible solution to the mixing model (Phillips et al. 2005).

We also computed the trophic position using the values of $\delta^{15}N$ and the equation proposed by Post (2002):

$$TP = \lambda + \frac{\delta^{15}N\_Secondary\_consumer - \delta^{15}N\_base}{\Delta n}$$

where λ is the trophic position of the organism used to estimate the $\delta^{15}N\_base$ and Δn is the enrichment in $\delta^{15}N$ per trophic position (Post 2002). The species selected for use as an estimate of $\delta^{15}N\_base$ was a Processidae shrimp. This shrimp has a trophic position of 2 and is abundant in the area. A value of 2.3‰ was assumed for the $\delta^{15}N$ isotopic enrichment (McCutchan et al. 2003).

RESULTS

Stomach content analysis. We collected 208 moonfish stomachs, 114 of which contained food. The collected moonfish ranged from 8.5 to 26.5 cm in fork length (FL) (Fig. 2). The size and age at first maturity of *Selene peruviana* are not known. However, because *S. setapinnis*, a related species from the eastern central Atlantic, reaches sexual maturity at a total length of 21.5 cm (19 cm FL) (Bastos et al. 2005), we assumed that the majority of the moonfish collected were juveniles. We identified 15 prey items, including nine crustaceans and five fish, in the stomach contents that we examined (Table 1).
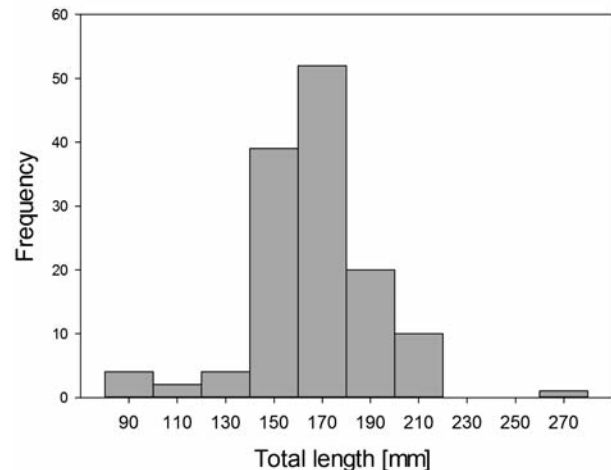

Fig. 2. Length frequency distribution of *Selene peruviana*, from the Southeastern Gulf of California, Mexico, used for stomach content analysis

The Amundsen plots (Amundsen et al. 1996) indicated that engraulid fishes were the most important diet component based on their frequency of occurrence (FO) and prey-specific abundance (Table 1). Likewise, the geometric index of importance (GII) also identified engraulids as the most important prey followed by ogyridid crustaceans and the remains of crustaceans that could not be identified at the species level because of their advanced state of digestion. Secondary prey items included shrimps *Processa* spp., the remains of fish, other unidentifiable organic matter and euphausiid crustaceans. The other prey items were considered to be occasional or rare (Table 1).

Trophic spectrum of the Pacific moon fish *Selene peruviana* from the southeastern Gulf of California, Mexico, expressed in absolute and relative values

	Prey item		FO	%FO	N	%N	W	%W	GII	PSA	Pref
Crustacea	Natantia	Ogyrididae gen. spp.	13	11.40	254	35.93	0.24	0.27	154.3	10.7	P
		Penaeidae gen. spp.	1	0.88	1	0.14	0.01	0.01	1.2	0.8	O
		Processa spp.	4	3.51	26	3.68	0.41	0.47	17.6	3.3	S
		Euphausiidae gen. spp.	2	1.75	13	1.84	0.02	0.02	8.7	1.7	O
	Brachyura	Brachyura megalops	1	0.88	1	0.14	0.01	0.01	1.2	0.8	O
	Copepoda	Copepoda gen. spp.	1	0.88	1	0.14	0.01	0.01	1.2	0.8	O
	Stomatopoda	Squillidae	1	0.88	1	0.14	0.18	0.20	1.3	0.8	O
	Other	Zoea	1	0.88	1	0.14	0.01	0.01	1.2	0.8	O
		Crustacean remains	17	14.91	118	16.69	1.07	1.22	78.6	14.0	P
Actinopterygii	Engraulidae	Engraulidae gen. spp.	59	51.75	257	36.35	78.81	89.55	227.9	48.8	P
		Engraulis mordax	1	0.88	6	0.85	2.18	2.48	5.3	0.8	O
		Anchoa spp.	2	1.75	5	0.71	2.46	2.80	5.5	1.7	O
	Clupeidae	Clupeidae gen. spp.	1	0.88	3	0.42	0.46	0.52	2.6	0.8	O
		Fish remains	10	8.77	13	1.84	1.03	1.17	13.9	8.3	S
Other		UOM	7	6.14	7	0.99	1.11	1.26	8.7	5.8	O

FO = frequency of occurrence, N = number, W = weight; GII = geometric index of importance; PSA = prey specific abundance (Amundsen 1996); Pref = diet preference code: P = preferential prey, S = secondary prey, O = occasional prey; UOM = Unidentified organic matter.

The trophic position determined based on the stomach contents was 3.72. The Levins index (B_i) reached the value of 0.17, which indicates that *S. peruviana* tends to be a specialist- or opportunistic predator that consumes preys abundant in the area.

Stable isotopes. We used 11 samples of moonfish muscle from fish ranging from 10 to 21 cm TL. We found values of δ^{15}N from 13.2‰ to 17.2‰ with an average of 15.4‰. The values of δ^{13}C ranged from –17.71‰ to –15.47‰ with an average of –16.5‰ (Table 2). The values for both isotopes were normally distributed (Kolmogorov–Smirnov test, $P > 0.2$).

The mixing models resulted in very variable feasible contributions for mostly all preys to the diet of *S. peruviana* as shown in Figs. 3 and 4, Table 2. Except for small portunids, the rest of the preys could contribute from very lower to around 50% of the diet. However most probable contributions are in the range of 1% to 10% as indicated by the frequency values.

The estimated trophic position was 3.9, which is a value close to that found by stomach contents analysis. The trophic positions for all prey types ranged from 3.6 to 1.5. The highest value was for *Opisthonema libertate* and the lowest value was for zooplankton.

DISCUSSION

The trophic composition found for *Selene peruviana* in the Mexican Pacific was similar to that found by López-Peralta and Arcila (2002) in the Colombian Pacific. The latter authors reported 15 prey types in the fish stomach contents. They also found that the main prey were engraulid fishes, which represented 35% of the diet. In this study, we found that engraulids represented 89% of the diet based on in the stomach content weight analysis. Both studies reported crustaceans associated with the bottom, such as shrimps, as secondary prey. Other crustaceans had a tertiary level of importance. Other species of the genus *Selene* have been reported to have feeding habits similar to those of *S. peruviana*. These species feed on small fish and crustaceans. López-Peralta and Arcila (2002) found that *Selene brevoortii* (Gill, 1863) in the Colombian Pacific feeds primarily on small fishes of the family Batrachoididae, shrimps, and benthic crabs. Hobson (1968) reported that *S. peruviana* in the Gulf of California preyed on anchovy-like fishes and on unidentified crustaceans. Similarly, the diet of *Selene setapinnis* (Mitchill, 1815) and *S. dorsalis* (Gill, 1863) in northwestern African waters is based on small fishes and crustaceans (Le Loeuff and Intés 1973, da Silva Monteiro 1998).

The results obtained from mixing models through SIA were not enough conclusive, probably due to the high number of sources (preys) and the low number of stable isotopes used in the analysis, furthermore the isotopic values of the preys used in the analysis were relatively similar between them (Fig. 4) making difficult to the mixing models define which is the most important prey (Newsome et al. 2007). However, the analysis suggests that stomach content results are within the range of feasible contributions of each prey.

In this study, based on the stomach contents analysis and partially on SIA (the distribution of feasible diet proportion were not well constrained limiting our conclusions), we found that engraulids were a major component of the diet; several species of Engraulide have been reported to be relatively abundant in the Gulf of California (Cisneros-Mata et al. 1991). Sierra et al. (1994)

reported that *S. peruviana* has a small mouth and well developed stomach muscles. Such morphological adaptations are suitable for the consumption of prey with a low and elongate body, such as engraulid fish and some crustaceans, like the ones identified during this study.

Studying stomach contents we found that crustaceans were after the fish one of the most important preys, where the ogyridid shrimps were the second most important prey. The SIA indicated that portunid crabs could also be an important prey in the diet of *S. peruviana* These crabs
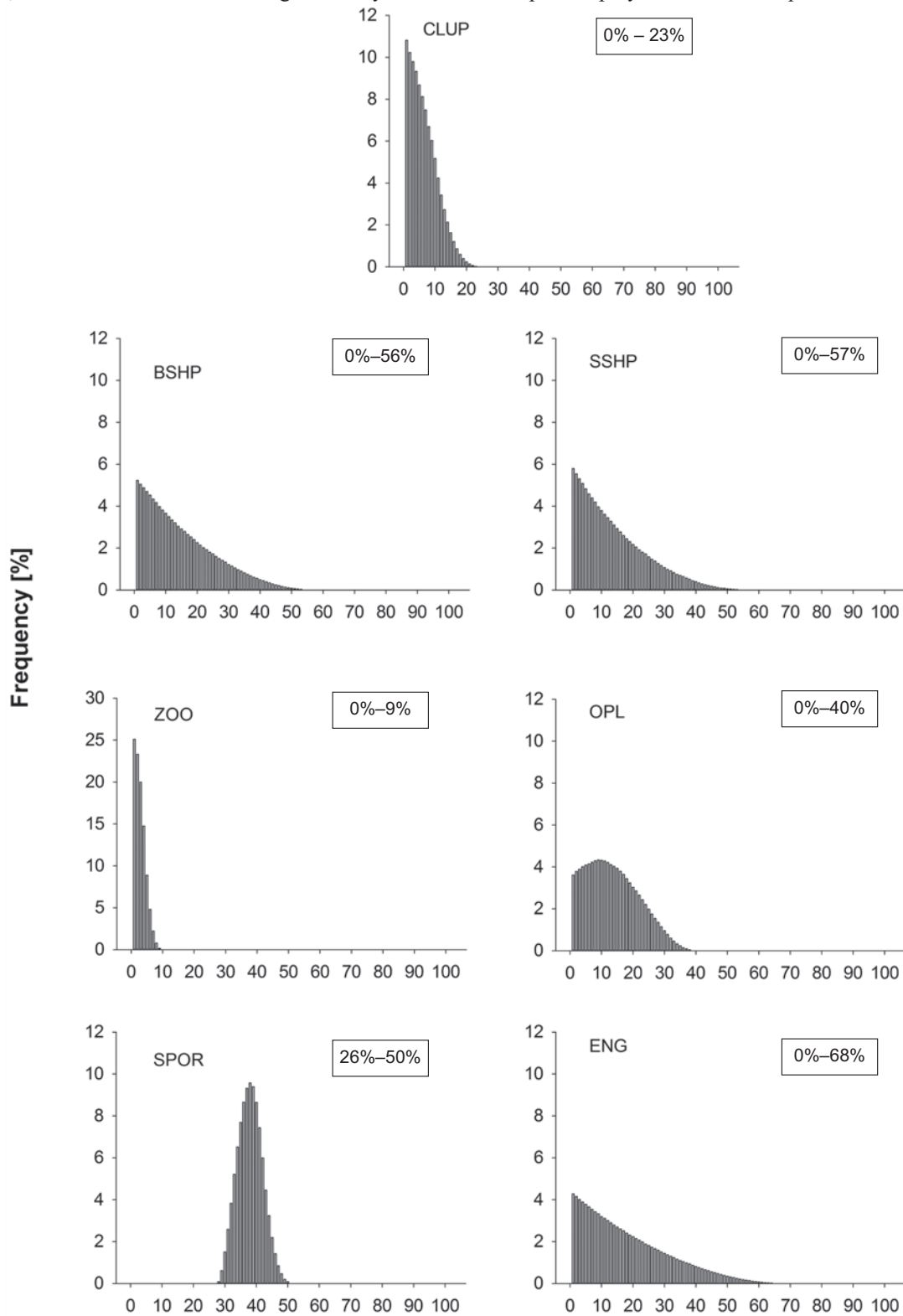

Fig. 3. Feasible contributions of 7 food sources to isotopic signatures of *Selene peruviana*, from the Southeastern Gulf of California, Mexico, using mixing models, values in boxes: 1% to 99% range of source contributions; ENG = Engraulidae, CLUP = Clupeidae, OPL = *Ophistonema libertate*, BSHP = big shrimp, SSHP = small shrimp, SPOR = small portunids, ZOO = zooplankton

Table 2

Values of $\delta^{15}N$ and $\delta^{13}C$ of *Selene peruviana*, from the southeastern Gulf of California, Mexico and its prey items, with indication of the diet contribution

Species or higher taxon		$\delta^{15}N$	$\delta^{13}C$	% Diet contribution
Selene peruviana		15.47 ± 0.97	−16.53 ± 0.66	
Prey item	ENG	13.62 ± 0.64	−16.81 ± 0.64	0–68
	CLUP	11.60	−18.16	0–23
	OPL	14.90 ± 0.37	−16.90 ± 0.60	0–40
	BSHP	13.82 ± 1.19	−17.14 ± 0.47	0–56
	SSHP	13.10 ± 0.98	−17.12 ± 0.45	0–57
	SPOR	12.63 ± 0.61	−15.36 ± 0.21	26–50
	ZOO	8.51 ± 1.36	−21.47 ± 1.13	0–9

ENG = Engraulidae (*Anchoa* spp*., Cetengraulis mysticetus*, and unidentified engraulids); CLUP = Clupeidae (small; < 7 cm); OPL = *Ophistonema libertate* (big; >10 cm); BSHP = big shrimp (> 4 cm; Penaeidae, Sicyonidae, and Processidae); SSHP = small shrimp (< 4 cm; Ogyridae and Solenoceridae); SPOR = small portunids (*Portunus* spp.; small, = 1 cm); ZOO = zooplankton (Copepoda).
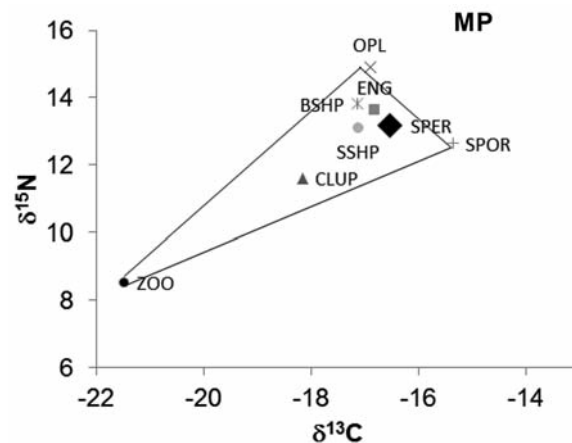

Fig. 4. Mixing polygon for $\delta^{13}C$ and $\delta^{15}N$ signature for prey items and *Selene peruviana*, from the Southeastern Gulf of California, Mexico. The mixing polygon shows predator $\delta^{15}N$ values after correction for dietary isotopic fractionation; ENG = Engraulidae, CLUP = Clupeidae, OPL = *Ophistonema libertate*, BSHP = big shrimp, SSHP = small shrimp, SPOR = small portunids, ZOO = zooplankton

could not be identified in the stomach contents, although we often found highly digested crustacean remains that might correspond to this prey. These items were reported as crustacean remains. These findings indicate the importance of using both stomach contents and stable isotopes analysis and mixing models to identify with more precision the main preys consumed by a predator (Benstead et al. 2006).

Other species of the genus *Selene* also feed on crustaceans (Hobson 1968, da Silva Monteiro 1998, López-Peralta and Arcila 2002). High abundance of crustaceans, such as shrimps and crabs, has been reported in the study area (Hendrickx 1996). These prey species are, therefore, accessible to the predator. Although the Levins index indicates that the trophic breadth of *S. peruviana* is relatively narrow, this species can acquire other prey items, such as crustaceans, under certain conditions.

The two methods for calculating trophic position produced similar values, which suggests that the fractionation value used was adequate, since this value was very similar to what we found when we compared the values of $\delta^{15}N$ of the predator against its preys.

According to these results, the trophic position of *S. peruviana* assumed values within 3.7–3.9. This relatively high trophic position was probably an effect of the consumption of fishes and of carnivore-detritivore crustaceans like the portunids and penaeids. Based on the $\delta^{15}N$ values, we can infer that *S. peruviana* acts as a predator in the food web. In addition, the values of $\delta^{13}C$ suggest that this predator tends to feed near the coast where the values of this isotope are relatively high (France 1995).

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