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Short Note

Orcas (*Orcinus orca*) Use Different Strategies to Prey on Rays in the Gulf of California

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Orcas or killer whales (*Orcinus orca*) are among the most cosmopolitan cetaceans on the planet (Rice, 1998). In the semi-enclosed sea of the Gulf of California in México (Figure 1a), sightings of orcas are considered relatively frequent year-round. However, little is known about their ecology and hunting behavior in this region (Guerrero-Ruiz et al., 1998, 2007; Niño-Torres et al., 2011).

Worldwide, orcas feed on a wide variety of prey, including marine mammals, sea birds, sea turtles,

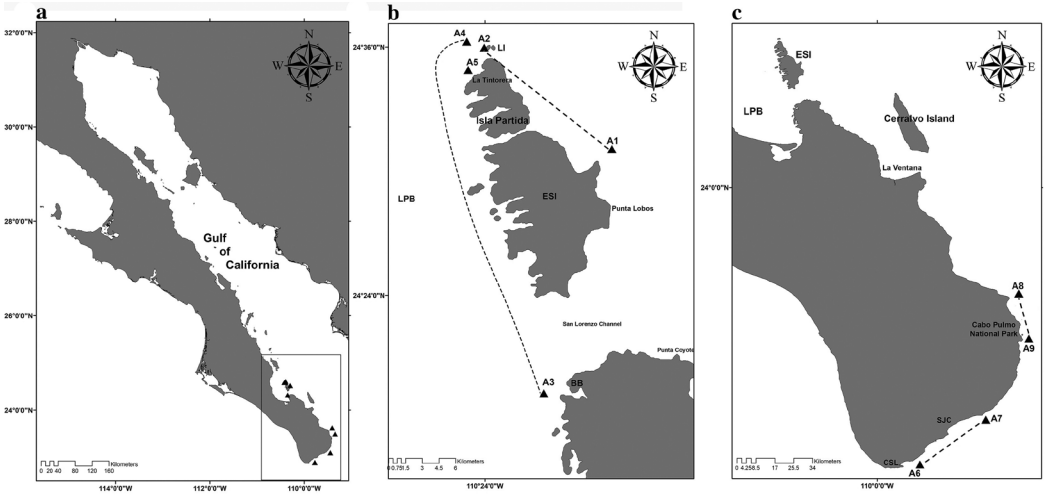

Figure 1. (a) Study area and orca (*Orcinus orca*) sightings in the southwest area of the Gulf of California, México; (b) close-up of La Paz Bay (LPB) where encounters A1 to A5 were documented; and (c) close-up of "Los Cabos" area where encounters A6 and A7 occurred, and Cabo Pulmo National Park where encounters A8 and A9 occurred. The main areas are indicated with the following abbreviations: LI = Los Islotes, ESI = Espíritu Santo Island, BB = Balandra Beach, CSL = Cabo San Lucas, and SJC = San José del Cabo. Dotted lines indicate the orcas' movements during the encounters in which predation behavior was documented: A1-A2, A3-A4, A6-A7, and A8-A9.

bony and cartilaginous fish, and cephalopods (Fertl et al., 1996; Nichol & Shackleton, 1996; Dahlheim & Heyning, 1999; Ford & Ellis, 2014; Vargas-Bravo et al., 2020). Although as a species they display a generalist foraging behavior, local groups or ecotypes of orcas typically specialize on a small range of available prey (Ford et al., 1998). To efficiently track and hunt target prey in multiple regions around the world, orcas use specialized techniques, including intentional beaching to capture South American sea lions (*Otaria byronia*) and southern elephant seals (*Mirounga leonina*) in the Atlantic and South Indian Oceans (Lopez & Lopez, 1985; Guinet, 1992); the production of surface waves to wash crabeater (*Lobodon carcinophaga*) and Weddell seals (*Leptonychotes weddellii*) as well as an Adélie penguin (*Pygoscelis adeliae*) off ice flows in the Antarctic Peninsula (Visser et al., 2008; Pitman & Durban, 2012); "karate chopping" thresher (*Alopias vulpinus*) and hammerhead (*Sphyrna zygaena*) sharks (Visser, 2005); cooperative herding of fish into a tight ball (using different techniques, including flashing their white undersides and releasing air bubbles) and stunning them with tail slaps in Norway (Similä & Ugarte, 1993); and cooperatively chasing and disabling large whales, dolphins, and schooling fish (Dahlheim & Heyning, 1999; Baird, 2000).

Hunting specializations are considered important for top predators, especially in cases where prey can cause injuries (e.g., stingrays with their spine, sharks with their teeth), mortality, stranding (Duignan et al., 2000; Visser, 2005; McFee & Lipscomb, 2009; Burdett & Osborne, 2010), or, in general, when a certain resource involves risks representing foraging costs (Lopez & Lopez, 1985; Ford & Reeves, 2008; Mukherjee & Heithaus, 2013). Orcas have been observed feeding on sharks and rays in different parts of the world (Table 1), and specific ray hunting tactics have been documented in New Zealand, including the use of the ocean bottom as a physical barrier, tossing rays, and releasing bubbles, perhaps to dislodge the prey (Visser, 1999). In the Gulf of California, there are records of orcas preying on both marine mammals and elasmobranchs (Table 2). However, there are only opportunistic records of the latter, without descriptions of the hunting strategies, behaviors displayed, or identification of the prey species (Guerrero Ruiz et al., 2007). Herein, we provide behavioral descriptions of predation events by orcas on elasmobranch species in the southern Gulf

Table 1. Evidence of orca (*Orcinus orca*) predation on elasmobranch species around the world (excluding the Gulf of California, which are given in Table 2). Note that although sharks identified to order, family, and genus are included herein. "Unidentified" sharks or those instances of "presumed" predation are not included. Also not included is the consumption of two egg cases from Joseph's shark (*Callorhynchus capensis*) (Best et al., 2010).

Species	Location	Source
Basking shark (*Cetorhinus maximus*)	New Zealand	Brown & Norris, 1956; Norris, 1958; Yukhov et al., 1975; Fertl et al., 1996; Visser, 2000b, 2001, 2005
Blue shark (*Prionace glauca*)	Monterey Bay, USA; Gulf of Mexico; New Zealand; Australia; North Pacific; South Africa, Northeastern Atlantic	Ternullo et al., 1993; Fertl et al., 1996; Visser, 2000b, 2005; Morrice, 2004; Dahlheim et al., 2008; Best et al., 2010; Passadore et al., 2015; Pitman et al., 2017; Ford, 2019; Mucientes & González-Pestana, 2020
Blue-spotted ray (*Dasyatis kuhlii*)	Papua New Guinea	Visser & Bonoccorso, 2003
Broadnose sevengill shark (*Notorynchus cepedianus*)	Patagonia-Argentina; False Bay, South Africa; Bay of Islands, New Zealand	Reyes & García-Borboroglu, 2004; Engelbrecht et al., 2019; Visser, pers. comm.
Bull (*Carcharhinus leucas*) or lemon (*Negaprion brevirostris*) shark	Golfo Dulce, Costa Rica	Fertl et al., 1996
Carcharinid shark (Unidentified species)	Central California coast, USA	Dahlheim et al., 2008
Carchanid shark: blue (*Prionace glauca*) or white-tipped (*Carcharhinus longimanus*)	North Pacific coastal	Morin et al., 2006

Eagle ray (*Myliobatis* sp.)	Brazil; Galápagos Islands, Ecuador	Castello, 1977; de Roy, 1993; Dalla Rosa et al., 1994
Eagle ray (*Myliobatis tenuicaudatis*)	New Zealand	Visser, 1999
Electric ray (*Torpedo californica*)	California, USA	Norris & Prescott, 1961
Galapagos shark (*Carcharhinus galapagensis*)	Galápagos Islands, Ecuador	Fertl et al., 1996
Giant manta (*Mobula birostris*)	Galápagos Islands, Ecuador; Papua New Guinea	Alava & Merlen, 2009; Visser & Bonoccorso, 2003
Grey reef shark (*Carcharhinus amblyrhynchos*)	Papua New Guinea	Visser & Bonoccorso, 2003
Hammerhead shark (*Sphyrna* sp.)	Galápagos Islands, Ecuador	Sonnino Sorisio et al., 2006
Hammerhead shark (*Sphyrna* sp.)	Kimbe Bay, Papua New Guinea; Genovesa Island, Darwin Bay	Skinner, 1994; Fertl et al., 1996; Merlen, 1999
Long-tailed stingray (*Dasyatis thetidis*)	New Zealand	Visser, 1999
Manta ray (*Manta* sp.)	Galápagos Islands, Ecuador	Watson, 1981
Manta ray (*Mobula* sp.)	New Guinea, Mozambique	Brown, 1988; Terrapon et al., 2021
Pacific sleeper shark (*Somniosus pacificus*)	British Columbia–Alaska	Ford et al., 2011; Ford, 2019
Pacific spiny dogfish (*Squalus suckleyi*)	North Pacific	Ford, 2019
Porbeagle (*Lamna nasus*)	Australia	Morrice, 2004
Portuguese dogfish (*Centroscymnus coelolepis*)	Mozambique	Terrapon et al., 2021
Salmon shark (*Lamna ditropis*)	North Pacific	Ford, 2019
Scalloped hammerhead shark (*Sphyrna lewini)*	Kimbe Bay, Papua New Guinea	Visser & Bonoccorso, 2003
School shark (*Galeorhinus galeus*)	New Zealand	Visser, 2000a
Shortfin mako (*Isurus oxyrinchus*)	New Zealand; Australia; South Africa	Visser et al., 2000; Morrice, 2004; Williams et al., 2009; Best et al., 2010
Short-tailed stingray (*Dasyatis brevicaudatus*)	New Zealand	Visser, 1999
Smooth-hammerhead shark (*Sphyrna zygaena*)	New Zealand	Visser, 2005
Thorny skate (*Raja taaf*)	Crozet Islands, Southern Indian Ocean	Tixier et al., 2016
Thresher shark (*Alopias vulpinus*)	New Zealand	Visser, 2005
Torpedo (electric) ray (*Torpedo fairchildi*)	New Zealand	Visser, 2000b, 2001
Whale shark *(Rhincodon typus)*	Gulf of California, México	O'Sullivan & Mitchell, 2000
White shark (*Carcharodon carcharias*)	California, USA; Plettenberg Bay, False Bay & Gansbaai, South Africa	Pyle et al., 1999; Best et al., 2010; Engelbrecht et al., 2019; Micarelli et al., 2021

Table 2. Evidence of orca predation on elasmobranch species in the Gulf of California (extracted from Guerrero-Ruiz et al., 2007)

Species	Date (d/mo/y)	Location	Behavior	Orca group size
Manta ray (*Mobula* sp.)	3/8/1983	Canal de Ballenas	Feeding	7
	17/1/2000	20° 37' N, 105° 17' W	Feeding	3
	21/10/2001	San Evaristo	Feeding	10
	21/2/2005	Isla Espíritu Santo	Feeding	10
	8/7/2005	Isla Espíritu Santo	Feeding	2
Whale shark (*Rhincodon typus*)	1990	Bahía de Los Angeles	Feeding	2
	23/9/1994	Bahía de La Paz	Feeding	3
Unidentified shark	6/4/1989	Bahía de La Paz	Feeding	12

of California, between La Paz Bay and Los Cabos (see Figure 1), from May to June 2018.

The predation events described herein were documented from a 7-m fiberglass boat with a 4-stroke outboard motor of 200 Hp. For each orca group encounter, we registered date, time, geographic location, group size, presence of calves or juveniles, traveling mode (which we defined as movement of individuals at a constant speed and defined direction), and any ray-related feeding behaviors (i.e., when orcas hunted, killed, and fed on rays or if they abandoned the rays after killing them). Survey effort on orcas was focused on areas where sightings of these animals were reported by local fishermen in the southwest portion of the Gulf of California (Figure 1). Predation events were recorded from the boat with a Canon 1DX mark II DSLR camera with a 24-105 mm lens. A second 1DX mark II camera with a wide-angle 11-24 mm lens was housed inside an underwater Nauticam housing to capture underwater photographs and video, and, whenever possible, images were taken from above using a Phantom 4 Pro drone. Moreover, photographs or high-quality video frame shots of dorsal fins were taken/extracted for photo-identification of individual orcas using distinctive features, including scars and nicks (Bigg et al., 1987), and the number and position of pseudo-stalked barnacles (*Xenobalanus globicipitis*) on each individual were noted as has been documented for other orcas (e.g., see Visser & Cooper, 2020). When the orcas were observed slowing their swimming speed (< 5 kts) or approaching potential prey, a swimmer—with snorkeling equipment and the underwater camera—gently entered the water and recorded the type of prey present and any hunting behavior. Prey species identification was confirmed by one of the authors (JEH-R) after reviewing the videos and photographs. To minimize disturbance and reduce the possibility of changing the animals' behavior, the swimmer entered the water from approximately 30 m away from the sighting and approached the animals slowly, trying to maintain a minimum safe distance of 5 m to avoid getting between the killer whales and their prey.

Five successful events of orca predation on rays were documented during seven sightings over 36 d between May and June 2018. In all sightings, we documented the presence of at least one calf or juvenile, identified as individuals that were one half to three quarters the size of an adult female (Visser, 1999). The sex of the adult males was confirmed by the size and shape of their dorsal fins, while the sex of the females was confirmed by analyzing images of their genital area while they turned and changed position. Our findings represent the first detailed descriptions of orcas foraging in the Gulf of California on three different elasmobranch species: Munk's devil ray or smooth-tail mobula (*Mobula munkiana*), cownose ray (*Rhinoptera steindachneri*), and pelagic stingray (*Pteroplatytrygon violacea*).

Hunting Encounters

Five successful events were documented. These encounters were labeled A1 to A9 and are described below:

1. *Encounter A1-A2*—The first event was documented on 6 May 2018 when a group of seven orcas (one adult male, three adult females, two unknown individuals smaller than the mature females, and one calf) were seen on the eastern side of the Espiritu Santo Island (ESI) to the north of Punta Lobos (24° 31' N, 110° 17' W). We followed them for 1.5 h until they arrived near Los Islotes (LI) (Figure 1b). The sex of the adult male was confirmed by the size and shape of the dorsal fin, while the sex of the females was confirmed by analyzing images of their genital area while they turned and changed

position. Upon arrival at LI (24° 35' N, 110° 24' W), three of the females began pursuing a school of ~200 smooth-tail mobulas who tried to maintain the integrity of the school, moving in a united manner, seeking to avoid the direction from which the orcas appeared. At least four confirmed kills were observed; and since the orcas sank with the rays in their mouths, we were not able to document whether they consumed the entire rays or only part of them. The confirmed deaths were carried out by the adult females, and these attempts were successful when they made synchronized attacks on the shoal, managing to hold the rays with their teeth to later press and tear them.

2. *Encounter A3-A4*—At around noon of the following day (7 May 2018), the same three females from the day before (from A1-A2, based on photo-identification) repeatedly charged and attacked a school of smooth-tail mobulas, between 150 to 180 individuals, in

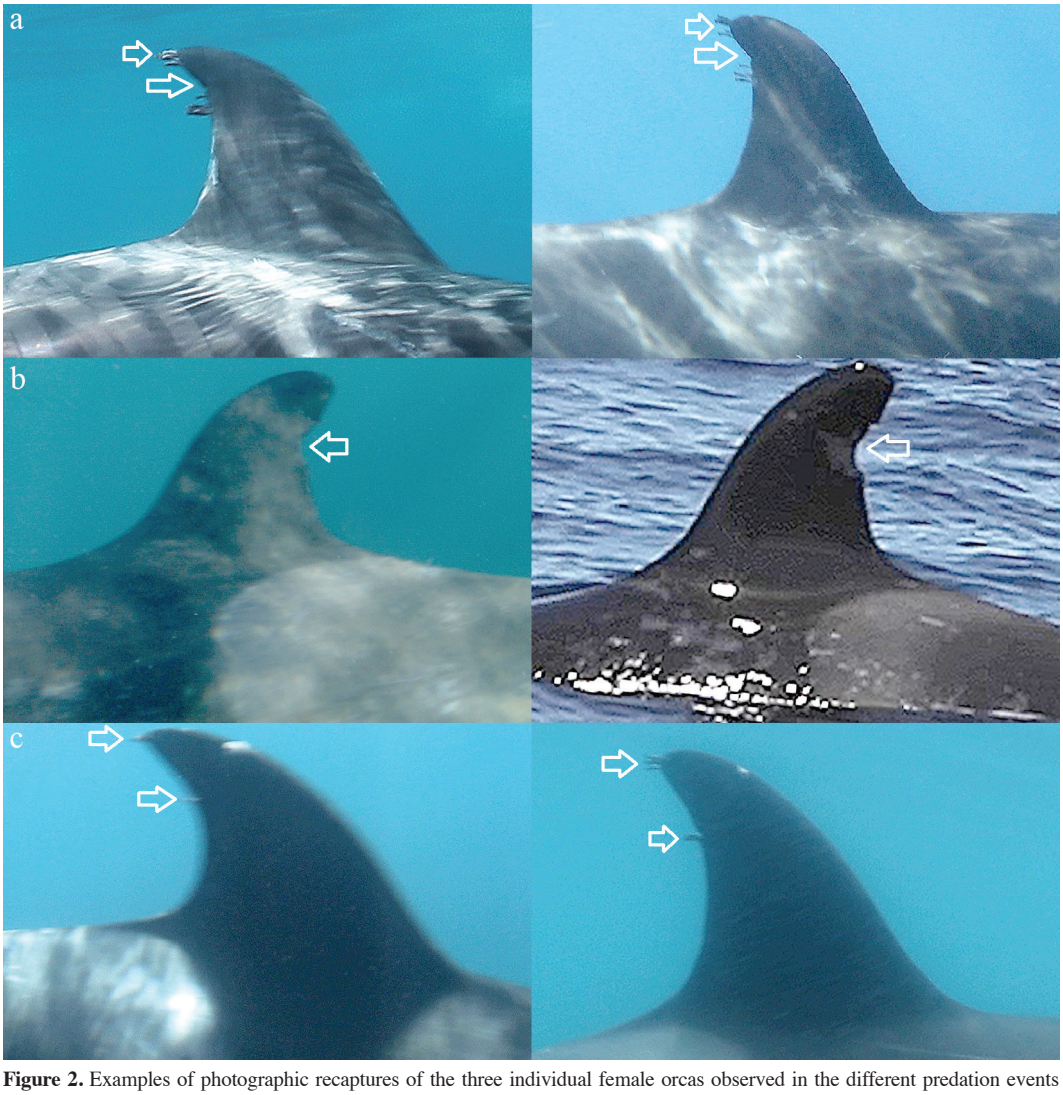

Figure 2. Examples of photographic recaptures of the three individual female orcas observed in the different predation events documented in this short note. Identification matches were made based on the overall shape of the dorsal fin (e.g., compared to the rounded or sharp tips of the fins), nicks in the trailing edges of their fins (e.g., see arrows in orcas a & b), and presence-position-number of pseudo-stalked barnacles (*Xenobalanus globicipitis*) on the trailing edge (e.g., see arrows indicating presence of barnacles in orcas a & c). (Photos provided by Jesús Erick Higuera-Rivas)

Figure 3. Sequence of underwater and aerial photos of predatory behavior by orcas attacking Munk's devil rays (*Mobula munkiana*) in the Gulf of California: (a) two females stalking and charging at a school of Munk's devil rays; (b) two females capture a Munk's devil ray; and (c) aerial view of orcas attacking a group of Munk's devil rays. (Photos provided by Jesús Erick Higuera-Rivas)

front of Balandra Beach (BB) (24° 19' N, 110° 21' W) in La Paz Bay (LPB) (Figures 1b, 2 & 3). During the first attack that we were able to document, only one orca caught a mobula, while the other two females relocated in preparation for another attack by charging at high speed and in a synchronized way towards the school (the same way as the day before), capturing one mobula each (Figure 3a & b). Orcas attacked the rays by targeting those closest to the edge of the school and grasping them by the wingtip and then repositioning the rays to hold them by the head. Once each orca caught a mobula, they all moved away heading north of LPB with the rays in their mouths (Figures 1b & 3b); however, due to the speed with which they moved, we were unable to confirm if they completely consumed their prey or only part of it. Every time the orcas charged and captured a ray, the school of rays regrouped and continued to move as a unit (Figure 3c). On their route from BB to LI, the three female orcas attacked other schools of mobulas they came across, ranging in size from a few dozen to a couple of hundred. Throughout these events, of the seven orcas sighted, only three were observed continuously carrying out the hunting activity. During each hunting attempt documented on this sighting, while one orca drove the school of mobulas in one direction, swimming with zigzag movements so as not to allow lateral escapes of the rays, the other two waited ahead to ambush them from the opposite direction (Figure 3). Due to the speed with which the lunges sometimes occurred, we were not able to document whether the orca in charge of pushing the rays in one direction was always the same.

Figure 4. Sequence of underwater and aerial photos of predatory behavior of orcas on a pelagic stingray (*Pteroplatytrygon violacea*) and on a cownose ray (*Rhinoptera steindachneri*) in the southeastern Gulf of California: (a) two female orcas observe, approach, and start tail slapping the stingray (large orca executes the tail slap while the smaller one observes); (b) the orca hit and stuns the stingray, the stingray expels two embryos after being tail-slapped, and the orca that hit the ray turns and heads towards the stunned ray as it passes near the ejected embryos; (c) one of the orcas shows its teeth as it passes and observes the expelled embryos but does not bite or take them and continues swimming; and (d) aerial view of one female orca approaching from behind and on the side, capturing a Pacific cownose ray. (Photos provided by Jesús Erick Higuera-Rivas)

3. *Encounter A5*—Four hours after the orcas were sighted near BB, they reached the LI area and chased another school of smooth-tail mobulas (Figure 1b). Based on our underwater observations of this and previous events, when the orcas did not catch the mobulas by their frontal region or their head, the prey typically managed to escape (Figure 2).

4. *Encounter A6-A7*—Based on photo-identification, the three adult female orcas identified on 6 May 2018 were resighted on 24 May 2018 in front of Cabo San Lucas (CSL) in traveling mode (Figures 1c & 2). On this occasion, they attacked a pelagic stingray by smacking it with their tails (Figure 4a & b). To achieve this, the orcas approached from below, then turned their bodies, placing their heads just below the pelagic stingray, and there they made an acceleration movement in which they ended up completely vertical with respect to the water line and made a whipping movement with their caudal fin with which they directly hit the body of the ray (Figure 4b).

5. *Encounter A8-A9*—On 10 June 2018, 17 d later, the same three adult female orcas were seen approximately 33 km northwest (23° 34' N, 109° 27' W) of Cabo Pulmo National Park (Figure 1c). As they navigated southwards, they attacked pelagic stingrays on five different occasions in a manner similar to days before by smacking them with their tails and sending some into the air. We think that some of the rays killed were not consumed since they were already dead. The orcas did not hold them in their mouths or bite them at any time; they simply continued traveling away from the rays. One of the pelagic stingrays attacked was gravid; and after being tail slapped several times, one last slap caused the stingray to expel two embryos from her cloaca. One of the orcas passed close to the embryos with her mouth open but did not consume them (Figure 4b). Several of the attacks ended when one of the three orcas grabbed an injured stingray and dove deeper with it outside of our visibility. In a different predation event during the same encounter, one of the females chased a cownose ray (Figure 4c), eventually capturing it and diving deeper with the elasmobranch in her mouth (Figure 4c).

Using photo-identification, we confirmed that at least three female orcas observed in every predation event were the same ones (e.g., Figure 2). Prior to this study, eight events of orcas hunting elasmobranchs had been documented in the Gulf of California throughout a period of 23 y (Table 2; Guerrero Ruiz et al., 2007). This study provides new information on orca foraging behavior, documenting several predation events throughout 36 d. Moreover, although there are pre-existing reports of orcas attacking ray species (Tables 1 & 2), these are the first accounts of predation and attack strategies used by orcas on Munk's devil rays, cownose rays, and pelagic stingrays.

Final Remarks

The tactic employed by orcas while hunting pelagic stingrays described herein looks similar to the hunting behavior described as "carousel feeding" observed in Norway in which orcas use underwater tail slaps to stun herring (Similä & Ugarte, 1993). Several other large predators, such as bottlenose dolphins (*Tursiops truncatus*), also employ this technique (Smolker & Richards, 1988). The tail-slapping behavior exhibited by orcas in our observations is consistent with the highly specialized hunting tactics described for these cetaceans in other areas of the world, which have been proposed as adaptations to the different types of prey available in their distribution areas from the poles to the tropics (Bigg et al., 1990; Visser, 1999, 2005; Baird 2000; Ferguson et al., 2012; Reeves et al., 2017).

The elasmobranchs hunted by the orcas in our observations are common species in the Gulf of California and along coastal areas in the Northeastern Pacific (Notarbartolo di Sciara, 1988; Clark & Nelson, 1997; Mollet, 2002; Croll et al., 2012); however, the three species of rays are subject to fishing pressure (targeted and as bycatch) and are considered susceptible to overexploitation in the Gulf of California (Salomón-Aguilar, 2015). Our observations suggest that in the Gulf of California, mobulas and cownose rays may be killed without being consumed, but a greater number of observations is required to determine the frequency and conditions in which this behavior can occur. One of the possibilities to be analyzed is that older females teach this technique to younger or less experienced orcas (Ford et al., 1998; Jourdain et al., 2017; Figure 4a).

Predation of orcas on rays has been documented in different regions of the world (Norris & Prescott, 1961; Watson, 1981; Brown, 1988; Visser, 1999; Visser & Bonoccorso, 2003; Alava & Merlen, 2009; Terrapon et al., 2021); however, the most detailed description was reported in New Zealand (Visser, 1999, 2000a) where benthic feeding behavior was documented. At this site, the orcas foraged at the seafloor in shallow waters, using the seafloor as a physical barrier to trap stingrays. They also used large bubbles, perhaps released to dislodge the prey. They manipulate the rays by grasping them by the tail, flipping (to induce tonic immobility) and

tossing them into the air (Visser, 1999, 2000b); this is similar to the behavior that we also observed. On several occasions during our observations, the orcas manipulated the mobula rays while holding them in their jaws, apparently to reduce the chance of a ray escaping. However, in all instances we documented, the rays were dorsal side up, so tonic immobility was not a contributing factor in preventing the rays from escaping. In the case of the pelagic stingrays, they were first stunned with several powerful blows from the orca tails, thereby avoiding the stingray's spine. The general differences in the predation tactics used by orcas in the Gulf of California and in New Zealand seem to center on the different zones in which the rays live (epipelagic zone compared to benthic zone, respectively), their schooling behaviour, and on the potential risks each prey species presents. For example, smooth-tail mobulas do not have barbs/stingers (Notarbartolo di Sciara, 1987), and they aggregate in large schools in the Gulf of California (Palacios et al., 2021). The foraging strategies of the orca when hunting mobulas included ambushes and taking the mobulas by the head and not flipping them upside down. Conversely, stingrays, as the name suggests, have stings/barbs which often contain poison, and interactions can result in death (Duignan et al., 2000). Although this is the only published record of such an event for an orca (and it occurred in New Zealand), death as a result of stingray barbs has been recorded for other cetaceans as well, including bottlenose dolphins (McFee & Lipscomb, 2009; Burdett & Osborne, 2010) and false killer whales (*Pseudorca crassidens*; Díaz-Delgado et al., 2018).

Field observations such as the ones reported herein are a fundamental method to increase our knowledge of the Gulf of California orcas for which little is known about their feeding habits and behavior. The fact that the same individuals were involved in all predation events could suggest that some orcas specialize in preying on rays in the Gulf of California.

Given the mostly unknown ecological role of orcas in the Gulf of California, the observations presented herein contribute to better understanding these individuals as currently the importance of the ray species in their diet is poorly known. However, the frequency of predation events in a short time frame in a relatively small area by identified individuals who were repeatedly involved in the foraging suggests that both the techniques used and the prey species are relevant for the feeding habits of these orcas. Additional studies and observations will be useful to determine the seasonal and spatial variations (currently unknown) of these predation events in the Gulf of California.

Orca populations are known to be distinguishable by a number of factors such as genetics, acoustics, foraging methods, and the prey they target to name just a few. These populations are often referred to as *ecotypes*. The ecotype of orcas observed in the Gulf of California is not clear, but some have been observed hunting both cetaceans (Guerrero-Ruiz et al., 2007) and chelonians (Esquivel et al., 1993; Sarti et al., 1994), which is consistent with the transient ecotype found off the northwest coast of North America. Some have also been observed hunting elasmobranchs (Guerrero-Ruiz et al., 2007), coinciding with a range of known ecotypes such as the offshore ecotype (Heimlich-Boran, 1988; Baird & Dill, 1995; Ford et al., 1998; Dahlheim et al., 2008) and the New Zealand coastal ecotype (Visser, 1999, 2000a; Visser & Cooper, 2020), as well as a number of undescribed ecotypes, including those from the Galápagos Islands (Sonnino Sorisio et al., 2006) and from Papua New Guinea (Visser & Bonoccorso, 2003). Recently, a new ecotype was proposed for the nearby central coast region of the Mexican Pacific; however, elasmobranchs were not described as part of their diet (Vargas-Bravo et al., 2020). Since our observations suggest that the group of orcas we documented in the Gulf of California may be exhibiting a foraging specialization in feeding on rays, a behavior that had not been previously documented in this area, an additional ecotype may be using this area, and continued studies will be important to help define this.

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