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Insights into the Feeding Habits of False Killer Whales (*Pseudorca crassidens*) in the Mexican Central Pacific

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Abstract

The false killer whale (*Pseudorca crassidens*) is a widely distributed odontocete, and some aspects of its basic biology, such as feeding patterns at different time scales, are not well known. Stable isotope values ($\delta^{15}N$ and $\delta^{13}C$) from the skin of ten false killer whales belonging to two distinct groups (A and B) sampled in October 2012 in the Mexican Central Pacific (MCP) were analyzed. Isotopic analyses were also run on muscle tissue from ten potential fish and squid prey species, some of which were extracted from billfish stomachs. Isotopic results for false killer whales showed mean values of 16.3‰ (Group A) and 17.0‰ (Group B) for $\delta^{15}N$, and -14.8‰ for $\delta^{13}C$ (both Groups A and B). Fish and squid isotopic values showed a trophic discrimination factor in relation to those of false killer whales of +3.3 to 4.0‰ for $\delta^{15}N$ and +2.9‰ for $\delta^{13}C$. This suggests that these whales probably fed within the study area on these prey species or on other species with similar isotopic values. Through photographic data, we identified individuals of Group B in the same area 2 mo later (December 2012) when they were observed feeding on fishes. One false killer whale from Group A had a fragment of billfish beak embedded in its body, indicating an interaction between these two species. Results suggest that false killer whales may share the same type of food resource with billfish species such as the sailfish, an abundant species in the MCP area.

Key Words: false killer whale, Mexican Central Pacific, stable isotopes, potential prey, trophic similarity, billfish

Introduction

A great quantity of information has been gathered on the odontocetes that are distributed in temperate coastal regions (e.g., Forney & Barlow, 1998; Sargeant et al., 2005; Newsome et al., 2009) which is in contrast with those in tropical oceanic regions, for which there is very little information. This is related, among other factors, to the economic limitations of most tropical countries that do not allow them to sustain significant monitoring of these populations far from the coast (Baird et al., 2008). One odontocete species that is poorly known is the false killer whale (*Pseudorca crassidens*). The species has a wide distributional range in deeper tropical and subtropical waters away from the coast, although occasionally it can be observed in shallow waters or at higher latitudes (Stacey et al., 1994; Odell & McClune, 1999; Baird, 2009a).

Until recently, strandings have been one of the main sources of knowledge on false killer whale biology (Odell & McClune, 1999); however, the availability of stranded individuals is not sufficient to obtain detailed information about some ecological aspects—for example, their feeding habits. There are some observations of false killer whales preying on some cephalopods and fishes (Odell & McClune, 1999), whose species are variable by location (e.g., Alonso et al., 1999; Baird et al., 2008; Baird, 2009b). It is therefore necessary to gather specific information on the trophic ecology of this odontocete.

Continuous monitoring of ecological aspects of marine mammals from waters of the Mexican Central Pacific (MCP) was started in 2010. During one of these research surveys, in October 2012, a group of 10 to 12 false killer whales was observed in coastal waters. One of these individuals had

an object that appeared to be a segment of billfish beak embedded in the dorsal region. We conceived two hypotheses that might explain this observation: (1) a predator-prey interaction of false killer whales preying on billfish as was reported by Baird et al. (2008); or (2) a spatial co-occurrence in our study area between top predators (false killer whale and billfish), resulting in possible sharing of food resources, which has not been documented.

Analysis of stable isotopes of nitrogen and carbon has been an effective technique to investigate aspects of feeding ecology (Martínez del Río et al., 2009) due to the fact that $\delta^{15}N$ and $\delta^{13}C$ values show predictable increases or trophic discrimination factors (TDF) (i.e., ~3 to 5‰ and ~0.5 to 2‰, respectively) between a source and its consumer at each step from the base of the trophic web to top predators (Minagawa & Wada, 1984). Because of this predictable relationship between prey and predator, it is possible, using $\delta^{15}N$, to determine the trophic position of consumers and their trophic width, which are dependent on the trophic level and variability of their prey, respectively (Minagawa & Wada, 1984; Newsome et al., 2007). Variations in $\delta^{13}C$ values have been useful proxies to describe habitat use in aquatic organisms (e.g., marine/fresh aquatic, coastal/oceanic, pelagic/benthic; France, 1995). These differences among habitats are related to a variety of physicochemical and biological factors (e.g., the taxonomic composition and growth rate of phytoplankton; Fry & Wainright, 1991).

In this study, stable isotope analysis was employed to determine feeding habits of the false killer whale in the MCP, including a probable trophic similarity (sharing of equivalent resources) between false killer whales and billfish from this region. This approach should be a useful tool to better the understanding of the ecology of this cetacean species in a specific location of its wide distribution.

Methods

False Killer Whale Sightings and Sample Collection

Two marine mammal research surveys were conducted in the autumn of 2012 in waters of the MCP (states of Michoacán-Jalisco-Colima; Figure 1) on board the 12-m sport-fishing vessel, *Mary Chuy III*. The first survey was from 1 to 9 October, mainly to cover coastal waters (up to ~55 km offshore); and the second survey was from 3 to 15 December, covering coastal and oceanic waters (up to ~110 km offshore). Tracklines were designed systematically for both surveys; however, their total coverage was dependent on weather conditions.

The search for marine mammals was carried out by three observers on the vessel from the flying bridge 4.5-m above the waterline, using Fujinon 7 × 50 binoculars. When false killer whales were sighted, the following information was gathered: date, time, geographic location (Garmin GPS map76CS), number of individuals, activity, and possible associations with other species. A smaller (5-m) boat with a 30-hp outboard motor was deployed for close approaches to take photographs using a digital camera (Canon EOS 50D) with 100 to 300 mm zoom lens and to collect skin samples for stable isotope analysis.

The subset of photographs selected to identify individuals were sharp, oriented perpendicular to the false killer whale, and showed the complete dorsal fin in order to distinguish its form, notches, and scars. A photographic catalogue permitted comparisons among individuals using the software *ACDSee Pro*, Version 3.

Skin samples were collected using a stainless steel biopsy punch (1.5-cm length by 0.3-cm diameter) attached to the end of an arrow shot from a crossbow (Barnett Panzer V, 68 kg draw weight).

Samples of Potential False Killer Whale Prey

Simultaneously with the October marine mammal survey, potential false killer whale prey samples were obtained from the stomach contents of five sailfishes (*Istiophorus platypterus*) and one striped marlin (*Tetrapturus audax*), which were caught in the area by trolling with a fishing rod. Four sailfishes were caught within 35 to 55 km from Manzanillo; the fifth sailfish was caught 19 km from Chamela Bay, 15 km north of Punta Etiopa; and the striped marlin was caught 28 km from Manzanillo Bay (Figure 1). For all hooked billfishes, the stomach was removed immediately after their death, and all of their contents were collected into plastic bags, which were labeled with date, time, geographic position, and species common name. It was not possible to identify the prey species from the stomach contents; we therefore took samples of undigested muscle of three fishes (size range: 12 to 16 cm), two of which had different morphological characteristics, and of three squids, which were either unique, largest, or one of the most frequent prey of a given billfish.

Using the same method employed to catch the billfishes, two yellowfin tuna (*Thunnus albacares*) were caught approximately 44 km from Punta San Telmo. One skipjack or striped tuna (*Katsuwonus pelamis*) and one mackerel tuna (*Euthynnus affinis*) were also caught at 22 and 17 km, respectively, from the Manzanillo coast (Figure 1). Muscle samples of these fishes were also collected into labeled plastic bags.

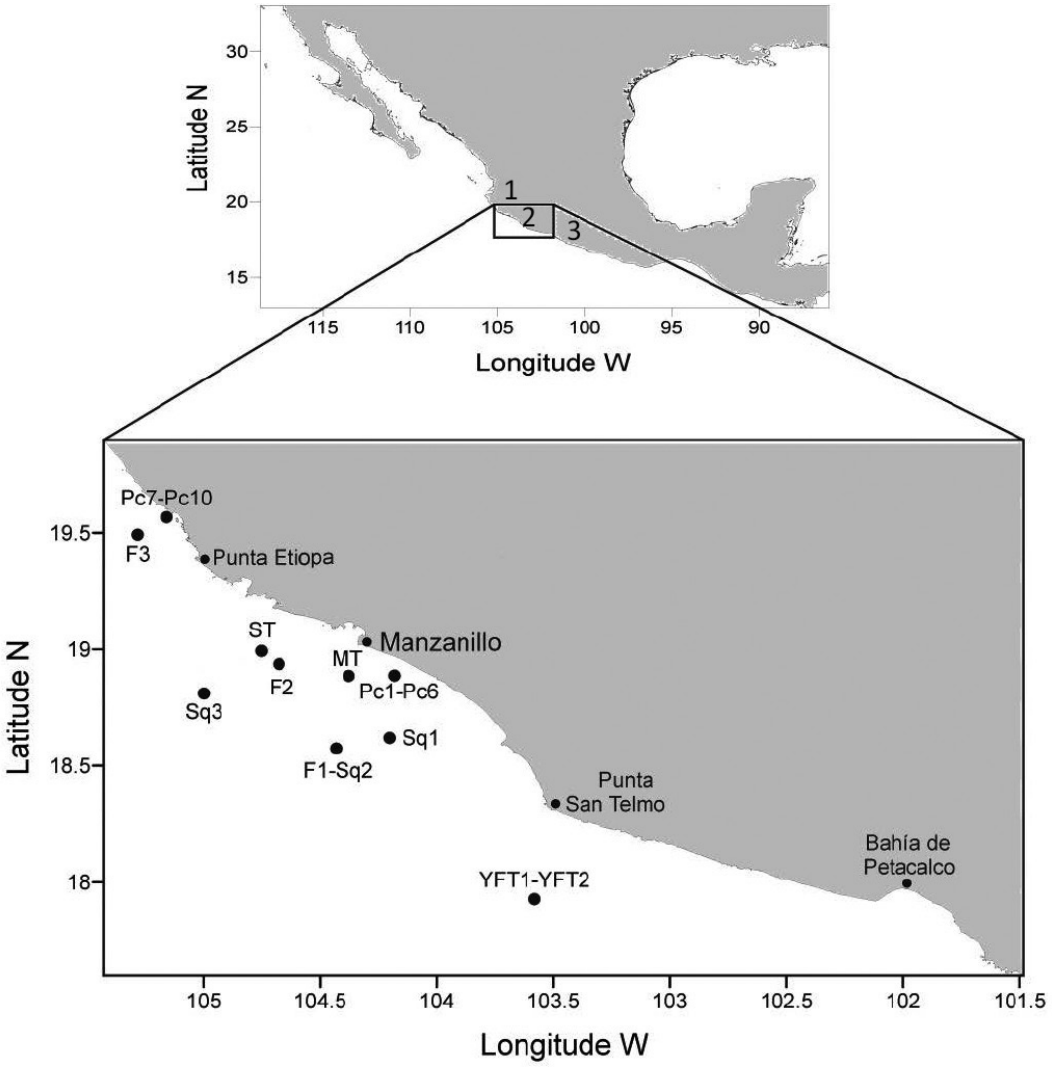

Figure 1. Study area in the Mexican Central Pacific (MCP; 1 = Jalisco, 2 = Colima, 3 = Michoacán), showing locations of sampling: Pc1-Pc6 and Pc7-Pc10 = false killer whale (*Pseudorca crassidens*) Groups A and B, respectively; MT = Mackerel tuna; ST = Striped tuna; YFT = Yellowfin tuna (n = 2); Sq = unidentified squids from billfish stomachs; and F = unidentified fishes from billfish stomachs.

Stable Isotope Analysis

False killer whale skin samples were preserved in a cryogenic vial in a container with liquid nitrogen, and muscle tissue of potential prey was preserved in a freezer at -10º C during survey days, and later kept in an ultra-freezer at -70º C (at a similar temperature as the liquid nitrogen). Samples were processed at the Chemistry Laboratory of the Centro Interdisciplinario de Ciencias Marinas (CICIMAR-IPN) in La Paz, BCS, Mexico. All samples were washed with distilled water and placed for 24 h in a lyophilizer (Free Zone 2.5 Liter Benchtop Freeze Dry System) to extract moisture. Lipids were extracted from false killer whale samples (predator) using a 1:1 chloroform/methanol solution and a sonication process to increase the effectiveness of the treatment. Lipids were not extracted from potential prey since this is not recommended when they are contrasted with a keratinous tissue (e.g., skin) from the predator under analysis (Newsome et al., 2010). Lipid extraction reduces the TDF of $\delta^{13}C$ to almost zero, which is significantly lower than the typical value of +2.0 to 3.0‰ reported for keratin

of predators compared to that (muscle) of their diet (Hobson et al., 1996; Newsome et al., 2010). Moisture-free samples of predator and potential prey were ground to a powder using an agate mortar. Subsamples of 0.8 to 1.2 mg were weighed using a Sartorius Premium ME5-F analytic microbalance with ± 0.001 mg precision. These subsamples were stored in tin capsules and sent to be processed at the Stable Isotope Laboratory of the University of California in Santa Cruz. The stable isotope proportion was represented using the delta (δ) notation, according to the equation proposed by DeNiro & Epstein (1978):

$$\delta^{15} N \text{ or } \delta^{13} C = 1{,}000[(R_{sample}/R_{standard}) - 1]$$

where R_{sample} and $R_{standard}$ are the molar quotients of the heavy isotopes over the light isotopes of the sample and standard, respectively. The standards internationally recognized for these elements are PeeDee Belemnite (PDB) for carbon, with a value of 0.011‰, and atmospheric nitrogen (N^2) for nitrogen, with a value of 0.004‰. To analyze the trophic amplitude (caused by prey or habitats with different $\delta^{15}N/\delta^{13}C$ values) of the false killer whale samples, we used the *SIBER* (*Stable Isotope Bayesian Ellipses in R*) routine located in the *SIAR* (*Stable Isotope Analysis for R*) package for *R* software. The variation in isotopic values was used to more accurately calculate the isotopic niche space (R Development Core Team, 2008; Jackson et al., 2011). This approach involves the use of Markov-Chain Monte Carlo simulations (bootstrapping) to construct ellipse parameters. Bivariate ellipses and convex hulls were used to delineate isotopic niche space ($\delta^{15}N$ to $\delta^{13}C$ 95% confidence interval ellipses). Niche area and overlap were estimated based on 100,000 posterior draws of the Bayesian standard ellipse parameters. Isotopic variation was incorporated into the posterior distribution, making *Pseudorca crassidens* (Groups A and B) niche space and area comparable.

Results

Search Effort and Identification of Groups

Marine mammal search effort during the October 2012 survey was 1,135 km, and 83 marine mammal sightings were recorded, corresponding to eight species, among which there were two false killer whale sightings. The first sighting (Group A) occurred on 1 October at approximately 10 km from the Colima coast, south of Manzanillo. The group size was estimated at 10 to 12 individuals, and six skin samples were collected. One of these individuals (Pc4) had a segment of apparent billfish beak in its dorsal region (Figure 2). The second sighting (Group B) occurred on 8 October at approximately 2 km from the Jalisco coast (in front of Chamela Bay, north of Punta Etiopa). This group was estimated at 15 to 20 individuals, and four skin samples were collected.

Figure 2. False killer whale (*Pseudorca crassidens*) Pc4 sighted in waters from the Mexican Central Pacific during a research survey (October 2012) with a billfish beak embedded in its dorsal region

The search effort for the second survey was 1,308 km, and 119 marine mammal sightings were recorded of 14 species. There was one false killer whale sighting of 30 to 40 individuals recorded on 10 December in the same location as Group B on 8 October. No skin samples were obtained for this group.

Through photo-identification analysis, nine individuals were identified from each one of these three sightings. There were no matches between Groups A and B; however, there were matches—five out of nine photo-identified individuals—between Group B on 8 October and the group that was recorded on 10 December.

Isotopic Comparison Between False Killer Whale Groups and Potential Prey

The $\delta^{15}N$ and $\delta^{13}C$ values of false killer whale skin of both groups (A and B) sighted in October were similar. However, Group B had slightly higher $\delta^{15}N$ values (+0.7‰) than Group A (Table 1), although differences were not significant (Mann-Whitney U = 8, $p > 0.05$). The mean $\delta^{15}N$ and $\delta^{13}C$ values for both groups were 16.6 ± 0.8‰ and -14.8 ± 0.3‰, respectively (Table 1).

Fishes, as a group (70% of available potential prey), had $\delta^{15}N$ values ranging from 11.0‰ to

Table 1. $\delta^{15}N$ and $\delta^{13}C$ values of false killer whale (*Pseudorca crassidens*) (Pc) skin and potential prey muscle from the Mexican Central Pacific

Analyzed subjects	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)
False killer whales		
Group A (6)		
Pc1	15.7	-15.2
Pc2	15.9	-14.9
Pc3	18.0	-13.9
Pc4	16.2	-14.9
Pc5	15.7	-15.2
Pc6	15.9	-15.2
Mean (± SD)	16.3 ± 0.7	-14.9 ± 0.3
Group B (4)		
Pc7	15.7	-15.3
Pc8	17.5	-14.7
Pc9	17.7	-14.8
Pc10	17.1	-14.4
Mean (± SD)	17.0 ± 0.7	-14.8 ± 0.3
Potential prey		
Fishes (7)		
Striped tuna	11.7	-17.1
Mackerel tuna	15.5	-16.8
Yellowfin tuna	13.6	-17.1
Yellowfin tuna	14.2	-17.0
Fish 1	11.0	-18.5
Fish 2	15.2	-18.2
Fish 3	13.4	-17.0
Squids (3)		
Squid 1	10.6	-18.0
Squid 2	11.4	-18.2
Squid 3	12.9	-19.6
Mean (± SD)		
Potential prey	13.0 ± 1.7	-17.7 ± 0.9

15.5‰, and $\delta^{13}C$ values that ranged from -18.5‰ to -16.8‰ (Table 1). If overall values of potential prey, including squids, are taken into account ($\delta^{15}N$:13.0±1.7‰; $\delta^{13}C$:-17.7±0.9‰), there would be a TDF of ~3.5‰ for $\delta^{15}N$ and of ~2.9‰ for $\delta^{13}C$ in relation to false killer whale skin from Groups A and B.

The *SIBER* analysis showed that there were similar polygon areas (given by trophic position [$\delta^{15}N$] and habitat use [$\delta^{13}C$]) between the two *Pseudorca* groups (0.43 vs 0.57). However, the ellipses generated for each group, which avoid bias caused by extreme values that constitute the polygons, indicated a wider trophic niche (larger ellipse area) for Group B (1.16) than for Group A (0.42) as well as low overlap (0.14) between the two ellipses (Figure 3).

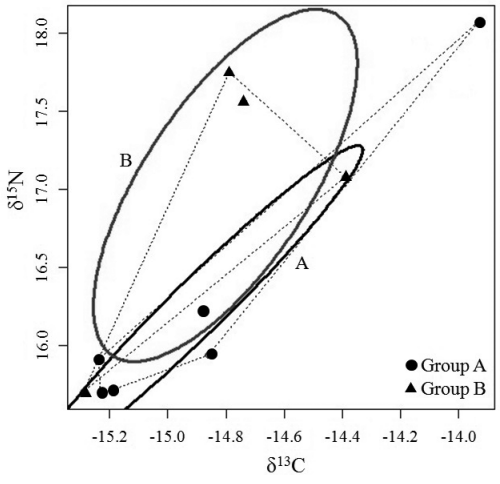

Figure 3. Trophic breadth of the two false killer whale groups (A and B) from the Mexican Central Pacific; dashed lines create the polygons for each group as a result of the areas formed by all stable isotope ($\delta^{15}N$ and $\delta^{13}C$) values. Ellipses generated for each polygon avoid bias caused by extreme values that constitute the polygons; the ellipses show a wider trophic niche (given by a larger area) for Group B (1.16) than for Group A (0.42), and a low overlap (0.14) between the two ellipses.

Discussion

Results of this study suggest that the false killer whales sighted in waters of the MCP may feed within the study area in a magnitude we cannot establish in detail, considering the limitations of our sample size (a common problem when working with protected pelagic species that are difficult to sample in the wild), and that our effort did not involve controlled conditions. In a contrasting scenario, taking into consideration the large movements by false killer whales (e.g., Kasuya, 1971; Baird et al., 2008), sampled individuals could have been showing a transient trend, based on isotopic signatures that did not fit with our sampled potential prey.

Additional evidence in this regard came from the third false killer whale sighting on 10 December. Finding matches between individuals of this group and individuals from the Group B of October demonstrates that the same false killer whale group revisited the same area within a period of 2 mo or possibly may have stayed there for an extended period. Several of the individuals in December were observed feeding on fishes, strengthening our suggestion of MCP as a feeding area. This is important in terms of the apparent existence of available resources for the false killer whale in our study area, within a time frame of ~70 d, which

is the period or isotopic information window that skin represents in other odontocetes such as the bottlenose dolphin (*Tursiops truncatus*) and the beluga (*Delphinapterus leucas*) (Hicks et al., 1985; St. Aubin et al., 1990). Thereby, the coastal waters of MCP could be an important feeding area for false killer whales as has been observed in other shallow continental shelf waters (Acevedo-Gutiérrez et al., 1997; Palmer et al., 2009; Zaeschmar et al., 2013).

The TDF between potential prey and false killer whale skin fell within ranges previously reported for other odontocete species in spite of the fact we did not work under controlled conditions such as age (however, we can ensure that we did not take samples from calves), sex, dispersion degree, and certainty in consumed prey. Our TDF results (especially $\delta^{15}N$) were similar to values obtained by Ruiz-Cooley et al. (2004) for squid muscle and sperm whale skin (2.7 to 5.0‰ for $\delta^{15}N$ and 1.1 to 2.4‰ for $\delta^{13}C$). Under controlled conditions, Browning et al. (2014) reported variable TDF in the skin of bottlenose dolphins (*Tursiops truncatus*), depending on the type of consumed prey (e.g., lipid content). These authors found $\delta^{15}N$ TDF between 1.7 and 2.9‰ and $\delta^{13}C$ TDF values that ranged between 0.5 and 2.0‰. Hobson et al. (1996) also found similar TDF values between the skin of four seal species and a controlled diet, with mean values of 2.3‰ for $\delta^{15}N$ and 2.8‰ for $\delta^{13}C$. These authors found higher $\delta^{13}C$ TDF values in inactive/keratinous tissues such as skin, nails, and vibrissae, in contrast with active tissues such as blood, muscle, kidneys, liver, and spleen (0.6 to 1.8‰). This enrichment difference among tissue types indicates a variable biochemical composition, which among other factors, is related to different isotopic values of the amino acids that compose each tissue (Martínez del Río et al., 2009). Glycine is an important amino acid in keratin, and it is enriched in ^{13}C, as a result of which $\delta^{13}C$ TDF values are high in tissues such as skin with respect to other tissues (Hobson et al., 1996; Lesage et al., 2002; Browning et al., 2014).

From photographic evidence of dorsal fins, it was determined that the two false killer whale groups (A and B) were composed of different individuals, despite having been sighted 60 km away from each other and only 6 d apart. Additionally, the Bayesian analysis suggested a low isotopic overlap, even though traditional statistics did not find significant differences, perhaps because of sample size. However, this probable separation would be the result of differences in $\delta^{15}N$ values, which indicated that Group B might have fed on prey with slightly higher trophic positions than individuals of Group A. Additionally, $\delta^{13}C$ similarities indicated that both groups might have fed in the same area over the last 2 mo. Statistical differences were not found in this regard; however, a false killer whale from Group A (Pc3) showed a $\delta^{15}N$ value considerably higher (18.0‰) than the rest of the individuals from that group. Without this Pc3 sample, statistical differences (15.9‰ vs 17.0‰; Mann-Whitney $U = 4$; $p < 0.05$) are observed between Groups A and B. It is possible to infer that the diet of Group A might be made up of a high proportion of prey with $\delta^{15}N$ values similar to the analyzed squid and striped tuna, indicating a lower trophic position compared with Group B, which might have fed in higher proportion on prey with similar isotopic values to the analyzed mackerel and yellowfin tuna (Table 1).

Our results on amplitude/overlap (*SIBER* analysis) between false killer whales have limitations. Our sample is small, maybe causing 50% of the samples for both Groups A and B to fall outside the *SIBER* ellipses; in spite of the fact that further sampling is needed, we consider that this analysis is useful to identify the most meaningful data within groups, even though they involve low sample sizes. We also have to acknowledge that our analyzed items may not be consumed by false killer whales; however, we propose arguments as relevant results on the basis of probable presence of ecological equivalents (different prey species with a similar trophic position and habitat).

Three types of observation during our study suggest the existence of overlap in prey resources between false killer whales and billfish, probably sailfish, since it was the most commonly caught species during the survey (five individuals) and, more importantly, because it is the most abundant billfish species in the area (Santana-Hernández et al., 2009). First, there is spatial overlap between their distributions (Figure 1). Secondly, our observation of a false killer whale with a fragment of billfish beak embedded in its back is evidence of a direct interaction. The positive identification of this structure was made considering the fragmented form and its white coloration inside, which coincides with keratinous and easily broken material of billfish beak (R. Baird, Cascadia Research Collective, and J. Jacobsen, Humboldt State University, pers. comm.). During sport fishing events, it is common to observe billfishes with broken or deteriorated beaks. Major (1979) reported an aggressive encounter between large whales and billfish (probably marlin) in Hawaii, as well as the existence of records of these fish being embedded in whales caught by whalers; these events were also reported by Oshumi (1973) for minke whales in the Antarctic. Finally, our isotopic analyses showed that TDFs between false killer whales and potential prey species from billfish stomachs were consistent with the whales and

billfish feeding on the same or similar prey. We were unable to conduct isotopic analyses on samples from the billfish collected in 2012. However, during June through September 2013, four sailfishes were caught in our study area, and their muscle samples showed a mean $\delta^{15}N$ value of 15.8 ± 0.6‰ (unpub. data from our project), which is close to $\delta^{15}N$ mean values from false killer whales under analysis, mainly Group A (16.34‰; Table 1), in spite of a different sampling period.

This study is an important contribution to the knowledge of the false killer whale of which little is known in terms of long-term feeding patterns. It also provides information on some aspects of the activities of this species around the Mexican Central Pacific. We recommend increasing this type of sampling, of both false killer whales and billfishes, as well as of identified (stomach contents) or potential prey, which would enable other data analysis techniques (i.e., mixing models) to contribute to better ecological knowledge of this odontocete and of the species with which it interacts.

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