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Focusing on the human dimensions to reduce protected species bycatch

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ABSTRACT

Bycatch is a major fisheries management issue that negatively impacts global marine ecosystems. Reducing protected species bycatch can be difficult because most commercial fishing gear is nonselective, many marine species occupy similar habitats as target species, and significant investments and collaborations are needed to test bycatch reduction solutions. Bycatch has been reduced in many fisheries, but could be further reduced using novel sociotechnical solutions. Sociotechnical solutions focus on how social and technical practices are embedded in complex social and economic systems, with a focus on human agency and context. To determine if sociotechnical solutions could apply to bycatch reduction, we examined a case study from the Hawaiʻi longline fleet. We interviewed 38 captains and crewmembers to better understand the potential of sociotechnical solutions to further reduce bycatch, but also any social barriers that may impede their adoption. Although the Hawaiʻi longline fleet is a leader in bycatch reduction and mitigation, our interviews uncovered how the fleet could further reduce bycatch through enhanced communication, relocation to avoid aggregations of protected species, and other innovative ideas developed by fishers. Overall, our research supports previous studies that emphasized the importance of addressing the human dimensions of bycatch reduction, but also identified some social barriers to sociotechnical solutions. To accomplish ecosystem-based fisheries management goals, scientists, managers, and fishers must acknowledge and address these social barriers and provide necessary institutional support to continue reducing bycatch in global commercial fisheries.

1. Introduction

Fisheries bycatch is a pressing conservation and management concern that affects the biodiversity and resilience of coastal and marine ecosystems (Gilman, 2011). When defined as unwanted, unused, or unmanaged species, bycatch may comprise as much as 40 % of all global marine fisheries catch, which highlights the pressing need to develop effective solutions (Davies et al., 2009). Addressing bycatch is challenging in many global fisheries due to data gaps, cascading effects on populations of marine megafauna, complex social-ecological relationships, and the sustained engagement with fishing communities needed to be successful (Cox et al., 2007; Komoroske and Lewison, 2015). In the United States, NOAA Fisheries defines bycatch as "discarded catch of marine species and unobserved mortality due to a direct encounter with fishing vessels and gear" (NMFS, 2016). NOAA Fisheries also has a mandate to minimize bycatch of endangered or protected species, including any marine mammals and seabirds that may interact with U.S. fisheries, and mitigate negative impacts on their populations. Therefore, to advance ecosystem-based fisheries management, marine fisheries must continually work to reduce protected species bycatch (Gilman et al., 2014).

Despite the challenges associated with bycatch reduction, a suite of mostly effective technical solutions has been developed to address them. These solutions include time-area closures (Gallagher et al., 2014), gear modifications (Curran and Bigelow, 2011), dynamic ocean management (Hazen et al., 2018; Howell et al., 2008a, 2008b, 2015), eco-labeling (Selden et al., 2016), and compliance interventions (Ayers and Leong, 2020a; Cox et al., 2007; Gilman, 2011). Together, these efforts have significantly reduced bycatch in many individual fisheries through mitigation activities which allow populations of important species to recover while keeping fisheries open (Gilman et al., 2007; Løkkeborg, 2003; O'Keefe et al., 2014). Although bycatch has been reduced

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significantly globally and in the U.S., there is continual pressure to reduce ecosystem impacts of commercial fisheries operations in sustainable fisheries (Hazen et al., 2018; Lewison et al., 2014). In U.S. fisheries, legislation authorizes NOAA Fisheries to continually reduce and minimize bycatch mortality and recover listed and protected species that interact with them (Dept. of Commerce et al., 2007; ESA, 1973; MMPA, 1972). Many technical solutions have been successful, but given continual pressure to reduce bycatch in U.S. fisheries, there is a need to better understand the social factors that hinder adoption or effectiveness of technical solutions.

One way to better understand social barriers to adoption is through a sociotechnical lens where the application of their insights can be referred to as 'sociotechnical solutions.' In contrast to technical solutions, 'sociotechnical solutions' consider the complex, linked social and technological practices embedded within social and economic systems (Smith et al., 2005) and explicitly examine the role of human agency and context in implementing new technologies. The social dynamics of technical solutions are multifaceted, but can include the structural, social, and cultural aspects of learning, as well as the economic and management systems that incentivize, facilitate, or hinder adoptions of new and effective bycatch reduction technologies (Campbell and Cornwell, 2008; Smith et al., 2005). Technical solutions may be ineffective when managers do not pay significant attention to these social dynamics, which can limit the effectiveness of technical solutions, hinder progress toward reduction of protected species bycatch, and slow transitions towards ecosystem-based management of fisheries. In fisheries bycatch research, "the human and institutional contexts of BRT [bycatch reduction technology], and more specifically how, when and why fishers do or do not employ BRT, are seldom addressed as research questions" (Campbell and Cornwell, 2008, p. 327). To address this gap and discover how social science can further reduce protected species bycatch, we sought to understand:

1. Which sociotechnical bycatch solutions are most promising to advance ecosystem-based fisheries management of pelagic ecosystems?
2. What social barriers limit adoption of sociotechnical solutions in the Hawai'i pelagic longline fleet and how might they be overcome?

To answer these questions, we present a case study of protected species interactions in the Hawai'i longline fishery. We conducted 38 in-person qualitative interviews with Hawai'i longline fishers about protected species bycatch reduction in 2019 to better understand whether sociotechnical solutions could further reduce protected species bycatch in the fishery. The Hawai'i longline fishery primarily targets bigeye tuna (*Thunnus obesus*) and was ranked 6th in the U.S. in landed value in 2017 (NMFS, 2020a). The Hawai'i longline fleet is considered a global leader in bycatch reduction, observer coverage, and compliance (Gilman et al., 2007), but several closures have occurred when the fleet reached bycatch limits for leatherback (*Dermochelys coriacea*) or loggerhead (*Caretta caretta*) sea turtles (Kittinger, 2007, p. 200) and false killer whales (*Pseudorca crassidens*) (Dawson, 2018). These closures have resulted in unintended consequences, which include increased sea turtle interactions with foreign fishing fleets (Chan and Pan, 2016) and increased fishing effort outside the U.S. Exclusive Economic Zone (EEZ) (Pan and Walden, 2015). Reaching limits for protected species bycatch has biological and socioeconomic impacts. Thus, there is a need to further investigate bycatch mitigation in this fishery.

2. Background

2.1. Protected species bycatch in the Hawai'i longline fishery

The NOAA Fisheries National Bycatch Reduction Strategy defines bycatch as "discarded catch of marine species and unobserved mortality due to a direct encounter with fishing vessels and gear" (NMFS, 2016, p. 4). Some of this bycatch has protected status under U.S. legislation, such as the Marine Mammal Protection Act, the Migratory Bird Treaty Act, and the Endangered Species Act. Together, along with the Magnuson-Stevens Fishery Conservation and Management Act which also encourages bycatch reduction (Dept. of Commerce et al., 2007), these laws enable NOAA Fisheries to regulate bycatch of seabirds, marine mammals, and other endangered or threatened marine species. In the Hawai'i longline fishery, these regulations may set a maximum level of interactions based upon a biological opinion. Meeting these maximum interaction levels may trigger time-area closures or gear restrictions. Therefore, it is of great importance to minimize these rare events and to keep the fishery open to provide a continued supply of pelagic seafood to Hawai'i, where seafood consumption is nearly twice as high as the mainland U.S. (Geslani et al., 2012, p. 11).

2.2. History, target species, fishing gear

Fishing vessels in Hawai'i have deployed longline gear for over a hundred years (June, 1950). Early longliners targeted pelagic tuna species relatively close to the main Hawaiian Islands (2–20 nautical miles) using rope-based fishing gear (June, 1950; WPRFMC, 1986). The fishery switched from ropes to monofilament line in the late 1980s and the fleet grew substantially as vessels targeted swordfish (*Xiphias gladius*) using shallow-set longline gear (Ito et al., 1991). Closures, and the potential for closures based upon protected species interactions has contributed to significant attrition in swordfish-targeted shallow-set longline trips. For reference, swordfish landings peaked in 1993 at 6000 metric tons, dropping to 1165 mt in 2017 (Skillman, 1998; WPRFMC, 2021, p. 100). The Hawai'i longline industry is a multicultural and multiethnic fishery. Nearly 70 % of fishing permits are owned by Vietnamese Americans, with just under 30 % of permits owned by Caucasians (Ayers and Leong, 2020b). Just a handful of permits are owned by Korean Americans, which once had a larger presence in the fishery (Barnes-Mauthe et al., 2013).

The Hawai'i longline fishery is separated and regulated differently based upon the gear type and target species. A small set of vessels target swordfish using shallow-set longline gear, while a majority of vessels target bigeye tuna using deep-set longline gear. Every shallow-set trip must be accompanied by a federal fisheries observer, but observers accompany vessels on approximately 20 % of declared deep-set trips. Both shallow- and deep-set fisheries deploy a monofilament mainline that is 3.2–4.0 mm in diameter, but they deploy gear at different depths, at different times of the day, using different branch line lengths and bait. Both types of gear utilize monofilament line that is hauled and stored on hydraulic reels. In addition, specific regulations govern both stern and side setting of gear to reduce seabird interactions. Vessels must also follow additional seabird regulations when fishing North of 23° N or when seabirds are present. Longline vessels can switch between shallow- and deep-set gear types, but they must declare only one type of gear 72 h prior to departing on a trip and each type of fishing involves different, specialized gear and configuration. For a more comprehensive list of regulatory requirements for the Hawai'i longline fleet see (Ayers and Leong, 2020b, p. 3; PIRO, 2020).

2.2.1. Shallow-set gear

The shallow-set fleet must set their gear at night (at least an hour after sunset) to avoid seabird interactions. Gear is deployed at depths of 30–90 m. Branch lines with single mackerel-type baited hook (fishing vessels cannot use squid bait due to potential for increased sea turtle interactions) off the main line are suspended 10–15 m below a mainline that is also suspended between floats from 20 to 75 m below the surface. Mainlines extend 26–52 nautical miles (48–96 km). Typically 4–5 branch lines are clipped to the mainline in between floats. A swordfish set will deploy 700–1000 10° offset 18/0 hooks in a single set. The Hawai'i shallow-set fleet deployed 0.9 million hooks in 2021 (WPRFMC, 2021, p. A-51). The average trip is 32 days with about 17 days spent fishing. Additionally, Hawai'i shallow set longline fishers are limited in aggregate to a total of 16 leatherback sea turtle interactions for the year. If they interact with 16 leatherback sea turtles, the fishery closes for the rest of the year. Further, if a vessel interacts with two leatherback turtles or five loggerhead turtles on a single fishing trip, the vessel must immediately stop fishing, return to port, and wait five days before it can depart again on a fishing trip. If the vessel interacts with two leatherback sea turtles or five loggerhead turtles again on a subsequent trip, then that vessel is prohibited from shallow-set longline fishing for the rest of the calendar year (WPFMC and PIRO, 2020, p. 10). Additionally, if a vessel reaches this trip limit two times in a calendar year, the vessel is only allowed one trip limit in the next year. That is, if the vessel reaches that trip limit just once in the next year, then they are prohibited from shallow-set longline fishing for the remainder of that year.

2.2.2. Sea turtle litigation and responses

Due to shifts in regulations, changes in market demand, and litigation over protected species interactions, a majority of fishing trips have targeted bigeye tuna using deep-set gear in recent years. Litigation between conservation groups and NMFS over the take of threatened or endangered sea turtles in the Hawai'i longline fishery date back to 1999 (Curtis and Hicks, 2000). Over the years, these lawsuits have spurred studies that estimated the impact of pelagic longline fishing on populations of several sea turtles Pacific-wide, examined the merits of different bycatch reduction measures, pioneered the use of satellite data and environmental factors to avoid sea turtles in real-time, and spawned several regulatory changes including trip limits for protected species interactions (Chan and Pan, 2016; Gilman et al., 2007; Howell et al., 2008a, 2015, 2008b; WPFMC and PIRO, 2020). Sea turtle bycatch is rare in the Hawai'i deep-set longline fishery.

2.2.3. Deep-set gear

In contrast, deep-set gear is set using a line shooter to help gear sink to target depths of 400 m. Mainlines extend 25–45 nautical miles (46–83 km) with at least 15 branch lines at lengths of 11–15 m clipped off at intervals in between radio buoy floats (put in place to track gear) along a mainline. Each branch line has a single, sardine-baited hook. The Hawai'i deep-set longline fleet deployed 65.4 million hooks in 2021 (WPRFMC, 2021, p. A-48). In terms of protected species interactions, a take reduction team process was initiated in 2010 to reduce the incidental take of False Killer Whales. The process led to various conditions, including limits to false killer whale serious injury determinations in the Hawai'i EEZ, which may lead to closure of an area south of the main Hawaiian Islands referred to as the Southern Exclusion Zone. As of December 2020, if Hawai'i deep-set longliners interact with four insular or pelagic False Killer Whales inside the Hawai'i EEZ, then the Southern Exclusion Zone is closed to longline fishing for the remainder of the year (NMFS, 2020b).

Hawai'i deep-set longline fishing is also governed by bigeye tuna catch limits, which are set via science-based assessments and international negotiations convened by regional fishery management organizations (RFMOs). Because of Hawai'i's geography in the Pacific Ocean, the fleet fishes in both the Western and Central Pacific Ocean, which is governed by the Western and Central Pacific Fisheries Commission (WCPFC) and the Eastern Pacific, which is governed by the Inter-American Tropical Tuna Commission (IATTC). These organizations set catch limits for bigeye tuna, the targeted species for deep-set longliners in Hawai'i. If catch limits are met, the fishery may be effectively closed unless a[1] specified agreement is in place with a U.S. territory to share a portion of their bigeye tuna allocation with the Hawai'i longline fleet (Ayers et al., 2018).

2.3. Industry size, limited entry permit system and other requirements

The Hawai'i longline fleet is managed via an array of state, federal, and international regulations, including a state commercial marine fishing license, a federal limited entry permit system, and other RFMO conservation and management measures (Ayers et al., 2018; Ayers and Chan, 2020; WPRFMC, 2009, 1994). All longline gear vessels, regardless of gear, must have a longline limited entry permit to operate in the Hawai'i exclusive economic zone or on the high seas. These permits are capped at 164, but only 140–150 are active in a given year. Each fishing vessel must also carry a High Seas Fishing Compliance Act permit, a Central Pacific Fisheries Commission Area Endorsement, a valid Marine Mammal Authorization Program certificate, a valid Protected Species Workshop certificate, a vessel monitoring system from and installed by NOAA Office of Law Enforcement, and must turn in a Western Pacific longline logbook within three days of returning from their fishing trip. Hawai'i longline captains must attend a protected species workshop each year. Additional regulatory requirements for the Hawai'i Exclusive Economic Zone and on the high seas are described in the Fishery Ecosystem Plan for Pelagic Fisheries of the Western Pacific (WPRFMC, 2009). Vessels are prohibited from fishing in the Papahānaumokuākea Marine National Monument and the Pacific Remote Islands Marine National Monument.

3. Methods

3.1. Research and sampling approach

Given the sensitivity of protected species bycatch, not all individuals were willing to discuss their experiences. Likewise, conducting interviews about this topic often entailed significant effort to build trust and rapport with fishing captains and crew. Further, many fishing captains were uncomfortable answering questions in English, which is not their first language, so many were conducted in their primary languages with translation assistance. Therefore, a random sample or census survey of all active vessels was not a good fit for this study. So in Fall 2019, the lead author conducted 38 open-ended, in-person interviews with current Hawai'i longline fishers onboard active fishing vessels that were willing to discuss their experiences with protected species (30 interviews with individual captains or owner-operators and 8 interviews with crew members).

For several months prior to fieldwork, we discussed the project with individual longline fishers and industry representatives at the Hawai'i longline association to build trust and rapport. Following these discussions, we pilot-tested our interview guide with several fishers to gather initial input. We also mailed a formal letter to all current Hawai'i longline limited entry permit holders and sent an email to each address associated with a limited entry permit prior to fieldwork. These materials contained background information on the project and an invitation to voluntarily participate in the study. We circulated a flyer about the project at several locations captains and owners receive information, including the NOAA Pier 38 office and the United Fishing Agency Fish Auction.

To identify initial interview respondents, we combined both intercept and snowball or network sampling methods (Bernard, 2013). Initially, for our intercept sample, the lead author approached individual captains and owner-operators opportunistically while their vessels were docked in port. Following our interviews with these fishers, we asked them to suggest other potential interviewees from their social network, then contacted them for interviews. This practice is commonly referred to as snowball or network sampling. To address any oversampling issues across industry strata associated with this approach, we followed up our intercept or network sampling with a purposive, stratified sample (Creswell, 2003). A similar approach was used successfully in previous research with the industry to ensure certain strata were included (Allen and Gough, 2007, 2006). Strata we considered when

[1] https://www.govinfo.gov/content/pkg/USCODE-2011-title46/pdf/USCODE-2011-title46-subtitleII-partF-chap81-sec8103.pdf.

identifying additional interviewees included ethnicity, vessel size classes, gear, permit ownership, and fishing experience. Although our interview sample was not probabilistic, it does reflect current participation across several strata (see Table 1). A set of guiding questions drove our unstructured interviews, but we remained open to other bycatch-related conversations. Individuals from industry, science, and fishery management reviewed and provided input on our interview guide (Appendix A). Our research was conducted in compliance with the University of Hawai‘i Institutional Review Board policies and procedures under Project no. 19449.

3.2. Fieldwork and data analysis

All interviews were conducted onboard vessels, in-person, on Pier 17 and Pier 38 in Honolulu, Hawai‘i, between August and December 2019. Interviews included 30 captains or owner-operators and 8 crew (2 American, 3 Indonesian, 2 Filipino, and 1 Vietnamese). Summary information on interviewees is available in Table 1. All interviews were conducted voluntarily with informed consent, and interviewees were not compensated. Interviews were frequently conducted with translation assistance. Due to the sensitivity of the topics, interviews were not audio recorded. Instead, all data reported in the results were captured via detailed, handwritten interview notes, which were translated into English and digitized prior to data analysis. To analyze these data, interview notes were initially coded or binned based upon thematic areas (Miles and Huberman, 1994) then later grouped into larger thematic bins using a grounded theory approach (Corbin and Strauss, 2008). All data were reported anonymously without any personally identifiable information.

4. Results

Captains and owner-operators were unequivocal about their desire to avoid protected species during fishing trips because if they encounter the animals, they frequently incur significant financial costs in terms of lost bait, catch, and tackle. These losses may be compounded when they result in regulatory closures and/or lost fishing time and profits. Therefore, Hawai‘i longliners often travel great distances to avoid protected species or relocate if they encounter the animals while at sea.

When Hawai‘i longliners find aggregations of protected species while out fishing, captains and owner-operators frequently communicate and share location information of the aggregations so that other vessels can avoid them. Many captains and owner-operators also had innovative ideas that could improve handling in terms of safety at sea and animal welfare and further reduce protected species interactions through avoidance.

Certain themes repeatedly emerged during interviews. Many came up in multiple questions, which warranted greater attention and analysis. Others, such as innovative ideas to avoid protected species or improve handling, were less prevalent but were synthesized, because it may only take one good idea to further reduce protected species bycatch. A list of all themes by question type was published in a NOAA technical report (Ayers and Leong, 2020b). The following themes are explored below in greater detail: the financial impacts of protected species encounters, relocation to avoid protected species, communication to avoid protected species, and innovative ideas to avoid protected species or improve handling.

4.1. Financial impacts of protected species encounters

This theme emerged when captains were asked to describe how protected species guidelines or regulations affect fishing trips (20 comments by 15 respondents), what happens after a protected species interaction (5 comments by 5 respondents), and how protected species affect location choice (10 comments by 8 respondents). The financial impacts of protected species interactions or encounters vary based upon the gear used and the animals that vessels interact with or encounter on fishing trips. In general, however, interactions with protected species are costly and fishers go to great lengths to avoid them. Below, financial impacts are separated by financial losses due to closures and financial losses due to depredation.

4.1.1. Financial loss due to closures

When vessels that target swordfish with shallow-set gear reach their allotted cap of leatherback sea turtles, the fishery closes for the remainder of the calendar year. Reaching this cap causes vessels currently at sea to stop fishing and immediately return to port (NMFS, 2020c). Additionally, specialized investments made on shallow-set gear such as lightsticks and potentially bait and hooks may not be employed on deep-set trips that target bigeye tuna. Switching from shallow- to deep-set gear does allow reuse of main line and branch lines (albeit at different lengths), but requires re-rigging and configuring gear, and potentially purchasing different size hooks, bait, 45 g lead weights to sink gear to deeper depths, and longer float lines.

Captains targeting swordfish felt that such financial penalties were overly punitive since they catch sea turtles accidentally:

> *Whatever is the government regulation, I try to follow, but I am not happy with the regulation about turtle. They should only count the one that was dead (as one catch), then it is rational. You know how we invest 30–40 thousand dollars for one trip? No one wants to come back in the middle of the trip just [due to the trip interaction limit] because turtle get hooked to someone's hook. Accident can happen anytime. No one knows to anticipate the situation.*

The quote illustrates how much vessels stand to lose if they are out fishing when the fishery is closed as well as their frustration with protected species injury or death determinations. Another fisher felt that caps may cause the shallow-set fishery to close for good: "Regulations

Table 1
Interview sample versus active population across various strata.

Category	Sub-category	Number of individuals interviewed	Active vessels/Permit holders in Hawai‘i longline fleet
Vessel ownership[a]	Single vessel owner-operator or captain	25 (83 %)	96 (85 %)
	Multiple vessel owner-operator or captain	5 (17 %)	17 (15 %)
Ethnicity[b]	Vietnamese American	22 (73 %)	111 (68 %)
	Caucasian	6 (20 %)	48 (29 %)
	Korean American	2 (7 %)	5 (3 %)
Vessel length[b]	Vessels less than or equal to 24 m in length	24 (80 %)	110 (76 %)
	Vessels greater than 24 m in length	6 (20 %)	35 (24 %)
Vessel permit[c]	Single permitted vessels	25 (83 %)	122 (84 %)
	Dual-permitted vessels (Vessels with both Hawai‘i and American Samoa longline limited entry permits)	5 (17 %)	24 (16 %)

[a] Data source: Hawai‘i Longline Limited Entry Permit Database, March 2019.
[b] Data source: Hawai‘i Longline Limited Entry Permit Database, December 2019.
[c] Hawai‘i Longline Limited Entry Permit Database, June 2020.

discourage swordfishing; if turtle cap was 50 it would make sense. I see the dead end future of this business, its only getting worse and worse." There is a fear among some that protected species regulations could potentially permanently shut down shallow-set longline fishing in Hawai'i.

4.1.2. Financial loss due to depredation

In addition to costs associated with gear, closures, and trips, Hawai'i longline fishers also incur significant financial loss due to depredation, when marine mammals or sharks predate bait or fish caught on baited hooks. Almost half of the interviewees mentioned this theme, with most specifically mentioning false killer whales. One interviewee described how these encounters can quickly turn a profit to a loss: "[our] last trip was 15 sets; whales ate 10 of them." Another captain was more descriptive of the break-even point following successive depredation events: "if a whale eats more than five sets, we lose money." This reinforces the importance of avoiding protected species as well as their willingness to pick up their gear and travel long distances to avoid protected species and depredation. One captain described the situation succinctly: "[we] …lose a lot of money if we encounter whales." While another described the futility of trying to avoid them: "almost impossible to get away these days." Other captains hypothesized that environmental changes or animal food conditioning may be the reason for increases in depredation events: "…move and still get whaled right away. Didn't used to be like that." Regardless of the cause, Hawai'i longliners may lose money and sometimes all of their profits when they encounter false killer whales during fishing trips.

4.2. Relocation to avoid protected species

This theme frequently came up when fishers were asked what happens after a protected species interaction (14 comments by 10 respondents), and how protected species affect location choice or decisions about where to go fishing (24 comments by 17 individuals). These comments revealed strong agreement that if they come across an aggregation of protected species, for example, sharks, sea turtles, or false killer whales, they would leave the area. But there was less agreement about 1) the threshold for when to relocate and 2) distance necessary to travel in order to safely avoid them.

4.2.1. Threshold for leaving an area

For some fishers, the threshold was very low. If they see false killer whales or sharks when they begin to set their gear, they immediately haul it back up and motor to another location. As one respondent said, "If I'm setting my gear and I see a whale, I'm cutting it [the set] short." For these fishers, the mere possibility of depredation and accompanying financial loss of bait or target catch—or worse, an accidental foul hook or incidental take of a false killer whale—is enough to leave the area. The risk outweighs any potential reward in terms of catch. For others, the threshold to leave the area is higher, depending on which types of animals are around. Vessels may need to travel long distances to avoid false killer whales, but not quite as far to avoid sharks. One respondent described their decision making process:

> *Sometimes we had to stop engine, turn off light, stop fishing for the whole day, wait until they [false killer whales] swam away from the area. Then we started fishing again. We spent a lot of money for a trip. If we met whale, we lost a lot of money. It is also not realistic to avoid the shark too. However, if we know fishes around, we still set hooks. For example, we should have 10 fishes in 10 hooks, but if sharks eat 4, we still have 6, then we still keep fishing but if we get only 3–4 out of 10, we might have to move.*

For this individual, the decision to leave the area is more difficult, particularly if they are catching fish. They know they may lose some of their bait or catch, but the potential reward may be enticing enough to stay in an area where they know sharks (regardless of their protected or endangered status) are around. Another fisher described running away from sharks: "If lots of sharks, sometimes move 20 miles away." But false killer whale encounters are different. As one captain described: "We try by all means to stay away from them." The animals are revered for their intelligence, but also feared for their ability to eat an entire set of catch, leaving only fish heads on the hooks for longliners to pull up onto the deck during a haul. Therefore, captains face a difficult calculus based on personal risk tolerance and specific conditions when they decide whether to pick up their gear and travel long distances to avoid these encounters.

4.2.2. Distance necessary to safely avoid protected species

When captains decide to relocate to avoid protected species like false killer whales, there was not a clear consensus about how far they need to move. That decision may depend on the species that they encounter.

Some captains described getting away from animals if they motored a short distance away from a fishing spot: "sometimes move at least 10 miles away when we see them." But another captain explained that traveling short distances may not be far enough: "[we] sometimes drive 6–7 h, if whales still around, drive a whole day and night further."

Many captains reported traveling 60–80 miles, sometimes 100 miles or more after encountering a false killer whale in order to ensure that they have safely distanced their vessel from the animals. Another captain described how far he travels when he encounters a false killer whale:

> *There is no other way but to move to other location, away from them. Normally about 75 miles away, sometimes more. If we encountered with whales, we lost tuna, it is like a bad luck. We have to stop fishing when whales are around.*

For this fisher, finding a false killer whale during a fishing trip can force his vessel to travel a day or more to get away from them. In some instances, this may not be far enough. Another individual described an even longer trip to avoid false killer whales: "[we] sometimes move 1–2 days because [false killer] whales will follow."

Previous research suggested that vessels may need to move at least 100 km (~ 62 miles) and as much as 250 km (~ 155 miles) to avoid repeat depredation events (Fader et al., 2021b; Forney et al., 2011), but more recent research by Fader et al. (2021a) found that fishing vessels traveled a median distance of 46 km over 4.7 h following a depredation event during observed fishing trips. Fader et al. (2021a) noted that vessels may need to move much further due to vessel clustering while fishing along with the elevated depredation risk following a depredation event, with the greatest conservation gains realized if a vessel moved 400 km and traveled 9 days.

4.3. Communication to avoid protected species

To further avoid protected species interactions, Hawai'i longline fishers frequently share location information of protected species sightings, interactions, encounters, and depredation events within their social networks. This theme was mentioned in four different thematic question areas, including what happens after a protected species interaction (25 comments by 19 respondents), how protected species affect location choice (2 comments by 2 respondents), what, if anything fishers do outside existing regulations to avoid protected species (3 comments by 2 respondents), and what additional information would be useful to help avoid protected species interactions (3 comments by 3 respondents).

Fishers commonly share information with one another at sea, over radios or satellite phones: "Basically we just call each other to inform that protected species are around." Since letting other captains know the location of protected species aggregations may inadvertently share confidential fishing information, many captains are only comfortable circulating this information with close friends or other vessels with whom they work closely. As one fisher described:

We went out fishing with a group, we often share information through satellite phone or radio to inform each other if we encounter with whale or shark. It helps not to waste our time. We are likely to share information among friends in our community.

Communicating this information not only helps prevent animals from being incidentally caught, it also saves fishers and their friends valuable time and money by avoiding these areas. Although fishers can be notoriously secretive about fishing spots, information about protected species may still get around. As another fisher explained, "I'm tight with two guys. Send info to each other every day. One of them communicates with everyone. They know everything that is going on." Therefore, even if one individual does not share information widely, someone in their network may communicate with other groups within the fleet. No matter how insular a given social network is, word can travel fast if depredation is intense or if an area has a high concentration of sharks, whales, turtles, or seabirds.

In terms of avoiding protected species and improving economic efficiency, close coordination with a group of boats at sea offers great benefits: "We go out fishing together, if we see [false killer] whale, the whole fleet moves to the new location."

Less commonly, some fishers mentioned that they wait to share information until they arrive back at port: "I got most of information from other captains, we talk story when we are at the port, when we drink beer and eat together." Although this information may have been more valuable in real-time, it still allows captains the opportunity to share their stories and the challenges they face making a living on the sea.

4.4. Innovative ideas to avoid protected species or improve handling

Fishing captains and owner-operators spend upwards of 300 days at sea annually, so it is not surprising that they would have innovative ideas to improve protected species bycatch mitigation. Their ideas were widespread, from simple homemade fixes that they believe could reduce certain interactions to nearly zero, to others that involved advanced technology to further avoid protected species interactions and encounters.

Many of the innovations outlined below were developed at the cost of the fishers. Numbers of individuals and comments regarding these themes are not reported because our goal was to collect ideas, not count them. Ideas are separated into five categories: handling, avoidance, simple solutions, innovative technologies, and additional useful information. These solutions present ideas that may further reduce interactions beyond existing NMFS handling guidelines and regulations. All ideas came directly from the fishers.

4.4.1. Handling

Many ideas for improving handling involve communication, hands-on training, or translation of existing materials. Since protected species interactions are rare events, it can be challenging to provide crewmembers adequate experience in managing them. Most Hawai'i longline crewmembers are foreign and speak little English. Likewise, some captains may not speak the primary languages spoken by their crews and they may not even speak a common, shared language to share important protected species handling instructions. Therefore, many captains highlighted the importance of leading by example when handling protected species:

I am directly involved in releasing protected species and showing my crew members how to do it. For example, if it is a small turtle, I will use a net to take him out of water and try to take the hook off his mouth. If the turtle is stuck with the fishing line around his body, we will cut all the line off before releasing him.

This quote illustrates the value of captains demonstrating proper use of handling guidelines in the rare event that a protected species is incidentally caught. Another captain suggested that crew should rotate responsibilities to ensure that everyone knows how to manage an encounter and is prepared: "Take turns doing different jobs on the boat so that the same person doesn't have to do it every time. Give everyone a chance to practice handling." But it is unclear whether protected species interactions, as rare events, would give all the crew members a chance to practice handling for all protected species.

Other respondents highlighted the importance of communication and translation of workshop materials and signage into primary languages. While some materials have been produced in multiple languages, suggestions from interviewees indicate they may not be distributed widely. For example, one captain suggested "Training for owner, captain, training to crew members in their own language, provide poster in their language, make sure they understand, check their knowledge." Another captain was more candid:

I can speak a little bit, but I don't know how to read in English. The materials I got are all in English. I am always worried if I misunderstand something. Due to my language incapacity, I might accidentally do something wrong without knowing it. I don't want to break the rules. If any new regulation comes I try to follow it, I don't want to be in the trouble with the government.

This quote further highlights the language barrier that exists for many fishers in the fleet, including captains. One captain suggested making training material available in a video format that crew can view aboard their vessels: "Make a video, DVD, website, or something so that crew can watch." Video content should include subtitles in primary languages spoken by captains and crew in the fleet. In August 2021, protected species workshop materials have been translated into Vietnamese, Tagalog, and Indonesian and provided along with an English language version to vessel owners and operators.

4.4.2. Avoidance

Below, simple solutions to avoid protected species interactions are presented first, followed with some more innovative technology that fishers developed on their own to avoid protected species. We conclude with some additional information, if provided by NMFS scientists, that fishers said could be useful to further avoid protected species.

4.4.2.1. Simple solutions. Homemade tori lines were some of the simplest solutions that Captains mentioned during interviews. One fisher described his tori line setup and specifically why he developed it: it does not make financial sense to catch seabirds:

It floats on the surface, doesn't get tangled in the lines, and has a length of splayed rope that jumps on the surface in the area where the lines are hauled in. Birds won't get near the lines with that thing busting the surface. Created it through trial and error. Started by towing a buoy, floats, it doesn't get stuck in the prop. I'm not trying to feed the birds my bait. It's not profitable for me to feed the birds.

This quote also illustrates the research and development or trial and error involved with a relatively simple homemade device to scare away seabirds. Other fishers also run tori lines: "I have three or four friends running tori lines." Another fisher had a very simple idea to keep birds away: turn off the satellite: "If you want to get away from white birds, turn off the satellite, let it stay standby, bird will not follow you. If you keep running for three hours, you will see birds will be gone. I think it works this way." Further evidence may be needed to substantiate the claim and erroneous or not, it does demonstrate that captains frequently consider causes of protected species interactions and ways to reduce them.

Another simple solution included opening some of the closed areas:

If the fleet is more spread out and less concentrated in certain areas, you're less likely to have an interaction. Closures actually increase interactions. You've squeezed all the boats into a smaller area to fish,

> *you've concentrated them into a smaller area, an area where there's more interactions now after the closure.*

Some areas have been closed to longline fishing such as the Papahānaumokuākea Marine National Monument and its recent expansion, and this fisher felt that concentrating fishers into other remaining productive fishing areas inside the Hawaiʻi EEZ may potentially increase protected species interactions.

4.4.2.2. Innovative technologies. Fishers also described several other innovative technologies to avoid protected species. These ideas may not be as simple as running a tori line to avoid seabird interactions, but they could also be effective at limiting interactions. One fisher explained that there are no easy solutions, but new gear and solutions are in the works: "Kind of a hard one. If it's going to happen, it's going to happen. Currently working on lighter hooks, heavier monofilament. There's something in the works, but it is more expensive." Current NMFS guidance suggests that if a vessel incidentally hooks a false killer whale, they should attempt to straighten the hook. But there are questions about how effective this guidance is, given the stress it may put on a hooked animal, the difficulty of executing it properly, not to mention the danger of gear flybacks on crew (Musyl and Phillips, 2021, p. 12). Switching to monofilament leaders would reduce dangerous interactions for crew handling sharks and other large animals, although if the monofilament breaks or is cut close to a marine mammal, more research is needed to gauge survivability of the animals released with hook and varying lengths of trailing monofilament line.

Another fisher explained that their hydraulic gear makes a lot of noise that marine mammals such as false killer whales are able to hear when vessels set or haul their gear underwater from long distances:

> *False killer whales are habituated to the sound of propellers, bearings. Hydraulics make a lot of noise. We use a hydraulic suppressor. Similar to a silencer on a gun. When we turned it on, I could no longer hear the hydraulics.*

If false killer whales learn to associate the noises made by hydraulics with fish, then a suppressor would reduce the proverbial dinner bell that attracts them to fishing boats, thereby limiting costly depredation events. Research indicates that most depredation occurs during hauling events (Anderson et al., 2020), so testing suppressors during haul times could be a promising way to reduce depredation.

4.4.2.3. Additional useful information. Fishers also identified additional useful information that NMFS could provide to further limit protected species interactions. One such idea involved studying depredation events across time and space: "Look at depredation data across time and space. Look where the events are happening and when." This fisher felt that patterns might emerge that could be shared with industry to avoid those areas at certain times of the year.

Another idea several fishers brought up was tagging and tracking more false killer whales: "Post a video clip or something on Youtube tracking the whale so that you can watch and avoid them. Put it on a website? Tag and track false killer whales and share the data. That's one example." By tagging and tracking false killer whales and sharing the information with industry, vessels could potentially avoid those areas. Another fisher thought that if acoustic technology were provided to industry, then they could listen for false killer whales before setting their gear: "Maybe listen for them and not set there? If it helps, then try it."

5. Discussion

Collectively, our interview results demonstrate the importance of learning from fishers about the potential of sociotechnical solutions to further reduce protected species bycatch. When asked about protected species bycatch, interviewees highlighted themes related to the financial impacts of protected species encounters, relocation to avoid protected species, communication to avoid them, and innovative ideas to avoid them or improve handling. These themes reveal ways that bycatch might be further reduced as well as which sociotechnical solutions may work in different situations to further reduce interactions and advance ecosystem-based fisheries management of pelagic ecosystems around Hawaiʻi. Below, we draw upon our case study to consider how financial costs incentivize bycatch avoidance, designing effective sociotechnical solutions can further reduce bycatch, then we consider the social barriers to sociotechnical solutions, and necessary institutional support for bycatch reduction to be successful.

5.1. Financial costs incentivize bycatch avoidance

Fisheries bycatch is often framed from the perspective of reducing biophysical impacts and does not adequately consider social, economic, and institutional impacts (Stephenson et al., 2017). Our interviewees were clear about the costs associated with fisheries bycatch. These costs must be weighed against any potential benefits from fishing in an area where the potential for bycatch might be elevated. Shark or false killer whale depredation events frequently result in the loss of valuable bait and catch. Some fishers we interviewed reported that these events or the mere presence of these animals may cause them to immediately haul their gear and relocate as much as 100 miles or more to try to avoid them. Catching sharks, false killer whales or seabirds is even worse, due to the danger that crew face to release them with as little trailing gear as possible or straighten hooks so that they might be released without any trailing gear to increase post-hook survivability (WPFMC, 2021). Therefore it is important to recognize the incentives Hawaiʻi longliners have to avoid protected species bycatch and the difficult choices they must make while fishing. Similar fisher efforts are likely in other fisheries, which highlights the need to consider social factors that contribute to or detract from technical solutions to bycatch reduction.

5.2. Suggested sociotechnical solutions

In many global fisheries, bycatch reduction research has focused on the technical aspects and experiments to determine their effectiveness. This research is necessary to accurately assess which technologies work from a biological perspective. But research on implementation, acceptance, and compliance of technology is often lacking, which can lead to an implementation gap (Campbell and Cornwell, 2008). Scientists, fishers, and managers have made significant progress to reduce protected species bycatch in the Hawaiʻi longline fishery. Over the past two decades, scientists have acknowledged that sociotechnical solutions are most effective when they "are practical and convenient for the crew as well as being economically viable—or better yet, that provide operational and economic advantages…" (Gilman et al., 2008, p. 321). An implementation gap in bycatch reduction can occur when the research identifies a potential solution, but the solution is not adopted or fully effective for a variety of reasons, such as education, uptake, compliance, or funding. Through our interviews, we sought to understand these social dynamics, how they may influence the uptake of technical solutions, and how to overcome barriers. Below, we focus on two suites of sociotechnical solutions described by fishers: communication to avoid protected species bycatch and locally appropriate ways to improve crew training for rare events.

5.2.1. Communication to avoid protected species bycatch

We discovered that captains do a lot on their own—outside of regulation—to reduce protected species bycatch. A single vessel-to-vessel VHF radio or satellite phone call at sea may keep vessels away from encounters with aggregations of protected species. Such a call does not require additional technology, only a willingness to both share location information and relocate to another fishing area. Although this intervention does not include any bycatch reduction technology, it does entail costs in terms of fuel and lost fishing time. Fleet communication and reporting of bycatch concentrations have been used in several fisheries in both the North Pacific and the North Atlantic and are posited to be effective when there are economic incentives to reduce bycatch, there is an industry association already in place, the bycatch are rare events, and there is enough observer coverage to ensure compliance (Gilman et al., 2006). All of these conditions are currently present in the Hawai'i longline fishery. Scaling up this intervention via such a system and utilizing anonymous, grid-level reporting could help vessels anonymously broker connections outside of their existing social networks. Such a system could simultaneously buffer preferential fishing location data by not sharing precise fishing locations and potentially further reduce protected species bycatch.

5.2.2. Crew training for rare events

To be effective, technical solutions require education, training, adoption, and diffusion, while paying attention to the social and political context (Hall et al., 2007). In Hawai'i longline fishing, protected species bycatch are rare events. Rare events can be difficult to predict (Siders et al., 2020) as well as difficult to train for, particularly for foreign crewmembers, which comprise most longline crew in Hawai'i. These foreign crewmembers cannot attend trainings in-person at a federal facility due to their special work status.[1] Foreign crew live aboard vessels for the term of their contracts and are documented by Customs and Border Protection (CBP), but they do not have work visas. Since they are not working on land, CPB restricts their movement to areas around the port unless they need health or safety assistance. So these logistics further challenge crew training.

Rare events such as protected species bycatch in the Hawai'i longline fishery demonstrate the importance of addressing the human dimension when designing bycatch solutions. Technical solutions require education tailored to local conditions. In this case it involves language barriers and training to adequately prepare crew to handle animals safely in a way that also protects their safety at sea. Addressing these issues via practice drills, rotating responsibilities, translation, and handling safety protocols can help ensure that bycatch regulations are observed and effective. Organizational research suggests that managers, captains or owners can play an important role in helping crew cope with rare events, from anticipation, to preparation, swiftly and safely responding, and ensuring crew learn from the experience (Lampel et al., 2009, p. 842). Similar to the findings of Campbell and Cornwell (2008), our results demonstrate how the human dimensions—in this case, communication and locally tailored education—can potentially enhance bycatch mitigation in the fishery. COVID-19 realities have hindered on-vessel crew training initiatives, but hopefully they can be reconsidered after the pandemic.

5.3. Social barriers to suggested sociotechnical solutions

Fleet communication and crew training are two practical and convenient sociotechnical solutions that appear to provide operational and economic advantages, but have not been widely adopted and implemented across the fleet. Below we focus on the social barriers to their implementation and adoption.

5.3.1. Social barriers to scaling up fleet communication

Despite the presence of enabling factors identified by Gilman et al. (2006) and their potential to further reduce bycatch, a 'one fleet' communication system has never been implemented in Hawai'i due to several social factors. First, longline fishing is a competitive endeavor (Fader et al., 2021b). Some captains and owners may be reluctant to share proprietary fishing location data inside the EEZ within the industry, let alone fishing locations outside the EEZ. If fishing location data outside the EEZ were to reach foreign fishing vessels, then there could be increased foreign fishing competition on the high seas. Second, a reporting system faces several challenges, including timely reporting, an entity to manage and share the data, and funding. The Western Pacific Fishery Management Council (Council) has attempted to help facilitate sharing of existing location data for protected species interactions, but have run into data confidentiality issues with NMFS, who expects industry to manage industry reporting on their own (WPFMC, 2020, p. 5; WPFMC and PIRO, 2020, p. 5). This leads into the third issue, the industry would need all active fishing vessels to collaborate and commit to a fleet communication system. Doing so requires building trust in the entity managing the data and the reporting accuracy of other fishers. Fourth, a communication system is also challenged by cultural and language barriers, which could further complicate timely and descriptive reporting information. Fifth, the Hawai'i longline fishery does not employ catch shares or individual fishery quotas IFQs, which might allow the creation of risk pools for species of concern or quota sharing or transfer.

5.3.2. Overcoming social barriers to fleet communication

Common pool resource theory suggests that actors will not self-organize and bear the costs of changing or developing new operational rules, such as establishing a one fleet communication system—unless they perceive benefits of working together exceed the costs or potential risk (Ostrom, 1990). Thus developing a new communication system must be cost-efficient or at least demonstrate that its benefits outweigh its costs. It must also address issues of trust in terms of data management and sharing. In other U.S. fisheries, this has been done through third party data sharing and development of products that conceal catch rates and instead report bycatch per unit catch, while separating data and enforcement tasks – a third party manages data, while the trade association penalizes vessels with higher bycatch rates (Gilman et al., 2006, p. 362). For the entire fleet to adopt a communication system on their own, they need evidence that it can be effective. In other bycatch reduction efforts, fishers pilot new technologies to ensure their effectiveness before wider deployment. Sociotechnical solutions such as fleet communication should operate similarly. Piloting in a smaller segment of the fishery, such as the shallow-set longline fleet, could be one option. Used in conjunction with Turtle Watch, a NOAA product that displays real-time sea surface temperature bands preferred by loggerhead sea turtles so that longline vessels can still fish while avoiding them, at sea communication could further help avoid triggering costly trip limits and fishery closures (WPFMC and PIRO, 2020). Any communication program must include language support to ensure all bycatch reporting information and products are understood by all segments of the fleet. Also, since not every vessel has email or internet access, upgrading vessels to allow email communication could allow turtle watch emails to reach captains each day. Lastly, any changes to catch shares or IFQs would need NMFS and industry support, which have been lacking in the past (Allen, 2014).

5.3.3. Social barriers to improved crew training

Crew training to assist with protected species handling already occurs in Hawai'i. Captains are responsible for attending a protected species workshop training and for sharing this information with crew on their vessel. But there is not an official protected species training requirement for Hawai'i longline crewmembers. Crew training is challenged by several social factors. The first is language. In general, crew speak one of 5–7 different languages, which complicates translation of any video or print material. Second, is logistical. Most Hawai'i longline crew are foreign and have a special work status which prohibits them from flying into Hawai'i, or leaving the port area when they are not fishing. This also prohibits crew from entering a federal facility to attend the protected species workshop. Furthermore, crew typically work on annual contracts and there is year to year turnover, so new crew must be trained each year (TRT, 2020, p. 1). Third is training for rare events (Siders et al., 2020). Straightening a weak hook on a large false killer whale, resuscitating a sea turtle, safely releasing a shark, or handling a hooked seabird can be difficult in the moment out at sea, even with significant training. Preparing for these events is challenging because it is difficult to replicate them in real life.

5.3.4. Overcoming social barriers to improved crew training

Several initiatives are underway to help improve protected species training for Hawai'i longline crew. To help address language issues, many of the materials in the protected species workshop materials now include illustrations that can be understood regardless of primary language. These materials can be shared with crew members to study at their leisure. The Hawai'i Longline Association (HLA) is currently developing an online portal to improve crew training that will include crew training materials such as handling and safety protocols (Tummons, 2021). The online portal should enable crew access to key materials that they can access on a mobile device, to improve understanding of importance of protected species handling as well as how to handle them safely, particularly for false killer whales and sharks. The fact that protected species bycatch are now rare events is a byproduct of three decades of successful efforts between fishers, scientists, and managers. If protected species bycatch decreases, there will be fewer opportunities to practice handling. But the online training portal should help prepare crew for the different handling scenarios that may come up at sea, just as the in-person course at the NOAA facility currently does for captains.

5.4. Necessary institutional support

Diffusion of innovations theory (Rogers, 2003) and social network analysis have shown how bycatch reduction innovations could potentially spread through different fleet factions and communications channels (Barnes et al., 2016; Barnes-Mauthe et al., 2013). But for these ideas to work and spread, fishers must develop trust, identify common ground, and resolve conflicts with different entities (Hahn et al., 2006). In the Hawai'i longline fishery, bridging organizations and take reduction teams have provided institutional support for bycatch reduction.

5.4.1. Fishery Management Council as a bridging organization

Bridging organizations can facilitate collaborations, build trust, identify common ground, and resolve conflicts among different entities. The Council serves as an important bridging organization in reducing bycatch in the Hawai'i longline fleet. The Council works closely with industry partners and NOAA Fisheries to facilitate data collection on new bycatch reduction technologies and also works with industry to help meet national standards outlined in the Magnuson-Stevens Act (MSA) on bycatch reduction, protected species, sustainable fisheries, and others goals (Dept. of Commerce et al., 2007). The Council works closely with the Hawai'i Longline Association, a trade association that represents Hawai'i longline fishers to meet MSA National Standards. The Council regularly convenes and facilitates meetings with industry, scientists, regulators, and others to develop take reduction plans, often proactively developing new guidelines or regulations to help reduce bycatch such as a recent effort to switch to monofilament leaders to reduce bycatch of sharks, which includes the endangered oceanic whitetip (Honore, 2021).

5.4.2. Take Reduction Teams to reduce False Killer Whale bycatch

Another recent collaborative effort involved a multi-disciplinary Take Reduction Team (Team) to reduce bycatch of false killer whales in Hawai'i's longline fishery (MMPA, 1972). In Hawai'i, the Team is a multi-year, collaborative process which resulted in new regulations that closed an area of the Hawai'i EEZ for the rest of the year if the fishery interacts with two false killer whales (Pan and Walden, 2015). Other efforts have piloted different gear types, such as weak circle hooks, strong terminal gear, and handling recommendations to potentially reduce false killer whale bycatch in the fishery (Curran and Bigelow, 2011). Although the effects of TRT actions to reduce bycatch have been mixed (Baird, 2019, p. 4), industry, scientists, and managers continue to work on solutions that can reduce false killer whale bycatch with minimal economic harm to fishers (Musyl and Phillips, 2021). One such example, electronic monitoring, in which cameras turn on during a haul to view landing and bycatch handling, was installed on 18 longline vessels by 2020 (NOAA Office of Science and Technology, 2020), an increase since 2017 (Baird, 2019, p. 5). Collaborations between industry, scientists, and managers require integration of multiple perspectives, data, sustained effort, trust, and small victories along the way (Wondolleck and Yaffee, 2000). Further reducing bycatch is challenging, but efforts made thus far in this fishery suggest that further efforts will be fruitful.

6. Conclusion

Fisheries bycatch remains a pressing conservation and management issue across the globe. Our research sought to understand the human dimensions of bycatch reduction using a case study from the Hawai'i longline fishery. The Hawai'i longline fishery and the U.S. fishery management process present an effective model that has significantly reduced protected species bycatch of several species over the past three decades. In the Hawai'i longline fleet technical solutions have and will continue to reduce protected species bycatch. But we identified two promising sociotechnical solutions—fleet communication and locally tailored crew training that could potentially further reduce bycatch that have not been widely implemented across the fleet. We considered barriers to their implementation as well as ways to overcome them based upon both theoretical and empirical evidence. If implemented at scale, they could further reduce bycatch in the fishery, improve survivability of protected species, and enhance ecosystem-based management of pelagic ecosystems around Hawai'i. Lessons from this fishery could apply to other global commercial fisheries seeking to further reduce bycatch.

CRediT authorship contribution statement

Adam Ayers: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing. **Kirsten Leong:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fishres.2022.106432.

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