MOUTHLINE AND DORSAL FIN INJURIES AS AN INDICATOR OF FISHERIES INTERACTIONS IN PYGMY KILLER WHALES AROUND THE MAIN HAWAIIAN ISLANDS

by

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ABSTRACT

Mouthline and Dorsal Fin Injuries as an Indicator of Fisheries Interactions in Pygmy Killer Whales Around the Main Hawaiian Islands

Emma Stock

Fisheries interactions, including bycatch, entanglement, and depredation, are a major global threat to cetaceans. Within the Hawaiian Islands, multiple commercial and recreational fisheries overlap with numerous resident cetacean populations, and the potential impacts of fisheries interactions on most species of cetaceans in Hawaiʻi remain poorly understood. This study evaluates fisheries-related injuries in pygmy killer whales (*Feresa attenuata*) across the main Hawaiian Islands using archival photo-identification data collected between 1986 and 2025. Using standardized injury-scoring protocols, this study quantifies the prevalence of dorsal fin and mouthline injuries and assesses variation across populations, sex, and social clusters. A total of 547 individuals were analyzed for dorsal fin injuries and 124 individuals for mouthline injuries following photo quality, distinctiveness, and visibility filtering. Results indicated that 18.5% of individuals exhibited dorsal fin injuries consistent with fisheries interactions, increasing to 27.2% when including possibly consistent injuries. Mouthline injuries were similarly prevalent, with 23.4% classified as consistent and 37.1% as at least possibly consistent. Injury prevalence did not differ significantly across populations, sexes, or most social clusters, suggesting widespread but relatively uniform exposure to fisheries interactions.

These findings highlight that a substantial proportion of individuals within Hawaiian pygmy killer whale populations show evidence of fisheries-related injuries, despite limited direct observation of interactions. The use of photo-identification data provides a critical, non-invasive method for detecting impacts that are likely underestimated in traditional monitoring programs. By establishing baseline estimates of injury prevalence, this study fills a key knowledge gap and provides a foundation for future monitoring and management. The results suggest that current mitigation frameworks may not fully capture the scope of interactions affecting small, island-associated odontocete populations, underscoring the need for expanded monitoring and more inclusive conservation strategies.

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Chapter One: Literature Review: Fisheries-Related Impacts on Pygmy Killer Whales in the Main Hawaiian Islands

Introduction

Fisheries interactions are among the most pervasive threats to odontocetes (toothed whales) worldwide, often leading to injury, mortality, and long-term population effects (Read, 2008). Understanding these interactions is particularly critical in Hawaiʻi, where both open-ocean and insular cetacean (whales, dolphins, and porpoises) populations overlap with diverse fisheries (Nitta & Henderson, 1993). These interactions include bycatch, entanglement, and depredation, and occur across nearly all major fishing gear types. Species with long lifespans, slow reproductive rates, and strong site fidelity are particularly vulnerable, as even low levels of human-caused injury or mortality can have disproportionate demographic consequences (Hall et al., 2000; Read, 2008).

This chapter aims to review fisheries interactions with odontocetes in Hawaiian waters, with an overarching focus on pygmy killer whales (*Feresa attenuata*), one of the least studied small cetaceans in the region. The first section, *Fisheries Interactions with Marine Mammals*, places Hawaiian fisheries interactions within a global context, emphasizing bycatch, entanglement, and depredation as primary interaction pathways.

The following section, *Hawaiian Fisheries and Odontocete Exposure,* describes the regulatory, cultural, and operational landscape of fisheries in Hawaiʻi and evaluates how spatial and monitoring limitations constrain assessments of cetacean interactions, particularly for nearshore and slope-associated species. Subsequent sections provide biological context relevant to fisheries exposure specifically for pygmy killer whales, including population structure, distribution, habitat use, and social organization.

Finally, the *Research Gaps and Study Rationale* section identifies the need for further study of pygmy killer whale injuries and population structure. This review concludes by outlining how systematic photo-based injury assessment can advance understanding of human–wildlife interactions and inform management strategies for vulnerable Hawaiian odontocete populations.

Fisheries Interactions with Marine Mammals

Fisheries interactions pose a significant threat to marine mammal populations worldwide (Read, 2008). Every year over 300,000 cetaceans die as a result of bycatch or fishing gear entanglement globally (Leaper & Calderan, 2018), with a number of these deaths occurring in Hawaiian waters. These interactions span nearly all fishing gear types and often lead to ecological, economic, and social consequences, including biodiversity loss, gear damage, reduced fishing efficiency, and in some cases, deliberate harm to animals by fishers (Gilman et al., 2006).

Interactions with fisheries can lead to harmful impacts on marine life beyond odontocetes Bycatch in marine fisheries is a globally recognized concern with ecological, social, and economic implications (Alverson et al., 1994; Hall et al., 2000; FAO, 1999a, 1999b, 2004; Gilman et al., 2005). Species with slow reproductive rates and long lifespans, such as marine mammals, are particularly vulnerable to fisheries-related mortality, which can lead to cumulative impacts that are difficult to detect yet capable of driving unsustainable population declines and biodiversity loss (Gilman & Freifeld, 2003; Gilman et al., 2006).

Depredation occurs when cetaceans remove bait or catch from fishing gear and is one of the most common odontocete–longline interactions (Northridge, 1984; Waring et al., 1990; Ashford et al., 1996; Dawson et al., 1998; Baird & Gorgone, 2005). Odontocetes are attracted to fishing vessels by the opportunity to feed and may learn to recognize acoustic cues from engine noise, gear haulers, depth sounders, and radio buoys to locate active vessels (Gilman et al., 2006).

Depredation can alter natural foraging behavior by encouraging cetaceans to target fishing gear, consume prey in atypical contexts, or shift their spatial distribution to overlap more closely with active fishing grounds (Gilman et al., 2006). Importantly, losses of fish removed from gear by depredating cetaceans are typically not incorporated into fisheries stock assessments, which are designed to estimate fish population dynamics rather than predator behavior. As a result, these assessments underestimate both the removal of prey from fishing operations and the frequency of non-lethal cetacean–fisheries interactions that do not result in observed bycatch (Gilman et al., 2006). This omission misrepresents the true scale of interactions that may lead to injury, such as hooking during attempted depredation or damange from struggling against the line. Depredation is therefore one of the most probable mechanisms underlying the mouthline and dorsal fin scarring documented in pygmy killer whales, making it central to understanding how fisheries-related injuries can occur even in the absence of observed capture or mortality events (Vanderzee et al., 2019).

Depredation is often identified by characteristic damage to retrieved fish (Lauriano et al., 2004; Gilman et al., 2006). Interactions primarily occur during gear hauling when bait or catch is near the surface, although depredation can also happen during the set or soak periods (Gilman et al., 2006). The ‘set’ refers to the deployment of longline gear into the water, when baited hooks are sinking to depth, while the ‘soak’ refers to the period when gear remains suspended at depth for hours or overnight, actively fishing (Gilman et al., 2006). Surface-level depredation requires less energy than deep dives to hooked fish, making this stage of fishing particularly attractive to odontocetes (Gilman et al., 2006).

Resident cetaceans may develop learned foraging strategies that allow them to repeatedly associate with specific fishing vessels, even when multiple boats are operating within the same area (Gilman et al., 2006). Such vessel-specific associations can lead to repeated depredation events involving the same individuals or social groups, increasing both the frequency and intensity of interactions with fishing gear (Gilman et al., 2006). Over time, this learned behavior may become reinforced within social groups through social learning, potentially leading to persistent, localized patterns of depredation and elevated risk of fisheries-related injuries for certain individuals or clusters within a population.

Hawaiian Fisheries and Odontocete Exposure

Hawaiian Fisheries

In Hawaiʻi, interactions between federally protected cetaceans and fishing gear have been documented for more than seven decades and continue to occur across multiple taxa and fisheries sectors (Nitta & Henderson, 1993). All cetaceans in U.S. waters are protected under the Marine Mammal Protection Act (MMPA), and several populations occurring in Hawaiʻi, including humpback whales (*Megaptera novaeangliae*), also receive protection under the U.S. Endangered Species Act (ESA). In addition to odontocetes, humpback whales experience recurring entanglements in commercial and recreational fishing gear in Hawaiian waters, with multiple cases reported annually through NOAA’s large whale disentanglement response program (Lyman et al., 2014; Bradford et al., 2015; NOAA Fisheries, 2023).

Marine mammal–fisheries interactions in Hawaiʻi occur within a complex regulatory and governance landscape involving multiple federal, regional, and international stakeholders. In U.S. waters, the primary legal framework governing these interactions is the MMPA, which prohibits the take of marine mammals but allows limited incidental mortality and serious injury in commercial fisheries, provided that impacts do not exceed population-specific sustainability thresholds (Taylor et al., 2000; Carretta et al., 2024). Under the MMPA, fisheries are categorized based on their likelihood of marine mammal interactions, and when mortality or serious injury exceeds a stock's Potential Biological Removal (PBR) level, NOAA Fisheries is required to convene a Take Reduction Team and implement a Take Reduction Plan (TRP) to reduce impacts to below PBR (Taylor et al., 2000; Baird et al., 2015b).

In Hawaiʻi, NOAA Fisheries serves as the lead federal agency responsible for implementing the MMPA, conducting stock assessments, overseeing observer and electronic monitoring programs, and enforcing take reduction measures (Forney & Kobayashi, 2007). Fishery management decisions for federal waters are informed by the Western Pacific Fishery Management Council (WESPAC), which develops fishery management plans for Hawaiʻi and U.S. Pacific territories under the Magnuson–Stevens Fishery Conservation and Management Act. While WESPAC does not directly manage marine mammals, its policies influence fishing effort, gear use, and spatial management, indirectly shaping cetacean exposure to fisheries (Western Pacific Fishery Management Council [WESPAC], 2024).

Fisheries themselves have deep cultural, historical, and economic significance in Hawaiʻi. Fishing has long been embedded in Native Hawaiian subsistence practices and local coastal livelihoods (Lowe, 2004). Beginning in the 1980s, the fishing sector expanded and diversified, growing into a mix of large-scale commercial fleets, small-boat operators, indigenous fisheries, and recreational fisheries across the islands (Pooley, 1993**)**. As fishing effort has intensified and diversified across nearshore and offshore environments, opportunities for direct interactions between cetaceans and fishing operations have also increased, particularly through behaviors that allow marine mammals to exploit fishing gear as a foraging opportunity.

In Hawaiian waters, interactions between marine mammals and fisheries involve diverse gear types, including longlines, handlines, and trolling lines, and have associated ecological and economic consequences (Northridge, 1984; Perrin et al., 1994; Reeves et al., 2013; Read, 2001; Gilman et al., 2006). Cetaceans may become entangled, hooked, or depredate catch, leading to injury or mortality, while fishers experience gear loss, operational disruptions, and economic costs (Ashford et al., 1996; Donoghue et al., 2002; Gilman et al., 2006). These repeated interactions can intensify conflict between fisheries and cetaceans, particularly in regions where spatial overlap is high, and opportunities for avoidance are limited.

As a result, fisheries interactions can extend beyond direct physical impacts to shape public perception of fisheries and human behavior toward cetaceans. Public perception of certain fishing methods, particularly longlines, has become increasingly negative due to reports of marine mammal injury and mortality (Gilman et al., 2006). In extreme cases, frustration among fishers over depredation and gear loss has escalated into retaliatory responses, including harassment or lethal actions directed at cetaceans (Yano & Dahlheim, 1994; Gilman et al., 2006; Dalla Rosa & Secchi, 2007). Such responses pose a disproportionate threat to small, isolated, or island-associated populations, including those in Hawai‘i, where limited population size and restricted ranges can magnify the consequences of even low levels of human-caused injury or mortality (Gilman et al., 2006).

Fisheries Interactions with Cetaceans in Hawaiʻi

Much of the current understanding of cetacean–fisheries interactions in Hawaiʻi is derived from studies of false killer whales (*Pseudorca crassidens*) and other nearshore odontocetes, providing critical context for interpreting injury patterns in pygmy killer whales. Across species, fisheries-related injury prevalence varies with habitat use, social structure, and depredation behavior, highlighting that interaction risk is not uniformly distributed across populations.

False killer whales are one of the best-studied odontocete species with respect to fisheries interactions in Hawaiʻi and provide a key comparative framework for assessing fisheries interactions in other species. However, monitoring of these interactions is uneven and limited. Observer coverage has declined substantially in the deep-set (tuna) longline fishery, and the fleet is transitioning toward electronic monitoring, which currently provides limited information on the scope of cetacean interactions (Harnish et al., 2024). While the longline fleet is transitioning to comprehensive electronic monitoring, nearshore commercial and recreational fisheries, which overlap extensively with resident odontocete populations, still lack monitoring altogether (Nitta & Henderson, 1993; Oleson et al., 2010). As a result, fisheries-related injuries are likely underestimated for island-associated odontocetes that primarily use nearshore and slope habitats.

Recent satellite-tagging and social network analyses demonstrate that Main Hawaiian Island (MHI) false killer whales are structured into four long-term social clusters with distinct spatial use patterns, some of which rarely enter offshore longline zones and instead overlap extensively with nearshore fisheries (Mahaffy et al., 2023; Harnish et al., 2024). Injury prevalence differs significantly among these social clusters (Harnish et al., 2024).

Necropsy evidence also supports repeated interactions, including a stranded false killer whale containing multiple fishing hooks in its stomach (Baird et al., 2015b). Together, these findings show that socially learned depredation behavior and cluster-specific habitat use strongly influence injury risk, an insight directly relevant to pygmy killer whales, which also exhibit strong site fidelity and stable social structure (McSweeney et al., 2009).

Sex bias in fisheries interactions has been clearly demonstrated for false killer whales in Hawaiʻi, where females exhibit higher rates of documented injury (Baird et al., 2015b). This pattern may reflect higher energetic demands during lactation and socially mediated prey sharing among females, increasing depredation risk, although prey sharing occurs between both sexes, not just females. Importantly, female-biased injury and mortality can have disproportionate demographic consequences, as the loss of lactating females often results in the death of dependent calves (Baird et al., 2015b; Kay et al., 2026). This highlights the importance of evaluating injury patterns by sex and social context in small, resident populations.

Bottlenose dolphins (*Tursiops truncatus*) and pantropical spotted dolphins (*Stenella attenuata*) provide additional evidence that nearshore odontocetes experience substantial fisheries-related injury in Hawaiian waters (Baird & Webster, 2020). Both species regularly overlap with nearshore fishing activity, increasing susceptibility to gear interactions (Baird & Webster, 2020). While early photo-identification studies suggested relatively low overall injury prevalence (7.5% across odontocetes), more recent species-specific analyses reveal substantially higher rates (Machernis et al., 2021).

Machernis et al. (2021) documented fishery-related scars on 27.5% of bottlenose dolphins and 13.1% of pantropical spotted dolphins off the islands of Maui Nui, with bottlenose dolphins exhibiting higher prevalence of multiple dorsal fin scars and more frequent mouthline injuries. Scar location differed between species, reflecting differences in foraging behavior and interaction pathways. Bottlenose dolphins showed high rates of mouthline and dorsal fin scarring, whereas spotted dolphin injuries were most commonly dorsal fin–associated. These interspecific differences underscore that injury prevalence and expression vary with behavior and habitat use, reinforcing the need to assess pygmy killer whales independently rather than predicting from other species.

Across false killer whales, bottlenose dolphins, and pantropical spotted dolphins, including photos of the head and mouthline, when available, substantially increased detection of fisheries-related injuries, demonstrating that reliance on dorsal fin imagery alone underestimates interaction prevalence (Machernis et al., 2021; Harnish et al., 2024). Severe dorsal fin injuries, including fin collapse, have been linked to line entanglement across multiple species of odontocetes, while mouthline injuries are especially indicative of depredation-related hooking events (Baird & Gorgone, 2005; Stack et al., 2019).

Collectively, findings from false killer whales, bottlenose dolphins, and pantropical spotted dolphins demonstrate that fisheries-related injury prevalence varies with habitat use, social structure, and depredation behavior. Pygmy killer whales are a rare, cryptic, and poorly understood species, yet available evidence indicates that some individuals exhibit mouthline scarring consistent with hook-and-line fisheries interactions (Vanderzee et al., 2019; Baird et al., 2024). This combination of limited ecological knowledge and documented injury underscores the need for a focused assessment of fisheries-related impacts on this species.

Pygmy Killer Whales

Taxonomy and Evolution

Pygmy killer whales are among the least frequently encountered odontocetes in Hawaiian waters, resulting in limited knowledge of their biology and ecology (Baird et al., 2024). They belong to the subfamily Globicephalinae (Vilstrup et al., 2011) and are most closely related to melon-headed whales (*Peponocephala electra*), from which they likely diverged approximately 2.5 to 4.5 million years ago (McGowen et al., 2020; Vilstrup et al., 2011).

No subspecies are currently recognized; however, genetic analyses suggest potential phylogeographic structure, with differentiation among individuals from Hawai'i, the eastern tropical Pacific, and the western North Atlantic (Hancock-Hanser et al., 2026). Globally, pygmy killer whales occur in tropical and subtropical waters of the Pacific, Atlantic, and Indian Oceans (Hancock-Hanser et al., 2026). They are often confused with melon-headed or false killer whales, highlighting the importance of photographic confirmation for reliable identification (Baird, 2010; Baird & Jefferson, 2024; Siciliano & Brownell, 2015**)**.

Pygmy killer whales possess the typical delphinid chromosome count of 2N = 44 (Yajing et al., 2018). Broader genetic studies, although still limited, indicate pronounced population structuring across the species range. Hancock-Hanser et al. (2026) analyzed mitochondrial DNA from 71 individuals throughout the Pacific and western North Atlantic and found strong phylogeographic differentiation between whales from Hawai'i, the eastern tropical Pacific, and the western North Atlantic. This structure suggests long-term separation among regional populations, though additional sampling is needed to fully resolve global genetic patterns (Hancock-Hanser et al., 2026).

Pygmy killer whales have distinctive coloration and body features that differentiate them from similar delphinids (Figure 1). Their coloration is most similar to melon-headed whales, although pygmy killer whales can be distinguished by differences in cape shape and head pigmentation (Baird, 2010). The body is tricolored, consisting of a dark gray dorsal cape (a band of pigmentation extending from the back toward the eye), lighter gray sides, and a pale ventral band that broadens near the genital region (Yamada, 1954). Diagnostic features include the sharp lower boundary of the dark cape below the dorsal fin and a small eyepatch separated from the darker crown by a lighter arc above the eye (Baird, 2025). White pigmentation around the mouthline is frequently observed in adults and may become more pronounced with age or following injury (McSweeney et al., 2009; Baird, 2025). In contrast, neonates and young calves possess a distinct bilateral band of white pigmentation extending from the mouth corner to the rostrum tip, along with more extensive pale coloration on the lower jaw and throat that together form what is referred to as a facial mask (Mahaffy et al., 2025).

Figure 1.

Pygmy Killer Whale

Note. Pygmy killer whale at the surface of the water (Photo: R.W. Baird).

Tooth structure also aids identification for deceased individuals. Pygmy killer whales have 8–12 teeth per side in the upper jaw and 9–13 per side in the lower jaw, compared with >20 teeth per row in melon-headed whales **(**Baird, 2025). Individuals frequently display long-lasting white scarring from tooth rakes or cookie-cutter shark bites (*Isistius* sp.) (McSweeney et al., 2009).

In addition to coloration, morphological differences, such as dorsal fin placement, help distinguish pygmy killer whales from false killer whales (*Pseudorca crassidens*). In pygmy killer whales, the distance from the anterior dorsal fin insertion to the blowhole is roughly twice the dorsal fin base length, versus 2.5 times in false killer whales (Baird et al., 2010).

Population Structure, Habitat Use, and Life History

Pygmy killer whales in Hawaiian waters exhibit well-defined population structure, restricted movements, and pronounced habitat specialization, with most research historically focused on a small, resident population off Hawaiʻi Island (McSweeny et al., 2009; Baird et al., 2015a). Together, patterns of abundance, spatial distribution, and habitat use indicate the presence of multiple island-associated resident populations with limited connectivity to open-ocean groups (Baird et al., 2011; Baird et al., 2015a; Baird et al., 2024). Satellite-linked tag data indicate that the Hawaiʻi Island resident population primarily occupies the west and southeast coasts of Hawaiʻi Island, ranging from northwest of Kawaihae to the island's southern tip, based on tag deployments conducted between in 2008 and 2009 (Baird et al., 2011). More recent long-term photo-identification and social network analyses have also identified a distinct Oʻahu resident population that ranges east to Penguin Bank, demonstrating that insular residency is not limited to Hawaiʻi Island alone (Baird et al., 2024).

Genetic sampling of pygmy killer whales in Hawaiian waters has been relatively limited but provides important insights into population structure. Tissue samples from 29 photo-identified individuals, including individuals from three single strandings and a five-animal mass stranding, show evidence of both shared lineages and distinct genetic groupings (Baird et al., 2024). The most common mitochondrial haplotype occurred in 12 individuals (41%), nine of which belonged to two long-term resident groups that primarily use different parts of the archipelago (Baird et al., 2024). The remaining 17 individuals exhibited seven additional haplotypes, including five whales from the same mass stranding that shared a single haplotype and a separate group of three whales sighted only once offshore that shared another haplotype

(Baird et al., 2024). These patterns suggest a mixture of resident lineages and less frequently encountered offshore groups.

At broader spatial scales, all pygmy killer whales within the Hawaiian Islands Exclusive Economic Zone (EEZ) are currently classified as a single management stock under the U.S. marine mammal stock assessment framework (Carretta et al., 2024). Line-transect surveys conducted in the early 2000s estimate an abundance of approximately 956 individuals (CV = 0.83) in Hawaiian waters, although this estimate includes both resident and pelagic animals and is based in just two sightings, and therefore associated with substantial uncertainty due to low encounter rates (Barlow, 2006). Abundance estimates for pygmy killer whales in Hawaiian waters have been derived from line-transect surveys conducted during the Hawaiian Islands Cetacean and Ecosystem Assessment Surveys (HICEAS), which used systematic survey effort across the Hawaiian Islands Exclusive Economic Zone (EEZ) to generate design-based estimates of cetacean density and abundance. These surveys produced abundance estimates of 3,854 individuals in 2002, 27,833 individuals in 2010, and 10,328 individuals in 2017, although the estimates have relatively wide confidence intervals, reflecting low encounter rates and uncertainty in detection (Bradford et al., 2021).

In contrast, long-term photo-identification studies conducted off Hawaiʻi Island since the early 2000s have documented a much smaller, demographically isolated resident population characterized by strong site fidelity and minimal inter-island movement (McSweeney et al., 2009; Baird, 2011). Similar patterns of site fidelity and social stability have now been documented for the Oʻahu resident population, further supporting the existence of multiple insular units embedded within a broader EEZ-wide stock designation (Baird et al., 2024). These findings underscore the mismatch between broad-scale management units and fine-scale population structure relevant to assessing localized anthropogenic threats.

Virtually nothing is known about the detailed life history of pygmy killer whales worldwide, with key parameters such as longevity, age at sexual maturity, and reproductive rates remaining undocumented (Donoghue & Perryman, 2009; Jefferson et al., 2015). However, based on similarities with closely related delphinids such as false killer whales and pilot whales (*Globicephala* sp.), pygmy killer whales are presumed to be long-lived and slow to mature, possessing life-history traits that increase sensitivity to anthropogenic mortality (Kasuya, 1986; Baird, 2009; Taylor et al., 2000). Given their restricted distribution, strong site fidelity, small population size, and specialized habitat use, pygmy killer whales in Hawaiʻi meet established criteria for small, resident populations, and Biologically Important Areas (BIAs) have been designated to support targeted management and conservation efforts (Baird et al., 2015a; Kratofil et al., 2023).

BIAs have been designated to support the management and conservation of pygmy killer whales in Hawaiʻi by identifying areas that are critical to key life-history functions, including foraging and long-term residency (Baird et al., 2015a). BIAs are spatially defined regions where small, resident populations consistently occur and are therefore more vulnerable to localized anthropogenic threats. For pygmy killer whales, BIAs largely overlap with slope habitats adjacent to the main Hawaiian Islands, particularly off Hawaiʻi Island, reflecting the species' strong site fidelity, restricted movements, and reliance on deep-water foraging habitats close to shore (Baird et al., 2015a).

Pygmy killer whales are primarily oceanic and rarely approach shore except around oceanic islands, where steep bathymetry brings deep-water habitat close to land (Baird et al., 2015a). Within Hawaiʻi, individuals are nonmigratory and show strong, long-term site fidelity to specific islands, particularly Hawaiʻi Island and Oʻahu, based on multi-decade sighting records spanning 1999–2024 (McSweeney et al., 2009; Baird et al., 2024). Although occasional movements of up to 200 km between islands have been documented, most individuals remain near their original sighting locations across multiple years (Baird et al., 2024).

Habitat-use patterns further reinforce this insular residency. Sightings occur most frequently over slope habitats at depths ranging from 500 to 3,000 m, and satellite-linked tag data indicate that individuals spend approximately 45% of their time in waters between 500 and 1,000 meters deep, suggesting a strong preference for deep, slope-associated foraging areas adjacent to island shorelines (Baird et al., 2024). This reliance on specific bathymetric features likely contributes to limited movements and increased vulnerability to localized anthropogenic threats.

Group size in pygmy killer whales is variable but generally small relative to many other social odontocetes. Individuals have been observed alone or in groups of up to approximately 40 animals, with a median observed group size of 12 individuals during at-sea encounters based on sightings collected between 1999 and 2024 (Baird et al., 2024). This median group size is similar to the typical size of long-term social clusters identified through photo-identification, although clusters represent persistent social units rather than instantaneous groupings observed at sea. When complete clusters are encountered together, observed group size and cluster membership may therefore overlap.

The largest group confirmed with photographic evidence consisted of an estimated 50–70 individuals (Owen & Donnelly, 2014). Although some reports describe groups of several hundred animals, these accounts lack photographic confirmation and are likely attributable to misidentification with melon-headed whales, a species that commonly forms large aggregations and is frequently confused with pygmy killer whales (Siciliano & Brownell, 2015; Baird & Jefferson, 2024). Field observations further indicate that pygmy killer whale groups often travel in tight, cohesive formations, consistent with stable social organization and long-term association among individuals (McSweeney et al., 2009). These groups are typically spatially cohesive and socially stable, showing long-term association patterns that persist for many years (McSweeney et al., 2009; Baird et al., 2024). Calves remain with their mothers for more than a decade, and adult females are often seen accompanied by multiple calves of different ages. Beyond these maternal networks, long-term association studies indicate the presence of broader, mixed-age social clusters composed of multiple adult males and females, suggesting that pygmy killer whales form extended social groups (McSweeney et al., 2009; Baird et al., 2024). A long-term study conducted in Hawaiian waters remains the only detailed examination of social organization in this species. This work has demonstrated that pygmy killer whales maintain strong social bonds, with individuals repeatedly associating across many years, highlighting the species complex and cohesive social structure (McSweeney et al., 2009; Baird et al., 2024). Pygmy killer whales also exhibit interspecific associations. They have been observed interacting with a variety of other odontocetes, including false killer whales, short-finned pilot whales, rough-toothed dolphins (*Steno bredanensis*), and bottlenose dolphins (Ross & Leatherwood, 1994; McSweeney et al., 2009).

Behaviorally, pygmy killer whales are considered cautious and disturbance sensitive. Roughly 60% of encounters in Hawaiʻi include some form of vessel avoidance, and individuals typically display slow, lethargic surfacing behavior. High-speed travel has never been documented across more than 70 encounters (McSweeney et al., 2009; Baird et al., 2010; Baird et al., 2024). Their distribution may also be influenced by anthropogenic noise; they are notably uncommon near Kaua‘i and Ni‘ihau, where Navy mid-frequency sonar is regularly used (Baird et al., 2024). When kept in captivity, they can present aggressive behavior towards humans, often charging and generating a ‘growling’ sound with their blowhole when approached (Pryor et al., 1965).

Bycatch reports of pygmy killer whales are few, though limited observer coverage and the potential for misidentification likely contribute to underestimation. Injuries consistent with hook-and-line fisheries have been documented, including one confirmed case involving a stranded individual in Hawai‘i (Baird, 2016; Vanderzee et al., 2019). Surface feeding behavior in pygmy killer whales has not been directly observed in the more than 120 documented encounters in Hawaiian waters, indicating that foraging likely occurs at depth or during nighttime hours rather than at the surface (McSweeney et al., 2009; Baird et al., 2024). Evidence of diet primarily comes from stomach content analyses of stranded individuals, which have revealed the consumption of several squid and fish species, including four identified squid species, three fish species, and unidentified myctophids (i.e. lanternfish; Sekiguchi et al., 1992; Zerbini & Santos, 1997; O’Dwyer et al., 2015; Elorriaga-Verplancken et al., 2016).

Squid and mesopelagic fishes, including myctophids (lanternfishes), are key components of the pelagic food web and play a central role in energy transfer between lower trophic levels and apex predators (Clarke, 1996). These taxa are also closely associated with pelagic longline fisheries, both directly and indirectly. Squid are widely used as bait in tuna and swordfish longline fisheries, and mesopelagic fishes constitute an important prey base for commercially targeted species such as yellowfin tuna (*Thunnus albacares*) and swordfish (*Xiphias gladius*) (Bertrand et al., 2002; Gilman et al., 2006). Diet studies of tunas and billfishes consistently show high reliance on squid and myctophids, creating strong trophic and spatial overlap between fishing operations and deep-diving predators that target similar prey (Clarke et al., 1998; Graham et al., 2007).

In Hawaiʻi, longline fisheries primarily target tuna and swordfish in offshore waters, deploying baited hooks that closely resemble the natural prey of pygmy killer whales in both size and type. This overlap likely increases the probability of depredation when pygmy killer whales attempt to remove bait or hooked prey that are visually, behaviorally, or acoustically similar to their natural prey items (Northridge, 1984; Baird & Gorgone, 2005; Gilman et al., 2006). Such depredation events increase the risk of hooking or entanglement, providing a plausible mechanism for the mouthline and dorsal fin injuries that were previously documented in Vanderzee et al. (2019) and that are assessed further in this study.

In addition to offshore fisheries, nearshore and small-scale commercial fisheries in Hawaiʻi target reef-associated and slope-associated fishes using handlines, troll lines, short-lines, and kaka-lines (Nitta & Henderson, 1993; Oleson et al., 2010). These fisheries operate in areas that overlap with pygmy killer whale habitat, particularly along island slopes and deep nearshore environments where individuals spend a substantial proportion of their time (Baird et al., 2024). Although these fisheries may not target identical prey species, they exploit ecologically similar prey assemblages and present concentrated, energetically efficient feeding opportunities. As a result, interactions may arise not from direct prey competition, but from the attraction of pygmy killer whales to fishing gear as an accessible substitute for naturally occurring squid and mesopelagic fishes (Gilman et al., 2006).

Research Gaps and Study Rationale

Most research on odontocete–fisheries interactions in Hawaiʻi has focused on pelagic or well-studied species such as false killer whales, leaving substantial knowledge gaps for cryptic, insular odontocetes such as pygmy killer whales. This study addresses that gap by evaluating the prevalence, distribution, and spatial clustering of mouthline and dorsal fin injuries in the pygmy killer whale populations found in Hawaiian waters, providing one of the first population-level assessments of fisheries-related injury risk for this species and establishing a baseline for future comparisons.

Research effort in Hawaiian waters has been disproportionately concentrated around the main Hawaiian Islands (MHI), particularly off the island of Hawaiʻi, where numerous small, resident odontocete populations have been well documented. This spatial focus has informed the identification of BIAs for species such as pygmy killer whales, which meet the criteria for small, resident populations with restricted movements and high site fidelity (Kratofil et al., 2023). Despite this progress, quantifying fisheries interactions for island-associated odontocetes remains challenging because most nearshore commercial and recreational fisheries lack observer coverage, making direct estimates of interaction rates difficult (Baird et al., 2015b). Understanding which cetacean species interact with fisheries, where these interactions occur, and how frequently they take place is essential for evaluating risk, informing mitigation efforts, and supporting effective conservation and management strategies under existing regulatory frameworks (Machernis et al., 2021).

Archival photo-identification data provides a critical alternative means of assessing fisheries interactions, allowing injuries to be detected and evaluated across individuals, social groups, and years. While head and mouthline photographs remain inherently difficult to obtain for a cryptic species such as pygmy killer whales, substantial growth of the photo-identification archive between 1994 and 2025 now enables the first systematic, population-level assessment of fisheries-related injuries using standardized methods. This expanded archive allows for synthesis of imagery collected across multiple platforms, years, and contributors, increasing the ability to detect spatial, temporal, and social patterns of injury that are unlikely to be captured through observer-based approaches alone. As such, this thesis utilizes an expanded photographic dataset to address gaps in understanding fisheries interactions with pygmy killer whales in Hawaiʻi.

Pygmy killer whales are naturally rare, difficult to detect, and among the least understood odontocetes in Hawaiian waters, yet evidence already shows that some individuals exhibit mouthline injuries consistent with fisheries interactions (Vanderzee et al., 2019; Baird et al., 2024). For small, demographically isolated populations, even a limited number of documented injuries can signal population-level risk, particularly when injuries may reflect repeated or ongoing interactions rather than isolated events. Identifying the presence, type, and distribution of such injuries is therefore critical for early detection of emerging conservation threats.

This study fills a critical knowledge gap in how pygmy killer whale populations in Hawaiʻi interact with fisheries by applying standardized, validated injury-scoring protocols to all available images, allowing for population-level estimation of fisheries-related injury prevalence. This baseline information is essential for comparing risk across populations, sexes, and social clusters in addition to determining whether this species is interacting with fisheries at levels that warrant management action.

Existing management frameworks, such as the Hawaiʻi False Killer Whale TRP, were developed to reduce serious injury and mortality by identifying high-risk fisheries and implementing mitigation measures, including gear modifications, handling protocols, and spatial restrictions (Taylor et al., 2000; Baird et al., 2015b). The TRP is explicitly focused on the pelagic false killer whale population and is primarily informed by interactions documented in offshore longline fisheries, rather than nearshore or island-associated populations (Baird et al., 2015b; Carretta et al., 2024). Importantly, the TRP does not explicitly consider other cryptic, island-associated odontocete species, including MHI false killer whales, and does not address nearshore commercial or recreational fisheries that operate outside the federally monitored longline sector (Nitta & Henderson, 1993; Oleson et al., 2010; Baird et al., 2015b). As a result, pygmy killer whales may experience fisheries interactions that are not captured by existing mitigation frameworks, particularly in nearshore and slope habitats where observer coverage is minimal or absent. By documenting injury prevalence and spatial patterns in pygmy killer whales, this study provides information needed to evaluate whether current management approaches adequately reflect the diversity of cetacean–fisheries interactions occurring in Hawaiian waters and whether additional monitoring or mitigation measures may be warranted.

Conclusion

Despite increasing recognition of the importance of injury assessments for understanding human impacts on marine mammals, pygmy killer whales remain among the least studied odontocetes in Hawaiian waters. These small, resident, island-associated populations occupy relatively well-defined ranges and depth habitats, yet documented evidence of fisheries interactions within these localized environments remains limited but concerning (Baird et al., 2024). This study moves beyond simply documenting the presence of injuries by explicitly examining how biological, social, spatial, and temporal factors influence the occurrence and distribution of fisheries-related mouthline and dorsal fin injuries in pygmy killer whales in Hawaiian waters.

By systematically applying standardized injury-scoring protocols to archival photo-identification imagery, this thesis quantifies the proportion of individuals exhibiting fisheries-related mouthline and dorsal fin injuries, while also evaluating whether injury prevalence varies by sex, population, and social cluster. This analysis approach allows for inference about whether fisheries interactions are randomly distributed or concentrated within particular social groups, providing insight into the potential role of learned depredation behaviors or differential exposure to fishing activities.

More broadly, this approach contributes to the literature on fisheries and cetacean interactions by advancing methodologies for detecting sometimes subtle but significant human impacts on vulnerable marine populations. By identifying patterns of injury linked to biological and social structure, this thesis provides a foundation for future monitoring, comparative studies across odontocete species, and the development of more inclusive fisheries management strategies that better account for cryptic, island-associated cetaceans such as pygmy killer whales.

Chapter Two: Introduction: Pygmy Killer Whales in Hawai‘i

Interactions between fisheries and cetaceans are a globally recognized conservation concern, contributing to injury, mortality, and population declines across numerous species (Read, 2008). These interactions include bycatch, entanglement, and depredation, and occur across nearly all major fishing gear types. Depredation, defined as the removal of bait or catch from fishing gear, is one of the most common mechanisms driving odontocete-fisheries interactions, and frequently occurs during longline hauling (Northridge, 1984; Gilman et al., 2006). This is the stage in longline fishing when lines that have been soaking are reeled in, bringing baited hooks or captured fish near the surface, but depredation can also take place during the set and soak stages of fishing operations (Gilman et al., 2006).

Depredation interactions have been documented globally for decades. One early reported case occurred in 1952 in Japanese distant-water tuna longline fisheries in the tropical South Pacific, where killer whales (*Orcinus orca*) were observed removing and damaging catch near Palau (Iwashita et al., 1963). A recent synthesis by Luck et al. (2025) further highlights the widespread nature of these interactions, documenting killer whale depredation across multiple fisheries and ocean basins. Repeated interactions with fishing gear can also leave lasting physical evidence on individuals. For example, the insular Hawaiian Islands false killer whale population, which frequently interacts with hook and fisheries, exhibits a high prevalence of dorsal fin disfigurements associated with longline hooks and gear (Baird & Gorgone, 2005; Harnish et al., 2024).

Odontocetes may learn to associate fishing vessels with feeding opportunities and use acoustic cues such as engine noise or gear deployment sounds to locate active vessels (Gilman et al., 2006). Species with long lifespans, slow reproductive rates, and strong site fidelity are particularly vulnerable to impacts from fisheries interactions, as even low levels of human-caused injury or mortality can have disproportionate demographic consequences (Hall et al., 2000; Read, 2008). In addition to ecological impacts, cetacean–fisheries interactions can generate economic losses through gear damage and catch depredation and may escalate human–wildlife conflict (Gilman et al., 2006). Frustration among fishers over depredation and gear loss has escalated into retaliatory responses, including harassment or lethal actions directed at cetaceans (Yano & Dahlheim, 1994; Gilman et al., 2006; Dalla Rosa & Secchi, 2007). Such retaliatory measures can include the use of guns, harpoons, and explosives (Luck et al., 2025).

In Hawaiian waters, interactions between odontocetes and fisheries have been documented for decades and involve both offshore and nearshore fishing operations (Nitta & Henderson, 1993). Despite its importance to understanding these interactions, monitoring coverage in many fisheries remains limited (Hall et al., 2000). In some fisheries in Hawaiʻi, such as the longline fishery, monitoring programs are increasingly transitioning from onboard observers to electronic monitoring systems (Carnes et al., 2019). Historically, however, observer coverage within the longline fleet has been dependent on target species. While the shallow-set longline fishery (which targets swordfish) has maintained 100% observer coverage for years, the deep-set longline fishery (which targets tuna) has had a much more limited degree of coverage (Harnish et al., 2024). Nearshore commercial and recreational fisheries lack systematic monitoring altogether, limiting the ability to quantify interactions with island-associated cetacean populations (Baird et al., 2015b; Harnish et al., 2024). As a result, the extent and distribution of fisheries-related injuries for most odontocete species in Hawaiʻi remain poorly understood.

The pygmy killer whale (*Feresa attenuata*) is among the least-studied small cetaceans globally, and is cryptic in nature and found in Hawaiian waters (Vanderzee et al., 2019; Baird, 2025). Abundance estimates for pygmy killer whales in Hawaiian waters have been derived from line-transect surveys conducted during the Hawaiian Islands Cetacean and Ecosystem Assessment Surveys (HICEAS), which used systematic survey effort across the Hawaiian Islands Exclusive Economic Zone (EEZ) to generate design-based estimates of cetacean density and abundance. These surveys produced abundance estimates of 3,854 individuals in 2002, 27,833 individuals in 2010, and 10,328 individuals in 2017, although the estimates have relatively wide confidence intervals, reflecting low encounter rates and uncertainty in detection (Bradford et al., 2021). However, these design-based estimates represent animals detected across the broader EEZ survey region and do not specifically estimate the abundance of the island-associated resident populations identified through photo-identification studies (McSweeney et al., 2009; Baird et al., 2011; Baird et al., 2024). Long-term photo-identification and satellite-tagging studies indicate the presence of small, demographically isolated resident populations with strong site fidelity off the islands of Hawaiʻi Island and Oʻahu (McSweeney et al., 2009; Baird et al., 2011; Baird et al., 2024). These populations occupy slope-associated habitats adjacent to islands and exhibit limited inter-island movements, characteristics that increase susceptibility to localized anthropogenic threats (Harnish et al., 2024).

Direct observations of feeding behavior in pygmy killer whales are notably absent (McSweeney et al., 2009; Baird et al., 2024). Across more than 120 encounters in Hawaiian waters, individuals have never been observed feeding at the surface, suggesting that foraging likely occurs at depth or during nighttime hours (McSweeney et al., 2009; Baird et al., 2024). Evidence of diet primarily comes from a few stomach content analyses of stranded individuals from South Africa, Brazil, Cape Verde, and Mexico, which have revealed the consumption of just four squid species, three fish species, and unidentified myctophids (i.e. lanternfish;

Sekiguchi et al., 1992; Zerbini & Santos, 1997; O'Dwyer et al., 2015; Elorriaga-Verplancken et al., 2016). Because these stomach-content records originate from multiple geographic regions, they may not represent the diet of pygmy killer whales in Hawaiian waters. Consequently, knowledge of pygmy killer whale diet remains extremely limited relative to most other odontocetes. Despite the limited data, the available evidence suggests that pygmy killer whales consume squid and mesopelagic fishes that are common components of pelagic food webs (Baird, 2025). Fishes targeted by Hawaiian longline and nearshore fisheries, such as tuna and swordfish, also feed extensively on squid and mesopelagic fishes, indicating indirect trophic connections within pelagic ecosystems (Gilman et al., 2006; Olson et al., 2010). This overlap creates potential pathways for interaction when fishing gear presents energetically profitable access to prey that resemble natural foraging targets.

Although fisheries interactions with pygmy killer whales have been infrequently reported worldwide, this likely reflects limited observer coverage in many tropical fisheries where the species occurs**,** the difficulty of distinguishing pygmy killer whales from closely related species like melon-headed whales (*Peponocephala electra*) and short-finned pilot whales (*Globicephala macrorhynchus*; e.g.*,* Yahn et al., 2019), and the cryptic nature of the species rather than an absence of interactions. Individuals in Hawaiian waters have been documented with mouthline injuries consistent with hook-and-line fisheries interactions, and at least one stranded individual showed evidence of prior hooking (Baird, 2016; Vanderzee et al., 2019; Baird et al., 2024). These observations raise concern given the small size and isolation of resident populations. Existing management frameworks, such as the Hawaiʻi False Killer Whale TRP (Take Reduction Plan), focus entirely on pelagic longline fisheries and do not address interactions involving nearshore commercial or recreational fisheries, which overlap extensively with resident odontocete populations (Baird et al., 2021). Importantly, documented injuries represent only individuals that survived hooking events. Because many cetacean deaths at sea go undetected, the true level of mortality from hooking, entanglement, or ingestion of fishing gear remains largely unknown. For small, insular populations, even a limited number of documented injuries may therefore indicate ongoing fisheries interactions and potential population-level risk, particularly if these events occur repeatedly over time.

Despite growing recognition of the value of injury assessments, no study has systematically quantified fisheries-related mouthline and dorsal fin injuries in pygmy killer whales. This study uses archival photo-identification data between 1986 and 2025 by Cascadia Research Collective (CRC) to systematically assess fisheries-related mouthline and dorsal fin injuries in pygmy killer whales across the main Hawaiian Islands. Specifically, we (1) estimate the prevalence of fisheries-related injuries identifiable from photographs, (2) evaluate variation in injury prevalence across populations, sex, and social cluster, and (3) examine limitations associated with using archival imagery. By establishing baseline injury prevalence and identifying patterns of risk, this study provides critical information for understanding human impacts on pygmy killer whales and informs future monitoring and management of cetacean populations in Hawaiʻi.

Chapter Three: Methods

The dataset includes photographs collected between 1986 and 2025 during dedicated small-boat surveys, as well as opportunistic submissions from collaborators and community scientists. Photographs collected prior to the transition from film to digital photography in the early 2000s were retained when image quality was sufficient for scoring but were generally lower resolution and less abundant per encounter than more recent digital images. Together, these sources provide longitudinal coverage of individuals across known populations and social clusters within the main Hawaiian Islands (MHI). Individuals were identified primarily using dorsal fin shape, notches, and scarring patterns. Assignments to population were based on long-term photo-identification records, movement patterns, association data and social network position (McSweeney et al., 2009; Baird et al., 2024). A social network from Baird et al. (2024) representing individuals from all three populations was used determine whether individuals connected to the main component of the network and clustered with individuals off Hawaiʻi Island (i.e., the HIMC) or Oʻahu (i.e., the OAMC) or if they were part of an isolated component (IC). Social cluster assignments were taken from Baird et al. (2024), which used the Louvain algorithm to detect clusters within the main component. Sex determination was based on genetic sampling, the presence of a post-anal keel in males, or repeated observations of calves consistently associated with adult females.

All available photographs of known individuals between 1986 and 2025 were manually reviewed to identify images showing the mouthline. Mouthline images were extracted by systematically reviewing all encounter-specific folders for each individual in the CRC pygmy killer whale photo-ID catalog using ACDSee Pro 7 or Nomacs (Version 3.22) photo management software. Selected images were copied into standardized folders labeled with individual ID, encounter date, and source (CRC encounter number or contributor name). Dorsal fin images were selected from the CRC "Best of IDs" folder within the photo-identification catalog, which contains representative dorsal fin images for each individual. When available, images from encounters immediately preceding the first detection of dorsal fin damage were also included to provide temporal context for injury assessment. An accompanying Microsoft Excel sheet was used to track image provenance and metadata, including encounter date, location, island, population, social cluster, sex, dorsal fin distinctiveness (1 = not, 2 = slightly, 3 = average, 4= very), number of images available for scoring, and which portions of the mouthline were visible (left, right, both, front, upper, lower). Photo quality was scored on a four-point scale (1 = poor, 2 = fair, 3 = good, 4 = excellent) following Baird et al. (2024). For all analyses, individuals were restricted to those with fair or better photo quality (PQ ≥2) to ensure reliable injury detection.

For mouthline analyses, the proportion of the mouthline visible across all images for each individual within each encounter was estimated in 10% increments. Mouthline image quality was scored on a four-point scale (1 = poor, 2 = fair, 3 = good, 4 = excellent), following criteria outlined in Baird et al. (2024). Individuals were included in mouthline analyses only if ≥50% of the mouthline was visible in an encounter and if image quality was rated ≥2. Individuals with dorsal fin or mouthline photo quality rated as poor (1) were excluded from injury analyses due to insufficient resolution for reliable injury detection.

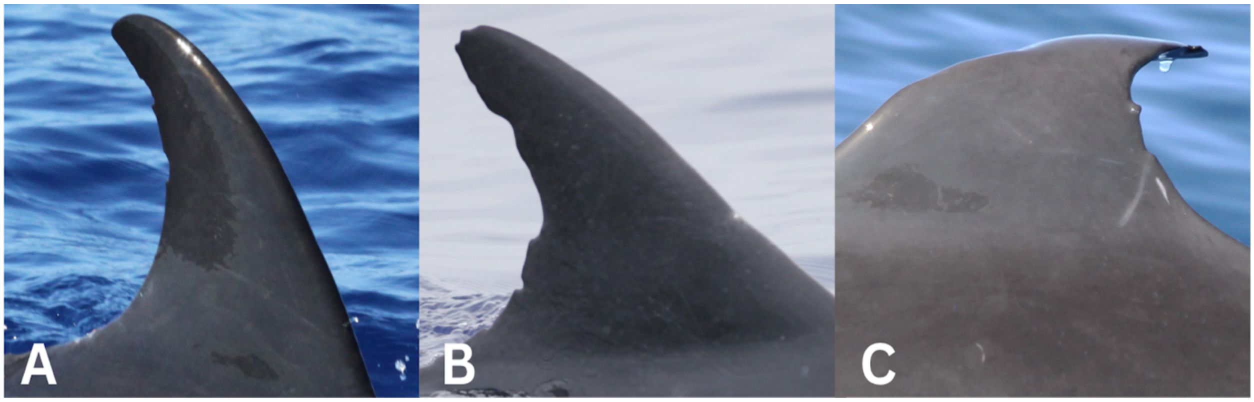
Changes in pigmentation and coloration across life stages are widespread in cetaceans, particularly between neonates, calves, and adults (Perrin, 2018). Younger individuals typically exhibit a more muted coloration, while contrast and pattern complexity tend to increase as they mature (reviewed in Krzyszczyk & Mann, 2012). In pygmy killer whales, neonates and young calves have a white facial mask-like pigmentation that transitions to gray as the individual matures (Mahaffy et al., 2025). White pigmentation around the mouthline is frequently observed in adults and may become more pronounced with age and following injury (McSweeney et al., 2009; Baird, 2025), potentially confounding visual classification of injury severity. The presence of barnacles on teeth or the mouthline was noted, as barnacle attachment indicates prior breaks in the skin or exposure of tooth material. Individuals exhibiting any indication of potential injury (e.g., mouthline notches, pigmentation irregularities, corner scarring, barnacles, or dorsal fin damage) were selected for formal injury scoring. Selected mouthline and dorsal fin images were independently scored by two reviewers following the protocol described in Harnish et al. (2024). Reviewers worked independently and were blind to one another's scores during the initial assessment. Each injury was scored at the individual level using a category classification system:

1. Not consistent with fisheries interaction
2. Possibly consistent with fisheries interaction
3. Consistent with fisheries interaction

Injuries classified as consistent with fisheries interactions included mouthline notches with broken skin, lip damage exposing teeth, severe scarring at mouth corners, irregular pigmentation patterns, barnacle attachment, or linear dorsal fin injuries consistent with line or gear contact (Figures 2, 3). Injuries likely attributable to natural causes (e.g., shark bites) were classified as not consistent. Injuries were classified as possibly consistent when features suggested a fisheries origin but were dubious due to size, clarity, or partial obstruction. Sightings of individuals were considered undeterminable when image quality or visibility precluded confident classification and were excluded from analyses. Following independent scoring, reviewer assessments were combined into a single dataset. Individuals without any visible injuries were retained for assessing injury prevalence among groups.

Figure 2.

Dorsal Fin Scoring



Note. Examples of each of the scoring category classification system on dorsal fins for pygmy killer whales around the main Hawaiian Islands. (A) HIFa470 dorsal fin classified as not consistent (1) with fisheries interactions (photo: J.M. Aschettino). (B) HIFa165 classified as possibly consistent (2) with damage to the leading edge and dorsal fin tip notch (photo: D.J. McSweeney). (C) HIFa547 classified as consistent (3) with a collapsed dorsal fin (photo: D.J. McSweeney).

Figure 3.

Mouthline Scoring

Note. Examples of each of the scoring category classification system on mouthlines for pygmy killer whales around the main Hawaiian Islands. (A) HIFa008 classified as not consistent (1) with fisheries interactions (photo: G.S. Schorr). (B) HIFa004 classified as possibly consistent (2) with scarring in right corner of the mouthline that could be from a line slice (photo: R.W. Baird). (C) HIFa625 classified as consistent (3) with a notch on the upper lip most likely from a hook (photo: C.J. Cornforth).

Reviewer scores were converted to numerical values (1 = not consistent, 2 = possibly consistent, 3 = consistent). Individuals with a mean highest score ≥2.5 for either the dorsal fin or mouthline were classified as having injuries consistent with fisheries interactions, while individuals with mean highest scores ≥2.0 and <2.5 were classified as having injuries possibly consistent with fisheries interactions.

Injury categories were assessed independently and included:

- Dorsal fin injuries consistent with fisheries interactions
- Dorsal fin injuries possibly consistent with fisheries interactions
- Mouthline injuries consistent with fisheries interactions

- Mouthline injuries possibly consistent with fisheries interactions
- Presence of either or both injury types consistent with fisheries interactions

Statistical analyses followed the framework used in Harnish et al. (2024) and were conducted in R (R Core Team 2026), primarily using the *tidyverse* (Wickham et al., 2019) suite of packages. Reviewer agreement was assessed using percent agreement and Cohen's kappa. Cohen's kappa was selected because it accounts for agreement expected by chance, providing a more robust measure of inter-observer reliability for categorical classification data. Injury prevalence was calculated as the proportion of individuals classified as having injuries consistent (and possibly consistent) with fisheries interactions.

Fisher's exact tests were used to compare injury prevalence across populations (OAMC and HIMC), and isolated components (ICs), defined as individuals not connected to the main component of the social network), social cluster (restricted to individuals in the main components, following the methods of Mahaffy et al., 2023), and between sexes. This test was selected because sample sizes for some groups (e.g., IC population, known-sex subset) were small. Because injury scores are ordinal and not normally distributed, non-parametric tests were used. Spearman correlations were used to assess rrelationships between injury scores and ordinal predictors (e.g., pigmentation, scarring, number of notches).

Chapter Four: Results

A total of 115,917 photos were available from pygmy killer whale encounters spanning 1986–2025. This value reflects the number of images associated with individuals in the photo-identification catalog and includes duplicate counts of the same photograph when multiple individuals were present in a single frame. As such, this value represents the total number of photo assignments rather than the number of unique images in the archive. Mouthline analyses spanned 1994-2025 due to the availability of suitable head and mouthline imagery. In contrast, dorsal fin analyses included the full dataset spanning 1986–2025, representing 750 identified individuals prior to filtering. After removing records with undeterminable scores and applying photo quality (PQ ≥ 2) and distinctiveness (Distinctiveness ≥ 2) filters, the dorsal fin dataset was reduced to 547 individuals (286 from the Hawai‘i Island main component [HIMC], 123 from the O‘ahu main component [OAMC], and 138 from isolated components [ICs]).

For mouthline analyses, photographs were initially available from 129 pygmy killer whale sightings between 1994 and 2025, representing 574 identifications of 218 individuals. After removing records with undeterminable scores, applying mouthline photo quality (PQ ≥ 2) and distinctiveness (Distinctiveness ≥ 2) filters, and restricting analyses to images with ≥50% mouthline visibility, the dataset was reduced to 305 identifications representing 124 individuals (62 from the Hawai‘i Island main component [HIMC], 42 from the O‘ahu main component [OAMC], and 20 from isolated components [ICs]).

Dorsal fin injuries

Reviewer agreement analyses were conducted prior to applying distinctiveness and photo quality filters to maximize sample size. Reviewer agreement for dorsal fin scoring was high (83.3% agreement across 693 individuals with valid scores from both reviewers prior to applying additional filtering criteria), with substantial agreement between reviewers (Cohen's $\kappa = 0.61$, $z = 21.3$, $p < 0.001$), indicating that dorsal fin injuries were consistently identified and classified. This high level of agreement supports the reliability of dorsal fin scoring as a method for assessing potential fisheries interactions.

The distribution of individuals across photo quality (PQ) categories was uneven, with 43 individuals in PQ1, 153 in PQ2, 342 in PQ3, and 155 in PQ4 (Figure 4). Mean dorsal fin scores increased across photo quality categories, with the lowest mean score observed in PQ1 (1.24) and the highest mean score observed in PQ4 (1.61). Intermediate mean scores were observed for PQ2 (1.30) and PQ 3 (1.37). A weak but significant positive correlation was detected between photo quality and mean dorsal fin score (Spearman's $\rho = 0.182$, $p < 0.001$). Dorsal fin scores also differed significantly among photo quality categories (Kruskal–Wallis $\chi^2 = 24.35$, $df = 3$, $p < 0.001$), indicating that higher-quality images were associated with slightly higher injury scores (Table 1, Figure 4). Because these analyses were conducted prior to applying the photo quality filter, the observed relationship likely reflects improved detectability and classification of dorsal fin injuries in higher-quality images rather than differences in sample size alone.

Table 1.

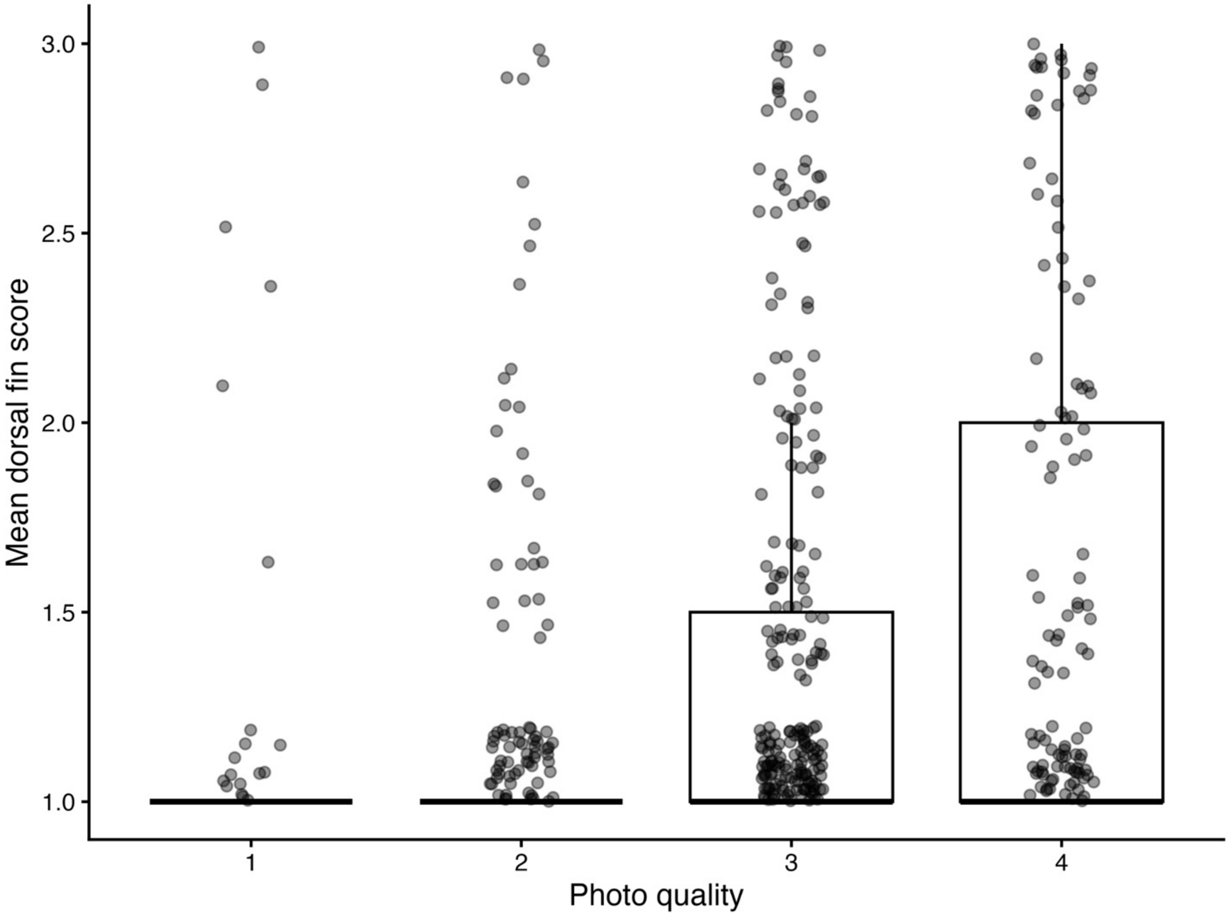
Dorsal Fin PQ Summary

Photo Quality (PQ)	Number of Individuals	Highest Mean Dorsal Fin score
1 (Poor)	43	1.24
2 (Fair)	153	1.30
3 (Good)	342	1.37
4 (Excellent)	155	1.61

Note. Photo quality categories range from 1 (poor) to 4 (excellent). Values represent the number of individuals assigned to each photo quality category based on the highest-quality image available per individual. Highest mean dorsal fin score reflects the mean of the highest injury score assigned to each individual within each photo quality category prior to applying photo quality filtering.

Figure 4.

Mean Dorsal Fin Score vs Photo Quality



Note. Distribution of mean highest dorsal fin injury scores by individual across highest photo quality by ID categories (PQ1–4). Points represent individual pygmy killer whales, and boxplots summarize the median and interquartile range, with whiskers indicating the range of values. Median scores are similar across photo quality categories.

Among the 547 individuals assessed after applying distinctiveness and photo quality filters and removing undeterminable scores, 101 individuals (18.5%) were classified as having dorsal fin injuries consistent with fisheries interactions, and an additional 48 individuals (8.8%) were classified as possibly consistent. Overall, 149 individuals (27.2%) exhibited injuries at least possibly consistent with fisheries interactions (Table 2). Collapsed dorsal fins were observed in four whales (0.7% of those assessed), with an additional five whales (0.9%) exhibiting dorsal fins beginning to collapse.

For statistical comparisons, individuals with mean dorsal fin scores ≥ 2 were classified as exhibiting injuries at least possibly consistent with fisheries interactions, thereby combining both possibly consistent and consistent injury classifications. Individuals with mean scores ≥ 2.5 were classified as having injuries consistent with fisheries interactions, while individuals with scores from 2.0–2.49 were classified as having injuries possibly consistent with fisheries interactions. Within the HIMC, 17.1% of individuals were classified as having dorsal fin injuries consistent with fisheries interactions and an additional 9.8% were classified as possibly consistent. Within the OAMC, 18.7% of individuals were classified as consistent and 6.5% as possibly consistent. Within ICs, 21.0% were classified as consistent and 8.7% as possibly consistent.

When injuries classified as possibly consistent or consistent with fisheries interactions were combined for statistical analyses (mean dorsal fin score ≥ 2), the overall proportion of affected individuals was similar across populations, with 26.9% of individuals in HIMC, 25.2% in OAMC, and 29.7% in ICs classified as exhibiting dorsal fin injuries at least possibly consistent with fisheries interactions. No statistically significant association was detected between population and injury presence (Fisher's exact test, $p = 0.701$), and all pairwise comparisons between populations were non-significant (Bonferroni-adjusted $p \geq 0.409$). These results indicate that the prevalence of dorsal fin injuries at least possibly consistent with fisheries interactions did not differ significantly among HIMC, OAMC, and IC populations.

When only injuries classified as consistent with fisheries interactions were included in statistical analyses (mean dorsal fin score ≥ 2.5), the proportion of affected individuals was also similar across populations, with 17.1% of individuals in HIMC, 18.7% in OAMC, and 21.0% in ICs classified as having dorsal fin injuries consistent with fisheries interactions. No association was detected between population and injury prevalence (Fisher's exact test, $p = 0.605$), and all pairwise comparisons between populations were non-significant following Bonferroni correction. These results indicate that the prevalence of dorsal fin injuries consistent with fisheries interactions did not differ significantly among HIMC, OAMC, and IC populations.

Dorsal fin injury prevalence was evaluated across eight social clusters (Clusters 1–8) within the HIMC and OAMC populations using individuals that met filtering criteria (distinctiveness ≥ 2, photo quality ≥ 2, removal of undeterminable scores, and assignment to a Louvain social cluster based on sightings from 1999–2025). A total of 312 individuals met these criteria and were included in the cluster analysis. The prevalence of dorsal fin injuries at least possibly consistent with fisheries interactions (mean dorsal fin score ≥ 2) ranged from 11.1% to 42.5% across clusters, with a mean prevalence of approximately 26.1% (Table 2). When only injuries classified as consistent with fisheries interactions were considered (mean dorsal fin score ≥ 2.5), prevalence ranged from 0% to 27.8% across clusters, with a mean prevalence of approximately 18.3%.

To evaluate whether dorsal fin injury prevalence differed among social clusters within populations, additional analyses were conducted separately for the HIMC and OAMC populations. No statistically significant association between social cluster and the presence of dorsal fin injuries at least possibly consistent with fisheries interactions (mean dorsal fin score ≥ 2) was detected within either population (HIMC: Fisher's exact test with simulated p-values, $p = 0.957$; OAMC: Fisher's exact test with simulated p-values, $p = 0.443$). These results indicate that the prevalence of dorsal fin injuries at least possibly consistent with fisheries interactions did not differ significantly among social clusters within either the HIMC or OAMC populations.

However, when only injuries classified as consistent with fisheries interactions were considered (mean dorsal fin score ≥ 2.5), no statistically significant association between social cluster and injury presence was detected within the HIMC population (Fisher's exact test with simulated p-values, $p = 0.639$), whereas a significant association was detected within the OAMC population (Fisher's exact test with simulated p-values, $p = 0.028$), indicating that the prevalence of dorsal fin injuries consistent with fisheries interactions differed among social clusters within OAMC.

Table 2.

Summary of Dorsal Fin Injury Prevalence Across Social Clusters

Social Cluster	Population	Total Individuals	Individuals Assessed	Injured	Percent Injured
1	HIMC	23	23	6	26.1%
2	OAMC	87	87	19	21.8%
3	OAMC	36	36	11	30.6%
4	HIMC	66	66	14	21.2%
5	HIMC	9	9	1	11.1%
6	HIMC	31	31	11	35.5%
7	HIMC	40	40	17	42.5%
8	HIMC	20	20	4	20.0%

Note. Values represent the number of individuals assessed within each social cluster, the number classified as exhibiting dorsal fin injuries at least possibly consistent with fisheries interactions, and the corresponding percentage affected. Injury classification was based on mean highest dorsal fin scores per individual ≥ 2 following application of distinctiveness and photo quality filters (Distinctiveness ≥ 2; PQ ≥ 2) and removal of undeterminable scores. All individuals assigned to social clusters were represented in the dorsal fin dataset after filtering, resulting in approximately 100% coverage across clusters.

Of the 547 individuals whose dorsal fins were assessed, sex was known for 53 individuals (25 females and 28 males), while the remaining individuals were of unknown sex. Among individuals of known sex, eleven females (44.0% of females) and seven males (25.0% of males) were classified as exhibiting dorsal fin injuries at least possibly consistent with fisheries interactions (mean dorsal fin score ≥ 2). When only injuries classified as consistent with fisheries interactions were considered (mean dorsal fin score ≥ 2.5), eight females (32.0% of females) and four males (14.3% of males) were classified as having dorsal fin injuries consistent with fisheries interactions. The proportion of affected individuals did not differ significantly between sexes using either classification threshold (mean score ≥ 2: Fisher's exact test, $p = 0.162$; mean score ≥ 2.5: Fisher's exact test, $p = 0.190$).

Mouthline injuries

As with dorsal fin scoring, reviewer agreement for mouthline scoring was calculated prior to applying distinctiveness, visibility, and photo quality restrictions in order to maximize sample size. Agreement between reviewers for mouthline scoring was 72.1% (Cohen's $\kappa = 0.438$, $z = 11.4$, $p < 0.001$), indicating moderate agreement (Figure 3). The distribution of individuals across photo quality categories was uneven, with only two individuals in PQ1, compared to 54 in PQ2, 67 in PQ3, and 39 in PQ4. Mean mouthline scores generally increased across photo quality categories, from 1.38 in PQ2 to 1.57 in PQ3 and 1.69 in PQ4, although PQ1 had a higher mean score (1.75) based on a just 2 individuals (Table 3, Figure 5). A weak but statistically significant positive correlation was detected between photo quality and mean mouthline score (Spearman's $\rho = 0.163$, $p = 0.038$). However, mean mouthline scores did not differ significantly among photo quality categories (Kruskal–Wallis $\chi^2 = 5.02$, $df = 3$, $p = 0.170$). Because these analyses were conducted prior to applying the photo quality filter, the observed relationship likely reflects slightly improved detectability of mouthline injuries in higher-quality images, although the effect was weaker and less consistent than that observed for dorsal fin injuries.

Table 3.

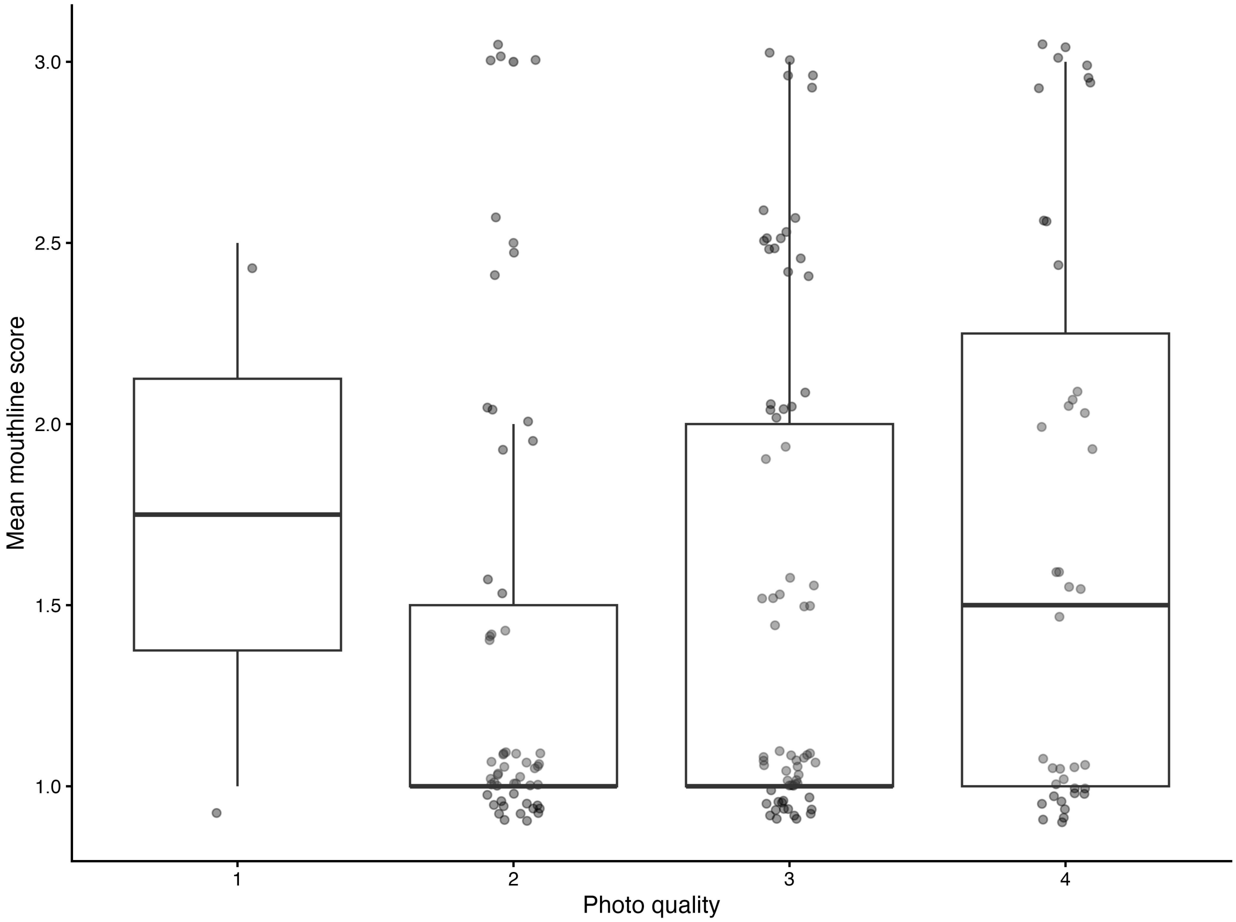
Mouthline Photo Quality Summary

Photo Quality (PQ)	Number of Individuals	Highest Mean Mouthline score
1 (Poor)	2	1.75
2 (Fair)	54	1.38
3 (Good)	67	1.57
4 (Excellent)	39	1.69

Note. Photo quality categories range from 1 (poor) to 4 (excellent). Values represent the number of individuals assigned to each photo quality category based on the highest-quality image available per individual. Highest mean mouthline score reflects the mean of the highest injury score assigned to each individual within each photo quality category prior to applying photo quality and visibility filters (PQ ≥ 2; ≥50% mouthline visibility). The small sample size in PQ1 (n = 2) should be interpreted with caution.

Figure 5.

Mean Mouthline Score vs Photo Quality



Note. Distribution of mean highest mouthline injury scores by individual across photo quality categories (PQ1–4). Points represent individual whales, and boxplots summarize the median and interquartile range, with whiskers indicating the range of values. Median scores were generally similar across photo quality categories, although slightly higher scores were observed in higher-quality images.

When individuals were grouped based on the presence or absence of mouthline injuries at least possibly consistent with fisheries interactions (mean mouthline score ≥ 2), mouthline visibility was similar between groups (Wilcoxon rank-sum test, W = 1546.5, p = 0.110). This analysis was conducted using all individuals with available mouthline visibility data prior to applying any visibility-based filtering criteria used in subsequent analyses. Median visibility was identical between groups (50%), with mean visibility of 63.0% for individuals classified as exhibiting mouthline injuries at least possibly consistent with fisheries interactions ($n = 46$) and 57.8% for individuals without such injuries ($n = 78$), indicating generally similar levels of photographic coverage across groups. Mouthline visibility was weakly positively correlated with mean mouthline score (Spearman's $\rho = 0.16$, $p = 0.038$), suggesting that increased visibility may modestly improve the detection of mouthline injuries. However, the relatively low median visibility among many individuals indicates that mouthline injuries may still be underdetected due to incomplete photographic coverage

Of the 124 individuals assessed for mouthline injuries after applying distinctiveness and photo quality filters, removing individuals with undeterminable scores, and restricting analyses to individuals with at least 50% of the mouthline visible, 29 individuals (23.4%) had mean highest mouthline scores by ID ≥ 2.5 and were therefore classified as having injuries consistent with fisheries interactions. An additional 17 individuals (13.7%) had mean scores between 2.0 and 2.49, indicating injuries possibly consistent with fisheries interactions. Combined, 46 individuals (37.1%) exhibited mouthline injuries at least possibly consistent with fisheries interactions (Table 5).

When injuries classified as possibly consistent or consistent with fisheries interactions were combined for statistical analyses (mean mouthline score ≥ 2), the proportion of affected individuals was similar across populations, with 33.9% of individuals in HIMC, 38.1% in OAMC, and 45.0% in ICs classified as exhibiting mouthline injuries at least possibly consistent with fisheries interactions. No statistically significant association between population and injury prevalence was detected (Fisher's exact test, $p = 0.654$).

Across individuals, mouthline visibility was weakly positively correlated with mean mouthline score (Spearman's $\rho = 0.19$, $p = 0.034$), suggesting that increased visibility may improve the detection of injuries. Median mouthline visibility also differed significantly among populations (Kruskal–Wallis $\chi^2 = 28.78$, $df = 2$, $p < 0.001$), with individuals from ICs having substantially higher visibility (median = 90%) than individuals from HIMC and OAMC (both median = 50%). Because analyses were restricted to individuals with at least 50% of the mouthline visible, differences in visibility among populations may have influenced the detectability of mouthline injuries.

When only injuries classified as consistent with fisheries interactions were considered (mean highest mouthline score ≥ 2.5), 27.4% of individuals in HIMC, 19.0% in OAMC, and 20.0% in ICs were classified as having mouthline injuries consistent with fisheries interactions. No statistically significant association between population and injury prevalence was detected (Fisher's exact test, $p = 0.577$), and all pairwise comparisons between populations were non-significant following Bonferroni correction.

Mouthline injury prevalence was evaluated across eight social clusters (Clusters 1–8) within the HIMC and OAMC populations. The number of individuals with mouthline photographs meeting filtering criteria varied substantially among clusters, ranging from 1 to 22 individuals. Relative to total cluster size, representation of individuals in the mouthline dataset ranged from 20.0% to 100.0%, indicating uneven photographic coverage across clusters. For example, Cluster 1 was almost fully represented (95.7% coverage), whereas several clusters had less than 50% representation. Interpretation of cluster-specific prevalence estimates should be made cautiously due to small sample sizes and uneven photographic coverage across clusters.

The prevalence of mouthline injuries at least possibly consistent with fisheries interactions (mean highest mouthline score ≥ 2) ranged from 25.0% to 100.0% across clusters, with a mean prevalence of approximately 46.0% (Table 4). Differences among clusters were inconsistent and strongly influenced by clusters with small sample sizes and limited photographic coverage, which may disproportionately affect percentage estimates. No statistically significant association was detected between social cluster membership and the presence of mouthline injuries at least possibly consistent with fisheries interactions (Fisher's exact test, $p = 0.672$), indicating that injury prevalence did not differ detectably among clusters.

When only injuries classified as consistent with fisheries interactions were considered (mean highest mouthline score ≥ 2.5), prevalence ranged from 14.3% to 100.0% across clusters, with a mean prevalence of approximately 37.8%. However, no statistically significant association between social cluster membership and the presence of mouthline injuries consistent with fisheries interactions was detected (Fisher's exact test with simulated p-values, $p = 0.242$), indicating that the prevalence of mouthline injuries consistent with fisheries interactions did not differ significantly among social clusters.

Table 4.

Mouthline Social Cluster Summary

Social Cluster	Population	Total Individuals	Individuals Assessed	Individuals Injured	Percent Injured	Coverage
1	HIMC	23	22	12	54.6%	95.7%
2	OAMC	87	21	8	38.1%	24.1%
3	OAMC	36	13	5	38.5%	36.1%
4	HIMC	66	7	2	28.6%	10.6%
5	HIMC	9	2	1	50.0%	22.2%
6	HIMC	31	3	1	33.3%	9.7%
7	HIMC	40	12	3	25.0%	30.0%
8	HIMC	20	1	1	100.0%	5.0%

Note. Values represent the number of individuals assessed within each social cluster using mouthline photographs meeting filtering criteria (Distinctiveness ≥ 2, PQ ≥ 2, ≥ 50% mouthline visibility, and removal of undeterminable scores), the number classified as injured (mean highest mouthline score ≥ 2), and the corresponding percentage injured. “Total individuals” represents all individuals assigned to each social cluster based on the broader dataset used for cluster detection (Distinctiveness ≥ 2, PQ ≥ 2 sightings from 1999–2025). Coverage (%) reflects the proportion of individuals within each cluster represented in the mouthline dataset. Percent injured was calculated using assessed individuals only. Clusters with small sample sizes or low coverage should be interpreted with caution.

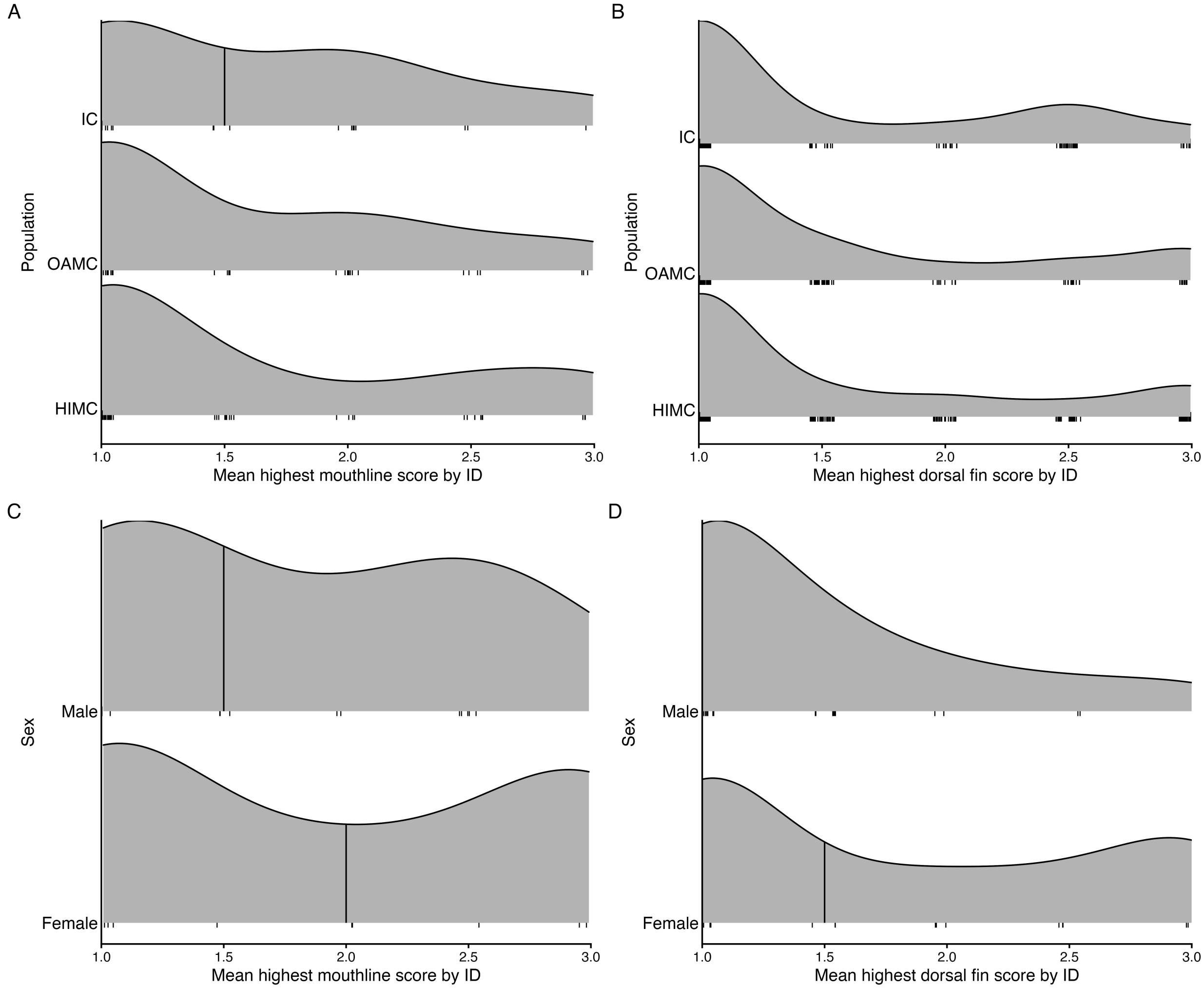
To evaluate whether mouthline injury prevalence differed among social clusters within populations, additional analyses were conducted separately for the HIMC and OAMC populations. No statistically significant association between social cluster and the presence of mouthline injuries at least possibly consistent with fisheries interactions (mean highest mouthline score ≥ 2) was detected within either population (HIMC: Fisher’s exact test with simulated p-values, p = 0.391; OAMC: Fisher’s exact test with simulated p-values, p = 0.999), indicating that the prevalence of mouthline injuries at least possibly consistent with fisheries interactions did not differ significantly among social clusters within either population.

When only injuries classified as consistent with fisheries interactions were considered (mean highest mouthline score ≥ 2.5), no statistically significant association between social cluster and injury presence was detected within either the HIMC population (Fisher's exact test with simulated p-values, p = 0.455) or the OAMC population (Fisher's exact test, p = 0.999; Figure 6). These results indicate that the prevalence of mouthline injuries consistent with fisheries interactions did not differ significantly among social clusters within either population.

Of the 124 individuals assessed for mouthline injuries, sex was known for 34 individuals (15 females and 19 males; Figure 6). Among individuals of known sex, eight females (53.3% of females) and nine males (47.4% of males) were classified as exhibiting mouthline injuries at least possibly consistent with fisheries interactions (mean highest mouthline score ≥ 2). No statistically significant difference in prevalence was detected between sexes using this threshold (Fisher's exact test, p = 0.999). When only injuries classified as consistent with fisheries interactions were considered (mean highest mouthline score ≥ 2.5), no statistically significant difference in prevalence between sexes was detected (Fisher's exact test, p = 0.999).

Figure 6.

Ridgeline Plots showing distribution of injury scores in relation to population and sex



Note. Ridgeline plots illustrating the density of mean highest fisheries interaction scores (A and C: mouthline score; B and D: dorsal fin score) by ID vs. population (A, B), and sex (C, D). Each datapoint is indicated below the ridgelines with a vertical tick mark. The median mean highest fisheries interaction score by ID is indicated with a vertical line. No vertical line indicates that the medians are all 1.0.

Individuals with both dorsal fin and mouthline scoring

A total of 124 individuals had both dorsal fin and mouthline scores available for comparison. Of these, 118 individuals had complete categorical classifications available for both scoring methods and were included in this analysis (Table 5). Within this subset, 27 individuals were classified as having dorsal fin injuries consistent with fisheries interactions (mean dorsal fin score ≥ 2.5), and 28 individuals were classified as having mouthline injuries consistent with fisheries interactions (mean highest mouthline score ≥ 2.5). Eight individuals were identified as having injuries consistent with fisheries interactions in both scoring categories. Overall, agreement between dorsal fin and mouthline classifications was high and was largely driven by consensus among individuals classified as lacking injuries consistent with fisheries interactions.

Table 5.

Cross-classification of dorsal fin and mouthline injury categories

Mouthline Classification	Dorsal Fin Consistent	Dorsal Fin Possibly Consistent	Dorsal Fin Not Consistent	Total
Consistent	8	4	16	28
Possibly Consistent	4	1	10	15
Not Consistent	15	6	54	75
Total	27	11	80	118

Note. Summary of dorsal fin and mouthline injury classifications for 118 individual pygmy killer whales with both dorsal fin and mouthline scores available from photographs collected between 1994 and 2025. Values represent individual whales rather than sightings or photographs. “Consistent” classifications represent mean scores ≥ 2.5, “Possibly Consistent” classifications represent mean scores from 2.0–2.49, and “Not Consistent” classifications represent mean scores < 2.0. Dorsal fin and mouthline analyses were restricted to individuals meeting photo quality criteria (PQ ≥ 2) and removal of undeterminable scores, while mouthline analyses additionally required ≥50% mouthline visibility.

The proportion of individuals classified as having injuries at least possibly consistent with fisheries interactions based on either scoring method (mean score ≥ 2) was similar across populations, with 39.3% of individuals in HIMC (24 of 61), 38.5% in OAMC (15 of 39), and 47.4% in ICs (9 of 19) classified as having injuries at least possibly consistent with fisheries interactions. No statistically significant association between population and injury prevalence was detected (Fisher's exact test, p = 0.793), and pairwise comparisons between populations were also non-significant (all Bonferroni-adjusted p = 0.999). When only injuries classified as consistent with fisheries interactions were considered (mean score ≥ 2.5), the proportion of affected individuals was also similar across populations. No statistically significant association between population and the prevalence of injuries consistent with fisheries interactions was detected (Fisher's exact test, p = 0.577), and pairwise comparisons between populations were non-significant following Bonferroni correction.

Among the 118 individuals with complete dorsal fin and mouthline classifications available for comparison, sex was known for 33 individuals (15 females and 18 males). The proportion of females classified as having injuries at least possibly consistent with fisheries interactions based on either scoring method (60.0%, 9 of 15) was similar to the proportion of males (50.0%, 9 of 18/ Fisher's exact test, p = 0.729). When only injuries classified as consistent with fisheries interactions were considered (mean score ≥ 2.5), no statistically significant difference in injury prevalence between sexes was detected (Fisher's exact test, p = 0.999).

Chapter Five: Discussion

Building on previous documentation of fisheries-related injuries in pygmy killer whales (e.g., Vanderzee et al., 2019), this study provides the first comprehensive population-level assessment of mouthline and dorsal fin injuries across populations, sexes, and social clusters of this species in Hawaiian waters. A substantial proportion of individuals exhibited injuries consistent with fisheries interactions, with 18.5% of individuals assessed showing dorsal fin injuries consistent with fisheries interactions and 23.4% assessed showing mouthline injuries consistent with fisheries interactions. These findings indicate that interactions with fishing gear are occurring within all three pygmy killer whale populations in Hawai‘i and demonstrate that archival photo-identification data can provide an effective, non-invasive means of detecting fisheries-related injuries in this cryptic odontocete species.

Although no previous study has quantified fisheries-related injury prevalence in pygmy killer whales, these findings are broadly consistent with patterns documented in other odontocetes in Hawaiian waters. Machernis et al. (2021) documented fisheries-related scarring in 27.5% of common bottlenose dolphins and 13.1% of pantropical spotted dolphins around Maui Nui, with bottlenose dolphins exhibiting substantially higher rates of mouthline and dorsal fin injuries than spotted dolphins. Similarly, Harnish et al. (2024) reported that 28.7% of main Hawaiian Islands false killer whales with both dorsal fin and mouthline scores available exhibited injuries consistent with fisheries interactions, compared to 11.7% of pelagic false killer whales and 0% of Northwestern Hawaiian Islands false killer whales. Dorsal fin injuries consistent with fisheries interactions were documented in 12.8% of main Hawaiian Islands false killer whales, while mouthline injuries were documented in 16.9% of individuals (Harnish et al., 2024).

The prevalence of injuries observed in pygmy killer whales is therefore more comparable to rates documented in the main Hawaiian Islands false killer whale population and Maui Nui bottlenose dolphins than to pelagic false killer whales or Maui Nui pantropical spotted dolphins. These differences likely reflect depredation behavior. Depredation risk depends not only on whether a species overlaps with fishing activity, but also on whether fishing gear provides access to prey or bait items that are attractive or recognizable to that species. Social structure may also influence injury patterns if depredation behavior is learned or spreads among associated individuals. Main Hawaiian Islands false killer whales, bottlenose dolphins, and pygmy killer whales all exhibit strong site fidelity and regularly use slope-associated or nearshore habitats that overlap with commercial and recreational fisheries (Baird et al., 2012; Baird et al., 2021; Harnish, 2021; Baird et al., 2024). In contrast, pelagic false killer whales primarily use offshore pelagic habitats, while pantropical spotted dolphins exhibit more variable habitat use patterns that can include both offshore and nearshore waters depending on region and island (Baird et al., 2015; Baird & Webster, 2020; Harnish et al., 2024). However, differences in observed injury prevalence may also reflect differences in gear type and survivorship. Interactions with pelagic longline gear may be more likely to result in mortality or serious injury than interactions with the lighter gear typically used in many nearshore fisheries, meaning that lower observed scarring rates in pelagic populations do not necessarily indicate lower interaction rates (Baird et al., 2015; Harnish et al., 2024).

Pantropical spotted dolphins in Hawaiʻi are also known to associate with tuna fisheries, with fishing vessels frequently trolling through dolphin groups to target associated yellowfin tuna (Baird & Webster, 2020). As a result, differences in injury prevalence among species likely reflect not only broad habitat use patterns, but also differences in the type, frequency, and spatial distribution of fisheries interactions. Differences in prey preferences and foraging ecology may also influence interaction risk. Pygmy killer whales, false killer whales, and bottlenose dolphins may interact more frequently with hook-and-line fisheries through depredation behavior or overlap with nearshore and slope-associated fisheries, whereas pantropical spotted dolphins may experience different interaction pathways associated with tuna-directed fisheries. In Hawai‘i, fishermen are known to intentionally associate with pantropical spotted dolphin groups to target yellowfin tuna, often trolling directly through dolphin groups while deploying hook-and-line gear (Baird & Webster, 2020). These interactions may expose pantropical spotted dolphins to fisheries in ways that differ from the depredation-related interactions more commonly described for false killer whales and other island-associated odontocetes.

Patterns Across Populations, Social Clusters, and Sex

Injury prevalence based only on injuries classified as consistent with fisheries interactions was relatively similar across populations. For dorsal fin injuries, prevalence was 17.1% in the Hawai‘i Island main component (HIMC; 49 of 286 individuals), 18.7% in the O‘ahu main component (OAMC; 23 of 123 individuals), and 21.0% in isolated components (ICs; 29 of 138 individuals). For mouthline injuries, prevalence was 25.8% in HIMC (16 of 62 individuals), 19.0% in OAMC (8 of 42 individuals), and 20.0% in ICs (4 of 20 individuals). No statistically significant differences in injury prevalence were detected between populations for either dorsal fin or mouthline injuries. However, statistical non-significance does not necessarily indicate biological equivalence, particularly given the smaller sample sizes for some groups from isolated components. The relatively similar prevalence of injuries among populations suggests that fisheries interactions occur broadly throughout the range of pygmy killer whales in the main Hawaiian Islands rather than being restricted to a single island or population unit. This pattern may indicate that interactions occur in habitats or fisheries that overlap multiple populations, including slope-associated and nearshore environments used throughout the archipelago.

This similarity could be driven in part by overlap with fishing activity, although exposure pathways may differ among populations. Fishing effort in Hawaiʻi is not evenly distributed, and pygmy killer whales may encounter different fisheries depending on their range and movement patterns. Resident populations are primarily associated with slope habitats adjacent to the main islands and exhibit strong site fidelity with limited long-distance movement (Baird et al., 2024). However, individuals from isolated components may range more widely and could interact with offshore longline fisheries, nearshore fisheries, or other fishing sectors. Therefore, similar injury prevalence among populations does not necessarily indicate identical fishery exposure, but may reflect multiple pathways of interaction with fishing gear. Both the Hawaiʻi Island and Oʻahu populations occupy similar depth ranges and nearshore-offshore gradients, which likely results in comparable exposure to fisheries operating in these environments. Because both nearshore and slope-associated fisheries occur across these regions, overlap between pygmy killer whales and fishing effort may be relatively consistent among populations (Baird et al., 2021; Baird et al., 2024; Harnish et al., 2024). In contrast to main Hawaiian Islands false killer whales, where injury prevalence varies among populations (Harnish et al., 2024), no detectable differences in injury prevalence were observed among pygmy killer whale populations. This pattern may reflect similarities in habitat use, prey availability, or overlap with fishing activity across the study area. However, the absence of statistically significant differences should be interpreted cautiously, as smaller sample sizes for some populations may limit the ability to detect biologically meaningful variation in fisheries interaction rates.

Across social clusters within the Hawai‘i Island main component (HIMC) and O‘ahu main component (OAMC) populations, dorsal fin injury prevalence ranged from 11.1% to 42.5% (mean = 26.1%), while mouthline injury prevalence ranged from 25.0% to 100.0% (mean = 46.0%). Although most comparisons among social clusters were not statistically significant, interpretation of these patterns is limited by small sample sizes in several clusters, particularly those represented by only one or two individuals. Variation among clusters may still reflect differences in habitat use, spatial overlap with fisheries, or socially mediated behaviors such as depredation. For example, Cluster 7 exhibited the highest prevalence of dorsal fin injuries (42.5%), while Clusters 1 and 8 exhibited the highest prevalence of mouthline injuries (54.6% and 100.0%, respectively). In contrast, Cluster 5 had comparatively low prevalence of both dorsal fin (11.1%) and mouthline injuries (25.0%). These observed differences may indicate that some social clusters within the HIMC and OAMC populations experience greater exposure to fisheries or engage more frequently in behaviors that increase the likelihood of hooking or entanglement. However, clusters with very small sample sizes should be interpreted cautiously, as prevalence estimates can be strongly influenced by a small number of individuals.

Although no statistically significant differences in dorsal fin injury prevalence were detected among social clusters within the HIMC population, a significant association was detected within the OAMC population when analyses were restricted to injuries classified as consistent with fisheries interactions. This pattern suggests that fisheries interaction risk may not be uniformly distributed among O‘ahu social clusters. However, differences among clusters should not be interpreted solely as the result of passive spatial overlap with fishing activity. Fisheries interactions may also reflect behavioral differences among individuals or social groups, particularly if some whales actively seek out fishing gear to depredate bait or catch. Because pygmy killer whales maintain long-term social associations, depredation behavior, if present, could be learned or socially transmitted among associated individuals, leading to elevated injury risk within particular clusters.

Sighting histories indicate that Cluster 2 exhibits stronger site fidelity to the leeward side of Oʻahu than Cluster 3, which could increase repeated exposure to areas with concentrated recreational boating and small-scale fishing activity. Previous work examining fisheries overlap in Hawaiian odontocetes identified portions of Oʻahu, particularly the north, east, and leeward regions, as areas with elevated overlap between odontocetes and nearshore fisheries (Baird et al., 2021). Similar socially structured variation in fisheries interaction rates has also been documented in main Hawaiian Islands false killer whales, where long-term social clusters differ in exposure to fisheries and prevalence of fisheries-related injuries (Baird et al., 2015b; Harnish et al., 2024). Although sample sizes for some OAMC clusters remained limited, these findings suggest that variation in injury prevalence may reflect both differences in spatial exposure to fishing activity and differences in the likelihood that individuals or social groups engage in depredation.

No statistically significant differences in injury prevalence were detected between sexes, although for dorsal fin injuries consistent with fisheries interactions, prevalence was higher in females (32.0%) than males (14.3%). Mouthline injury prevalence was only a bit higher (53.3%) in females than in males (47.4%). These results suggest that male and female pygmy killer whales may engage in depredation at similar rates. This contrasts with findings from main Hawaiian Islands false killer whales, where females exhibit significantly higher rates of fisheries-related injuries than males (Harnish et al., 2024). In false killer whales, elevated female injury prevalence has been hypothesized to reflect increased energetic demands associated with reproduction and lactation, as well as prey-sharing behaviors that may increase depredation risk (Harnish et al., 2024). The absence of a similar pattern in pygmy killer whales may reflect differences in prey type and foraging ecology between species. False killer whales commonly target large pelagic fishes such as tuna and mahi-mahi and frequently engage in depredation of commercially valuable game fish, behaviors that may involve coordinated social foraging and prey sharing. In contrast, pygmy killer whales are believed to primarily consume squid and smaller mesopelagic fishes, which may involve different foraging strategies and potentially less sex-specific exposure to fisheries interactions.

Alternatively, the absence of sex-based differences may reflect the limited sample size of individuals with known sex, particularly for mouthline analyses. Sex was known for only 33 individuals included in the comparison of dorsal fin and mouthline injuries (15 females and 18 males), reducing the statistical power to detect subtle differences between sexes, should they exist. Increasing the number of individuals with known sex, particularly through expanded genetic sampling or long-term observations of reproductive behavior, would improve the ability to evaluate sex-based differences in future analyses.

Detection Limitations and Photo-Based Bias

Changes in photographic methods over the study period likely influenced injury detectability and represent an important limitation of this study. Early portions of the dataset included pre-digital film photographs, which were generally lower in resolution and provided fewer usable images per encounter than more recent digital photography. As a result, subtle injuries, particularly small mouthline injuries, may have been more difficult to detect in earlier images, potentially biasing prevalence estimates downward. This limitation was likely more pronounced for mouthline assessments than dorsal fin assessments because mouthline scoring often required close, high-resolution photographs with sufficient visibility for reliable evaluation. Although photo quality and visibility filters were applied to reduce these biases, variation in image quality and photographic coverage across the study period remains an important limitation.

Detection of injuries was influenced by both photo quality and mouthline visibility, particularly for mouthline assessments. In photographs where the mouthline was visible, mean mouthline visibility of injured individuals (63.0%) was similar to uninjured individuals (57.8%), with median visibility of 50% for both groups. Because mouthline visibility was often incomplete, some injuries were likely undetectable even when present. Coverage also varied substantially among social clusters because suitable mouthline photographs were not available for all known individuals. As shown in Table 4, coverage ranged from 5.0% in Cluster 8 to 95.7% in Cluster 1, with several clusters represented by fewer than one-third of known individuals. These differences in photographic coverage likely reduced confidence in prevalence estimates for some clusters, particularly those with small sample sizes. Injury appearance may also vary depending on the stage of healing when photographed. Recent injuries may appear more distinct and easier to classify, whereas older healed injuries may become less apparent or more difficult to distinguish from natural pigmentation. Given that visibility, photographic coverage, and healing state all influence the ability to identify injuries, these results suggest that mouthline injury prevalence is likely underestimated.

Despite these limitations, mouthline injury prevalence was comparable to or higher than dorsal fin injury prevalence. This finding is expected, given that hooking due to depredation of bait or catch is likely to result in a mouthline injury, while dorsal fin injuries would primarily occur when a hooked individual struggles against the line in a way that damages the fin. This suggests that dorsal fin–based assessments underestimate total fisheries interaction rates by failing to capture some hooking-related injuries. A similar pattern has been documented in false killer whales, where mouthline injuries provide important additional evidence of fisheries interactions beyond what is detectable from dorsal fins alone (Harnish et al., 2024). Together, these findings suggest that dorsal fin injuries represent only a subset of fisheries interactions, particularly those involving entanglement or tension-related gear contact, whereas mouthline injuries may better reflect hooking events associated with depredation.

From an epistemological perspective, this distinction is important because it highlights how commonly used metrics in photo-identification studies can shape our understanding of fisheries interactions. Dorsal fins are more consistently photographed and are typically the primary feature used for individual identification of odontocetes, but they may not provide a complete representation of interaction types. As a result, studies that rely solely on dorsal fin imagery may systematically underestimate the frequency of interactions involving hooking, leading to incomplete or biased assessments of interaction rates. While dorsal fin based injury assessments remain a valuable and accessible metric, they should be interpreted as a minimum estimate of interaction frequency. Incorporating mouthline assessments and improving data collection strategies will be critical for developing more accurate and comprehensive estimates of fisheries interactions in pygmy killer whales and other odontocetes.

The application of a dorsal fin distinctiveness restrictions may introduce bias when estimating fisheries interaction rates because individuals with low dorsal fin distinctiveness are more likely to be excluded from the analysis. In pygmy killer whales, individuals classified with low distinctiveness (distinctiveness = 1) are disproportionately composed of calves and younger animals that have not yet accumulated persistent scarring or notching on the dorsal fin. Younger individuals may also be less susceptible to fisheries interactions if they remain closely associated with or partially dependent on their mothers and are therefore less likely to independently engage in depredation or other direct interactions with fishing gear. This interpretation is consistent with patterns documented in false killer whales, where fisheries-related injuries first appeared at an estimated age of 2 years for dorsal fin injuries and 4 years for mouthline injuries, with injury prevalence generally increasing with age class (Harnish et al., 2024). Excluding these individuals could therefore slightly inflate estimated injury prevalence by disproportionately removing animals with lower expected interaction risk from the dataset. In this study, 103 individuals met all other dorsal fin filtering criteria but were excluded solely due to the distinctiveness threshold. However, younger individuals are still capable of acquiring serious injuries, as demonstrated by individual HIFa547, which exhibited a collapsing dorsal fin as a young calf. This suggests that fisheries interactions are not restricted to older individuals, and that some injuries may still occur early in life. That said, applying a distinctiveness threshold reduces the likelihood of mismatched identifications and improves confidence in individual-level analyses. These tradeoffs highlight the importance of considering how methodological filtering decisions may influence estimates of the proportion of individuals in the population that have fisheries-related injuries, particularly when evaluating age- or life-stage-specific patterns.

Photo quality influenced the interpretation of injuries, particularly for dorsal fin analyses. The elevated mean dorsal fin scores observed in the lowest photo quality category (PQ = 1, poor) likely reflect increased uncertainty in injury classification rather than true biological patterns. Poor-quality images may obscure fine-scale features needed to distinguish between natural scarring and fisheries-related injuries, potentially reducing consistency among reviewers. For mouthline analyses, the relationship between photo quality and injury scores was less clear, likely because mouthline assessments were additionally constrained by visibility and photographic angle. At the same time, restricting analyses to higher-quality images may introduce additional bias by disproportionately excluding encounters with poor viewing conditions, distant animals, brief surfacings, or individuals that were difficult to approach photographically. These conditions may not occur randomly across encounters or individuals and could be associated with differences in behavior, group composition, age class, or habitat use. As a result, applying photo quality thresholds may influence which individuals are retained in the dataset and therefore affect estimates of fisheries interaction prevalence. However, restricting analyses to higher-quality images was necessary to improve confidence in injury classification and reduce the likelihood of misidentifying natural markings or photographic artifacts as fisheries-related injuries. Unlike false killer whales, where some injuries may heal toward the original background coloration, injuries in pygmy killer whales appear to heal white. This may increase the long-term visibility of older injuries, especially along the mouthline.

Future studies should aim to address these limitations through targeted data collection and methodological refinement. Increasing the collection of high-quality head and mouthline images should be a priority, as these provide critical information on hooking-related injuries that may not be detectable from dorsal fins alone. Integrating multiple forms of injury documentation, including dorsal fin injuries, mouthline injuries, and body scarring, may improve the detection of different fisheries interaction pathways, including hooking, entanglement, and tension-related gear contact. In addition, incorporating alternative identification methods, such as genetic sampling, could reduce bias associated with distinctiveness restrictions and improve representation across age classes, particularly for calves and younger individuals that are less likely to possess distinctive dorsal fin markings. That said, pygmy killer whales are often very difficult to approach (Baird, 2016), and thus increased genetic coverage may not be feasible.

Implications for management and conservation

The prevalence of injuries observed in this study indicates that pygmy killer whales likely have regular fisheries interactions. The vast majority of interactions are unlikely to be recorded through traditional bycatch monitoring, particularly in nearshore commercial and recreational fisheries where systematic observer coverage is absent (Nitta & Henderson, 1993; Oleson et al., 2010). Current management frameworks in Hawaiʻi primarily focus on pelagic longline fisheries and well-studied species such as false killer whales (Harnish et al., 2024). However, the lack of significant differences across populations in this study suggests that fisheries interactions may also be occurring in nearshore and slope habitats used by pygmy killer whales, including fisheries that are not currently represented in observer or bycatch monitoring programs (Hall et al., 2000; Read, 2008).

Expanding monitoring efforts to include nearshore fisheries could benefit multiple odontocete species in Hawaiian waters. Potential approaches include increased use of electronic monitoring systems across a wider range of fisheries, improved reporting of depredation events, and observer coverage in nearshore fisheries. Public outreach and education efforts aimed at reducing depredation-related interactions may also help mitigate risk.

Future Directions

Future work should aim to incorporate age-class data and temporal analyses to better understand when fisheries-related injuries occur and how interaction rates may be changing over time. Estimating the timing of injury acquisition, both in terms of age class and year, would provide valuable insight into patterns of exposure and vulnerability within the population. Calculating rates of injury occurrence across years would allow for evaluation of whether fisheries interactions have increased, decreased, or remained stable over time. Similar approaches are currently being considered for false killer whales to assess whether depredation behavior is still spreading throughout the main Hawaiian Islands populations. Applying comparable analyses to pygmy killer whales would provide important context for evaluating the effectiveness of current regulations and could help inform future management strategies.

Conclusion

This study demonstrates that a substantial proportion of pygmy killer whales in Hawaiian waters exhibit injuries consistent with fisheries interactions. These interactions appear to be widespread across populations and social clusters and are likely driven by overlap with depredation of bait or catch in hook and line fisheries. For a small, resident species with strong site fidelity, even moderate levels of interaction may have important population-level consequences. The prevalence of fisheries-related injuries documented in this study likely represents only a subset of total fisheries interactions occurring within pygmy killer whale populations in Hawaiian waters, as individuals that die from hooking, entanglement, or ingestion of fishing gear are unlikely to be recovered to determine cause of death or represented in long-term photo-identification catalogs unless photographed shortly before death. Consequently, the patterns documented here reflect survivorship among individuals repeatedly exposed to fisheries rather than the full magnitude of fisheries-related mortality occurring within these populations. By quantifying injury prevalence, this study establishes a critical baseline for assessing fisheries impacts and highlights the need for expanded monitoring and management that includes cryptic, island-associated odontocetes.

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