WESTERN PACIFIC REGIONAL FISHERY MANAGEMENT COUNCIL

ISSUE PAPER

Seeking Consensus under the MMPA - Review of False Killer Whale interaction mitigation strategies in the Hawaii Deep-set longline fishery with recommendations

SSC Working Group on Alternative Approaches to Reduce Impacts to FKWs
Adopted by the SSC at the 141st Meeting

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1.0 Introduction

Interactions between the pelagic stock of false killer whales (*Pseudorca crassidens*), (FKW) and the Hawaii-based deep-set longline fleet are rare events that continue to be problematic for the sustainability of longline fisheries that primarily target bigeye tuna, both inside and outside the US EEZ around Hawaii. FKW are known to predate on both bait and catch, and they may be able to acoustically track longline vessels during setting and hauling. NOAA National Marine Fisheries Service (NMFS) formed the Take Reduction Team (TRT) in 2010, and the TRT recommended a draft Take Reduction Plan (TRP) in July 2010. NMFS implemented the TRP in 2012. There have been ongoing efforts to achieve consensus and to demonstrate that both the regulatory and non-regulatory measures that have been proposed or tried experimentally can reduce the mortality and serious injury (MSI) estimates to meet the criteria set forth in the Marine Mammal Protection Act (MMPA). Reaching consensus on recommendations to revise regulatory measures by the TRT has been difficult to achieve; however, this is not uncommon for TRTs for other species (Mcdonald 2015). Flexibility in approaches to estimating population abundance, risk and potential biological removal (PBR), and to develop and assess mitigation measures, may be warranted (Rizzardi, 2014).

This contentious issue has plagued the pelagic longline fleet, led to sometimes failed experimental measures, and taken up time and resources on the part NMFS Protected Resources Division (PRD), the Hawaii Longline Association (HLA), the Western Pacific Fishery Management Council (WPFMC) Scientific and Statistical Committee (SSC) to develop mitigation measures. This paper was developed by four members of the SSC who were part of a Working Group formed in 2020 to review and consider alternative measures to the experimental weak circle hook measure that turned out to be ineffective. This Working Group came about as a result of the TRT's inability to reach consensus on effective regulatory measures. The TRT did recommend on-going assessment of non-regulatory measures, and the Working Group considers those recommendations below.

This paper reviews and synthesizes the ongoing efforts to mitigate deleterious interactions between FKW and the Hawaii longline fleet through 2021, and brings together disparate pieces of information scattered in various reports, including previous SSC discussions of this matter. The paper sketches the history of the formation of the FKW TRT, and its efforts to reach consensus on an acceptable suite of mitigation measures, both regulatory and non-regulatory. The paper then reviews the course of events leading up to the TRT's difficulties in reaching consensus on regulatory measures, and evaluates a range of measures and assesses their likelihood of providing a positive impact, offering suggestions for a path forward.

The paper evaluates the types of demographic data that are lacking, but perhaps necessary to make scientifically credible risk estimates for the FKW population of concern. The paper considers PBR as required under the MMPA, and comments on issues surrounding the difficulties in estimating PBR given a lack of adequate population demographic data. The paper concludes by recommending that the serious injury (SI) criteria be re-evaluated, and makes recommendations for future research that would enable such reconsideration.

1.1 Need for Evidence-based Evaluation

Effective, evidence-informed marine fisheries policy-making depends on policy-relevant science. Scientific evidence requirements concern not only the capture species but also protected marine species such as the false killer whale (FKW) that are incidentally caught in the Hawaii deep-set longline fishery. Robust synthesis of the scientific evidence on the exposure of FKWs to pelagic longline fisheries and the demographic consequences of that exposure are needed to better inform bycatch mitigation policy.

Many barriers exist to evidence-informed policy other than evidence synthesis (Rose et al 2018), and some of those barriers relate to advocating the synthesized evidence in the appropriate policy forum and in a way that is meaningful to fisheries management agencies and policy-makers. Given these considerations, the Working Group addresses both (1) the synthesis of the relevant scientific evidence concerning alternative measures to reduce FKW bycatch and (2) what might be the appropriate policy instruments for applying this evidence.

1.2 Overview of PBR and Take Occurring in the Fishery

The 1994 amendments to the MMPA mandate that, as part of the Stock Assessment Reports (SARs), PBR estimates must be developed for each marine mammal stock in U.S. waters. PBR is defined as "the maximum number of animals, not including natural mortality, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population (OSP)." In addition, the MMPA specifies that PBR must be calculated as the product of three elements: the minimum population estimate (N_{min}), half the maximum net productivity rate (0.5 R_{max}), and a recovery factor (F_r). Guidance for determining each of these elements is provided in the NMFS Guideline for Assessing Marine Mammal Stocks (GAMMS) (NMFS 2016).

NMFS recognizes three false killer whale stocks in the Hawaii Islands Stock Complex (pelagic, main Hawaiian Islands, and Northwestern Hawaiian Islands stocks), and two additional stocks in the greater Western Pacific (Palmyra Atoll and American Samoa stocks) (Caretta et al 2020). The primary focus of the FKW TRP is the pelagic stock, which is a transboundary stock ranging inside and outside of the U.S. EEZ around Hawaii with an unknown outer extent on the high seas.

False killer whale interactions in the Hawaii deep-set longline fishery are monitored through a federal observer program that provides coverage for approximately 20% of the trips. For interactions that resulted in the animal being released alive, NMFS determines whether the interaction was likely to be a serious injury based on its Serious Injury Determination Policy (Policy Directive 02-238 and Procedural Directive 02-238-01). Under the policy, small cetaceans released alive are assigned to SI or non-serious injury (NSI) categories based on the type of injury, amount of gear remaining, and other conditions specific to each interaction. NMFS interprets SI as an injury that is more likely than not to result in mortality, or any injury that presents a greater than 50 percent chance of death to the animal. For the purpose of evaluating the impacts of SI against PBR, SI is considered 100 percent removal from the population regardless of the injury type and other available information for that interaction, and thus the population-level impact of a SI is considered equivalent to a mortality. Most of the false killer whale interactions in the Hawaii longline fishery result in the animal released alive with varying amounts of trailing gear remaining, which result in the interactions being categorized as SI. The total interactions for the fleet are estimated based on an expansion of these observed interactions Further consideration of these issues is contained in Caretta (2020).

At the time of the initial FKW TRT deliberations in 2010, the abundance estimate of the pelagic stock of false killer whales within the EEZ was 484, based on a reanalysis of the 2002 Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS) data. The resulting PBR was 2.5, and the mean annual MSI inside the EEZ was estimated at 7.3.

The 2010 HICEAS resulted in a higher abundance estimate of 1,540 pelagic false killer whales inside the EEZ, resulting in an increased PBR of 9.3. These estimates became available after the initial deliberations of the FKWTRT in 2010 but before NMFS published the final rule to implement the FKWTRP. At the time of the FKW TRP implementation in December 2012, the 5-year mean annual MSI for the pelagic false killer whale stock was 13.6 individuals inside the EEZ, and 11.2 on the high seas. By early 2018, the latest 5-year (2011-2015) mean estimated annual MSI was 7.5, and the mean estimated annual MSI since the TRP implementation (2013-2015) was 4.1, indicating that the current MSI levels of pelagic false killer whale stock had been reduced below the PBR.

The latest HICEAS survey was conducted in 2017. The newest abundance estimates from the 2017 survey, published in 2020, indicates that the current best estimate of the false killer whale pelagic stock abundance based on a 2017 survey is 2,086 animals, resulting in a PBR of 16 (Oleson 2020). The assessment also updated the abundance from the previous two surveys conducted in 2002 and 2010, now estimated at 2,086 and 2,144, respectively, although the assessment did not explicitly test for population trend (Bradford, 2020)

1.3 Formation and Output of the TRT and TRP

The False Killer Whale Take Reduction Plan (FKW TRP) was implemented in December 2012 to reduce false killer whale interactions in the Hawaii longline fishery. Take reduction plans are required under the MMPA when, among other conditions, the MSI levels of a marine mammal stock exceed the PBR estimated in the MMPA SAR, and the stock interacts with a fishery classified as Category I or II under the MMPA List of Fisheries (LOF).

The Hawaii longline fishery was first classified as a Category I fishery in the 2004 LOF. At the time, the population estimate of the false killer whale stock around Hawaii was 268 for the entire U.S. EEZ around Hawaii, resulting in a PBR of 1.2, and the MSI was estimated at 4.4. NMFS did not convene a Take Reduction Team (TRT) at first due to funding limitations. In the interim, the Council established a Marine Mammal Advisory Committee (MMAC) in 2005 to explore ways to reduce false killer whale interactions in the Hawaii longline fishery. MMAC met over three meetings between 2005 and 2009, generating recommendations for research and assessments needed to fill the information gaps. NMFS established the FKW TRT in 2010, including representation from the Council, State of Hawaii, federal agencies, academic and scientific organizations, fishing industry, and environmental groups. During the TRT deliberations, the abundance estimate of the pelagic stock of false killer whales was 484, PBR was 2.5, and the mean annual MSI inside the EEZ was estimated at 7.3.

The FKW TRT submitted a draft FKW TRP to NMFS in July 2010. NMFS published a proposed rule based on the team consensus plan in July 2011 and published the final rule in November 2012. The goals of the TRP were to reduce the MSI occurring within the U.S. EEZ around Hawaii to less than the stock's PBR within six months, reduce MSI to below 10% of PBR within five years, and to not increase the MSI on the high seas. The main components of the FKW TRP were the required use of "weak" circle hooks intended to allow release of false killer whales without remaining gear, measures to improve captain and crew response to interactions, modification to the MHI longline exclusion zone established under the Council's Pelagic Fishery Management Plan (FMP, currently the Fishery Ecosystem Plan) in 1992, and a triggered Southern Exclusion Zone closure that would prohibit fishing in a portion of the U.S. EEZ around Hawaii if two false killer whale interactions inside the EEZ resulted in a MSI determination in a year.

1.4 History of Measures Implemented and TRT Deliberations

The Working Group finds that the weak hook measure under the current False Killer Whale Take Reduction Plan has not been successful, and that the Southern Exclusion Zone closures have not resulted in further reduction in interactions. The TRT, after a nearly three-year deliberation process, did not reach consensus on alternative approaches to improve the effectiveness of the existing measures. The TRT in late 2020 concluded that consensus could not be reached on recommendations on management measure changes, but agreed to several non-regulatory and research priorities that focused on the following:

- Encouraging NMFS in coordination with HLA to train deck bosses and crew (in addition to owners/operators);

- Recommending that NMFS conduct or support research regarding FKW depredation on longline gear, with the goal of identifying mechanisms to reduce and avoid depredation without causing significant economic impacts to the fishery;

- Recommending that NMFS conduct or support research to quantify and assess post-release FKW mortality; and

- Recommending conducting data synthesis when possible.

Over the past ten years, the SSC has made a number of recommendations for minimizing impacts to false killer whales and improving assessment of population impacts. These recommendations include conducting population viability analysis and developing probability-based serious injury determination criteria. As noted above, formation of the Working Group and development of a comprehensive issues paper was recommended to summarize available information on these issues, and to inform recommendations to the Council on future mitigation measures as well as population assessments.

2.0 Cetacean Avoidance Research and Interaction Reduction Measures

Interaction and depredation of catch and bait by toothed cetaceans is well known in pelagic longline fisheries which may alter cetacean foraging behavior and distribution, financially impact fisheries, and contribute to resource waste and discarding (Gilman 2006). Hamer (2012) lists 32 peer-reviewed publications documenting 20 odontocete species interacting with longline gear and the number has likely increased with time. A wide range of potential solutions to mitigate the impact of these interactions have been attempted and many have been evaluated through applied research (Swimmer 2020). Studies or management approaches to reduce these impacts include the use of acoustic strategies to repel marine mammals from fishing gear or to reduce their ability to locate the gear, improved communication and move on policies to physically separate marine mammals from fishing effort, gear driven deterrents that drop over and mask catch from depredation and release mechanisms to reduce the physical impact of gear interactions (Clarke 2014).

Several methods have been trialed or considered to mitigate fishery impacts during false killer whale interactions including a variety of acoustic studies, “move on” studies, physical encasement around catch, “weakened gear” strategies, and removal of trailing gear. A summary of these studies and management measures more specific to interactions between false killer whales and the Hawaii deep-set tuna longline fishery are described below.

2.1 Acoustic Research

A range of acoustic approaches have been applied to studying and potentially mitigating fishery interactions with marine mammals. A variety of acoustic harassment devices (AHD) have been trialed across several fisheries in an attempt to reduce depredation or entanglement with the gear (McPherson 2003). These devices create underwater sounds deemed noxious to the target species or create a masking effect making the vessel and gear difficult for the cetaceans to locate. Studies have found that odontoctetes species will quickly habituate and adapt to overcome acoustic harassment methods rendering them ineffective (Tixier 2015, Mooney 2009). Pinnipeds and toothed whales are intelligent species and can key in on and be attracted to the signal from AHDs creating a “dinnerbell effect.” The FKW TRT has recommended against the use of AHDs to mitigate FKW interactions in the fishery and NMFS has no plans to utilize AHD technology.

The auditory signals and echolocation of false killer whales have been found to be species-specific allowing for the acoustic monitoring of FKW in situ and without verification by human observers (Oswald 2007, 2011, 2013; Bauman-Pickering 2015). FKW depredate both target tuna and finfish bycatch in the fishery and are known to take bait from the hooks as they have been simultaneously recorded with video and acoustic devices (Thode et al. 2016). Passive acoustic monitoring (PAM) in the form of acoustic recording devices attached to commercial deep-set longline gear has been used to document the occurrence and timing of FKW in proximity to longline sets (Bayless 2017). The animals appear to be more present and active near the gear during the haul-back phase of the fishing operation when most depredation events are believed to occur.

2.2 Move-on Studies

Depredation or damage to target longline catch by odontocetes can be significant, prompting vessel operators to move location to avoid the source of the damaging interaction. Often, this may be a movement of only 3 to 5 hours steaming at 9 knots or less due to the desire to commence the next day setting operation to continue the full fishing cycle. This distance is considered inadequate to avoid FKW that can easily cover these distances and catch up with the fishing gear on the next set. Relevant work is being conducted by Fader (in press) that used a modeling approach to examine observer-collected data from the Hawaii deep-set longline fishery to examine patterns in odontocetes depredation by false killer whales.

The study found that in order to achieve a 50% reduction in depredation rate it would be necessary to move about 400 km or wait about 9 days before setting. Waiting 9 days is clearly unrealistic in a fishery where catch is stored fresh on ice, trip lengths are generally between 12 to 20 days and where fish held longer than 10 or 12 days may begin to see diminishing quality, shelf life and value. However, it may be possible to move about 400 km before setting the gear and still have enough total fishing time to complete a profitable trip.

2.3 Catch Shielding Devices

A variety of devices have been tested in longline fisheries that are designed to cover up a hooked fish thus creating a physical, psychological or sensory barrier to depredation (Clarke 2014, Hamer and Childerhouse 2013, Mcpherson and Nishida 2010, Swimmer 2020). These devices are normally attached near the branch line clip to the mainline and when triggered by a hooked fish will descend and deploy around the catch. These devices have included sheaths of fine netting, monofilament streamers, wire streamers, fine steel chains and monofilament cages or cones (Rabearisoa 2012, Hamer 2012, 2015).

Two similar studies carried out in Australia and Fiji tuna longline fisheries and in the Hawaii deep-set tuna longline fishery evaluated anti-depredation shielding devices consisting of monofilament streamers, steel trace streamers, a monofilament cone and a capsule-like plastic pod that contained stainless steel chains (Hamer 2015, 2019). The pod device had the advantage of being small, self-contained and easily attached or removed from a standard branchline with no dangling lines or wires prone to tangling. The pull from a hooked fish releases and opens the pod which deploys two thin chains around the hooked fish. The effect of these devices on CPUE in both studies was broadly similar, especially for the pod equipped branchlines. Significantly higher catch rates were noted for bigeye tuna, pomphret (*Eumegistis illustris*) and eight other frequently caught fish species. Depredation by sharks and in particular, the cookie cutter shark (*Isistius brasiliensis*) was also noted to decrease for gear protected catch. Low numbers of odontocete depredation were noted in the Australia-Fiji study but only on unprotected control branchlines, suggesting the mitigation devices may be having some positive, protective role. However, the rate of odontocete interaction was too low to allow a statistically significant analysis.

The Hawaii study was designed to evaluate the efficacy of a modular, manufactured device (the pod) compared to simple wire or monofilament devices constructed on the vessel of inexpensive materials. These objectives highlight the problems and issues that deploying these gears face. In order to be effective, a catch shielding device will need to be deployed on every branchline unless an observed spillover effect is realized that extends to adjacent branchlines. The gear should ideally be easily constructed or inexpensive to purchase, compact for storage, not prone to tangling, be easily and quickly deployed or removed from the gear, not add greatly to the storage area needed in the branchline baskets and not negatively impact target catch rates. Most of these conditions were not met by the experimental gear that required considerable storage space on already crowded vessels and could cause tangling in the branchline baskets or when deployed.

Some shielding gear slowed sink rates which can increase bait depredation by seabirds while some gears required an extra deck hand to deploy, remove and store the gears creating additional burden to overall costs and accommodation space. Economic losses to the fishery can periodically be high due to depredation but the fishing industry appears at this time to be willing to bear that expense rather than adopt these gear-based solutions to mitigate a relatively rare interaction event.

2.4 Line cutter devices

Hawaii pelagic longline fisheries must comply with numerous federal regulations and conditions to mitigate protected species interactions (50 CFR 665 Subpart F). A suite of gears are required to be carried onboard to deal with hooking or entanglement of sea turtles, including long-handled line clippers and dehooking gear. The deep-set fishery operating north of 23° N latitude is also required to equip branchlines with a 45 g weight within 1 meter of each hook to reduce seabird bait depredation when setting gear. The majority of gear in the deep-set fishery deploys baited circle hooks rigged on a short steel wire trace of < 1m that attaches to a 45 g leaded swivel that attaches to the remaining branchline consisting of monofilament with a diameter/thickness of 2.0 mm or larger.

The long-handled line cutters currently approved for the fishery are not capable of severing wire trace and severing the monofilament above the 45 gram, leaded swivel is not desirable as it releases the animal with the hook, wire trace and weighted swivel still attached, hence the support for a hook-straightening protocol designed to release bycaught cetaceans with no hook or trailing gear. Efforts to develop an improved line cutting device have been supported by the 2019 NMFS Bycatch Reduction Engineering Program (BREP) that funds research to develop technical solutions and improved practices to reduce bycatch impacts on federally managed fisheries. A device has been designed that will clip to and slide down a branchline that is capable of easily severing wire leader used in the fishery. A prototype device was tested on a commercial longline vessel where 14 incidentally caught blue shark (*Prionace glauca*) were released in good condition by severing of wire leader close to the hook (McMahan 2021 pers. comm.). Currently, the device remains in prototype form.

The need for such a powerful device may become unnecessary considering a move by the industry to switch to all monofilament leaders. HLA, which represents the majority of effort in the Hawaii pelagic longline fishery, announced that members will transition to monofilament leaders in 2021 (HLA 2020) (Ayers and Leong 2020). The proposal is non-binding, but efforts to implement this change within a federal regulatory framework are in progress. A shift to monofilament increases the possibility of cutting the leader close to the hook with simple long handled devices but a danger of gear flyback and injury of the crew remains. HLA has noted the importance of this issue and the need to develop gear and release protocols that consider crew safety as a priority.

2.5 Weak circle hooks

The use of "weak circle hooks" paired with relatively strong branchlines have been trialed and used as a strategy to release a larger non-target species of interest (e.g. odontocete) while retaining smaller target species, often bigeye or yellowfin tuna (Clarke, 2014, Swimmer, 2020). The intent is for hooks to straighten and release non-target species that are free of hooks or trailing gear. Longline hook strengths were evaluated in the Atlantic as a means to reduce interaction impacts to Atlantic pilot whales (Bayse and Kerstetter 2010). That study tested 16/0 strong and weak hooks, finding no significant difference in CPUE or weight of yellowfin and bigeye tuna taken by the weak hook type. The weak circle hook strategy was evaluated in the Gulf of Mexico yellowfin fishery to reduce unwanted bycatch of much larger Atlantic bluefin tuna (*Thunnus thynnus*) with promising results. The study found no significant CPUE difference in target yellowfin tuna and most finfish species examined while bluefin tuna catch was significantly reduced by 56.5% with weak hooks (Bigelow et al 2012, Foster and Bergmann 2010). As a result, the use of weak circle hooks is required for domestic pelagic longline vessels operating in the Gulf of Mexico (https://www.federalregister.gov/citation/76-FR-2313).

A similar study in the Hawaii deep-set bigeye tuna fishery evaluated catch rates of "strong" 15/0 circle hooks (4.5 mm wire diameter) against "weak" 15/0 hooks of 4.0 mm wire diameter (Bigelow et al 2012). Catch rates of the targeted bigeye tuna were not significantly reduced on the weak hooks though the sea trials were not conducted during the period when larger bigeye tuna occur in the fishery. Observers engaged in the study collected 76 hooks that had been straightened, of which 6 were strong and 70 of the weak hook type. One strong circle hook was observed to have been straightened by a false killer whale depredating bait during line retrieval resulting in its release. Fish catch were retained on 27 partially straightened weak hooks including 21 bigeye tuna, four blue marlin, one yellowfin tuna and one bigeye thresher shark suggesting the weak hooks were so weak that loss of target catch could become an issue.

Research has examined the pulling force required to straighten different hook types placed in the soft tissue of the dorsal lip area and mandible bone of odontocete cadavers (short-finned pilot whales (*Globicephala macrorhynchus*), Risso's dolphins (*Grampus griseus*), and false killer whales (*Pseudorca crassidens*) recovered from stranding events (Mclellan 2015). Five hook types were evaluated that included 16/0 and 18/0 circle hooks of the same model from two different manufacturers (4 hooks) representing "weak" polished steel and "strong" carbon steel circle hooks. A 9/0 "J" style hook was also evaluated.

The force required to straighten and release the hooks varied considerably by hook size and hook manufacturer, which also correlated with steel alloy type. The 16/0 polished steel circle hooks straightened and released at the lowest forces (51 – 85 kg) while the 18/0 carbon steel circle hooks did not straighten until 132 – 251 kg of force was applied. The polished steel circle hooks straightened along their entire length, exposing the sharpened barb that sliced through the lip tissue to release. The carbon steel circle hooks also straightened along most of their length but the barb often broke off and embedded in the jaw before the hook released. Only the larger 18/0 circle hooks had sufficient gape to encircle and attach to the mandible with pulling force applied to two short finned pilot whales and one Risso's dolphin. Hook straightening and release was achieved at 182 kg and 243 kg but the experiment was suspended in a third trial when straightening and release could not be achieved. In all three trials, bone fractures resulted from the applied force.

The TRP requires the Hawaii deep-set longline fishery to only use "weak" round wire circle hooks with a maximum wire diameter of 4.5 mm paired with a "strong" monofilament branchline with a minimum diameter of 2.0 mm with a point offset of 10 degrees or less. Other materials used in branchline composition must have a minimum breaking strength of 181.4 kg (400 lb.). These gear requirements are supported by training and handling guidelines for the captain to direct the crew to apply "active tension" to the branchline in an attempt to apply sufficient pressure to straighten the hook and release the cetacean without hook or trailing gear. There are also requirements for the captain to be notified and come on deck if an interaction occurs to direct the release attempt (77 FR 71260) (Federal Register, 2012).

The use of weak circle hooks has remained the primary regulatory measure to deal with bycaught false killer whales in the Hawaii based longline fishery since the TRP was developed in 2012. During the eight-year period (2013 to 2020), 55 false killer whale interactions with the deep-set longline fishery have been documented by Hawaii Longline Observer Program (HLOP) observers (Fader et al 2021 to 2018, unpublished TRT presentation update). The gear came free on two occasions (3.6%) or the hook broke on one interaction (1.8%) with two incidents not observed or recorded. The overwhelming majority of interactions ended when the branchlines broke (22 times, 40.0%) or were intentionally cut by the crew (23 times, 41.8%) resulting in the animal being freed with the hook in place and trailing variable but often lengthy sections of gear. The mitigation strategy has succeeded on only five occasions (9.1%) with hooks straightening and releasing the animal without hooks or trailing gear.

2.6 Additional measures considered with recommendations for further study

2.6.1 Acoustic-related studies

A number of acoustic strategies to reduce FKW interaction with longline gear have been proposed that include: 1) underwater signaling devices to mask vessels and vessel activity, 2) broadcasting decoy sounds to occupy and distract cetaceans from fishing vessels, 3) using acoustic devices and sound transmission to interfere with cetacean echolocation, 4) use of sonobuoy transmission to track cetaceans useful for fleet avoidance, 5) identifying the exact source of onboard acoustic generation that cetaceans may be keying in on to identify longline vessels, and 6) investigate the acoustic signature of vessels with historically low cetacean interaction to be replicated by other vessels (Gilman, 2006). Considering the intelligent nature of these animals, the likelihood of these approaches producing lasting positive results is likely to be low.

Acoustic detection and visual detection of false killer whales from longline vessels indicates that the animals are most attracted to the vessels when gear and catch is being hauled and this is likely to be when most depredation events occur. Work continues by NMFS in an attempt to identify what acoustic signals may be most important that false killer whales are focusing on when targeting vessels for depredation. This information may be useful to identifying, masking or eliminating mechanical sounds that increase the likelihood of attracting depredating cetaceans.

2.6.2 Move on studies

The nature of the Hawaii tuna longline fishery that targets sashimi grade bigeye tuna held on ice limits the ability of vessels to make lengthy time/area shifts in their operation. Once the first tuna is landed, cleaned and iced the time clock starts that determines how many additional days of fishing can occur before returning to port with the catch in marketable condition. Waiting to set for several days is not an economically viable solution in this fishery, nor is steaming for great distances. However, it may be worthwhile to steam away from a serious depredation event and lose one or two days of fishing.

2.6.3 Catch shielding gear

Various catch shielding devices that deploy a physical or psychological barrier around catch to deter depredation have been trialed on longline gear with mixed results (Clarke 2014, Hamer and Childerhouse 2013). Some degree of depredation reduction on target catch and deterrence of shark depredation, particularly for cookie cutter sharks has been documented (McPherson and Nishida 2010). These gears are simple, easily constructed and inexpensive but can become bulky and tangle in branchline storage bins or when deployed. The storage of this gear on smaller vessels when not deployed is another issue. Small modular units that store the shielding device until triggered address the storage and tangling issues and can be easily added or removed from longline gear but are costly to produce (Hamer 2019).

In order for shielding devices to be accepted by industry and useful for mitigation of depredation, they will need to be effective, inexpensive, non-tangling, and easily added and removed from longline gear and be compact enough to be stored onboard. The gear should also be easily deployed and not require additional crewmen or overly burden existing crews. Due to issues in meeting these criteria, further trials or research on the efficacy of catch shielding devices have not been proposed or trialed.

2.6.4 Line cutting devices

Further development of a heavy-duty line cutter capable of severing wire trace is likely to be shelved if the Hawaii-based fishery moves to, or is required to adopt, monofilament leader material. If vessels effect this change, severing the leader close to the hook is possible with the required long-handled line cutters that are required to be carried during fishing operations. However, pulling an active false killer whale or other cetacean close enough to cut the line close to the hook will require heavy tension on the line and place the crew in danger from gear flyback when the leaded swivel is cut free. Cutting leader to release bycaught toothed whales is also an issue with the fishery as releasing animals with the hook in the head or mouth and some amount of trailing gear is usually assessed as a mortality/serious injury (MSI) by current NMFS guidelines (NMFS 2012). Cutting the leader in this manner provides little incentive to release cetacean bycatch by cutting the line close to the hook and the issue of gear flyback is also of concern. I n line with TRT recommendations, NMFS will be investigating technical solutions to reducing danger and injury to crewmen from gear flyback when hooks or leaders release under load.

2.6.5 Weak hook mitigation strategy

The CPUE of target and common fish bycatch between “strong” (4.5 mm wire diameter) hooks against “weak” (4.0 mm wire diameter) hooks found no significant reduction in bigeye catch rates with the weaker hook (Bigelow, 2012). However, 70 of the weak hooks tested in the study were retrieved that had been straightened or partially straightened with 27 of these still retaining bigeye tuna or marketable non-target finfish. This suggests that the 4.0 mm wire diameter hook may be too weak and prone to releasing bigeye tuna, particularly since the study did not cover the season when larger bigeye is available to the fishery.

The weak hook strategy currently regulated for the fishery requires the use of a “weak” circle hook of 4.5 mm maximum wire diameter paired with a “strong” branchline (minimum 2.0 mm diameter leader or maximum of 181.4 kg test). This configuration has not proved effective in releasing bycaught false killer whales in the Hawaii deep-set longline fishery. In the period of 2013 to 2020, hooks straightened to release false killer whales during only 5 out of 55 observed interactions (9.1%). The majority of the interactions (81.4%) were terminated when the crew cut the branchline at the rail or the branchline broke when it was secured to the vessel, releasing the animal with various amounts of trailing gear.

NMFS began a study to evaluate circle hook strength in 2021 that is in progress. The study was delayed by two years in part due to issues related to the COVID-19 pandemic. The study is designed to test “strong” circle hooks of 4.5 mm wire diameter against “weak” 4.2 mm wire diameter circle hooks and relatively strong 2.3 mm diameter monofilament branchlines. The study is designed to compare the catch rates and value of bigeye tuna and large, salable finfish taken by the fishery between the strong and weak circle hooks to examine the economic impact of using the weaker hooks. The field trials were timed to occur during months when larger bigeye are available to the fishery. Basically, the study is designed to test the economic impact of adopting a "weaker" circle hook of smaller wire diameter than the currently required 4.5 mm diameter hooks and paired with a stronger branchline.

Fishery participants on the TRT have expressed support for the use of stronger leader and branchline material to facilitate hook straightening, but have opposed any changes to hook strength, while supporting additional crew training, depredation research and examining factors that contribute to serious injury determinations.

2.6.6 Research Discussion

The utility of "move on" studies that recommend lengthy spatial or temporal shifts to avoid FKW interaction are limited due to practical considerations of trip length in relation to catch quality.

Further work with catch shielding devices does not appear promising when considering practical considerations of gear storage, deployment costs and potential for tangling or impacting operations and crew requirements.

The use of acoustic harassment devices is generally regarded as counter-productive due to the dinnerbell effect and promoting targeted depredation. However, there may be some merit in continued research to identify acoustic gear and vessel characteristics or acoustic masking strategies useful to reduce vessel detection and depredation.

The "weak hook" straightening strategy using current gear regulations has not proved useful in releasing bycaught FKW in the Hawaii fishery since the regulated adoption of the weak hook strategy in 2013. In only a handful of cases has the hook straightened to release the animal free of hooks and trailing gear. It has been noted that securing the branchline and applying active tension is highly stressful to the animal and creates a dangerous situation for the crew with potential for gear flyback and can contribute to more serious injuries to the whale if the hook is ingested. The debate continues as to whether the health and condition of false killer whales is improved by cutting the leader as close to the hook as possible or by the current strategy to apply tension on the line in an attempt to straighten hooks.

The impact of different amounts of retained or trailing gear on the post release condition of false killer whales needs to be assessed to better inform and update the process for distinguishing serious from non-serious injury of marine mammals. The guidelines currently in place were developed from a 2007 workshop convened by NMFS and published in a set of procedural directives in 2012 that provides the process and criteria for distinguishing human-caused serious from non-serious injury to marine mammals (NMFS 2012). Under the guidelines for small cetaceans, animals with a hook retained in the head, mouth or ingested is assessed as a serious injury. An interaction with a small cetacean released with trailing gear of varying lengths is generally assessed as a serious injury based in part on Anglis and DeMaster (1998). While removal of the hook is desirable, the relative benefit of reducing stress and injury by leaving the hook in place and removing as much gear as possible with a long-handled cutting device should be evaluated. Research on other protected species such as sea turtles and oceanic whitetip sharks have shown that removal of trailing gear can significantly increase post-release survival (Chaloupka, 2004, Hutchinson, 2021). It is recommended that NMFS devote significant agency resources to research the post-hooking condition and mortality of FKWs and similar odontocetes and the impact of retained hooks and trailing gear on the animal's condition.

The replacement of wire trace with monofilament leaders in the Hawaii deep-set fishery opens up options for new designs of relatively simple line cutting devices compared to a device capable of severing wire trace. The development of improved line cutting gear designed to remove line very close to the hook and the weighted swivel while designed to minimize flyback should be promoted in collaboration with fishery participants. One area of development could be for a small device that could be slid down the branchline to sever the monofilament leader when underwater and close to the hook but below the weighted swivel. Gear spring back should be low if the line is cut underwater. Such a device would also be useful for releasing oceanic sharks with minimal trailing gear.

A hook study is being conducted in 2021 to further inform the "weak hook" strategy and is designed to evaluate the economic cost of target catch retention by different hook strengths. It is possible that a different ratio of hook strength to branchline diameter could provide better results from the current situation. However, other mitigation approaches need to be considered. It should be noted that hook strength and straightening characteristics will vary depending on many criteria such as the steel alloy, hook manufacturer model and shank cross-section type (round or flat) (Mclellan et al 2015). The strength of monofilament leader of the same diameter will also vary by make and type. All available hook and line characteristics should be considered and tested when developing gear-based regulations.

2.7 Recommendations for Action – Operational Measures

Upon review of existing research, the Working Group provides the following recommendations and observations regarding *Odontocete* interactions and fishery impacts:

1. The "move on" strategy where boats travel long distances or wait extended periods after a depredation is inappropriate for a fishery marketing fresh, iced product with limited storage time.

2. Catch shielding gears have many logistical issues related to their storage, potential for tangling and time, and effort required to add or remove gear to mitigate such a rare event.

3. Acoustic deterrents can quickly become ineffective and contribute to the "dinnerbell effect." However, the identification of key acoustic signals that FKWs use to depredate catch should be identified to make a vessel less detectable than others.

4. "Weak hook" mitigation strategies should only be mandated after thorough testing of hook and line strength, target catch retention and thorough training of captain and crews under different hooking scenarios. Emphasis should be placed on gears with standardized characteristics.

5. The utility of severing the branchline close to the hook to leave a minimal amount of trailing line should be further assessed in relation to post-release condition and serious injury determinations.

6. Efforts to develop novel line cutting devices that also protect from gear flyback should be promoted.

3.0 Evaluation of PBR and Serious Injury Determinations as Applied under the MMPA

FKW has a wide geographic range in the Pacific Ocean (Figure 1) and is exposed to anthropogenic hazards such as pelagic fisheries, including the US Hawaii-based deep-set pelagic longline fishery (Anderson, 2020, Fader, 2021). FKWs incidentally caught in U.S. pelagic longline fisheries can die on the gear, or if released alive, sustain serious injuries that might lead to post-release mortality or impaired reproduction (McLellan, 2015, Bradford & Forney 2017). Nonetheless, FKW interactions with U.S. pelagic longline gear in waters around the Hawaiian Archipelago are extremely rare (Figure 2; Anderson 2020). Note, estimates provided are capture estimates and not the MSIs (Bradford and Forney 2017) or so-called "mortality and serious injury" estimate used for PBR risk assessment.

There are three "demographically-independent" FKW populations in Hawaiian waters with limited gene flow between these populations (Caretta 2020, Martien 2019). There are also FKW populations found in U.S. EEZ waters around Palmyra Atoll and American Samoa, which are considered as two separate stocks to the Hawaiian Archipelago stock (Caretta 2020).

There are no demographically based models of FKW population dynamics to help inform bycatch mitigation strategies for any of the 3 FKW "populations" or "management units" exposed to the U.S. Hawaii-based pelagic longline fishery. This is because there is a lack of demographically relevant information available for these FKW populations that hinders the development of evidence-informed bycatch mitigation strategies. Even so, no substantive efforts exist to derive estimates of key demographic parameters such as age class-specific FKW mortality and recruitment rates that are considered essential for the development of risk assessment models for long-lived marine species exposed to anthropogenic hazards in general (Bjorndal 2011) and specifically for marine mammal species (Cáceres and Cáceres-Saez 2013).

This data deficiency is evident not just for FKWs but for cetaceans in general (Baker and Clapham 2004, Mannocci 2012, Cáceres and Cáceres-Saez 2013, Kreb 2020), presumably because of the logistical challenges in deriving robust estimates of key demographic parameters let alone reliable age class-specific abundance estimates.

Given these data deficiencies, the question now exists about how best to address FKW bycatch mortality. Several so-called "sparse-data" methods have been proposed to help determine population-specific bycatch mortality limits for marine mammal species, including: (1) potential biological removal (PBR), (2) depletion-corrected average catch (DCAC), (3) replacement yield (RY), and (4) a metric based on the slope of an observed relative abundance trend (Punt et al

2021a). Punt et al (2021a) concluded that PBR was no worse for use than the other three data-limited methods.

3.1 Potential Biological Removal Concept

The PBR method is commonly used for marine mammal and seabird risk assessments given sparse demographic data (Marsh 2004, Robards 2009, Dillingham and Fletcher 2011, Lonergan 2011, Mannocci 2012, van Der Hoop 2013, Carettta 2020, Kreb 2020, Punt 2020, 2021b). In fact, the PBR method is the approach required by the MMPA for determining the allowable level of human-induced mortality or serious injury for those stocks (populations) subject to management under the US MMPA (Wade 1998, Bradford & Forney 2017).

PBR is a simple form of harvest control rule comprising the product of 3 components: (1) some recent minimum population size estimate (N_{MIN}), (2) an estimate of the maximum intrinsic population growth rate ($0.5*R_{MAX}$), and (3) a recovery factor (F_R) that is assumed in the range $0.1 < F_R < 1.0$ in order to ensure the recovery of any depleted stock (Wade 1998, Punt et al 2020).

Section 118 of the MMPA requires that commercial fisheries "reduce incidental mortality or serious injury of marine mammals to insignificant levels approaching a zero mortality and serious injury rate", where "*insignificant*" has been defined by NMFS as 10% of the species-specific PBR level (50 CFR § 229.2). So, a "*significant*" fishery-related mortality for the stock is then defined as > (0.1*PBR).

Under the MMPA, mammal stocks must be classified as either (1) strategic or (2) non-strategic, where "*strategic*" stocks are those where anthropogenic mortality is "*significant*" or the stock is declining/depleted, or the stock is listed under the ESA. ***Importantly, the mortality levels to be used to define "significant" are supposed to be based on fishery-independent data***.

When the bycatch of a marine mammal population subject to U.S. jurisdiction exceeds PBR, then a TRT is convened to develop a TRP. Further background to the history, development and testing of the PBR concept as prescribed by the MMPA regulatory context can be found in Brandon (2017), Punt (2018) and Punt (2020).

3.2 Estimating a Key Component of PBR

A keystone component of the PBR calculation is an unbiased absolute abundance estimate and its precision to help derive the N_{MIN} (Wade 1998, Punt, 2020). This component is much harder to derive robust unbiased estimates and precision than say the R_{MAX} component that could readily be derived from meta-analytic summary of other studies.

Interestingly, PBR defines the N_{MIN} for the whole stock, not for instance just the adult portion. This is a major deficiency in the model because the immature age classes of long-lived marine mammals or marine turtle species may sustain greater anthropogenic sources of mortality than the reproductive adult portion of the stock (Chaloupka, 2002). The risk depends on the age class- and/or sex-specific exposure to an anthropogenic hazard.

Presumably, to be precautionary, PBR should be calculated for the age class/sex with the greater relative reproductive value. However, the PBR concept assumes all anthropogenic mortality impacts are not age class- or sex-dependent, which is most likely demographically unrealistic in most cases for marine mammals. The question then arises if it is practical to determine age class- and/or sex-specific N_{MIN} even if it isn't an explicit requirement under the MMPA.

Leaving aside the practicality of determining age class- and/or sex-specific, it has been shown recently that age and sex structure of a population can have a significant effect on the PBR level estimate (Punt 2018, Punt 2020), especially if there is sex-biased bycatch mortality (Brandon 2017). Punt (2018) suggests that reducing the recovery factor (F_R) could help account for apparent transient ageclass effects when calculating the PBR but this would be quite an arbitrary application and unreproducible.

Perhaps more practical is the focus on more robust estimates of abundance for each of the three FKW populations exposed to the Hawaii-based pelagic longline fishery. The 2017 NMFS ship-based line-transect sampling efforts were a substantial commitment in this direction for the pelagic and NWHI populations and in the recent 2020 survey for the MHI population as well, although these surveys do not provide age class- or sex-specific estimates of population size.

Importantly, the uncertainty in population size estimates used for the PBR can also bias the PBR level estimate (Punt 2020) further supporting the need for reliable population size estimates to enable application of the PBR concept. In fact, PBR depends on the availability of unbiased and precise absolute abundance estimates, which are often unavailable.

Punt (2021a) have proposed three alternative methods to PBR based on bycatch mortality or so-called "removal" estimates and relative population abundance estimates. However, these methods were found using a simulation-based testing framework to be more affected by parameter uncertainty than PBR and also required precise estimates of bycatch mortality. So, the conundrum continues — PBR and several alternatives depend on either unbiased and precise absolute abundance estimates or precise bycatch mortality estimates. More importantly, PBR does not account explicitly for the long-term population-level consequences of exposure to fishing gear.

3.3 Variations on the PBR Theme

Recent extensions of the PBR method have been proposed such as accounting for indirect bycatch effects (Moore 2013), including depensation effects for depleted populations (Haider, 2017) and application of the PBR concept within a data-quality-dependent tiered system (Brandon 2017).

Punt (2021b) used PBR within a stock assessment framework to evaluate bycatch risk for two species of South American pinniped. Meanwhile, Robards (2009) argued that the PBR concept was not appropriate for risk assessments for the ice-associated pinnipeds such as Pacific walrus in a rapidly changing Arctic environment. Instead, Robards (2009) advocates for consideration of ecosystem-based approaches but readily acknowledge that the MMPA does not make adequate provision for such approaches.

3.4 Marine Mammal Examples of PBR Application

PBR estimates for the Hawaiian FKW populations are provided for instance in Caretta (2020).

Marsh et al (2004) used the PBR concept with empirical estimates of key demographic parameters to assess harvest risk in the Torres Strait (northeast Australia) dugong fishery and concluded that the current harvest rate was unsustainable. Mannocci (2012) used both a deterministic matrix population projection model and PBR to assess common dolphin bycatch risk in the Bay of Biscay (French Atlantic coast) and concluded that estimated bycatch rates posed a significant risk for the long-term viability of these populations.

More recently, Kreb (2020) used PBR to assess the risk of exposure to coastal development (shipping, fishing, oil spillage) on Irrawaddy dolphin populations resident in Balikpapan Bay (East Kalimantan, Indonesia). There was a serious lack of empirical estimates of Irrawaddy dolphin demographic parameters for that study.

3.5 Mortality and Serious Injury Determination

The PBR estimated for each FKW stock exposed to the Hawaii-based pelagic longline fishery comprises not only observed mortalities but also the observed "seriously injured" FKWs (Bradford and Forney 2017). The combined mortality and serious injury metric (MSI) is based on an assumption that FKWs released alive from the longline gear might (1) still die at some later time post-release due to capture-induced injury or (2) suffer ongoing morbidity that could manifest as impaired growth or reproductive capacity.

Post-release mortality (PRM) is a straightforward metric to determine for FKWs captured and released alive from the longline gear as has been done for loggerhead marine turtles exposed to the same fishery (Chaloupka 2004). P RM has not been estimated for any FKW population. PRM is straightforward to estimate but post-release sublethal effects due to various levels of injury are not simple to estimate — and no attempt has been made to derive such estimates for any FKW population. Consequently, current MSI estimates are incomplete, inaccurate and quite vague due to the unreproducible concept of "serious injury" as currently applied. Recently, Punt (2020) using a model-based evaluation of PBR, found that sublethal effects on birth rates in their model scenarios for marine mammals was not likely to impair the recovery of the stock exposed to fishing gear.

Meanwhile, uncertainty in PRM and sublethal effects could be accounted for in FKW PBRs by adjusting the recovery factor (F_R) component of the PBR calculation (Punt 2020). But this is not a principled or reproducible means for accounting for PRM and/or sublethal effects in the determination of the allowable level of human-caused mortality for a FKW population exposed to the Hawaii-based pelagic longline fishery. The SSC previously advised the Council as follows on this issue in 2013:

> “ … that NMFS consider a team-based determination in the serious injury determination process, especially for data-poor cases, and that NMFS expand the membership of the determination working group to include non-NMFS scientists, cetacean veterinarians, fishery experts and vessel captain and crew, as appropriate, to further improve the clarity and transparency of the process. Furthermore, NMFS should continue to enhance the quality of data collected by observers by improving training to minimize the number of cases that are classified as “unidentified blackfish” or M&SI “cannot be determined (CBD)”.

3.6 An Alternative Risk Assessment Framework

As noted above, PBR does not account explicitly for the long-term population-level consequences of exposure to anthropogenic hazards such as pelagic longline gear. A *population consequences of disturbance* (PCoD) conceptual framework has been advocated to assess the likelihood of population-level consequences given marine mammal exposure to anthropogenic hazards (Pirotta 2018). This simple framework comprises a 4-level sequence ranging from observed changes in individual behaviour (level 1) to population-level effects such as impaired reproductive, survival or population growth rates (level 4). Surprisingly, there have been few applications of the PCoD framework to marine mammal risk assessments (Pirotta 2018).

A recent PCoD application is the risk assessment undertaken for the West Australian humpback whale stock exposed to a simulated commercial seismic survey scenario (Dunlop 2021) — they found no evidence that seismic surveys would have an effect on female humpback breeding rates and little evidence that population growth rate would be affected. While not a specific PCoD application, Punt (2021b) nonetheless uses PBR within a simple stock assessment model given data limitations to assess trends in abundance and also population growth rates for 2 pinniped species (level 4 effects).

A PCoD approach to assessing the potential consequences of FKW population exposure to pelagic longline fisheries is needed. Within this conceptual framework, the focus should be on estimating population-level effects on long-term FKW stock viability to better support evidence-informed FKW bycatch mitigation policy. Hence robust and transparent capture-mark-recapture sampling and modelling approaches for the insular FKW population needs to be undertaken to derive reliable estimates of key demographic parameters (survival, breeding, recruitment) and population size. This would support application of rigorous stochastic population dynamic based risk assessment approaches such as proposed by Hilborn and Ishizaki (2013) for the Hawaiian FKW populations (level 4 effects).

3.7 Conformance-based monitoring of FKW captures

PCoD review of the FKW populations is important to derive a robust form of risk assessment. However, it is equally as important to regularly know the long-term status of each FKW population exposed to the Hawaii-based pelagic longline fishery. Conformance monitoring has been advocated at previous SSC meetings as a simple, robust and effective means to monitor and report on protected species bycatch in the Hawaii-based pelagic longline fisheries. Specifically, a statistical process control chart approach using a generalized statistical model for over- or under-dispersed data using the Conway-Maxwell Poisson model (Sellers 2012, Huang 2017) was proposed as shown in Figure 2. The purpose of this device is to:

- identify an anomalous or non-conformance shift or trend in the FKW bycatch time series process (control limits: 2014, 2018)
- help identify an appropriate management response to any bycatch anomalies based on either *k*-sigma- or probability-based control limits
- and to present this information is a simple but robust analytic framework that can be readily updated as new data are acquired sequentially in a comprehensive monitoring program

The process control chart would help to put the annual FKW captures in context with the expected sampling behavior for such a rare event and the current PBR. This could lead to an evidence-informed mitigation response to an identified anomaly. Preferably the control charts would be constructed for specific FKW age classes.

4.0 Summary and Conclusions

Section 118 of the MMPA directs the NMFS to prepare a TRP for each 'strategic' marine mammal stock that interacts with a Category I or Category II fishery. Such plans also may be developed when a Category I fishery has a high level of mortality and serious injury involving one or more marine mammal stocks, even though it does not exceed the PBR of the marine mammal stock.

NMFS uses TRTs to develop recommendations for measures to be included in TRPs, and to monitor the implementation of those plans until NMFS has determined that take reduction goals have been met TRTs are appointed to formulate consensus-based take reduction measures for marine mammals. Since 2018, the TRT formed for FKW has been unable to reach consensus over revised measures to be included in a TRP for the species.

In view of this situation, representatives from the Council's SSC conducted an in-depth review of the best available scientific information to evaluate the status of information pertaining to FKW. Recommendations provided below are intended to help guide future management recommendations made by the Council to NMFS, and to assist parties in formulating measures for inclusion in a TRP for the species.

4.1 Syntheses and Draft Recommendations for SSC

1. FKW are a wide-ranging species in the Pacific Ocean (Figure 1) and are potentially exposed to the risk of capture in pelagic longline fishing gear. FKWs are caught infrequently in that gear (Figure 2).

Recommendation: Develop take reduction measures that recognize the already-low mortality rate of FKW caught in fishing gear.

2. The post-release mortality rate of FKW from fishing gear is presently unknown. Indirect, sublethal effects of capture and release of FKWs that might impair reproductive behavior is also unknown. At-vessel and post-release mortality rates estimates are essential for assessing the risk of FKW expose to the US-based pelagic longline fisheries in the Pacific. Understanding whether there are any meaningful sublethal effects on long-term population viability is also important.

Recommendation: Conduct a post-release study on FKWs using satellite tags or other technology to assess mortality rates and sublethal affects. Develop cost-effective methods to determine robust estimates of sublethal effects attributable to capture and release from pelagic longline.

3. The current risk assessment framework for FKWs caught in the US-based pelagic longline fisheries is based on the PBR. The background to the PBR approach and some recent variants were reviewed. It is clear that the PBR method in any form does not account explicitly for the long-term population-level consequences of exposure to anthropogenic hazards such as pelagic longline gear. It is presently assumed that long-term consequences exist for the FKW populations exposed to longline gear. Available scientific data do not strongly support this assumption. A rigorous risk assessment framework should be established to support an evidence-informed bycatch mitigation policy. Such a framework should assess the demographic consequences of exposing FKW to the longline fishery.

Recommendation: Implement a PCoD, comprised of a 4-level sequence ranging from observed changes in individual behaviour (level 1) to population-level effects such as impaired reproductive, survival or population growth rates (level 4). PCoD review of the FKW populations is important to derive a robust form of risk assessment. However, it is equally as important to regularly know the long-term status of each FKW population exposed to the Hawaii-based pelagic longline fishery. PCoD is a simple, robust and effective means to monitor and report on protected species bycatch in the Hawaii-based pelagic longline fisheries.

4. A stochastic population dynamic-based, risk assessment model does not exist, and could be useful in assessing the applicability of PBR and its variants for bycatch management in the FKW population. PBR is a legal concept provided for under the MMPA. However, the application of PBR to a species such as FKW may not be appropriate, or suffer significant limitations that should be better understood to ensure the results of such analyses are the best available scientific information.

Recommendation: Develop a population dynamic-based model to assess the applicability of PBR for bycatch management. Use the results of such modelling to inform selection of appropriate take reduction measures for the US-based pelagic longline fishery.

5. Management uncertainties and challenges associated with FKW in the US-based longline fishery have not been resolved through a consensus-based TRT process established by NMFS

under the MMPA. Prior scientific recommendations made by the SSC have not been addressed or included in a TRP for FKW.

Recommendation: Make use of the SSC process provided in the Magnuson-Stevens Act to help inform measures considered by the TRT and other parties in formulating a TRP. Subject SSC recommendations and work products to independent scientific peer review in published literature to confirm the validity of such recommendations and work products.

6. It is important to regularly and reliably know the long-term status of each FKW population exposed to the Hawaii-based pelagic longline fishery. Conformance monitoring has been advocated at previous SSC meetings as a simple, robust and effective means to monitor and report on protected species bycatch in the Hawaii-based pelagic longline fisheries. This would lead to an evidence-informed mitigation response to an identified anomaly.

Recommendation: The Council and NMFS should adopt conformance-based monitoring of FKW captures in the Hawaii-based pelagic longline fisheries and report the conformance and any anomalies in the SAFE Report.

7. The economic impacts of current FKW regulatory measures and depredation events on commercial fisheries is not well understood. The costs and benefits of regulatory measures on the commercial fishery should be better understood so that decisionmakers and the public are aware of the impacts of these measures on commercial operations. Conducting baseline economic studies will also help inform future management decisions under the MSA and National Environmental Policy Act.

Recommendation: The Council should undertake a study to assess the economic impacts of FKW regulatory measures on Hawaii-based pelagic longline fisheries and report the results of such studies to NMFS. This study should be updated over time to assess the cumulative impacts of such regulatory measures on commercial fisheries.

5.0 Literature Cited

Anderson D, Baird R, Bradford A, Oleson E (2020) Is it all about the haul? Pelagic false killer whale interactions with longline fisheries in the central North Pacific. Fisheries Research 230: 105665

Anglis, R. P. and D.P. DeMaster. 1998 Differentiating Serious and Non-serious Injury of Marine Mammals Taken Incidental to Commercial Fishing Operations: Report of the Serious Injury Workshop, 1-2 April 1997, Silver Spring, Maryland. NOAA Technical Memorandum. NMFS-OPR-13. January 1998

Anon. 2020. Report of the 138th Meeting of the Scientific and Statistical Committee, November 30 – December 1, 2020. Web Conference. Western Pacific Regional Fishery Management Council. Honolulu, Hawaii.

Ayers, A. , Leong, K. 2020 Stories of Conservation Success: Results of Interviews with Hawaii Longline Fishers. NOAA Administrative Report H-20-11. https://doi.org/10.25923/6bnn-m598

Baird R (2019) The perils of relying on handling techniques to reduce bycatch in a partially observed fishery: a potential fatal flaw in the false killer whale take reduction plan. Paper Presented at the Document PSRG-2019-14 Presented to the Pacific Scientific Review Group, March 5-7, 2019, (Olympia, WA: Protected Species Research Group)

Baker C, Clapham P (2004) Modelling the past and future of whales and whaling. Trends in Ecology and Evolution 19: 365-371

Bauman-Pickering, S., Simonis, A.E., Oleson, E.M., Baird, R.W., Roch, M.A., Wiggins, S.M., 2015. False killer whale and short-finned pilot whale acoustic identification. Endanger. Species Res. 28, 97–108.

Bayless A, Oleson E, Baumann-Pickering S, Simonis A Marchetti J, Martin S, Wiggins S, Acoustically monitoring the Hawaiʻi longline fishery for interactions with false killer whales, (2017) Fisheries Research,190, 122-131, ISSN 0165-7836, https://doi.org/10.1016/j.fishres.2017.02.006.

Bayse S.M. & Kerstetter, D.W. 2010. Assessing bycatch reduction potential of variable strength hooks for pilot whales in a western North Atlantic Pelagic Longline Fishery. J North Carolina Acad Sci., 126(1): 6–14.

Bigelow, K.A., Kerstetter, D.W., Dancho, M.G., & Marchetti, J.A. 2012. Catch rates with variable strength circle hooks in the Hawaii-based tuna longline fishery. Bull. Mar. Sci., 88(3):425–447

Bjorndal K, Bowen B, Chaloupka M, Crowder L, Heppell S, Jones C, Lutcavage M, Policansky D, Solow A, Witherington B (2011) Better science needed for restoration in the Gulf of Mexico. Science 331: 537-538

Bradford A, Forney K (2017) Injury determinations for cetaceans observed interacting with Hawaii and American Samoa longline fisheries during 2010-2014. US Department of Commerce, NOAA Technical Memorandum NOAA-TM-NMFS-PIFSC-62. https://doi.org/10.7289/V5/TM-PIFSC-62

Brandon J, Punt A, Moreno P, Reeves R (2017) Towards a tier system approach for calculating limits on human-caused mortality of marine mammals. ICES Journal of Marine Science 74: 877–887

Cáceres M, Cáceres-Saez I (2013) Calculating effective growth rate from a random Leslie model: application to incidental mortality analysis. Ecological Modelling 251: 312–322

Carretta J, Forney K, Oleson E, Weller D, Lang A, Baker J, Muto M, Hanson B, Orr A, Huber H, Lowry M, Barlow J, Moore J, Lynch D, Carswell L, Brownell R (2020) US Pacific Marine

Mammal Stock Assessments: 2019, U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-629

Chaloupka M (2002) Stochastic simulation modelling of southern Great Barrier Reef green turtle population dynamics. Ecological Modelling 148: 79-109

Chaloupka M, Parker D, Balazs G (2004) Modeling post-release mortality of pelagic loggerhead sea turtles exposed to the Hawaii-based longline fishery. Marine Ecology Progress Series 280: 285–293

Dillingham P, Fletcher D (2011) Potential biological removal of albatrosses and petrels with minimal demographic information. Biological Conservation 144: 1885–1894

Dunlop R, Braithwaite J, Mortensen L, Harris C (2021) Assessing Population-Level Effects of Anthropogenic Disturbance on a Marine Mammal Population. Frontiers in Marine Science 8: 624981

Fader J, Elliott B, Read A (2021) The challenges of managing depredation and bycatch of toothed whales in pelagic longline fisheries: two US case studies. Frontiers in Marine Science 8: 123.

Haider H, Oldfield S, Tu T, Moreno R, Diffendorfer J, Eager E, Erickson R (2017) Incorporating Allee effects into the potential biological removal level. Natural Resource Modeling 2017: e12133

Hamer, D. J., Childerhouse, S. J., and Gales, N. J. (2012). Odontocete bycatch and depredation in longline fisheries: a review of available literature and of potential solutions. *Mar. Mam. Sci.* 28, E345–E374. doi: 10.1111/j.1748-7692.2011. 00544.x

Hamer, D. J., and Childerhouse, S. J. 2013. Mitigating odontocete by-catch and depredation in longline fisheries: non-lethal physical and psychological deterrence at the hook. Final Summary Report to the Pacific Islands Forum Fisheries Agency (FFA), World Wildlife Fund (WWF) South Pacific, and Pacific Islands Tuna Industry Association (PITIA). Australian Marine Mammal Centre (AMMC), Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC). 14 pp.

Hamer DJ, Childerhouse SD, McKinlay JP, Double MC, Gales NJ, 2015. Two devices for mitigating odontocete bycatch and depredation at the hook in tropical pelagic longline fisheries. *ICES Journal of Marine Science* 72(5): 1691-1705.

Hamer DJ, Candy SG, Curran D, Itano D, Fougner S, Ishizaki A, 2019. Mitigating interactions of the Hawaii pelagic longline fishery with false killer whales: assessing the comparative efficacy of manufactured and vessel-constructed deterrent devices. DBMS Global Oceans Unpublished Report Series 123. Report to the Western Pacific Regional Fishery Management Council (WPRFMC) Contract # 17-turtle-004. 29 pp.

Hamilton, S., Baker, G.B. Technical mitigation to reduce marine mammal bycatch and entanglement in commercial fishing gear: lessons learnt and future directions. 2019. *Rev Fish Biol Fisheries* **29,** 223–247 (2019). https://doi.org/10.1007/s11160-019-09550-6

Hilborn R, Ishizaki A (2013) A model of the false killer whale pelagic stock in the Hawaiian EEZ. Prepared for the Western Pacific Regional Fishery Management Council pp 17

Huang A (2017) Mean-parameterized Conway–Maxwell–Poisson regression models for dispersed counts. Statistical Modelling 17(6): 1–22

Hutchinson, M. , Siders, Z., Stahl, J., Bigelow K. 2021 in review. Quantitative estimates of post-release survival rates of sharks captured in Pacific tuna longlinefisheries reveal handling and discard proctices that improve survivorship. PIFSC Data Report , DR-21-001.

Kaschner K, Watson R, Trites A, Pauly D (2006) Mapping worldwide distributions of marine mammals using a Relative Environmental Suitability (RES) model. Marine Ecology Progress Series 316: 285-310

Kreb D, Lhota S, Porter L, Redman A, Susanti I, Lazecky M (2020) Long-term population and distribution dynamics of an endangered Irrawaddy dolphin population in Balikpapan Bay, Indonesia in response to coastal development. Frontiers in Marine Science 7: 746.

Lonergan M (2011) Potential biological removal and other currently used management rules for marine mammal populations: a comparison. Marine Policy 35: 584-589

Mannocci L, Dabin W, Augeraud-Véron E, Dupuy J, Barbraud C, Ridoux V (2012) Assessing the impact of bycatch on dolphin populations: the case of the common dolphin in the eastern North Atlantic. PLoS ONE 7(2): e32615

Marsh H, Lawler I, Kwan D, Delean S, Pollock K, Alldredge M (2004) Aerial surveys and the potential biological removal technique indicate that the Torres Strait dugong fishery is unsustainable. Animal Conservation 7: 435–443

Martien K, Taylor B, Chivers S, Mahaffy S, Gorgone A, Baird R (2019) Fidelity to natal social groups and mating both within and between social groups in an endangered false killer whale (Pseudorca crassidens) population. Endangered Species Research 40: 219–230

McDonald D, Ringling-Gallagher D, Participant perceptions of consensus-based, marine mammal taker reduction planning (2015) Marine Policy 61, November 216-226. https://doi.org.10.1016/j.marpol.2015.08.004

McLellan W, Arthur L, Mallette S, Tornton S, McAlarney R, Read A, Pabst D (2015) Longline hook testing in the mouths of pelagic odontocetes. ICES Journal of Marine Science 72: 1706-1713

Moore J (2013) Management reference points to account for direct and indirect impacts of fishing on marine mammals. Marine Mammal Science 29: 446-473

NMFS 2012. NMFS Instruction 02-038-01.\, Effective DateJanuary 27. 2012. Protected Resources Management Process for Distinguishing Serious fromNon-Serious Injury of Marine Mammals. Process for Injury Determinations

Oswald, J.N., Rankin, S., Barlow, J., Lammers, M.O., 2007. A tool for real-time acoustic species in the eastern tropical Pacific Ocean. Mar. Mamm. Sci. 19, 20–37.

Oswald, J.N., Carretta, J.V., Oswald, M., Rankin, S., Au, W.W.L., 2011. Seeing the species through the trees: using random forest classification trees to identify species-specific whistle types. J. Acoust. Soc. Am. 129, 2639.

Oswald, J.N., 2013. Development of a Classifier for the Acoustic Identification of Delphinid Species in the Northwest Atlantic Ocean. Final Report. Submitted to HDR Environmental, Operations and Construction, Inc. Norfolk, Virginia under Contract No. CON005-4394-009, Subproject 164744, Task Order 003, Agreement # 105067. Prepared by Bio-Waves, Inc., Encinitas, California.

Pirotta E, Booth C, Costa D, Fleishman E, Kraus S, Lusseau D, David Moretti D, New L, Schick R, Schwarz L, Simmons S, Thomas L, Tyack P, Weise M, Wells R, Harwood J (2018) Understanding the population consequences of disturbance. Ecology and Evolution 8: 9934–9946

Punt A, Moreno P, Brandon J, Mathews M (2018) Conserving and recovering vulnerable marine species: a comprehensive evaluation of the US approach for marine mammals. ICES Journal of Marine Science 75: 1813–1831

Punt A, Siple M, Francis T, Hammond P, Heinemann D, Long K, Moore J, Sepúlveda M, Reeves R, Sigurðsson G, Vikingsson G, Wade P, Williams R, Zerbini A (2020) Robustness of potential biological removal to monitoring, environmental, and management uncertainties, ICES Journal of Marine Science 77: 2491–2507

Punt A, Siple M, Francis T, Hammond P, Heinemann D, Long K, Moore J, Sepúlveda M, Reeves R, Sigurðsson G, Víkingsson G, Wade P, Williams R, Zerbini A (2021a) Can we manage marine mammal bycatch effectively in low-data environments? Journal of Applied Ecology 58: 596–607

Punt A, Sepúlveda M, Siple M, Moore J, Francis T, Hammond P, Heinemann D, Long K, Oliva D, Reeves R, Sigurðsson G, Víkingsson G, Wade P, Williams R, Zerbini A (2021b) Assessing pinniped bycatch mortality with uncertainty in abundance and post-release mortality: a case study from Chile. Fisheries Research 235: 105816

Rabearisoa, N., P.Bach, P. Tixier, G. Guinet (2012) Pelagic Longline Fishing Trials to Shape a Mitigation device of the Depredation of Toothed Whales. Journal of Experimental Marine Biology & Ecology 432-433 55-63.

Rizzardi, K. (2014) Marine Mammal Protection Act Implementation in an Era of Climate Change. in: Ocean and Coastal Law in the Climate Change context: Domestic and International Regulator Challenges. Oxford University Press. Available at SSRN:https://ssrn.com/abstract=2576358

Robards M, Burns J, Meek C, Watson A (2009) Limitations of an optimum sustainable population or potential biological removal approach for conserving marine mammals: Pacific walrus case study. Journal of Environmental Management 91: 57-66

Rose D, Sutherland W, Amano T, González-Varo J, Robertson R (2018) The major barriers to evidence-informed conservation policy and possible solutions. Conservation Letters 11(5): e12564. https://doi.org/10.1111/conl.12564

Sellers K (2012) A generalized statistical control chart for over- or under-dispersed data. Quality and Reliability Engineering International 28: 59-65

Swimmer, Y., Zollett, E. A., and Gutierrez, A. (2020). Bycatch mitigation of protected and threatened species in tuna purse seine and longline fisheries. *Endang. Species Res.* 43, 517–542. doi: 10.3354/esr01069

Thode, A., Straley, J., Tiemann, C.O., 2007. Observations of potential acoustic cues that attract sperm whales to longline fishing in the Gulf of Alaska. J. Acoust. Soc. Am. 122, 1265–1277.

Thode, A., Wild, L., Straley, J., Barnes, D., Bayless, A., O'Connell, V., Oleson, E., Sarkar, J., Falvey, D., Behnken, L., Martin, S., 2016. Using line acceleration to measure false killer whale (Pseudorca crassidens) click and whistle source levels during pelagic longline depredation. J. Acoust. Soc. Am. 140, 3941.

Thode, A., Straley, J., Tiemann, C.O., 2007. Observations of potential acoustic cues that attract sperm whales to longline fishing in the Gulf of Alaska. J. Acoust. Soc. Am. 122, 1265–1277.

Tixier, P., N. Gasco, G. Duhamel, C. Guinet 2015. Habituation to an acoustic harassment device (AHD) by killer whales depredating demersal longlines, *ICES Journal of Marine Science*, Volume 72, Issue 5, May/June 2015, Pages 1673–1681, https://doi.org/10.1093/icesjms/fsu166

van Der Hoop J, Moore M, Barco S, Cole T, Daoust P, Henry A, McAlpine D, McLellan W, Wimmer T, Solow A (2013) Assessment of management to mitigate anthropogenic effects on large whales. Conservation Biology 27: 121-133

Wade P (1998) Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Marine Mammal Science 14: 1–37

WPRFMC (2019) Annual Stock Assessment and Fishery Evaluation Report Pacific Island Pelagic Fishery Ecosystem Plan 2018. Remington T, Fitchett M, Ishizaki A, Spalding S (Eds)

Western Pacific Regional Fishery Management Council. Honolulu, Hawaii USA, pp 353 + Appendices

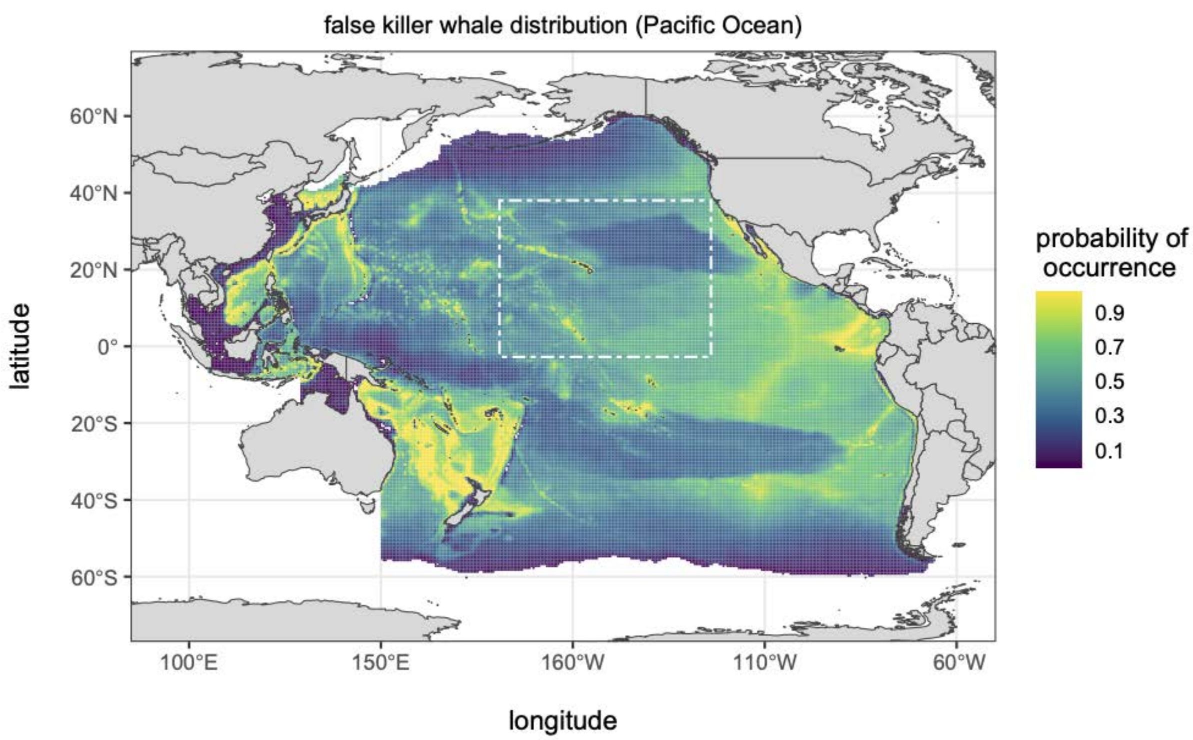

Figure 1 Spatial distribution of the false killer whale in the Pacific Ocean with the probability of occurrence by half-degree cells (data sourced from AquaMaps: Kaschner et al 2006). The white dashed bounding box shows the approximate extent of the Hawaii-based pelagic longline fisheries. It is apparent that FKWs have minimal exposure to the Hawaii-based pelagic fisheries.

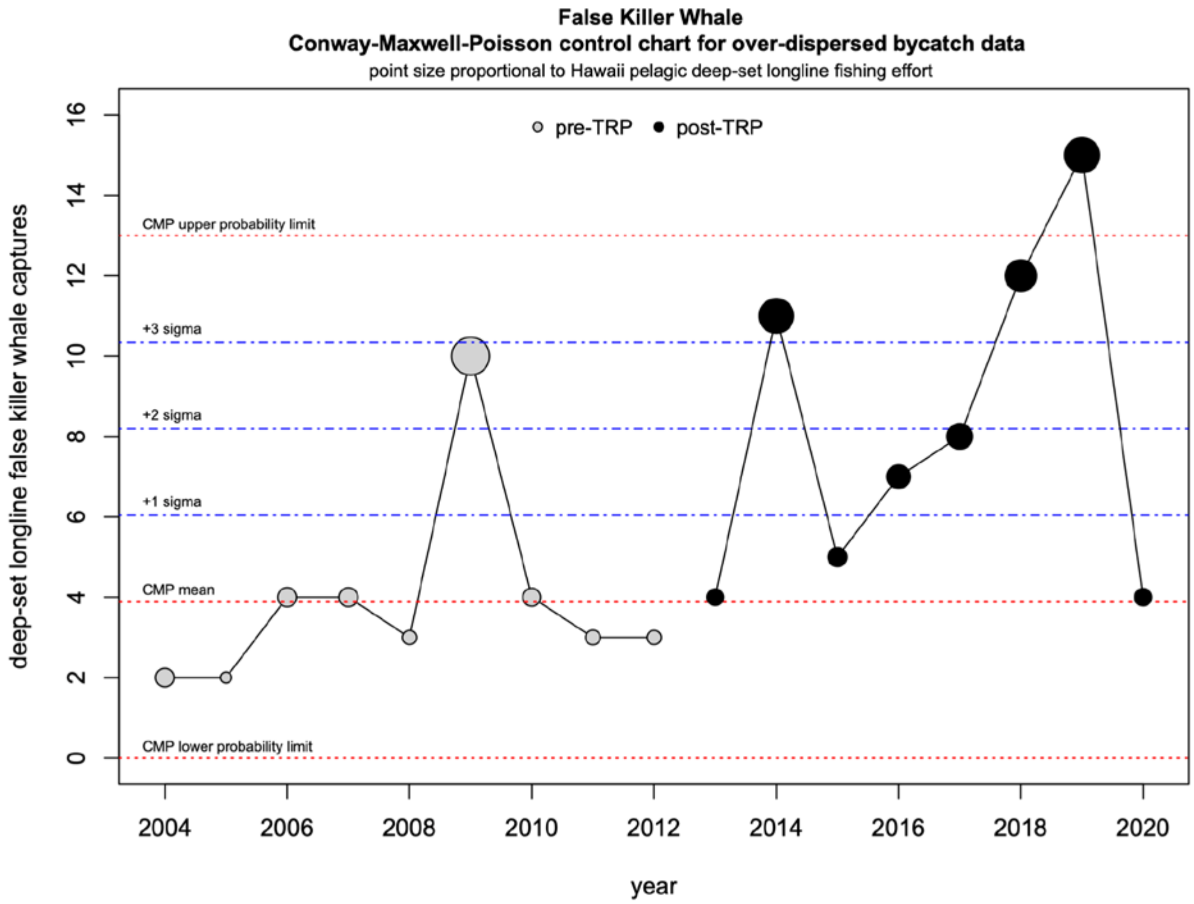

Figure 2 Statistical process control chart for FKW bycatch in the Hawaii-based deep-set pelagic longline fishery (2002 - 2020). Both k-sigma and probability control limits are shown derived from a Conway-Maxwell-Poisson statistical model (Sellers 2012, Huang 2017) fitted to the over-dispersed FKW bycatch time series prior to the TRP (2013). It was apparent that 2014, 2018 and 2019 were anomalous bycatch years based on a 3-sigma control limit while 2019 was an anomalous bycatch year based on an upper probability-based control limit. Those anomalous years were also the years with the highest FKW CPUEs (fishing effort proxy). The expected Conway-Maxwell-Poisson mean estimated for the 2002-2012 or pre-TRP series was ca 4 FKWs per annum. Data sourced from WPRFMC (2019). TRP = Take Reduction Plan.