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Orca (*Orcinus orca*) and shark predator-prey interactions within Cabo Pulmo National Park in the Gulf of California, Mexico

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Orcas (*Orcinus orca*) have a worldwide distribution and as apex predators feed on a wide variety of prey, including marine mammals, seabirds, sea turtles, cephalopods, teleost fish and elasmobranchs. Historically, there have been few observations of orca predation on large elasmobranch species nor are they commonly identified in the stomach contents of deceased orcas. In recent years there has been an increase in observational records of orca predation, such as on white sharks (*Carcharodon carcharias*) in South Africa, which could indicate that elasmobranchs serve a greater importance in their diet than previously considered. These events are often documented by members of the public due to the development and affordability of innovative cameras, including the use of the drones (unoccupied aerial vehicles). Here we describe new predator-prey interactions between orcas and large shark species in Cabo Pulmo National Park (CPNP), a small no-take marine protected area located in the Gulf of California. In this paper, we were able to successfully identify individuals from the described orca pods in the region; specifically, the same individuals hunting sharks over a period of nearly two years. We discuss the potential implications of these new ecological interactions, given the importance of tourism to sustain the management of CPNP, as cascading impacts have been documented elsewhere in light of orca predations on sharks.

KEYWORDS

UAV, Orca, predation, elasmobranch, marine protected area

Introduction

Orcas (*Orcinus orca*) are found worldwide in temperate, tropical, and polar waters (Forney et al., 2006), and throughout their entire range they serve as true apex predators and thus strongly influence the structure and function of marine food webs through direct (e.g., consumptive) and indirect (e.g., predation risk) effects. Orcas are flexible consumers

and exhibit a suite of complex cognitive abilities that aid in foraging (Paulos et al., 2010; Hill et al., 2022). As a result, orcas have “predatory access” to virtually every marine species with which they overlap, including those species which pose the greatest energetic challenges due to their speed/mobility, size, defense mechanisms, or cognitive capabilities. Large elasmobranch fishes, such as sharks (but also many species of ray), are likely underestimated in the diet of orcas (Fertl and Darby, 1996), although records are now beginning to increase in the scientific literature (e.g., Jorgensen et al., 2019; Towner et al., 2022; Higuera-Rivas et al., 2023), prompting new questions into the scale and impact of predator-prey interactions between orcas and large elasmobranchs, especially sharks which also serve as apex predators in many ecosystems (Towner et al., 2023, 2024; Dixon et al., 2023).

Orcas have been studied extensively in coastal areas of the northeastern Pacific Ocean; however, populations in tropical pelagic regions have been little studied. Knowledge of their ecology, population structure, and other characteristics is limited. Three ecotypes of orcas have been identified in the northeastern Pacific differentiated by their external morphology, behavior, and feeding ecology: ‘resident’ (prey on fish), ‘transient’ (prey on marine mammals), and ‘offshore’ (prey on fish) (Baird and Stacey, 1988; Ford et al., 1998; Baird, 2000; Dahlheim et al., 2008). Genetic and acoustic attributes also define the ecotypes (Barrett-Lennard et al., 1996; Hoelzel et al., 1998). Multiple populations of these ecotypes are known to exist along the west coast of North America and there are 52 groups documented in the Eastern Tropical Pacific (ETP) region extending southwest from California to Hawaii and to Peru (Olson and Gerrodette, 2008). The orcas distributed in regions of the ETP show different morphological characteristics and a generalist feeding habit compared to other ecotypes (Ortega-Ortiz et al., 2023). Orcas in the Gulf of California belong to the ETP community and have been observed feeding on both marine mammals and elasmobranchs, but they have yet to be assigned as a separate ecotype (Guerrero-Ruiz et al., 1998; Higuera-Rivas et al., 2023).

Cabo Pulmo National Park (CPNP) is a small (71 km²) marine protected area located on the south-east coast of the Baja California Peninsula, Mexico at the entrance of the Gulf of California. It has become a world-renowned scuba-dive destination in recent years due to the high rates of marine biodiversity and abundant fish populations, including sharks, resulting from the closure of fishing activities in 1995. Shark ecotourism is highly popular within CPNP (Gallagher and Hammerschlag, 2011), with bull sharks (*Carcharhinus leucas*) serving as one of the main attractions and which can be observed across multiple dive sites (Lara-Lizardi et al., 2022).

Seasonal aggregations of adult blacktip sharks (*Carcharhinus limbatus*) occur throughout the park each winter between December and April, a phenomenon that has been noticed by locals since 2008 (Ayres et al., 2021a) and by visual censuses carried out from a vantage point close to the shore since 2013 (Asúnsolo-Rivera, 2016; El-Saleh, 2016). Using unoccupied aerial vehicles (UAVs), sharks can be clearly observed occupying coastal shallow (< 5m) waters, with largest aggregations (over 1000 individuals) recorded in the northern sector of the park before the afternoon

crepuscular period (Ayres et al., 2021a). This aggregating behavior has been linked to thermoregulation, as the shallow water sea surface temperature reaches its peak (~ 23.5°C) during this time between 1500 – 1600hrs. Another driver of shallow water habitat use may be predator avoidance, which has been demonstrated in adult *C. limbatus* in Florida, USA, that seek refuge from patrolling great hammerhead sharks (*Sphyrna mokkaran*) (Doan and Kajiura, 2020).

Here, we present new empirical observations of orcas hunting and predating on sharks in the Gulf of California, specifically within the boundaries of CPNP, using a combination of observation techniques. Specifically, we describe three discrete orca and shark predator-prey interaction events spanning two years, to profile the contemporary landscape of trophic interactions occurring at the top of the food chain in this ecologically significant region. We discuss our results as they relate to similar orca and shark interactions occurring in other locations globally, while highlighting the importance of citizen science and the value of expert naturalists in forecasting ecological change at the local level.

Method and results

A set of three discrete events were documented within the boundaries of Cabo Pulmo National Park (CPNP) Gulf of California, Mexico between 2022 and 2023, all of which describe the predatory behavior of orcas interacting with sharks: (I) an orca pod patrolling the well-known aggregation site of *C. limbatus* in the north of the CPNP; (II) an orca pod attempting to kill *C. leucas* inside the CPNP; and (III) orcas (of the same pod I), successfully predating on *C. leucas* in the south of the CPNP (Figure 1).

Event I: orca pod patrolling aggregation site of *C. limbatus* in the north of CPNP

On January 9th 2022, in the north of CPNP (23°27.441'N 109° 25.555'W) at 13:35hrs, a total of six orca (one adult male, four adult females and one calf) from a previously described pod of individuals (Higuera-Rivas et al., 2023) were filmed via an unoccupied aerial vehicle (DJI Mavic 2 Pro) deployed from a 26-foot fiberglass boat with a 4-stroke outboard motor (115 hp). Two adult female orcas split off from the rest of the group at 13:40hrs and approached the shore in a directed fashion, with one individual orca moving to within ~ 100 meters from the coast (Figures 2A, B) into the known location site of the seasonal blacktip shark (*C. limbatus*) aggregation described in Ayres et al. (2021a). At the time of the filming, no aggregations of *C. limbatus* aggregations were observed, possible due to orca presence. However, during the 7-minute occurrence within the shark aggregation site, one shark was located by the two female orca, but the shark immediately swam into deeper water, presumable after detecting the orcas. The two orcas did not chase the individual shark (Figure 2C). The orcas then reunited with the rest of the group. This separation of only some of the adult or semi-adult females from the rest of the group is a common strategy when searching for potential prey. High-quality aerial video frame shots were extracted for photoidentification and topside imagery

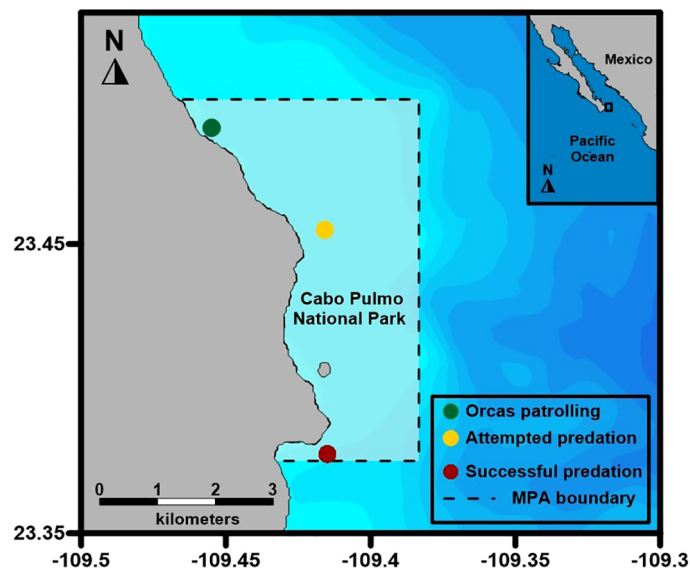


FIGURE 1
Map of Cabo Pulmo National Park and location of all three (I-III) events described in the present study.

from a Canon 1DXMK2 and 100-400mm Canon lens were taken, using distinctive features, including the eye patch, scars and nicks on dorsal fins (Bigg et al., 1987). One adult female orca, could be identified as “Quetzalli” from a distinctive notch near the base of the dorsal fin

(Figure 2D), thus confirming that this group is part of the elasmobranch-eating pod of orca in the region. The photoidentification and progression of dorsal notch on “Quetzalli” is shown in Supplementary S1, Supplementary Material. Another adult



FIGURE 2
Aerial drone imagery of orcas patrolling in north of CPNP in known blacktip shark (*C. limbatus*) aggregation site on January 9th 2022 (A) The orcas swim along the coast. (B) One orca moved close to the coast (the far arrow) while “Quetzalli” (the near arrow) remained far from the coast. (C) The orcas locate a sole blacktip shark (the circle). (D) The unique eye patch and distinctive notch on the dorsal fin of “Quetzalli” are visible (black arrows). (E) The unique eye patch and distinctive round dorsal fin of “Waay” (black arrows). (F) Distinctive dorsal fin of “Waay”. Photo credits: Jesús Erick Higuera-Rivas.

female orca was identified as “Waay” from the shape of the dorsal fin (Figures 2E, F), that had previously been observed preying on rays and other shark species in the Gulf of California in 2018 (Higuera-Rivas, unpublished field observations).

Event II: attempted predation of *C. leucas* at aggregation site in CPNP

On January 21st 2022, in the middle sector of CPNP (23° 27'17.712"N, -109°24'56.736"W) at 10:25hrs, a total of seven orcas (six females, one calf) were filmed by local dive guide (Carlos Lozano Hernandez) with an unoccupied aerial vehicle (DJI Mavic Air 2) deployed from a nearby beach. What followed was a coordinated attack by three of the adult female orcas attempting to predate on a bull shark (*C. leucas*) close to the dive site known as ‘El Vencedor’ which is approximately 15 m in depth. The shark could be seen on surface when one orca charged the shark on its side (Figure 3A), missing the shark only to return to try again immediately, then turning upside down and attempting to hit the shark with her tail, a hunting technique known as ‘lob-tailing’ or ‘tail-slapping’ (Figure 3B). The shark avoided the hit by swimming erratically and escaping. Following this, the second orca entered the

frame and repeated the same behavior, first charging the shark head on, but missing, and then returning with a lob-tailing technique. Two more lob-tailing attempts by the second orca were made before the shark honed towards a local dive boat (26-foot fiberglass boat with a 4-stroke outboard motor, 115 hp), the engine was off, and tourists onboard observed the event take place (Figure 3C). The shark directly hit the starboard side of stern, splashing frantically and erratically circling the vessel before hitting the port side of the stern. One of the adult female orcas approached the vessel, making circles around and underneath the hull for approximately 30 seconds. The shark is not seen on the footage and is possibly underneath the dive boat, the orcas then leave the area, as the boat obstructed their ability to clearly hit the shark. The orcas were not seen again on the drone footage or by the passengers onboard. It was not possible to photo-identify the orcas involved in this attack, based on the available footage.

Event III: successful predation of *C. leucas* in CPNP

On December 6th 2023, in the south of CPNP (23°22'28"N, 109° 25'1"W) at 13:30hrs a total of five orcas (four adult females and one



FIGURE 3

Aerial drone imagery of orcas hunting a bull shark (*C. leucas*) in CPNP (A) The first orca charged the bull shark head on, and after missing employed (B) lob-tailing behavior to attempt to hit the shark with its tail. (C) Bull shark honed to local dive vessel to seek refuge from the orca predation. Photo credits: Carlos Lozano Hernandez.

calf) were sighted and filmed by a dive operator (Luis Mario Castro Arvizu from local dive operation ‘Cabo Pulmo Sport Centre’) using an unoccupied aerial vehicle (DJ Mavic Air 3) deployed from a 26-foot fiberglass dive vessel (115hp). Four adult female orcas were observed close to the surface in the same frame, one of which was seen with a shark in its mouth and two others appear to be sharing another shark below the surface (Figure 4A). The two orcas sharing the shark can then be observed closer to the surface where it is more apparent that it is a large shark species (Figure 4B). The sharks were identified as bull sharks (*C. leucas*) due to their morphology and their size relative to the orcas. One of the orcas then released the shark, followed by the second orca and it was left motionless just below surface, when the drone footage ends. In the same event, underwater footage with a GoPro was obtained in which one orca has carried the shark in its mouth (Figure 4F). The initial attack on the sharks was not witnessed but the predation event was successful as shown by the drone footage and underwater footage. From the underwater footage, two of the orcas can be identified as ‘Niich’ and ‘Waay’ as part of the elasmobranch-eating pod (that includes Quetzalli). ‘Niich’ has a wide notch just above the center of her dorsal fin (Figure 4D) and this image can be matched to an image from a previous predation event in the Gulf of California in

2018 (Figure 4C) where she was observed hunting pelagic stingrays (Higuera-Rivas et al., 2023). The orca “Waay” was photo-identified among the individuals in the group patrolling the zone of the blacktip shark aggregation of CPNP in Event I (Figure 4E), and can be seen in this post-kill social interaction with the bull shark (Figure 4F). She can be identified from the shape of her dorsal fin which is more rounded at the top (Figures 4E, F).

Discussion

Orcas have been documented feeding on elasmobranchs within the Gulf of California for over 50 years (Guerrero-Ruiz et al., 2007). The Gulf of California provides critical habitat for a wide range of marine mammal species such as pinnipeds which are resident year-round, as well as many species of dolphin and other large cetaceans which migrate seasonally such as blue whales (*Balaenoptera musculus*), grey whales (*Eschrichtius robustus*), and humpback whales (*Megaptera novaeangliae*). All these species are known to occur within the diet of orcas throughout their global distribution. The suite of prey options, combined with the semi-enclosed nature of the Gulf itself makes this region a highly profitable foraging



FIGURE 4

(A) Adult female orcas involved in bull shark predation event in CPNP a) Arrow points to shark in the mouth of adult female orcas. (B) Two adult female orcas share bull shark (*C. leucas*) closer to the surface. (C) Image of “Niich” in San Jose del Cabo, Los Cabos, Mexico in May 2018, during predation event on pelagic stingrays. (D) Image of “Niich” in CPNP during bull shark predation (Event III) (E) “Waay” in CPNP in blacktip shark aggregation site (Event I). (F) “Waay” in CPNP with bull shark carrion in mouth (Event III). Photo credits: Jesús Erick Higuera-Rivas (C, E) Luis Mario Castro Arvizu (A, B, D, F).

ground for orcas. The events described here represent the first documented predator-prey interactions between orca and sharks within the boundaries of the marine protected area of CPNP.

The increase in use, availability and affordability of camera equipment including UAVs and underwater cameras is contributing to the ability to record these sightings and predation events. Two of the three events described in this paper were filmed by members of the public and uploaded to social media, which globally as a platform is helping advance and increase our scientific knowledge and understanding of the marine environment. In this sense members of the public become ‘citizen scientists’. Based on the footage, we were able to identify the three orcas in this predator-prey interaction as “Quetzali,” “Niich” and “Waay.” One limitation of obtaining videos from social media and using citizens for science can be a lack of data available, in particular, suitable imagery (clear and high resolution) that can be used to identify individuals involved in predation events.

The abundance of sharks in CPNP has markedly increased in recent years. Within ten years of the park’s creation (1995), local fish biomass was estimated to have increased by over 400% (Aburto-Oropeza et al., 2011), and in turn the increase in abundance and diversity of shark species (Reyes-Bonilla et al., 2016; Ayres et al., 2021b), that was not expected. This increase in the presence of sharks may have facilitated recent interactions with orca, especially because of the decline in shark populations that has occurred in the surrounding area that are not protected throughout the Gulf of California and Mexican Pacific due to shark fishing (Bizzarro et al., 2007).

A long-term monitoring project of the *C. limbatus* aggregations in CPNP was initiated in 2019 using a UAV to complete aerial surveys (Ayres et al., 2021a, b). The north beach of CPNP is surveyed every two weeks during the *C. limbatus* season to document abundance and their arrival to the park after their northerly migration in late spring into the Gulf of California. In the 2021 – 2022 (December – April) season, aggregations of *C. limbatus* were seen in the north beach of the park in December and at the start of January, however, they were not seen again in large aggregations until mid- March, approximately two months after Event I and have not been seen in this area on the aerial surveys during the 2022 – 2023 season. This clear absence of sharks coincides with the presence of orcas in the park. The site-specific absence resulting from orca predation risk is further supported by the fact that aggregations of *C. limbatus* (~100 individuals) were seen on surveys completed further south, in the center of CPNP over the season. This second survey area is protected by a reef break which would restrict access by orcas (especially at low tide), unlike the north area which has a sandy slope into deeper water in which orcas can easily navigate. The *C. limbatus* could therefore be seeking refuge in these more protected areas although in smaller aggregation sizes, as in previous years over 1000 individuals were recorded along the aggregation site in the north. Bull sharks were not seen at the dive site ‘El Vencedor’ where the attempted predation (Event II) occurred until three weeks after the event (personal communication from local dive guides). Our results therefore suggest that orcas could be in the process of creating an

ecological “landscape of fear” (e.g., Gallagher et al., 2017) for these sharks that have only in recent years been documented in such abundances. Further evidence is required to support if the landscape of fear phenomenon is taking place in CPNP which will be provided by the on-going aerial monitoring of the park and the reported occurrences of bull sharks by divers at these sites.

The risk of predation orcas impose on sharks in other areas such as off South Africa, has caused an apparent shift in the presence of white sharks (*Carcharodon carcharias*), in which the majority of the population has disappeared entirely from several known aggregation sites along the coastline of the Western Cape of South Africa (Towner et al., 2022). These ecological shifts have dramatically affected local ecotourism operators and the socioeconomics of the industry which relied on white sharks (Gallagher and Hammerschlag, 2011). As the local ecotourism industry in CPNP relies heavily on sharks as a non-consumptive resource in diving operations, similar effects stemming from orca displacement of sharks would be dramatic, as a study recently reported an average of \$694 USD is spent per visiting person per day at CPNP with an average of a 4-day stay (Pasos-Acuña et al., 2020). The continued aerial monitoring of CPNP and collaborations with local members of the public will determine the potential long-term effects of orca presence in the region and what effects of their predation on shark populations may be for local marine ecosystems and the communities that depend on them.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Ethics statement

Ethical approval was not required for the study involving animals in accordance with the local legislation and institutional requirements because The aerial imagery from the UAVs was already obtained and contributed by local members of the public in which no animals were harmed.

Author contributions

KA: Conceptualization, Writing – original draft, Writing – review & editing. AG: Supervision, Writing – original draft, Writing – review & editing. JH: Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmars.2024.1407379/full#supplementary-material>

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