2021

EFP 18-03 Final Report

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Executive Summary

Salmon excluders are one of the approaches used by pollock fishermen in Alaska to help reduce their salmon bycatch. Salmon excluders are modifications to the intermediate section of pollock trawl nets designed to allow/incentivize salmon to escape the trawl. Unlike sorting grids and grates commonly used to control bycatch in shrimp and other bottom trawl fisheries, salmon excluders rely entirely on differences in swimming behavior between target and bycatch species, and escapement occurs with little or no physical contact with the net and excluder components.

There are two general designs of salmon excluders in use in the Bering Sea pollock fishery. One is known as a "flapper" design and the other is called an "over/under" (O/U). The general concept for these devices is that they have large escapement portal(s) where meshes are removed from the outside netting to allow salmon to escape from the retentive section of the net. Both the flapper and O/U designs are based on salmon being much stronger swimmers than pollock and the assumption that a salmon's natural behavior is to swim into the direction of the water flow.

With salmon excluders there is also potential that some fraction of the target catch will be able to escape. The balance that salmon excluder designers must strike is to entice as large a fraction of the salmon to swim out as possible while retaining a sufficiently high fraction of the pollock to make use of the excluder for pollock fishing feasible.

Collective endeavors by the pollock industry and fishery research collaborators to decrease Chinook salmon bycatch with gear modifications started in 2003. Since then, the North Pacific Fisheries Research Foundation (NPFRF) has focused its endeavors on a suite of systematic tests of salmon excluders in both the Bering Sea and the Gulf of Alaska (GOA) using Exempted Fishing Permits (EFPs). NPFRF's EFPs have allowed testing to occur in the year-round and seasonal salmon bycatch closure areas in the Bering Sea. This was incorporated into the research planning to help increase encounter rates and hence statistical power to detect the effects of the excluder. Testing the efficacy of salmon excluders in areas where encounter rates are low is generally impractical because salmon bycatch is in actuality a relatively rare event in the context of quantity of pollock caught annually relative to the number of salmon taken incidentally.

In its application for EFP 18-03, NPFRF explained that based on results from its earlier salmon excluder EFP tests, Bering Sea salmon excluders were not performing with the same consistency and efficacy as those in the GOA pollock fishery. At the same time, in the years leading up to this EFP Chinook salmon bycatch rates in the Bering Sea steadily increased, creating the impetus propose this EFP in an effort to improve excluder designs.

The first objective for this work was to provide for an iterative process for improvements to excluders over multiple years based on systematic testing and adjustments to excluders based on what was learned from the trials at each stage. The excluders of interest in this EFP were different versions of flapper and O/U excluders with different modifications to hoods and placement of the escapement portal(s). In its EFP application NPFRF proposed to work with each of the horsepower classes of Bering Sea vessels (small catcher vessel [CV] or <=1,800 HP; large CV or > 1,800 HP; and catcher processor [CP]) on the excluder design and "specifics of construction" that each horsepower class of pollock vessel prioritized. While these are not official vessel horsepower categories and may be not perfectly correspond to all vessels in the fishery, the intent was to recognize that excluder performance has varied greatly by towing power of vessels as seen from NPFRF's past research. The F/V Storm Petrel was

selected to represent the small (<=1800 HP) catcher vessel sector, the F/V Destination represented the large (>1800 HP) catcher vessel sector, and the CP Starbound represented the catcher processor sector.

Tracking of escapement relied on underwater recording video cameras deployed by field project managers on each EFP vessel. The focus of improvements for tracking escapement was to ensure cameras were placed where they could best collect definitive data on escapement. All video data collected had a time-stamp synchronized to the laptop computer used for downloading data, and all cameras had synced time which made video review much more straightforward. Number of salmon escapes were counted along with the number of pollock escapes. For all three vessels, standard NMFS Observer catch composition sampling was done for all EFP hauls. To determine weight of pollock escapement as a fraction of overall pollock catch per haul, the average weight of individual pollock from species composition sampling of retained catch was then applied to the number of pollock that escaped per haul.

Given O/U excluders had been shown to be quite effective for reducing Chinook salmon bycatch in the GOA pollock fishery where vessels are small relative to most Bering Sea pollock boats, this design was preferred for the Storm Petrel. Additionally, Storm Petrel's O/U the first year included extra escapement portals on the sides of the hood intended to achieve even more salmon escapement than had occurred in the GOA. After seeing these side escapement portals didn't appear to improve Chinook escapement but made the hood unstable, side escapement portals were closed on Storm Petrel's excluder the second year. In the third year, the excluder design was maintained from the earlier trial but a 5-minute slow-down period was added during haulbacks to attempt to provide additional opportunity for escapement. Salmon escapement rates decreased rather than increased over the three testing seasons, and so the objective to iteratively improve Chinook salmon escapement was not achieved on the Storm Petrel. Overlapping confidence intervals around escapement rates for each test suggest that escapement rates stayed about the same over the EFP despite steps that logically should have increased escapement rates.

With the Destination being a 3,000 HP catcher vessel, it was thought that its towing characteristics would be more like catcher processors than lower HP catcher vessels. For this reason, the salmon excluder selected for 2018 test on the Destination was a flapper excluder referred to as a "Winston Flapper" design. This design started with the general flapper excluder design with a heavily weighted mesh panel but was modified to have an additional smaller hood-and-weighted flapper panel placed in the forward section of the original flapper. The Destination switched back to O/U designs for the remaining two test seasons. The two O/U excluders for Year 2 and Year 3 were designed to aggressively achieve high rates of salmon escapement culminating with a 'double-bridge' design in 2021. The 2021 design had escapement portals located in very close proximity to the aft end of the excluder's mesh panels so that salmon would have only a short swim to get out of the net. As with the Storm Petrel, iterative improvement on the Destination was not achieved.

In 2018, a variation of the "Winston Flapper" was tested on the Starbound, a prototype design of the Winston Flapper tested on the Destination that same year. The video footage from Year 1 on Starbound in fact showed that the Winston Hood appeared to be largely ignored by Chinook salmon and that it accounted for no escapes. To attempt to get more salmon to escape, the CP sector decided that the 2019 test should include a modification to the main hood of the Winston flapper to make escapement more accessible to salmon. This change was based on video footage from the first year of testing where salmon were seen hovering in the hood directly adjacent to where they could swim out but many doing this did not actually escape. The modification to the hood for Year 2 involved changing the taper of the meshes in the hood so that it did not come as far forward. Despite the intent, a significantly lower Chinook escapement rate was the result for the 2019 season. Based on the first two seasons of the EFP, the Winston Hood portion of the excluder had not proved to have positive effects on Chinook salmon escapement, so it was removed. For Year 3, side escapement portals were added to the cut-back hood of the excluder, once again aiming to entice salmon noted in the video to aggregate in the hood section just a short distance from where they would otherwise escape. The Year 3 median escapement rate for Starbound was 36% which was an increase over 2018 and the very poor rate in 2019, but was not a steady improvement as proposed. Pollock loss on the Starbound, meanwhile, steadily increased between the three years of testing, however the loss rate was viewed as operationally feasible.

As described above, Objective 1 was to make iterative improvements to Chinook salmon escapement based on data from each successive field test and consensus input for the pollock vessel HP class. While each EFP vessel had one or more test seasons with Chinook escapement results in the low to mid 30% range (and with quite low pollock escapement, hence good selectivity), the expected result of improved Chinook escapement rates with adjustments each season was not achieved. The most likely explanation for our results is that factors affecting salmon excluder escapement rates (e.g. water flow, relative amount of light) remain poorly understood.

NPFRF's second objective was to collect data concurrent with the excluder trials to advance the collective understanding of factors (referred to "covariates" by statisticians) affecting Chinook salmon escapement rates. Our application noted that key factors affecting Chinook escapement rates might be the relative amount of pollock passing through the excluder section of the net along with Chinook salmon, relative speed of water flow in the excluder section of the net, and the relative amount of light. To evaluate these, our plan was to collect information/data with synchronized time-stamps during the haul to compare them to times in the escapement camera video footage.

A critical assumption made in the design for Objective 2 was that Chinook escapements were a one-step process occurring in a fairly discrete and/or consistent timeframe. This assumption proved to be incorrect in ways that were not foreseeable. With EFP 18-03 deploying multiple cameras at different ends of the excluder's escapement pathway, a new perspective on how escapements actually occur was revealed. Specifically, cameras placed to track salmon escapements in combination with secondary cameras deployed aft of that location to track instantaneous amounts of pollock in the excluder section revealed that salmon escapements often take as long as 20-30 minutes, at times even longer. This had large implications for our proposed methods.

Attempts were made to identify when prolonged salmon escapements started and to effectively track when salmon moved out of the flow of fish back through the net and started moving forward of the aft end of the excluder panel(s). However, this could only be identified in a limited number of cases such as when water clarity was good or when dense amounts of pollock were not blocking the camera view.

Our investigation of effects of light on salmon escapement rates originated from feedback received in the excluder workshops prior to the commencement of this EFP. In 2019, data collection on all three vessels included light sensors. Light proved to be an equally challenging covariate to observe given that our salmon excluder work involved testing with lighted cameras to account for escapement rates. Another challenge was that the light sensors we deployed were not sufficiently rugged for the testing environment on pollock vessels in A-season fishing conditions.

To account for differences in escapement rates when EFP vessels were turning or hauling back the net relative to normal towing speed in a straight line, the EFP field project managers arranged for the captain and mate of each EFP vessel to record vessel activity with time stamps throughout hauls. We learned from the additional camera deployments, however, that instantaneous factors such as amount of pollock in the excluder section, relative amount of light, and specific vessel activity were often not directly relatable to salmon escapements. In recognition of this unforeseen limitation to our approach and data collection methods, we bracketed time around escapement times to see if escapements overlapped to some degree with covariates of interest within the allotted timeframe. This was a useful exercise, but it didn't reveal any discernable correlations. And the varying duration of the escapement process confounded our ability to compare escapements to the covariates of interest for this study. We nonetheless continue to suspect the factors we identified are very important for predicting escapement.

Clearly this EFP encountered several challenges in its study of covariates. The inability to track escapements and water flow in the net was perhaps the most disappointing aspect of Objective 2 for the EFP. The low degree to which Objective 1 was achieved underscored the need for better understanding of factors that singularly or in combination affect excluder performance in order to modify excluders for better performance. Adjustments intended to improve escapement rates were made at each stage in the EFP. These made good sense to fishermen and to others familiar with pollock fishing and pollock nets and were informed by viewing video of escapements, near escapements, and salmon clearly not reacting to the excluder. Having a better understanding of the covariates should reveal adjustments to excluders that increase escapement.

In the end, however, what works based on understanding these factors may not make sense to fishermen based on their interpretation of what salmon are doing (or not doing) as they move through a pollock net. Our study did elucidate many of the challenges for collecting covariate data and linking it to outcomes. In light of this, our efforts should assist other researchers to make additional progress in this important area of research for excluder improvement.

Introduction

Salmon excluders are modifications to the intermediate section of pollock trawl nets designed to allow/incentivize salmon to escape the trawl. There are several versions of salmon excluders in use in the Bering Sea pollock fishery. Figure 1 below illustrates the general location where excluders are installed relative to the overall extent of a typical pollock net. The specific location where the excluder device is installed in the net also varies, from the tapered intermediate to just in front of the “stuffing tube” (straight section that leads to the cod-end).

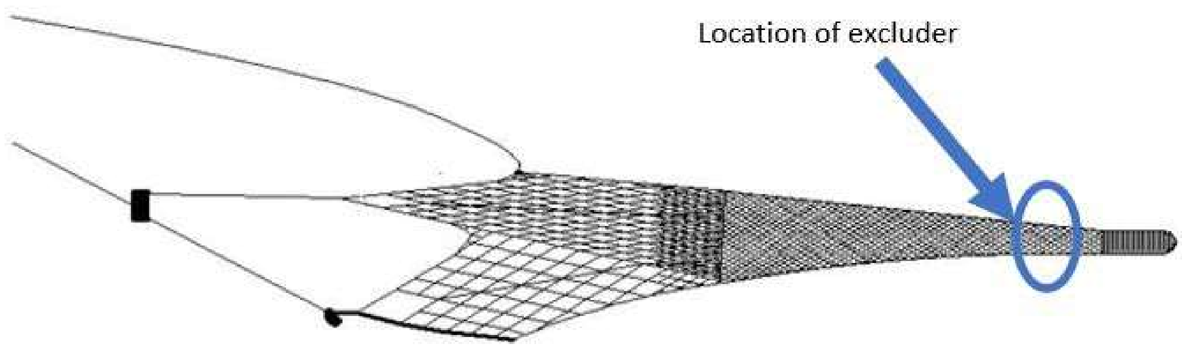

Figure 1: General location of salmon excluders on pollock trawl nets.

There are two general designs of salmon excluders in use in the Bering Sea pollock fishery (although other designs are in development by other researchers). One is known as a “flapper” design and the other is called an “over/under” design (or “O/U”, Figure 2). Variations on these basic designs can also be found.

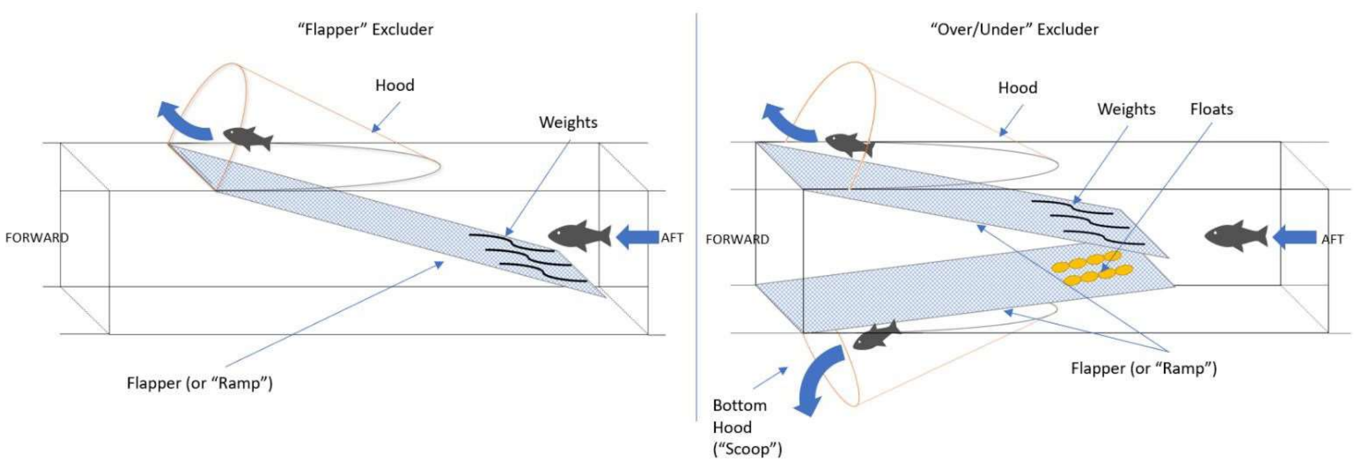

Figure 2: Conceptual diagrams of excluder designs tested during this EFP: the “flapper” (left) and the “over/under” (“O/U”, right). The flapper design has one portal (or “escapement hole”) through the top hood, and the O/U has two portals (one through the hood, the other through the “scoop”).

Excluders have large escapement portal(s) where meshes are removed to allow salmon to escape from the retentive section of the net. Escapement portals are typically located ahead of weighted or floated mesh panels that create an abrupt change in the otherwise gradually reducing taper of the net. The idea is that these mesh panels restrict water flow and so create a lee or disruption in water flow as the catch moves back through the net. This is intended to allow or encourage salmon to get out of the flow of water and fish moving through the net as the target catch is entering the greatly narrowed retentive section. Once salmon reach this lee, they will theoretically sense the opportunity to get out of the congestion of fish and swim forward to access the escapement portal(s). Salmon either escape immediately when passing through the excluder portion of the net, or after reaching the aft portion of the net and then swimming forward.

Designing an excluder to disrupt water flow through the net is analogous to simulating a boulder or downed tree on a river to create lees and eddies. Salmon are adapted to use these behaviors later in life when they return to rivers to spawn. Breaks in water flow in rivers provide salmon the opportunity to stop and rest, and then get their bearings before continuing upstream. In contrast, pollock are not specifically adapted to utilize disruptions in water flow and this, along with the fact that salmon are stronger swimmers, is the behavioral concept behind these two designs of excluders. In both excluder designs the relative speed at which fish pass through the net slows down in the excluder section due to the presence of the single weighted flapper panel (flapper design) or floated and weighted (O/U design) mesh panels.

From video observations of salmon moving back through trawl nets, it has been clear that dense aggregations of pollock in the net can serve as an impediment to salmon escapement. For this reason, both designs include a “hood” (or “scoop” if on the bottom of the O/U excluder design) area just behind the weighted or floated mesh panel intended to afford an unobstructed pathway forward outside the general flow of pollock towards the escape portal(s). Salmon that find their way up into the hood of a flapper excluder must still swim forward up the ramp section to the single escapement portal at the top of the net (Figure 2). The O/U design allows salmon to escape out the top similar to the flapper excluder and also includes an escapement pathway out the bottom of the net. Like the flapper’s mesh panel, the top O/U mesh panel is weighted, and a second one on the bottom is floated with trawl floats attached to the free aft section of the bottom mesh panel (Figure 2).

O/U excluders require a more customized, vessel-specific approach to construction and installation because the weight on the top mesh panel and floatation on the bottom panel need to have the right amount of floatation and weight for the panels to come together in the center. This typically requires iterations of adjustments in amounts of weight and floatation with video cameras used to verify outcomes in the process of “tuning” the excluder to achieve the desired shape at towing speed.

With excluders there is also potential that some fraction of the target catch will be able to escape as well. The balance that salmon excluder designers must strike is to encourage as large a fraction of salmon to swim out while retaining a sufficiently high fraction of pollock to make fishing feasible. This is important in order to avoid significant additional fishing hours, which would reduce fishing efficiency and possibly result in additional catch of salmon. To meet this challenge, the designer must understand hydrodynamics of trawl nets, salmon and pollock behavior, physiology of salmon in their marine phase, and vessel net towing characteristics. Excluder designers also need to understand the fishery and how vessel operators approach fishing under economic pressures and bycatch constraints.

Previous research and fieldwork

Collective endeavors by industry and fishery research collaborators to decrease Chinook salmon bycatch with gear modifications in the Bering Sea pollock fishery started in 2003[1]. That year, the North Pacific Fisheries Research Foundation (NPFRF) began what has become a considerable effort to work with the pollock industry and interested scientists to design and test salmon excluders in both the Bering Sea and Gulf of Alaska (GOA). Prior to NPFRF's application for this permit, parallel efforts by individual fishermen and sectors of the pollock fishery also occurred (e.g. At-sea Processors Association led by Dr. Ed Richardson). These parallel efforts occurred with different degrees of collaboration with NPFRF and the major pollock net manufacturers (e.g. Swan Nets USA).

NPFRF has since 2003 focused its endeavors on a suite of systematic tests of excluders in both the Bering Sea and the GOA using Exempted Fishing Permits (EFPs). These efforts have been stepwise, and each has produced publicly available reports and presentations of results available through the North Pacific Fishery Management Council[2]. NPFRF's EFPs have provided participating vessels an allowance to catch additional pollock and accompanying groundfish and salmon outside normal specified annual commercial catches. The intent for this was to enable participating fishermen to follow the testing protocols for NPFRF's *systematic testing* (holding the scientific treatment of interest constant over a planned number of replicates, and full accounting of escapements relative to total catches) under fishing conditions as similar as possible to the regular fishery. Catch allowances provided by EFPs alleviate pressures of the normal fishery that tend to restrict the ability to conduct systematic testing.

NPFRF's EFPs have also allowed the testing to occur in the various permanent and seasonal salmon bycatch closure areas. This has afforded the opportunity to collect data where salmon bycatch rates are expected to be relatively high, and hence testing should have more power to detect the effects of the excluders on salmon catch rates. Allowances for additional Chinook catches have not counted against the pollock fishery's bycatch caps thereby allowing participants to conduct testing where Chinook encounters are expected to be high. Having these set asides has proven instrumental in ensuring participation in EFP work and following experimental protocols rigorously.

In its application for EFP 18-03, NPFRF explained that based on results from its latest salmon excluder EFP tests (conducted in 2015-2016), Bering Sea salmon excluders were not performing with the same consistency and efficacy as those in the GOA pollock fishery[3]. This was attributed to the fact that the Bering Sea fleet is different in terms of the size and horsepower of vessels compared to the GOA fleet. Specifically, NPFRF's testing in the central GOA in 2013 and 2014 showed Chinook escapement rates of 35%-55% with the most promising result in the fall of 2014 showing median escapement at close to 55% for one of the two test vessels. By contrast, the 2015-2016 NPFRF EFP in the Bering Sea recorded much

[1] John Gauvin, *Salmon Excluder EFP 11-01 Final Report*, 2013 <https://media.fisheries.noaa.gov/dam-migration/efp-salmonby-final-report-0111.pdf>.
[2] Gauvin, *Salmon Excluder EFP 11-01 Final Report*; John Gauvin, John Gruver, and Katy McGauley, *C3 CGOA EFP Central Gulf of Alaska Salmon Excluder EFP 13-01 Final Report*, 2015 <https://media.fisheries.noaa.gov/dam-migration/efp-salmonby-final-report-0113.pdf>; John Gauvin, *Bering Sea Salmon Excluder EFP 15-01 Final Report*, 2016 <https://meetings.npfmc.org/CommentReview/DownloadFile?p=a94e693a-f95d-4e32-9c42-2dc2cb63efab.pdf&fileName=D3 Salmon Excluder EFP.pdf>.
[3] Gauvin, *Bering Sea Salmon Excluder EFP 15-01 Final Report*.

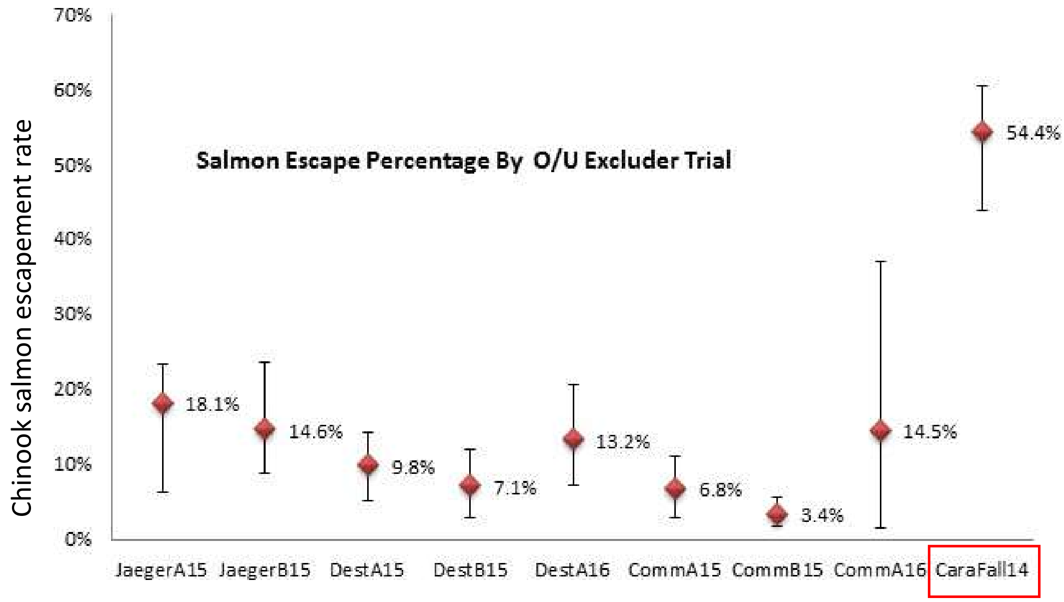

Figure 3: Percent of salmon that escaped during EFP trials, listed by vessel, year (2014, 2015, 2016), and season (A and B). Vessels conducting trials in the Bering Sea include the C/P Northern Jaeger, C/V Destination, and C/V Commodore. The result shown in the figure from the GOA (outlined in red) occurred in the fall of 2014 aboard the C/V Caravelle. Note that Chinook is the main bycatch species found in the GOA pollock fishery. Confidence intervals in the figure (α= 0.05) illustrate inter-tow variability in escapement rates.

lower Chinook salmon escapement rates for three size classes in Bering Sea vessels participating in the study. Those rates in the Bering Sea ranged from 3%-18% (see results in Figure 3).

Confidence intervals (α= 0.05) around those seasonal average escapement rates in Figure 3 indicate that even the upper end of the range of escapement rates for Bering Sea vessels is still well below intervals around median escapement rates achieved in the GOA. As illustrated, not only have median rates of escapement been lower in the Bering Sea, but inter-tow variability in Chinook escapement rates for each vessel and season associated with Bering Sea trials have been quite large in some tests (e.g. Comm A16, see Figure 3).

Results covered in Figure 3 were conducted employing the same basic excluder designs (versions of O/U excluders) and the same testing methods (EFPs holding excluder designs constant during the tests). While the O/U excluders used in both the GOA and Bering Sea were the same basic designs used in Bering Sea trials, excluders for Bering Sea trials were "scaled up" in size and material strength to be of appropriate size for the larger size/horsepower of Bering Sea pollock vessels.

In the years leading up to and creating impetus for this EFP, the Chinook salmon bycatch rates in the Bering Sea steadily increased (see Figure 4). The perception from fishermen was that the increase was due to an increase in Chinook salmon abundance on the pollock fishing grounds. This perceived increase had vessel operators concerned that the "Rolling Hot-Spot Closure" bycatch management measures, in combination with excluder usage, would not be sufficient to avoid triggering the consequences of

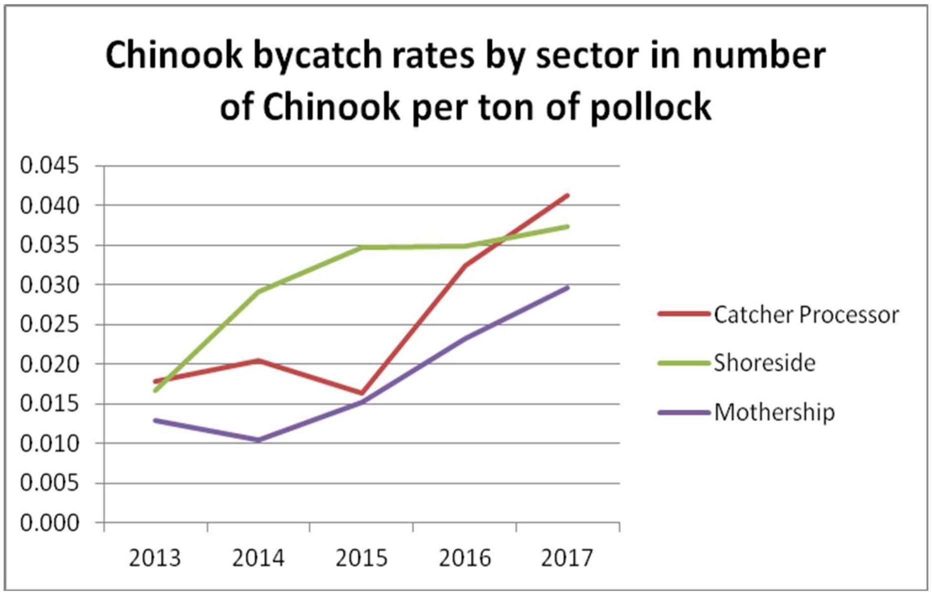

Figure 4: Bering Sea "A" season Chinook bycatch rates (number per metric ton of pollock) for catcher-processor, catcher vessels delivering to motherships, and catcher vessels delivering shoreside 2013-2017.

bycatch control measures in place under Amendment 91. This concern was further fueled by individual vessel-specific bycatch allowances nearly being exceeded in 2017 and much earlier in the season than expected. Others were concerned they would not be able to stay under their Chinook allowances for 2017 despite their efforts to avoid catching Chinook salmon.

In terms of excluder design, NPFRF's tests prior to this EFP had essentially focused on the "latest" ideas for excluder designs as new concepts emerged. The specific excluder concepts and models were developed mostly from John Gruver, a former pollock fisherman and originator of the first salmon excluder designs. Since his original designs for "funnel and tunnel" excluders, Mr. Gruver worked with various Bering Sea pollock fishermen and pollock net makers who had installed his early models and made modifications using video they collected in the regular pollock fishery. Mr. Gruver's designs then evolved to flapper and O/U excluder models with considerable variation in key elements (e.g. how far salmon need to swim forward to escape). As fishermen tried Mr. Gruver's latest excluder designs, their feedback led to adjustments based on what seemed to be promising design elements. Some of these became the excluders that were later prioritized for more rigorous evaluation in NPFRF's various field tests through EFPs.

In more recent years the focus for excluder designs was on different versions of flappers and O/U excluders with different modifications to hoods and placement of the escapement portal(s). Fine-tuning of these excluder devices mainly involved figuring out where to locate the escapement portals relative to the back end of the mesh panels. This relationship determines how far forward a salmon must swim to access escapement. Designs vary between incorporating a longer pathway (resulting in "greater overlap"), versus lower or even "zero overlap" models where a salmon (or pollock) can immediately access the escapement portal when they pass through the aft end of the excluder (Figure 5).

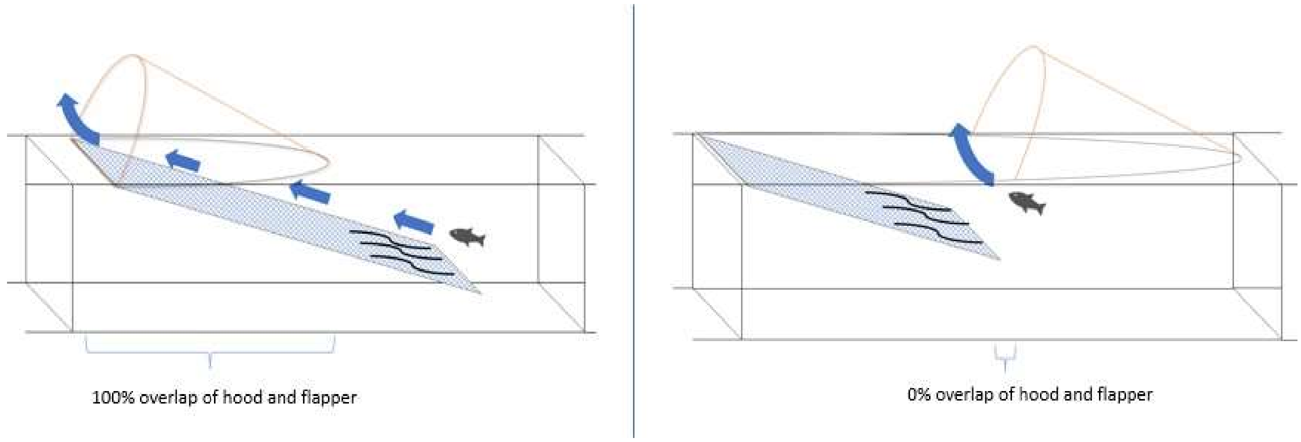

Figure 5: Conceptual figure demonstrating the difference between a large overlap excluder and a "zero overlap" excluder, resulting in different distances for salmon to travel to escape.

Objective 1:

Improve Bering Sea excluder performance starting with the most promising excluder design and make iterative changes based on results of field testing

In the early stages of excluder development prior to this EFP, NPFRF's focus was testing a suite of the "latest idea" excluders. For this EFP, however, the fishermen shifted to the belief that a sufficient number of excluder designs and ideas were already available to the different horsepower classes of vessels. Going forward captains felt the emphasis should be on fine- tuning and optimizing existing designs to improve performance.

This change in approach was evident from a series of meetings NPFRF organized with the Bering Sea pollock fishery prior to applying for this EFP. From these discussions it was clear that fishermen were already incorporating many of the elements of the different excluders that NPFRF and others were working on. This was occurring, however, in an *ad-hoc* way and many of the workshop attendees expressed interest in seeing some systematic testing of the existing designs in an effort to refine them. Likewise, many of the fishermen and other attendees were interested in doing additional small adjustments intended to improve performance or enhance salmon escapement (such as the addition of artificial lights).

Another common theme from the workshops was that while fishermen welcomed assistance with design tuning/testing, they wanted to work on the excluder designs they now felt, based on their own testing and regular usage in the pollock fishery, were most likely to be practical for their horsepower class of vessel. In recognition of this feedback, NPFRF proposed in its application for this EFP to work with each of the horsepower classes of vessels (small CV or <1,800 HP, large CV or >= 1,800 HP, and CP) on the excluder design and "specifics of construction" that each vessel category prioritized. Specifics of construction means excluder construction characteristics such as the use of heavier duty materials for larger, greater horsepower vessels.

The process would start with selection of the excluder design/construction each vessel class felt was most promising and held the most potential for improvement. Following collection and analysis of performance data during the first field season starting January 2018, NPFRF would review the results with interested fishermen and gear manufacturers from each vessel class. This discussion would lead to development of consensus among fishermen in the horsepower category on modifications to the excluder device to improve performance. Another systematic performance test would be done the following winter season to see if the adjustments created the expected improvements in performance. Lastly, one final year of modification and systematic testing would be done for a total of three years. The goal was to obtain incremental improvements in Chinook salmon escapement rates each field season resulting from each iterative improvement to the excluder design.

Another important focus for this EFP was the development of excluders to reduce *Chinook* bycatch. Chinook is the species that is predominantly caught in winter (A-season pollock fishing) although late in the fall (B-season pollock fishing) Chinook catch rates have increased to A-season levels in some years. Earlier studies/industry efforts on excluders tended to approach the problem as general salmon bycatch instead of focusing on a specific species of salmon. This essentially assumed that excluders that work for one species will work for the other. In its 2017 workshops, NPFRF heard that this was not reflective of pollock fishermen's on-the-water experiences. For example, excluders that fishermen felt were allowing chum salmon to escape at high rates were not necessarily working well for Chinook. This also matched the results from NPFRF's earlier tests which at times showed considerably lower escapement for Chinook salmon in winter tests than for summer trials when chum is the predominant bycatch species.

Another motivation for taking a species-specific focus came from feedback at the workshops. Pollock fishermen related they had heard from commercial salmon seiners that chum salmon are "divers" and are notorious for diving to get under seine nets. Likewise, they heard from salmon trollers that Chinook apparently tend to prefer positioning themselves deeper in the water column during the day than chums. For this reason, salmon trollers set their gear much deeper during bright daylight hours when fishing for Chinook.

Finally, fishermen pointed out that the bycatch management measures in the Bering Sea are all primarily focused on reducing Chinook bycatch. Fishermen wanted the focus on reducing Chinook because the hard-cap limit and bycatch avoidance area closures limit access to normal pollock fishing grounds in some years or cause vessels to move to alternative fishing grounds (both situations increase operating costs) throughout the season. Chinook bycatch caps, if exceeded, trigger shutdown of fisheries for the year or necessitate expensive leasing of additional bycatch allowances[4]. Pollock fishermen also said emphatically that their organizations have pointed out to the North Pacific Fishery Management Council that the industry is focusing/prioritizing the reduction of Chinook bycatch and that to focus more widely reduces their ability to deliver on this goal.

For all these reasons, NPFRF focused this EFP on reduction of Chinook bycatch and requested that the permit support testing only in winter (A-season). In adopting that focus, NPFRF recognized that it was taking on what may well be a generally more challenging focus because winter pollock fishing targets densely schooled pre-spawning aggregations of pollock. Target species catch rates in winter, therefore, can be exceedingly high, often well in the range of 100-200 tons of pollock per hour. Captains thought this creates challenges for getting Chinook to use the excluder as they are forced into the codend by dense aggregations of pollock. Even if Chinook do attempt to respond to elements of the excluder design, captains thought they may be "walled in" or blocked by large amounts of pollock.

[4] North Pacific Fishery Management Council, 'Fishery Management Plan for Groundfish of the Bering Sea and Aleutian Islands', 2020.

Data collection and review methods for Objective 1

Tracking of escapement relied on underwater recording video cameras deployed in nets by field project managers. These methods have been described in previous EFP reports[5] so we have focused here on where methods have changed relative to what has been done in the past.

Improved camera designs and video methods for tracking escapement

The focus of improvements for tracking escapement with video was to ensure cameras were placed where we could best collect definitive data on escapement (Figure 6). This was prioritized because at times in the past it has been difficult to confirm whether salmon moving towards the escape portal have actually left the net, due mainly to limitations in the visible distance cameras capture with sufficiently clear visibility.

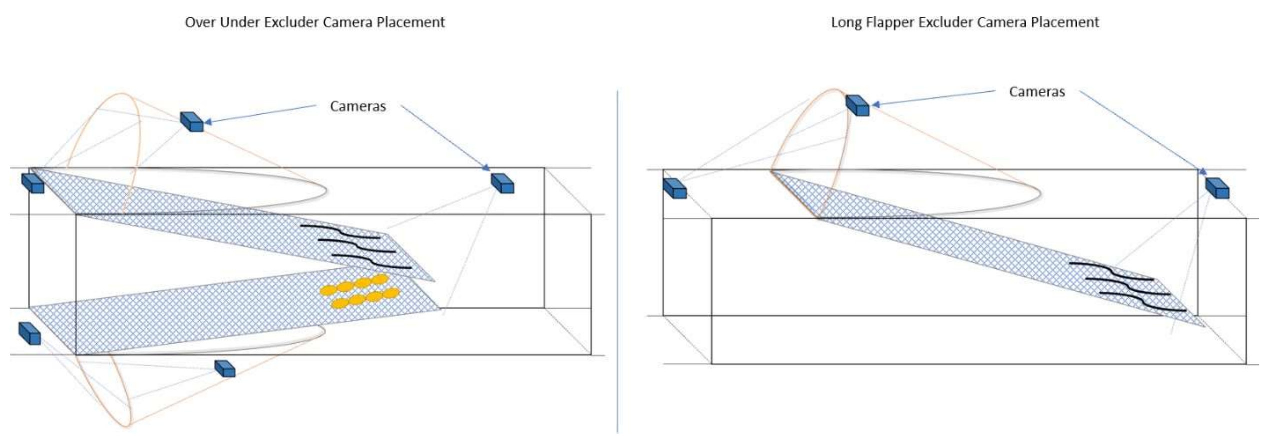

Figure 6: General camera placements for the O/U and Flapper excluder designs.

Information on success rates for captured video footage is presented in Table 1. "Success" is the proportion of tows where at minimum one camera at each of the escapement portals collected data sufficiently to determine salmon escapements throughout the entire duration of the haul. This relatively high rate of success was due to NPFRF's prioritization of using two cameras at each escapement portal when possible. This proved to be expensive in terms of equipment and video review costs but worthwhile because the "redundant" camera covered for most of the times if the main camera failed. While we had a high overall success rate, on the Starbound we still had a failure rate of ≈15% in two of the three season and this required us to drop several of the EFP tows from the analysis. The total number of tows on the Starbound was much higher, however, because we were able to conduct the tests on non-EFP tows (either AFA or CDQ tows) for that vessel given the ability to conduct testing on trips that combined EFP and non-EFP hauls using the same testing protocol on a CP vessel.

[5] Gauvin, *Salmon Excluder EFP 11-01 Final Report*; Gauvin, *Bering Sea Salmon Excluder EFP 15-01 Final Report*; Gauvin, Gruver, and Mcgauley.

The design of the cameras themselves was improved with the usage of second-generation cameras by Williamson & Associates, a company specializing in undersea cameras.

Table 1: Number of tows used for video review out of total number of tows conducted during an EFP year and season. Data was intended to be collected in years 2018, 2019, and 2020. Data collected on the Storm Petrel and the Destination for the 2020 season were lost, and so data collection was repeated in the 2021 A season for these vessels.

VESSEL	YEAR, SEASON	NUMBER OF TOWS USED FOR VIDEO REVIEW	TOTAL NUMBER OF TOWS CONDUCTED	% SUCCESS RATE
STORM PETREL	2018A	8	8	100.0%
	2019A	11	11	100.0%
	2021A	12	12	100.0%
DESTINATION	2018A	11	11	100.0%
	2019A	12	12	100.0%
	2021A	11	12	91.7%
STARBOUND	2018A	30	35	85.7%
	2019A	27	32	84.4%
	2020A	26	27	96.3%

Pre-EFP haul camera placement testing

Prior to commencing the tests each season, pre-EFP hauls were done to ensure the excluder achieved the intended shape. These tows were done with the cod-end closed but with the net towed in the water column above the pollock hence avoiding any significant catches. The pre-test tows not only established that the excluder and net were achieving the intended shape, but also determined cameras were functioning as intended and placed well so that escapement portal areas were visible. If any problems were detected with the shape or rigging, these were resolved and additional pre-test verification tows were done to ensure everything was as intended prior to commencing the official test tows.

Catch accounting methods utilizing certified flow scales and tank volumetrics

For the Starbound and the Destination, round (unprocessed) weights of groundfish per haul were determined through the use of motion-compensated flow scales. The scale equipment used for this was the same as what NMFS Alaska Region requires for catch accounting on trawl catcher processor vessels in the pollock fishery. Thus, CP Starbound's round weight catch weight estimation and accounting for the EFP followed the same procedures used in its regular operations in the Bering Sea pollock fishery. The Destination is a Bering Sea catcher vessel that normally delivers unprocessed catches stored in refrigerated seawater (RSW) to a shore-based processing plant where official catch accounting occurs. The Destination, therefore, is not required to have a certified scale for at-sea weighing of catch, but the vessel actually utilizes the same flow scale equipment as the catcher processor vessels, reportedly for internal catch accounting and tank filling purposes. Given this, for Destination's EFP testing, sea samplers for the EFP performed the same daily weight calibration and accuracy verification tests for the flow scale on the vessel that are done by observers on trawl catcher processors fishing pollock.

To allow for haul-specific estimates of pollock catches on the Storm Petrel, bin and tank volumetrics were used. The Storm Petrel has 8 RSW tanks, and above each tank on deck is a "bin" where crew can separate out catch when necessary, and equipped with a hatch to pass the fish into the corresponding tank below when ready (Figure 7). Catch from each haul was dumped from the cod-end into the trawl alley, and then pushed in to the 2P bin. The fish then travelled up an incline belt, and onto an athwartship belt where the Sea Sampler and crew collected any salmon in the haul (there was a platform located above this portion of the belt with access to the belt itself). The remained of the catch went to a third belt, where catch was sorted in to the 2S, 3S, or 4S bin and respective tanks. Hauls were generally over 60 MT, so the crew knew that would fill two tanks and have a little left over. Generally, for vessel stability and efficiency of filling tanks the catch would be dumped in to the 2S, 3S, or 4S tanks first. If these tanks were full, catch would be dumped in to the 2S, 3S, or 4S bins, and then a hose would transport the catch athwartship to the 3P or 4P tanks. If the catch wasn't expected to fill the tank fully, the number of times a bin filled and was dumped into the tank was tallied. The volume to weight relationship of each bin was estimated prior to the beginning of field work for the EFP in 2018 using pollock that was then weighed on an official scale at the processing plant.

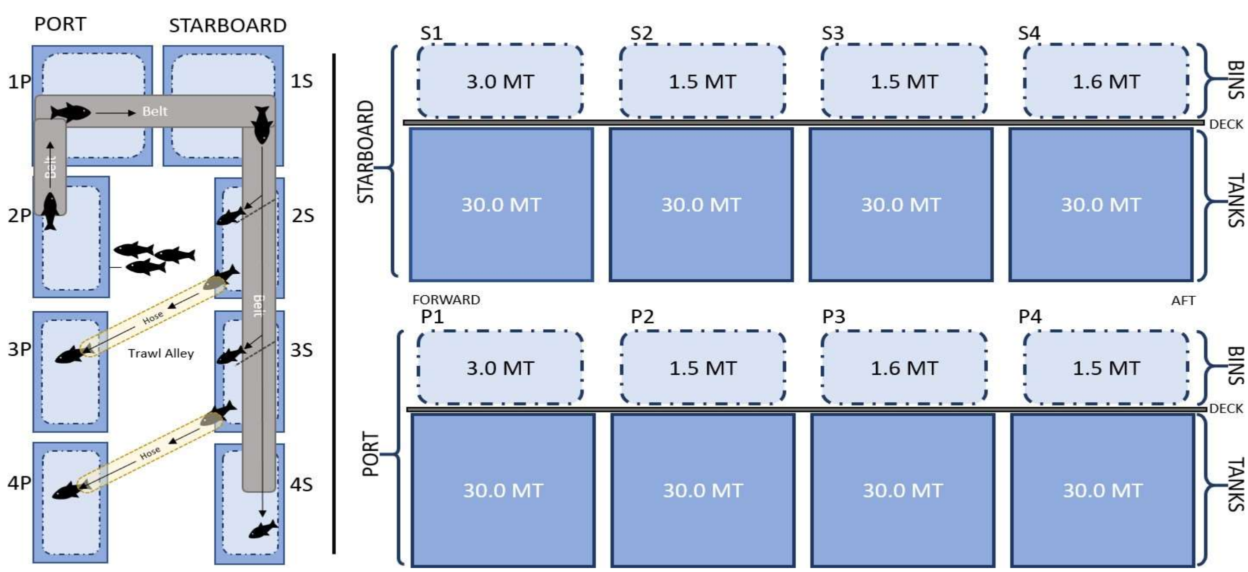

Figure 7: The tank, bin, and belt setup on the Storm Petrel to estimate tow-level catch weights of groundfish.

For all three EFP vessels, standard NMFS Observer catch composition sampling was done for all EFP hauls. Methods used by sea samplers (who were required to have all the training of regular fishery observers for this fishery) followed the same procedures as are in place for the Bering Sea pollock fishery for vessels outside of the Electronic Monitoring EFP currently underway. The fraction of groundfish catch per haul that was pollock was therefore determined by applying the species composition fraction that was pollock in the catch composition sampling to the weight of hauls determined by flow scale weights for Starbound and Destination and through volumetric equivalents for Storm Petrel.

Video review

All video data collected had a time-stamp synchronized to the laptop used for downloading data (Figure 8), and all cameras had synced time which made video review much more straightforward. Video review methods followed standard protocols for slowing down frame rates at key segments to allow for careful accounting of salmon and pollock escapement.

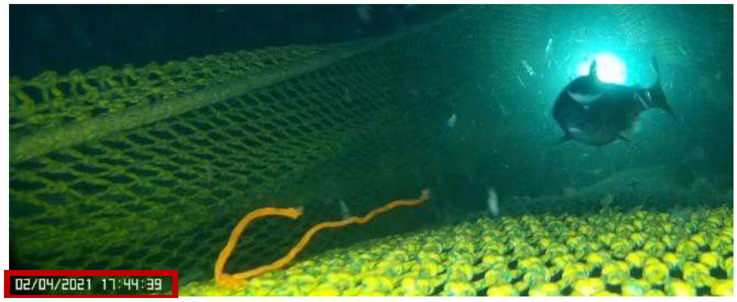

Figure 8: Time and date stamp on each video.

To determine weight of pollock escapement as a fraction of overall pollock catch per haul, the number of pollock that escaped was carefully accounted for during the video review. The average weight of individual pollock from species composition sampling was then applied to the number of pollock that escaped per haul (see Appendix 3: Pollock Weights by Tow). With this approach to estimation, it is assumed that pollock that escaped were equivalent in size to retained pollock in the sampled catches. Industry participants have been informed of how this assumption could downwardly (or upwardly) bias estimated pollock escapement if escaping pollock tend to be larger (or smaller) than retained catch. Given the low overall numbers and estimated rates of escapement for pollock, however, industry participants expressed little concern for potential bias in the assessment of pollock loss rates.

Outcomes for Objective 1

Storm Petrel (<=1800 HP Bering Sea Catcher Vessel)

The F/V Storm Petrel was selected to represent the small (<=1800 HP) Bering Sea catcher vessel. This vessel operates within the Northern Victor fleet and delivers its catch to Icicle Seafoods. The crew of the Storm Petrel had not been involved in as many research projects as other EFP vessels but were keen to share their knowledge and expertise and to take on the challenge of the EFP. The captain, Acacio Domar, had some experience with using underwater cameras on the Storm Petrel and on a vessel where he was captain prior to the Storm Petrel. Mr. Domar had also participated in an excluder workshop in St. John's in 2017.

Year 1 (2018)

Given O/U excluders had been shown to be quite successful on the smaller trawl vessels fishing pollock in the GOA, this design was preferred for the Storm Petrel. Note that the GOA catcher vessels are generally lower in horsepower than the Storm Petrel, but because the Storm Petrel was at the smaller end in terms of horsepower and size for Bering Sea vessels, it was thought that the O/U would be the most promising design to test.

In preparation for the test, it was decided that Storm Petrel's O/U excluder should include additional opportunity for escapement since the vessel does tow faster than GOA catcher vessels. To do this, 10-foot-long diamond cutouts in the hood and scoop of the excluder were added to the basic GOA design (Figure 9), and so in total their excluder had six escape portals. The hood and scoop also had a large profile to provide space for escapement, and the diamond cutouts allowed for escapement more proximate than the edge of the hood or scoop.

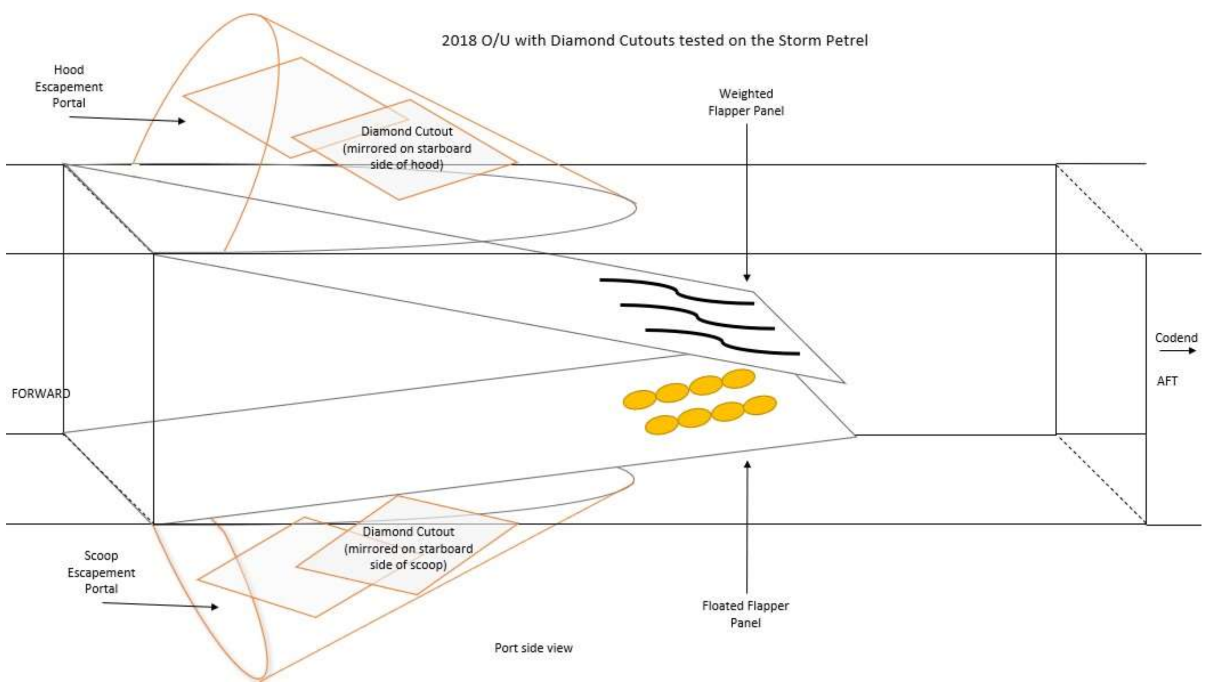

Figure 9: The O/U excluder design tested on the F/V Storm Petrel in 2018. This design was based on the O/U designs used on GOA vessels.

The inner mesh panels of this design, meant to direct the catch into the center of the excluder, were tacked to the side panels of the excluder. This was to prevent the panels from 'falling out' of the hoods and/or tangling the net during setting. The large area provided by the hood and scoop gave sufficient space for the salmon to swim up or down toward an escape portal.

The first year (2018) tests on the Storm Petrel encountered some unanticipated challenges related to the aspects intended to create additional opportunity for salmon escapement. Specifically, the pre-test video revealed that the hood and scoop with the cutouts created a relatively unwieldy shape and unstable environment for the installation of cameras to track escapement, thought to be caused by the relatively small surface area of webbing. This meant that cameras placed to track escapement were unstable relative to what was experienced in other O/U excluders without the cut outs. The result was that it was difficult to have a steady view of the escapement area.

Several other conditions also created challenges for tests on the Storm Petrel in 2018. Chinook bycatch rates were relatively high at the outset of the 2018 A-season then dropped off precipitously. The Storm Petrel was last in the EFP testing order that season, and so by the time her test started, Chinook bycatch rates had dropped off significantly. Additional delay occurred with the adjustments to camera placements and all the while Chinook bycatch rates continued to drop off. This led to only two of the expected four EFP trips being made in the 2018 season and tests were curtailed when the vessel and EFP field project manager struggled to find areas with appropriate conditions (i.e. areas with sufficiently high Chinook bycatch rates).

Nonetheless, the median Chinook escapement rate attained in the limited first season was approximately 40% (Table 2). This rate is higher than most A-season Bering Sea tests have attained in NPFRF's tests focusing on Chinook in earlier EFPs. The 40% total escapement rate is not much lower than the GOA performance that the smaller CV sector was aiming to match. That said, the small number of hauls completed that 2018 season and high level of variability in haul-specific performance likely contributed to the relatively wide (20% to just over 60% range) 95% confidence intervals (α= 0.05, Figure 10).

Table 2: Salmon and pollock captures in the cod-end, escapes, and escapement rates for each of the testing seasons for this EFP.

VESSEL	YEAR	SALMON			POLLOCK			
		Cod-end (Number)	Escapes (Number)	Total Escape %	Cod-end (MT)	Escapes (MT)	Total Loss %	# Tows Tested
STORM PETREL	2018A	140	93	39.91%	331.8	6.1	1.81%	8
	2019A	65	36	35.64%	687.4	4	0.58%	11
	2021A	26	12	31.58%	697.0	1.0	0.15%	12

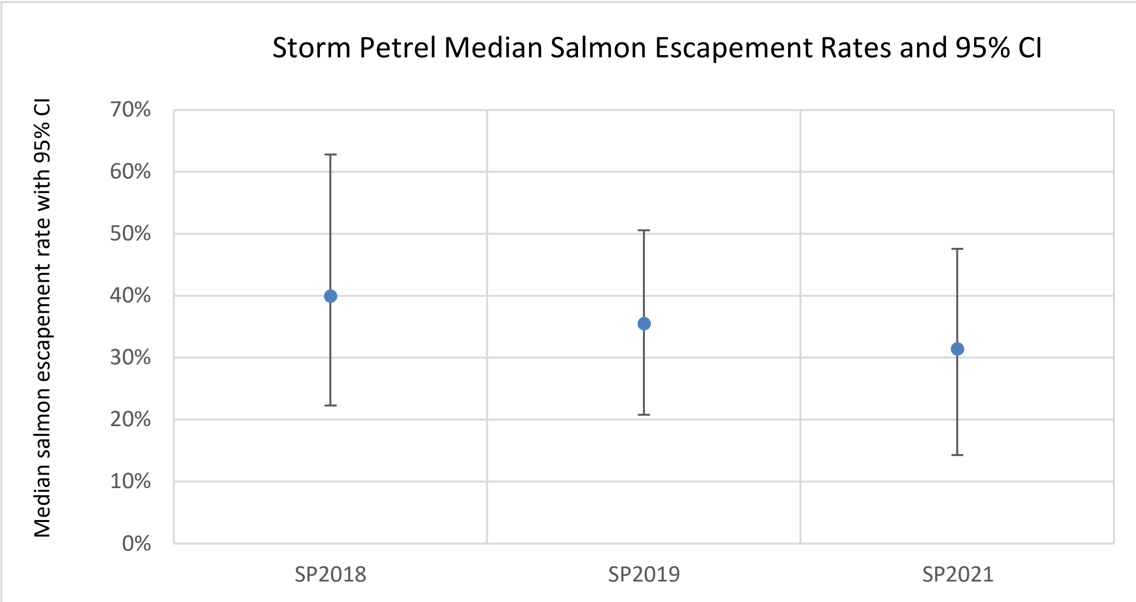

Figure 10: Median salmon escapement rates and 95% confidence intervals for data observed on the Storm Petrel for the 3 years that that EFP testing was conducted.

Results for pollock escapement were quite low, hence encouraging despite the large number of escapement portals and surface area that could allow pollock to escape (Figure 11). The weight of pollock that escaped amounted to just under 2% of the overall pollock catch. This was a very promising result given the relatively high pollock A-season CPUE for pollock in 2018. Pollock escapement of this magnitude is not likely to be a concern for the economics of everyday use of an excluder of this design.

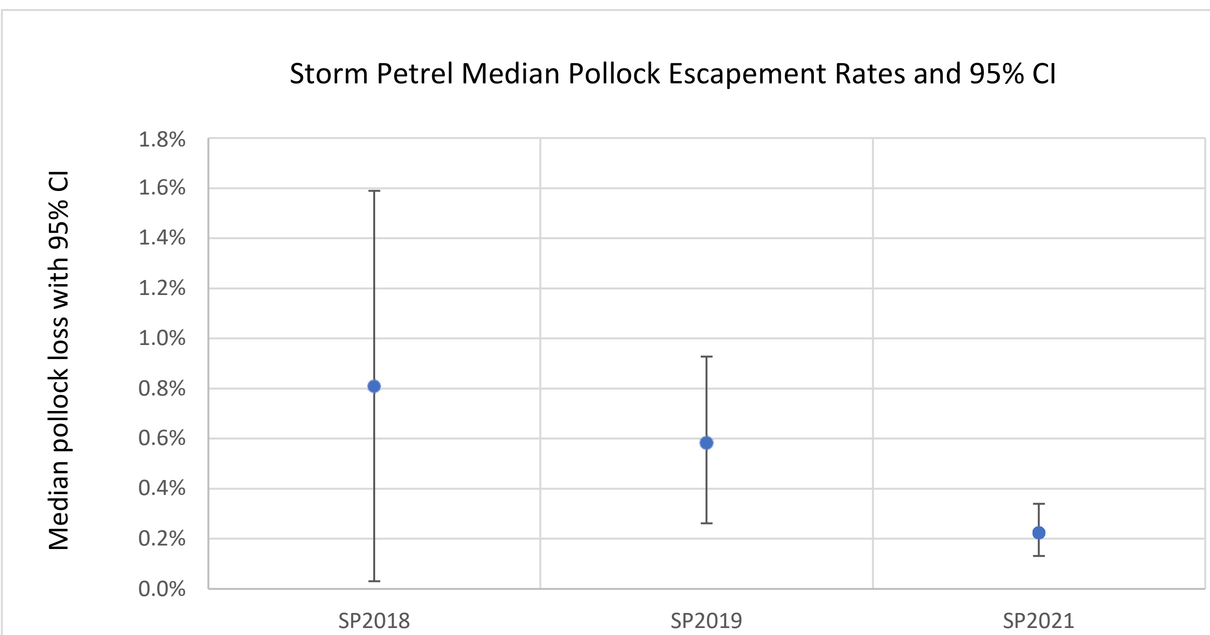

Figure 11: Median pollock loss rates and 95% confidence intervals for data observed on the Storm Petrel for the 3 years that that EFP testing was conducted.

Year 2 (2019)

Video review from Year 1 tests on the Storm Petrel showed that the cutouts were causing most of the problems with the shape of the excluder and ability to track escapement with cameras. Video review also revealed that the cutouts did not seem to be aiding Chinook escapement as no salmon escapes were noted through the cutouts themselves. For this reason, participating fishermen in the lower horsepower sector agreed for the next round of testing to replace (sew back in) the diamond-shaped mesh panel cutouts for the Year 2 trials (Figure 12). The rest of the O/U excluder design was kept constant with the same large hood and scoop, and the two mesh panels of the excluder tacked to the side panels. Removal of the diamond cut outs would effectively reduce the number of escape portals from the original six down to two.

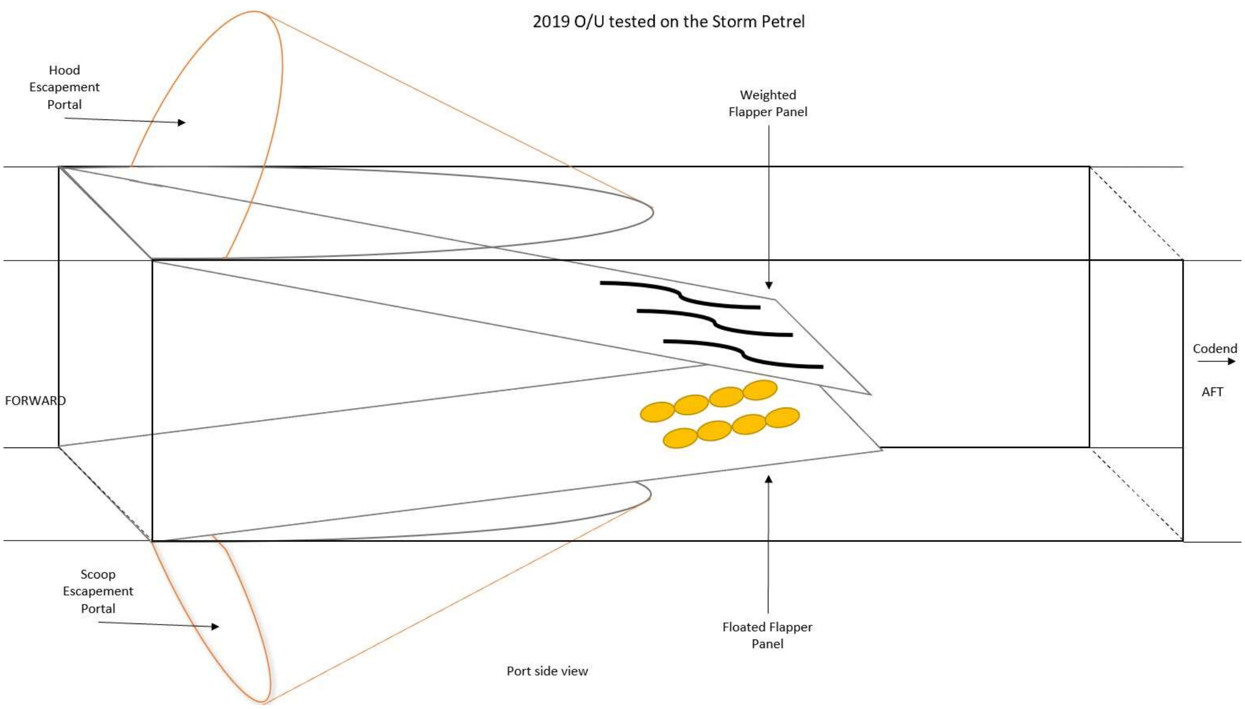

Figure 12: The O/U design tested on the Storm Petrel in 2019. The diamond-shaped cutouts in the hood and scoop were replaced, reducing the number of escape portals from six to two.

Pre-test video confirmed that this plan effectively addressed the problems with camera stability seen in Year 1 for the Storm Petrel's testing. With this resolved, the 2019 testing was able to complete the full four EFP trips and testing proceeded without the delays experienced the year before.

2019 testing for the Storm Petrel (and the other two test vessels as well) entailed lower Chinook encounter rates unfortunately, which meant that the vessel had to spend considerably more time relocating to areas where Chinook encounters were sufficiently high for this EFP work. The results from 2019 showed a slightly lower median escapement rate (≈36%) but considerably narrower 95% confidence intervals spanning from just over 20% to roughly 50% (Table 2, Figure 10Figure). While slightly lower than the upper end of the range attained in 2018, the field project manager, captain, and crew all felt more confident in the results given that haul to haul variability was lower and they had managed to do all the testing that was planned. In fact, given the largely overlapping confidence intervals it is probable that Chinook escapement performance in 2019 was not actually statistically different.

Pollock escapement in 2019 was once again quite low with the estimated rate being 0.6% of the overall pollock catch (Table 2, Figure 11

Year 3 (2021)

The same design from the 2019 trial was used for the 2021 trial (Figure 13). A few small modifications were made to the webbing around the excluder to ensure that the hood and scoop took better shape while the vessel was underway.

The substantive adjustment for the Storm Petrel in the 2021 trials was a change in the way fishing was conducted. Specifically, given that the captain, crew, and others in the sector who provided input were pleased that the vessel had achieved reasonably high escapement rates in the first two years of testing, the sector preferred to leave the excluder design as unchanged as possible. Instead, the plan for 2021 was to include a five-minute period at the end of each tow prior to net retrieval where the vessel slowed to about half its normal towing speed and the net was towed slowly, at a rate intended only to keep its shape during the slow-down. This change was motivated by the observation during video review from 2019 that in many cases Chinook could be seen trying to escape during haul-back but failing to do so. The idea was that more of these would succeed if the water flow was reduced for a longer period of time than would occur without the five-minute slow-down.

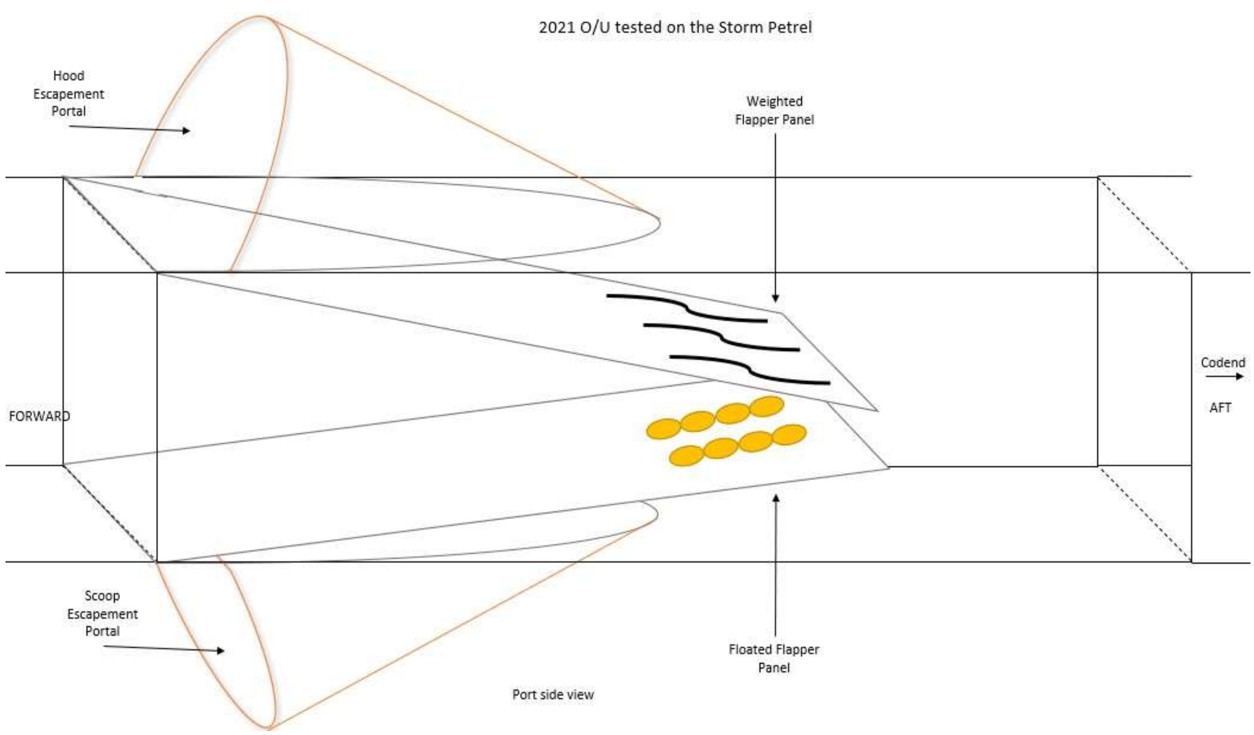

Figure 13: The O/U design tested in 2021. There was no major change made to the design of the excluder itself, and rather fishing behavior was the variable that was changed.

Prior to starting the testing in 2021, the field project manager with help from the captain collected video observations to establish the vessel speed and net haul rate that would keep the net open but reduce the water flow rate. This pre-test video also allowed them to establish the amount of time this would need to be maintained to establish a five-minute period of slower water conditions while maintaining the net's shape. This was generally a slow-down period from an average of roughly 3.5 knots to an average of 1.2 knots. The field project manager and captain decided that the captain would slow down to a target RPM (in this case, slow down to 1000 RPM), which would be easier to maintain consistently rather than trying to maintain an exact speed. This speed was thought to allow the best chance for salmon to swim out of the excluder. The field project manager and captain decided that adding a 5-minute slow-period at the end of the tow was the best way to maintain a consistent approach to slow-downs between tows, as it is difficult to accurately anticipate the length of a tow.

Following establishment of the slow-down procedures, the 2021 testing proceeded with relatively little challenges. The vessel was able to complete all the testing slated for Year 3 and average Chinook escapement rates were approximately 32% (Table 2, Figure 10). 2019 and 2021 Chinook escapement rates overlap nearly completely at the high end. The intervals do extend below 20% at the low end of the range in 2021, suggesting that escapement was slightly lower in 2021.

Of perhaps more importance, however, was that none of the salmon escapes observed took place during slow-downs. This could be for a variety of reasons: our overall sample size (number of Chinook encountered in the test) was low compared to the previous years, and so perhaps there simply weren't enough salmon to observe escapes during a slow-down. Another possibility was that slow-downs were only done at the end of the haul immediately prior to net retrieval, which was determined by the project manager and the captain to be the easiest method to maintain consistency between tows and therefore keep the systematic testing approach. Hence it is possible that conducting a slow down at a mid-point in the tow would be more effective for salmon escapement because Chinook caught earlier in the haul might be less fatigued at that point. It is also possible that slow-downs could increase Chinook escapement rates if they had been for longer than the five minutes. This might better achieve a sufficient duration of slow water to allow Chinook to swim forward to accomplish escapement. Additionally, if the slow-down occurs at the end of the tow and there is a full codend, it may have been more difficult for salmon to swim forward at this stage, or even not possible if the codend is very full with fish.

Ultimately, however, it is possible that slow-downs do not aid in salmon escapement, and any correlation observed between slow-downs and salmon escapements reported by other boats that have tried this adjustment to fishing was random and not causal. In any case, results were somewhat disappointing for Chinook escapement given the slow-downs were expected to be the best way to increase performance.

A concern expressed by the captain and others in this vessel category regarding the plan to do five-minute slow-downs during haul-backs was that pollock escapement rates would increase. This concern was not borne out by the test. In fact, not only was pollock escapement lower than for the earlier tests (0.2% compared to 1.8% in 2018 and 0.6% in 2019) but statistical confidence intervals around pollock escapement were tightest in 2021, therefore indicating that pollock escapement was very likely to be close to nil and hence well below expectations (Figure 11).

Overall, the objective to iteratively improve Chinook salmon escapement was not achieved on the Storm

Petrel. This could be due, again, to a variety of reasons. Three seasons worth of two to four trips per test may not be sufficient to observe the long-term average escapement of this excluder in this fishery for this vessel class. Finding consistent salmon numbers in the first place can be the most challenging aspect of this type of project. It is also possible that the modifications made did not improve performance and instead had a negative effect.

Destination (>1800 HP Bering Sea Catcher Vessel)

The F/V Destination was selected by the NMFS review panel to fill the large (>1800 HP) catcher vessel category. It is an AFA-qualified pollock trawler with a long history in the Bering Sea pollock fishery. The vessel has participated in previous salmon excluder NPFRF projects (in 2004-2008, 2011-2012, and 2015- 2016). The crew are all familiar with the use of the cameras and the goals of the project, were experienced fishermen, and had used a wide variety of excluders. The Destination was also involved with the testing of the new Williams & Associates tube style camera system in 2017 in preparation for this EFP work.

Year 1 (2018)

With the Destination being a 3,000 HP catcher vessel, its towing characteristics are thought to be more similar to catcher processors than lower HP catcher vessels. For this reason, the salmon excluder selected for the 2018 test on the Destination was a style of flapper excluder called a Winston Flapper design which came out of independent work on excluders for catcher processors done by Dr. Ed Richardson. The decision to test a flapper excluder stemmed from reports from catcher processor vessels suggesting that good escapement would occur with the Winston Flapper excluder design.

The Destination's Winston Flapper excluder was a long flapper design similar to the CP design, originally with one hood-and-weighted flapper but modified to have an additional smaller hood-and-weighted flapper placed in the forward section of the original flapper (Figure 14). This created, in a sense, two hoods that were nested. The smaller hood is often referred to as the Winston Hood, and was designed through fieldwork done by the catcher processors to give salmon an additional and shorter/quicker escape route relative to the route available via the main flapper and hood. The Winston Flapper design therefore had two escape portals from the top panel of the excluder.

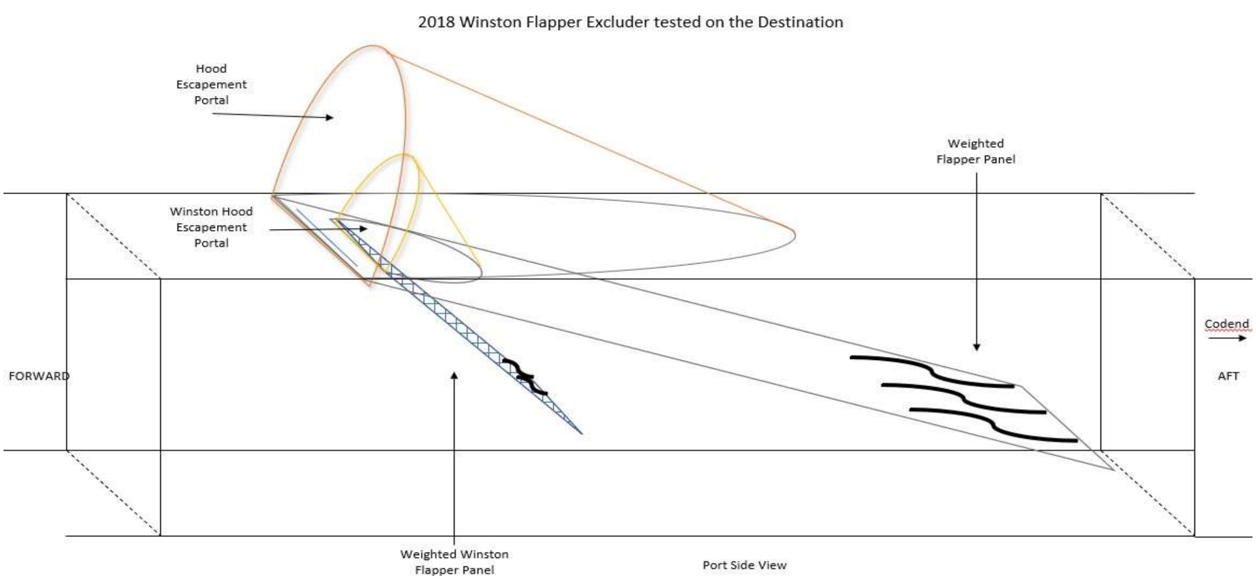

Figure 14: The Winston Flapper excluder design tested on the Destination in 2018.

It is important to note, however, that the CP tests that were the basis of the selection of this device for the Destination test had only been done in B-season when chum salmon were the main salmon species encountered. This may explain some of the results detailed below. The specific Winston Flapper excluder tested on the Destination was a slightly scaled down version of the one that was also being tested on the Starbound in 2018.

The overall salmon escapement rate for the Destination in 2018 was 32.2%, while the overall pollock loss rate was 1.29% (Table 3, Figure 15, Figure 16). While this was not the higher Chinook rate observed in the GOA vessels, it was viewed as a decent starting point. Of note from the video review, however, was that effectively all of the escapement with this excluder came from the aft (traditional) route at the end of the flapper panel and not from the Winston Hood. This begged the question of whether all the engineering and construction that went into adding the shorter escapement route really added any advantages or even affected its Chinook escapement results in any way.

Table 3: Salmon and pollock captures in the cod-end, escapes, and escapement rates for each of the testing seasons for this EFP.

VESSEL	YEAR	SALMON			POLLOCK			
		Cod-end (Number)	Escapes (Number)	Total Escape %	Cod-end (MT)	Escapes MT)	Total Loss %	# Tows Tested
DESTINATION	2018A	80	38	32.20%	889.5	11.6	1.29%	11
	2019A	90	40	30.77%	877.2	6.6	0.74%	12
	2021A	78	14	15.22%	808.9	9.3	1.14%	11

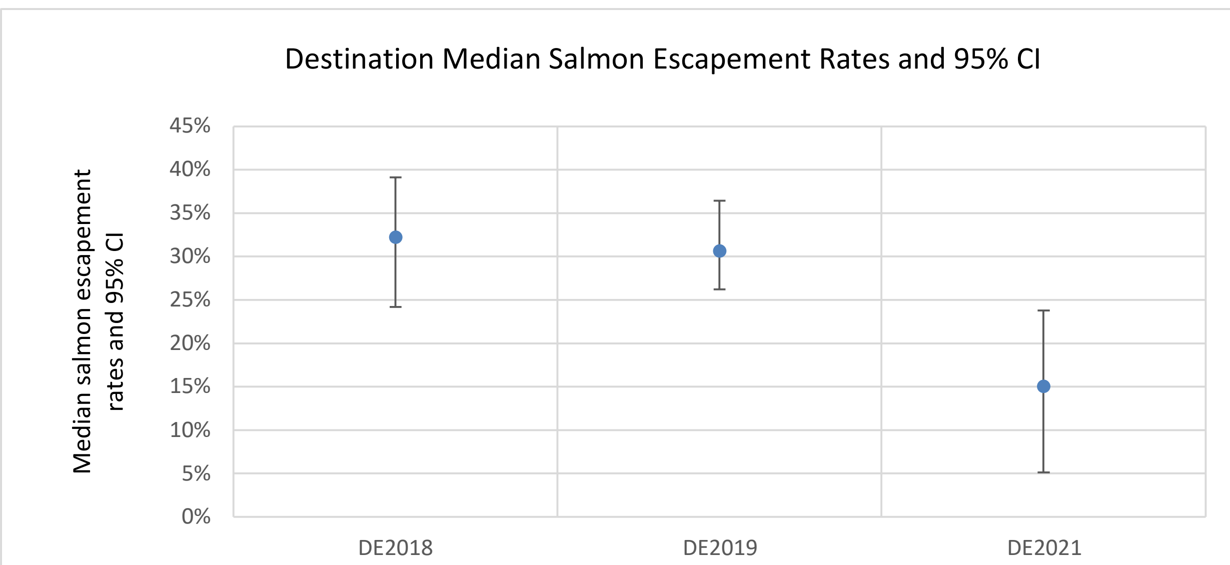

Figure 11: Median salmon escapement rates across all three years of the EFP observed on the Destination.

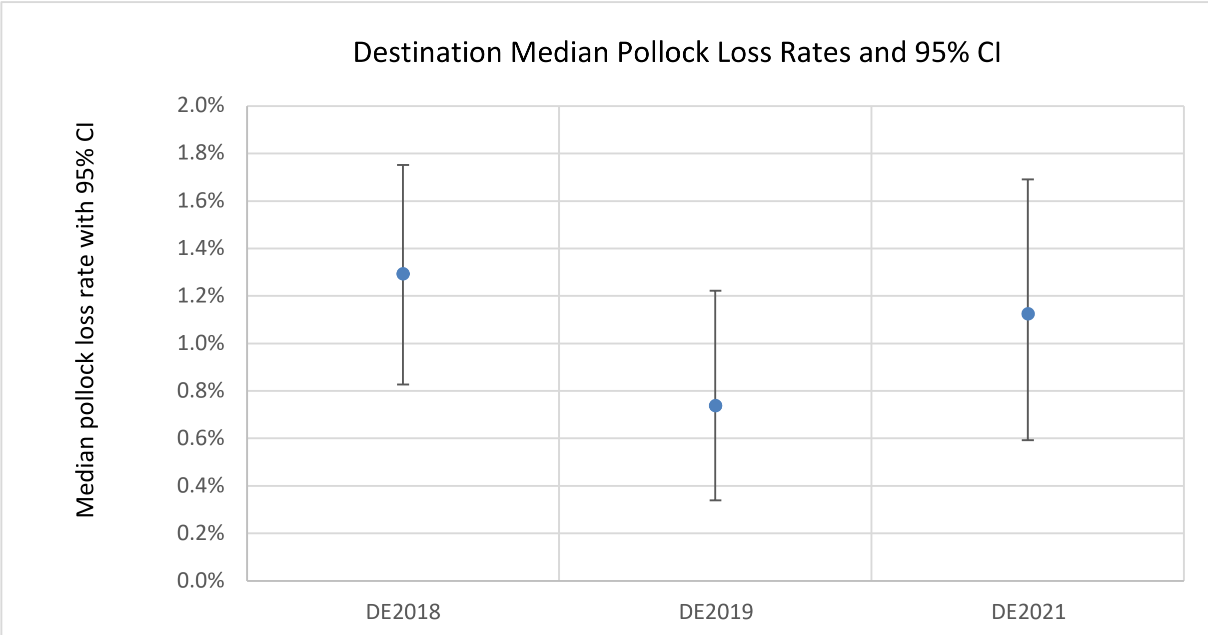

Figure 12: Median pollock loss rates and 95% confidence intervals for data observed on the Destination for the three years that that EFP testing was conducted.

In reviewing these results with interested fishermen in the large HP catcher vessel sector after the first season, there was general agreement about removing the Winston Hood. At the same time the sector felt that it might be better to focus on expanding the number of escapement portals which would potentially improve Chinook escapement. Pollock loss was also low and viewed as a workable amount of loss given the amount of catch so the focus was to more aggressively improve Chinook escapement in the upcoming season.

Year 2 (2019)

After additional review of the Year 1 video showing failed Chinook escapes, the sector's preference for the next EFP test was to shift to testing a new approach to an O/U excluder design. The reasoning was that the sector didn't feel a flapper excluder would be the best way to provide escapement opportunities based on what was seen from the previous year's video segments of failed escapes by Chinook.

The specific O/U design for 2019 included a tapered back hood and scoop and two flapper panels gored together on the sides to create a tube. The device had 12 feet of overlap (Figure 17). This meant that the mesh panels ended approximately 12 feet aft of where the leading edge of the hood and scoop begin. Based on earlier O/U designs, this one had a relatively small amount of overlap and thought to be a design that would facilitate Chinook (and possibly pollock) escapement relative to ones with greater overlap.

With this new version of an O/U excluder it was expected that the target catch would pass through the tube created by the mesh panels and continue into the cod-end. Salmon, however, would feel a lee after coming out of the tube and swim either up or down towards an escape portal, which were quite proximate to the back of the panels. Little in the way of forward swimming by salmon would be required.

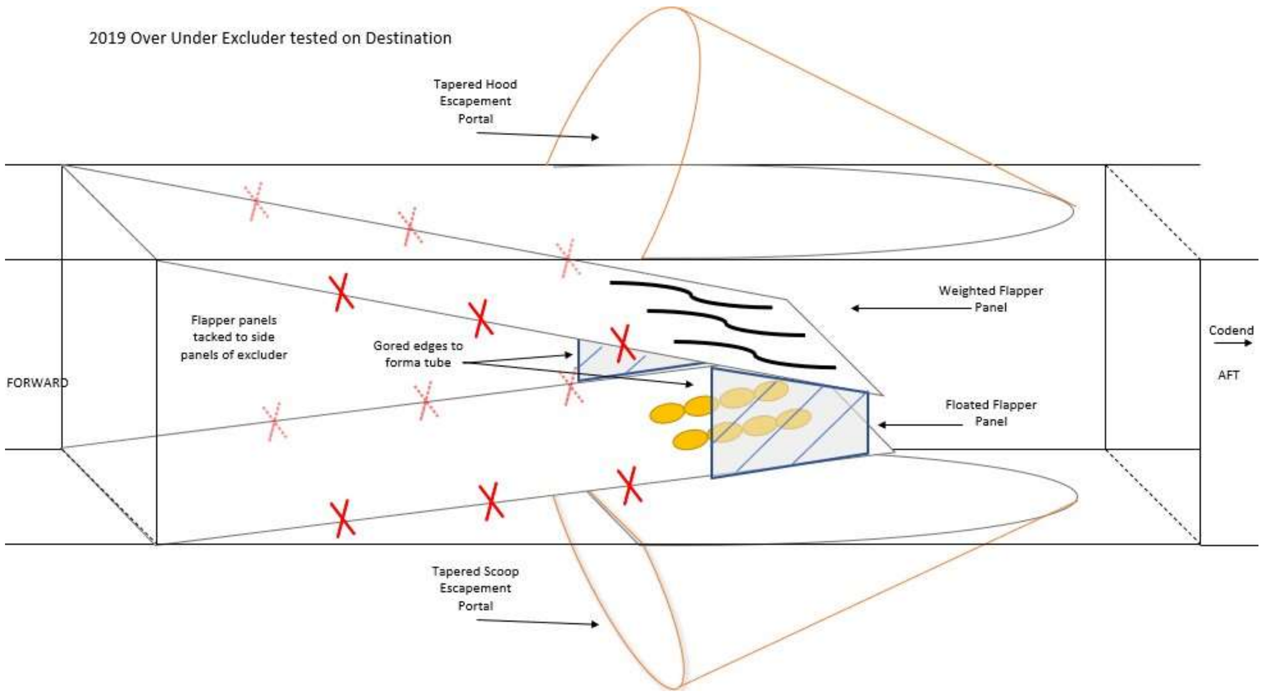

Figure 17: The O/U design tested on the Destination in 2019. This design, while similar in concept to the O/U used on the Storm Petrel, had a lower amount of overlap between the hood/scoop and flappers, providing a large escapement area and short swimming distance for salmon to reach the escapement area. The angle of the hood and scoop openings was also tapered back.

From the outset, it was recognized that the low amount of overlap might be problematic in terms of the mesh panels slipping out through the escapement portals during setting. This would mean the excluder would not take the correct shape and, in the extreme, could result in nearly all the catch being able to go out of the escapement portals because the mesh panels would not be there to block access. To avoid this, the flapper tube was tacked to the side panels of the excluder so that they stayed within the excluder while setting. Based on the pre-test video tows, the loose tacking of the weighted and floated panels to the side panels adequately addressed this potential problem and the testing took place free of problems of this sort.

The 2019 tests resulted in median Chinook escapement rate that was slightly lower compared to Year 1 (from 32.2% to 31.7%, Table 2, Figure 15). Confidence intervals for Year 2, however, were slightly tighter indicating less inter-tow variability during this testing year. Confidence intervals around mean escapement rates for Chinook in 2018 and 2019 completely overlap and hence likely lack any significant statistical difference. In short, while there was a small decrease in salmon escapement from Year 1 to Year 2, it is plausible that there is no significant difference between the years, and so results remained consistent. This implies that changing from a Winston Flapper to an O/U excluder that was specifically intended to address the problems seen in 2018 (Chinook having to move forward over a relatively long distance and then failing to escape) plus the addition of a second escapement pathway on the bottom unfortunately didn't result in a higher rate of escapement.

Pollock loss rates were lower in Year 2 as well with the loss rates decreasing from 1.29% to 0.74% (Figure 16). The upper bound of the confidence interval for Year 2 is nearly at the median of Year 1, which indicates that these two results are likely different from each other. Neither the 1.29% or the 0.74% loss are seen as detrimental to normal fishing efficiency.

Year 3 (2021)

After reviewing the escapement results and video clips of Chinook that escaped or attempted to escape but failed (clips the field project manager thought represented the bulk of the behavioral responses to the 2019 O/U excluder), a plan for improvement was developed between John Gruver and the Destination's captain and other fishermen who offered suggestions for this vessel HP category. The result was an extreme rethink of O/U designs, resulting in a "double bridge" design (Figure 18). The "double bridge" O/U included a wider opening above and between where the top and bottom panels would meet. This was made possible by the two bridges of webbing material and floats or weights across the wide opening forward of the hood and scoop. The bridges were also meant to create a lee for salmon to use, similar to the idea of a salmon ladder. The concept was that the salmon would swim against the water flow, find the lee created by one of the bridges, hold there, then swim out of the net. Escapement should therefore be easy for Chinook because the device provided a nearby opening across a very high percentage of the circumference of the net. Due to this elongated escape route and bridges, the hood and scoop were positioned further back on the excluder than the original O/U design. The hood and scoop had a gradual taper back and webbing along the wings to create a fence-like feature. This flattened the arch of the hood and scoop relative to previous O/U designs. The result was essentially a "zero overlap" O/U excluder as is evident in Figure 18.

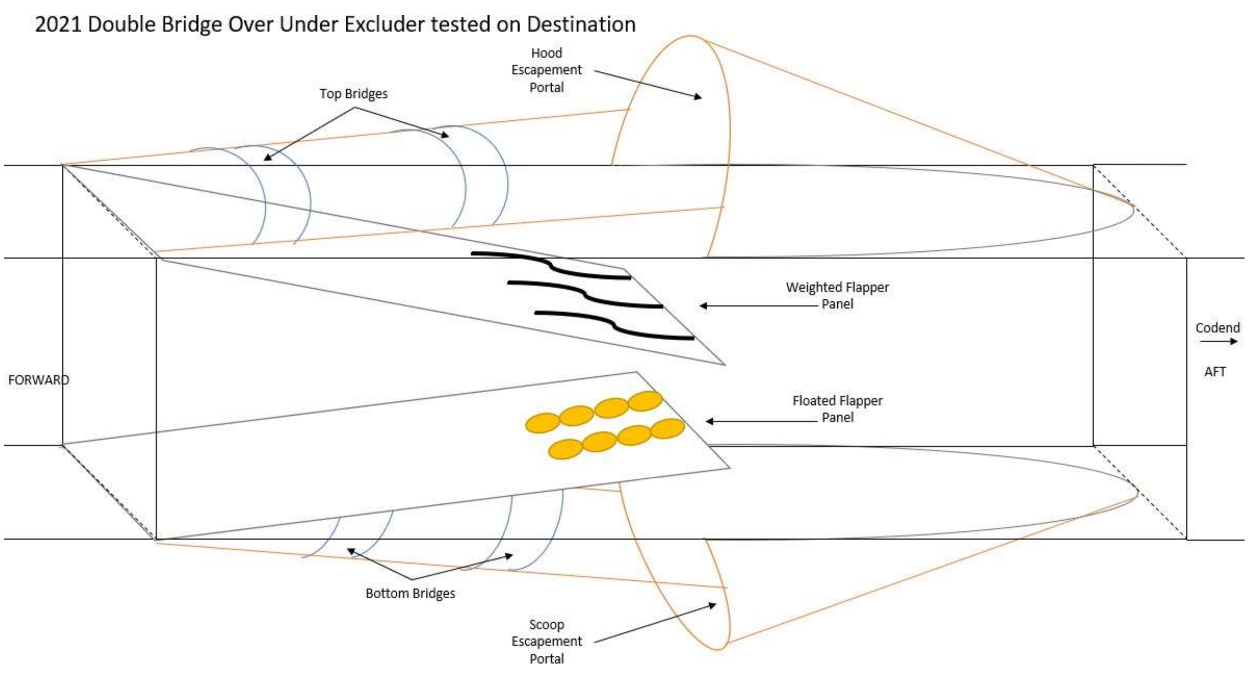

Figure 18: The double-bridge O/U excluder model tested in 2021 on the Destination.

This design was intended to remove the need for Chinook to swim forward to escape because the aft end of the floated and weighted panels is where the hood and scoop begin. This, to NPFRF's knowledge at the time, was the most aggressive approach to affording an easy escapement pathway for Chinook relative to other O/U designs.

Given the innovative aspects of this design and potential for large pollock escapement with "zero overlap", the shape of the device was once again informally looked at by the captain and crew of the Destination in the 2020 B-season fishery. In that second look, the bridges created concerns for becoming tangled when the net was being set. To help remedy this, an attachment between the inner mesh panels and side panels was added to keep the panels inside the excluder. Other modifications that were made included shortening the "wings" of the hood and scoop so there was less of a "fence", and steepening the taper of the hood and scoop to increase the arching effect. The thought process was that cutting back the wings of the hood and scoop would create additional area for Chinook to escape, and that increasing the arch of the hood and scoop would increase the waterflow and area for salmon to escape. This improved version was expected to be the greatest opportunity for escapement and was tested in the 2021 EFP testing season.

Despite high expectations, the Chinook escapement rate for this device in the 2021 testing season was lower than the previous two years, essentially half of what it was the previous year (15.22%, Table 3, Figure 15). The confidence intervals appear to be wider than previous years, particularly 2019, indicating more inter-tow variability. As was seen in the 2021 final season on the Storm Petrel, the Destination also had a relatively low number of salmon in the 2021 final testing season. This probably added to the between-haul variability for the Destination or may indicate that the modifications made to the excluder for the third year did not improve escapement for this excluder design and this vessel class. This outcome was quite counterintuitive given an O/U excluder with essentially no overlap represented the most accessible escapement opportunity for Chinook among all O/U and flapper designs evaluated in this EFP.

While pollock loss decreased in Year 2 on the Destination, it climbed slightly again in Year 3, though the median remained below the 2018 median pollock loss rate (Figure 16). Confidence intervals for Year 3 were nearly identical to Year 1 as well, indicating the pollock loss for the two years were essentially identical and that modifications made to the excluder probably did not change the amount of pollock loss that occurred.

Starbound (Catcher Processor)

The Starbound was selected to represent the Bering Sea catcher processor (CP) class. The vessel has a 7,000 HP main engine with two 1,800 gen. sets available for reserve towing power. For all three years of testing on the Starbound, variations of a weighted flapper excluder were used. CP sector participants feel that excluders for their sector need to be less structurally complex given towing characteristics of high HP vessels. They feel that other designs, such as the O/U, would require extensive tuning and sizing to achieve their intended shape and might not be practical. For CP vessels this would require very large excluder mesh panels and excessive amounts of weight and floatation to achieve the desired shape. This is due to the degree to which CPs achieve trawl door spread and consequently higher mesh opening ratios which then make the aft end of the net quite large relative to catcher vessels. The CP sector is also concerned with the possibility that the upper or lower mesh panels could slip out of the escapement portals during setting, a problem that some catcher vessels have experienced.

For all the above reasons, the preference for the Starbound was a flapper design installed in the straight section just ahead of the stuffing tube. To meet the objectives of the EFP, the sector wanted to focus on improvements such as additional escapement portals or cutting back hoods in key areas.

Year 1 (2018)

The Starbound normally fishes with two net/excluder/cod-end setups in order to fish around the clock to meet the processing capacity of the vessel. In 2018, while the two net and excluder designs were the same and so alternated between tows, one cod-end was used and so was removed and reattached between tows to ensure the same setup for each haul.

In 2018, a variation of flapper excluder called a “Winston Flapper” was tested on the Starbound (Figure 19), essentially the prototype of the Winston Flapper tested on the Destination that same year. The Starbound’s Winston Flapper had a long flapper panel which originally had one hood and a weighted mesh flapper panel, but was modified to have an additional smaller hood-and-weighted flapper panel placed in the forward section of the original flapper panel. Similar to the Destination, the two hoods are nested, and the smaller one is referred to as the Winston Hood. This modification to the original flapper excluder device is designed to give salmon an added, shorter escape route prior to the aft edge of the main flapper. This design therefore had two escape portals from the top of the excluder.

The pre-EFP test tows in 2018 were done with very few problems. Escapement rates for the Starbound in 2018 were similar to the other two vessels, around the low 30% range (31.19%, Table 4, Figure 20). Pollock loss, meanwhile, was very minimal, with very little variability between tows (Figure 21).

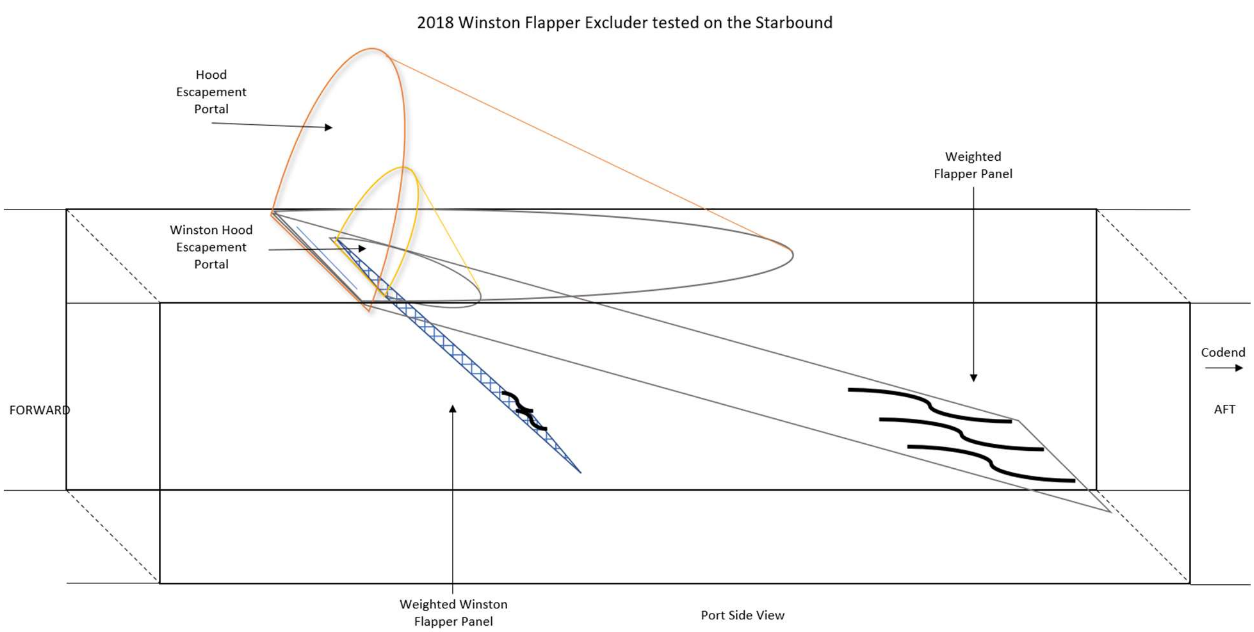

Figure 19: Winston Flapper excluder design tested on the Starbound in 2018.

Table 4: Salmon and pollock captures in the cod-end, escapes, and escapement rates for each of the testing seasons for this EFP.

VESSEL	YEAR	SALMON			POLLOCK			
		Cod-end	Escapes	Total Escape %	Cod-end	Escapes	Total Loss %	# Tows Tested
STARBOUND	2018A	620	281	31.19%	2735.05	5.4	0.25%	30
	2019A	188	19	9.18%	2791.7	26.2	0.93%	27
	2020A	27	15	35.71%	2969.6	39.4	1.63%	26

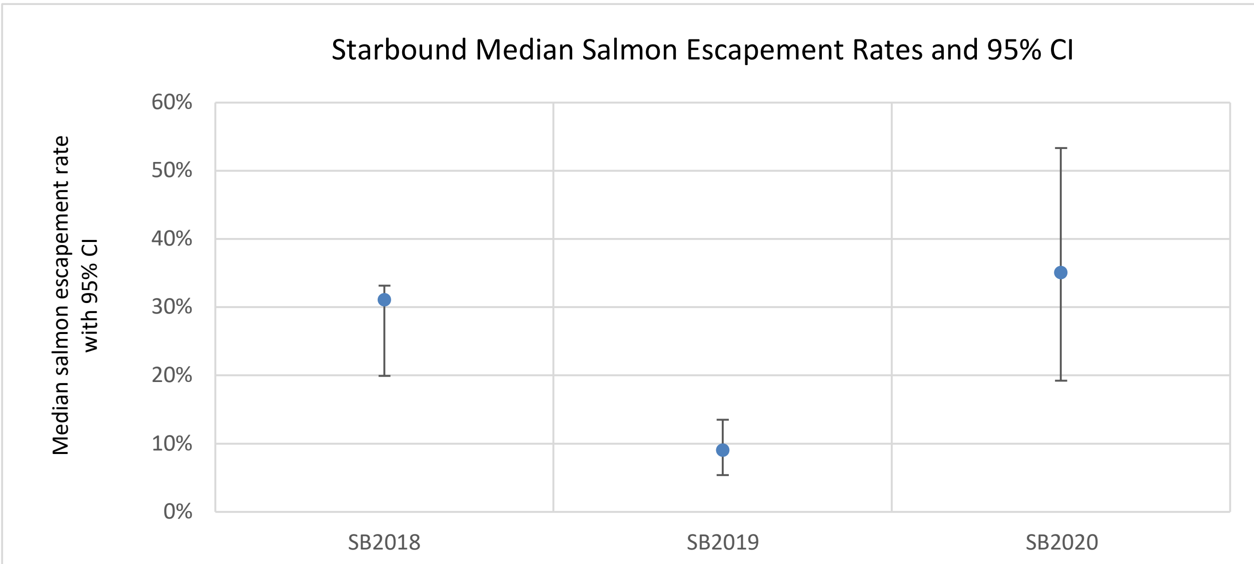

Figure 13: Starbound median salmon escapement rates with 95% confidence intervals for all 3 years of the EFP.

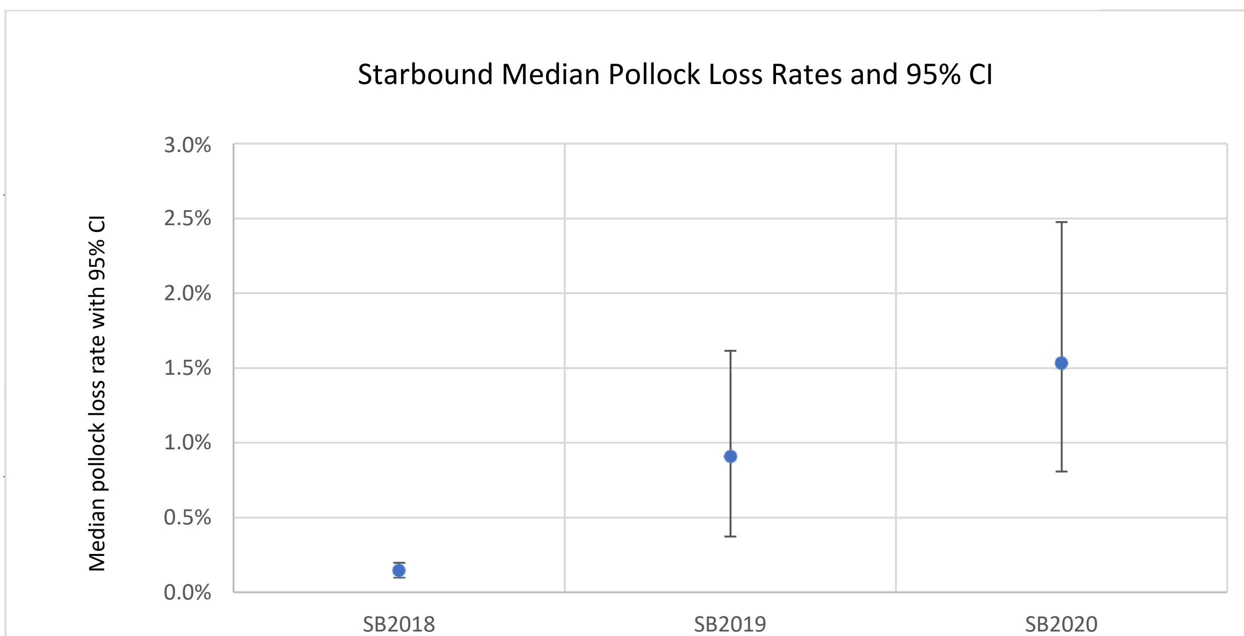

Figure 21: Median pollock loss rate and 95% confidence intervals for each of the 3 years of this study on the Starbound.

Year 2 (2019)

The video footage from Year 1 on the Starbound in fact showed that the Winston Hood appeared to be largely ignored by Chinook salmon and that it accounted for none of the 280 Chinook escapes in the video review in Year 1. This was an unanticipated outcome because the Winston Flapper pathway is in fact a shorter and more direct route for salmon to escape. In fact, the original impetus for adding the Winston Flapper was based on video footage showing chum salmon trying to find a way up through the long flapper panel. This behavior, noted in excluder research done by the CP sector, occurred in June and July during B-season when Chinook are unlikely to be the salmon species taken as bycatch in the pollock fishery. This begged the question of whether to remove the Winston Flapper and its hood after the initial 2018 test, but the consensus was to leave it for at least one more year because at a minimum it didn't seem to negatively affect escapement.

Another observation from the 2018 video from the EFP was that many Chinook salmon made their way up into the larger hood above the flapper panel but stayed there without eventually escaping. Getting these Chinook to swim out was therefore a focus for the 2019 season because adding these to the escapements would have meaningfully increased the overall rate of Chinook escapement for 2018.

To attempt to get more of these salmon to escape, the sector decided that for the 2019 test they would modify the main hood. To do this, the gear manufacturer that built the excluder changed the taper of the meshes making up the hood so that it did not come as far forward. This is similar to the effect of reducing overlap of the panel because this decreased the overhead barrier and hence should allow for a more direct vertical escape route (Figure 22). The height of the hood stayed the same, so there was plenty of space for salmon to get out of the catch, but by tapering back the angle of the opening of the hood, the salmon would have less of a distance to swim forward to escape. Based on

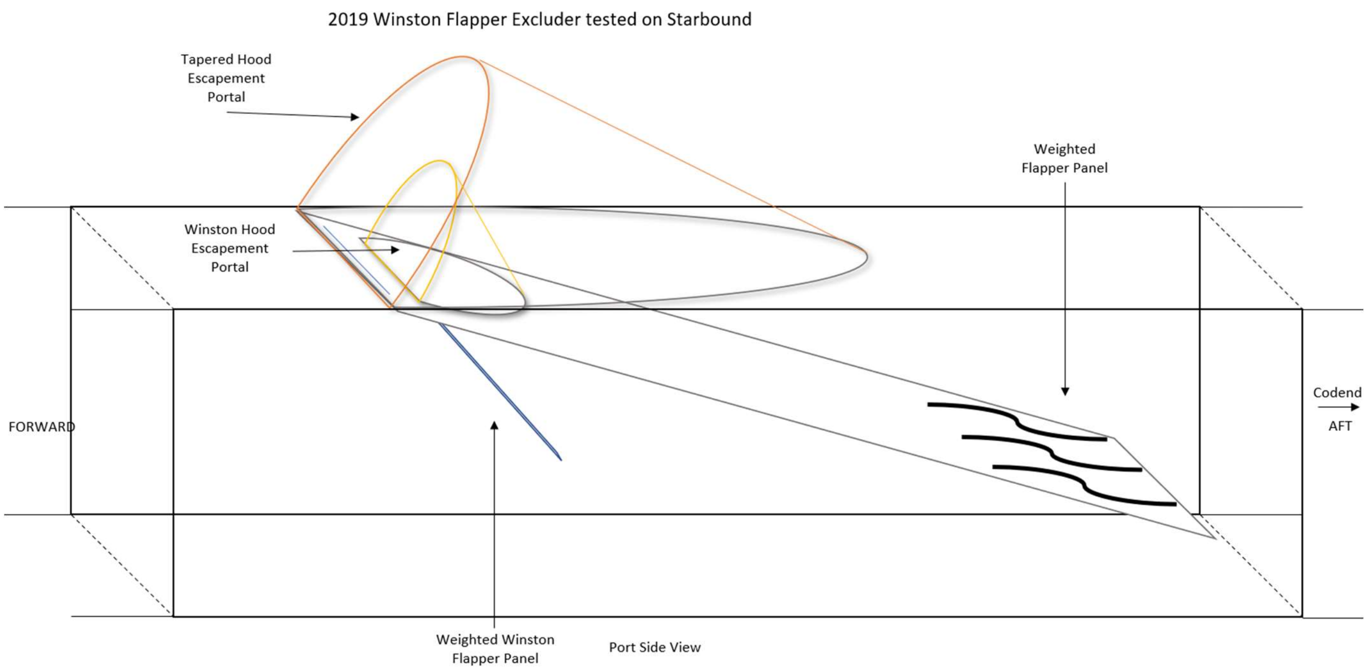

Figure 22: A modified Winston Flapper excluder tested on the Starbound in 2019. The main modification made is that the hood was tapered back to minimize the distance that salmon needed to swim in order to escape.

what was seen in the 2018 video, this was seen as a logical way to increase escapement by making it easier for the Chinook that at times accumulated in this area but never swam out of the net.

Despite the intent of the adjustments to the excluder for the 2019 tests, a significantly lower median Chinook escapement rate was the result for the 2019 season. In fact, the median escapement rate was only 9% instead of the sector's expectation for improvement over 30% in 2018. Perhaps most surprising with these results was that the confidence intervals around the 2019 results were quite narrow, indicating that the 9% rate was likely to be a large decrease in escapement performance rather than being attributed to variability (Table 4 and Figure 20).

In reviewing this result with the sector following the video review for the 2019 test, several possible explanations for the low escapement rate emerged. It was agreed that the modifications to the hood were unlikely to be responsible for the much lower 2019 Chinook escapement results. The sector felt that the explanation was more likely to be the very high pollock catch rates per hour in 2019. This, they felt, reduced the Chinook escapement rates by creating a high degree of congestion in the excluder section of the net such that Chinook were unable to find the way out or unable to access it even if they did sense the area of slower water behind the flapper panel.

Another possible explanation was that the higher pollock catch rates may have done something to affect the condition of the pollock and salmon passing back through the net. This was based on looking at the video footage from the 2019 tests which showed pollock moving back through the excluder section lethargically, almost lifelessly at times. One idea that was discussed was the possibility that fish passing back through the net had contacted stinging jellyfish as they passed through the excluder section. The catch during the Starbound EFP did have large amounts of jellyfish although whether jellyfish could create this type of outcome is not clear.

Another idea was that the high pollock catch rates may have caused pollock (and possibly even salmon) to become pinned on the meshes of the net ahead of the excluder or on the excluder's weighted mesh panel itself. This could effectively start to drown the fish by limiting their capacity to circulate water through their gills and could explain why the fish passing back at times looked lethargic.

In the end these possible explanations were discussed and there was little in the way of consensus as to whether these or other factors were most likely to explain the 2019 outcome. What was agreed was that nothing done to change the excluder's hood could have had such a significant negative effect on the pollock's vitality, nor could the changes in the hood really create or cause the decline in Chinook escapement. Pollock loss also increased with the modifications to the hood. The increase was from 0.25% to just under 1% (Table 4, Figure 21). While confidence intervals around this result suggest it is a statistically significant result, the low level of pollock loss is not likely to affect the economic feasibility of fishing with the excluder.

Year 3 (2020)

Based on the first two seasons of the EFP, the Winston Flapper portion of the excluder had not proved to have positive effects on Chinook salmon escapement. The sector therefore agreed to take the Winston Flapper and hood out of the excluder. With that change it was now a weighted flapper design with one weighted flapper acting as a ramp, and one floated hood providing space for salmon to escape.

Again, the focus for the sector was to encourage more Chinook escapement for those fish that used the flapper pathway to get out of the flow of target catch but didn't actually escape. To do this, the captain and crew wanted to try adding escape holes in the hood so that Chinook could swim out without having

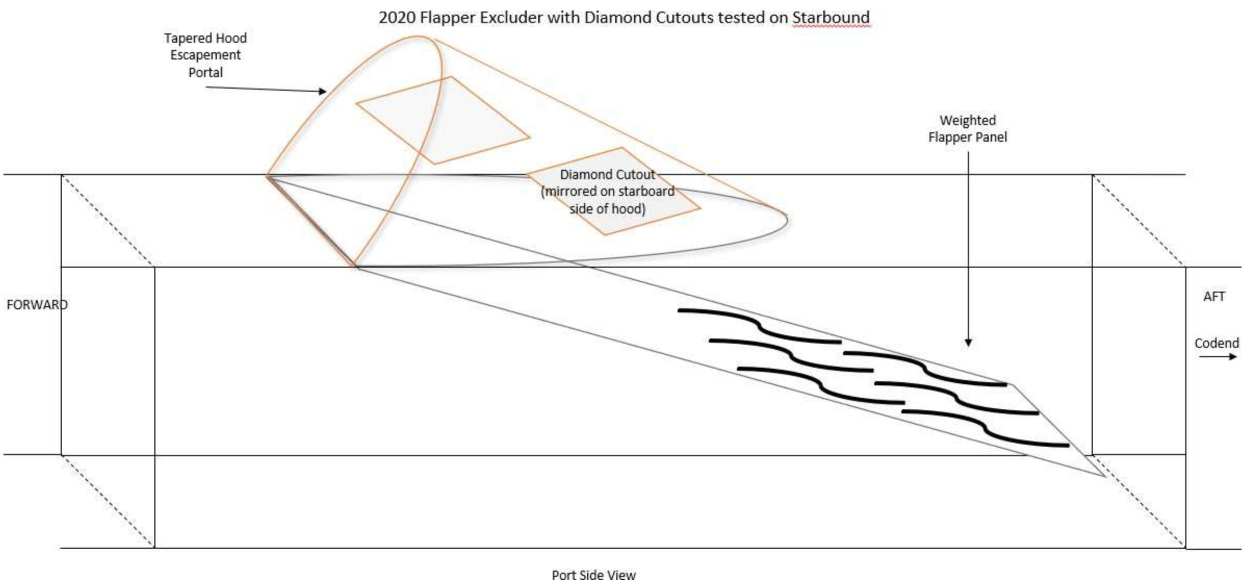

Figure 23: The Winston Flapper design with two diamond-shaped cut-outs tested on the Starbound in 2020.

to swim all the way to the forward edge of the hood. Accordingly, two diamond-shaped holes about 4 feet in length were cut out of the port and starboard sides of the hood (Figure 23). This modification increased the number of escape portals to three. The idea is that the salmon would have a chance to escape out of the diamond cutouts prior to swimming out of the hood, giving a lateral direction to escape as well as through the traditional route swimming all the way forward.

The EFP tests in 2020 for the Starbound encountered considerably fewer salmon per ton of groundfish similar to what was seen for all three EFP vessels in their final year of testing (though Year 3 testing for the Destination and Storm Petrel occurred in 2021). The Year 3 median escapement rate for Starbound was 35.71% which was an increase over the 2018 and the low rate in 2019 (Table 4, Figure 20). Inter-tow variability was quite large in Year 3 however, which resulted in large confidence intervals around the median and therefore the escapement rates were between 20% to 50% escapement. From the sector's perspective, the lower numbers of salmon encountered in the EFP gave them less confidence in the 35.71% escapement result being a true improvement over escapement in 2018. Overall, the 2018 and 2020 seasons had much better results than the very low escapement seen in 2019.

Pollock loss on the Starbound, meanwhile, steadily increased between the 3 years of testing (Figure 21). There was almost no variability in pollock loss in Year 1, but the variability increased steadily with each successive season of the EFP. The median pollock loss in Year 3 was 1.5%, but once again the sector felt this loss rate was operationally sustainable.

Objective 1: Overall conclusions, lessons learned, and future questions

As described above, Objective 1 was to make iterative improvements to Chinook salmon escapement based on data from each successive field test and input from the respective pollock vessel HP classes. Input included not only their review of the escapement rates for salmon and pollock but additional information about the testing conditions for each season, the pre-EFP images of the shape elements of the excluders, and video clips selected by the field project manager to be indicative of typical Chinook escapes and failed attempts at escapement.

As is evident from the resulting escapement rates for each vessel class per testing year presented above, the expected result of improved Chinook escapement rates with adjustments each season was not achieved (Table 5, Figure 24). Instead, the initial year result for each class of vessel had the highest or close to the highest Chinook escapement. Following the first year, participants made adjustments to the excluder based on what made sense or, in the case of the Destination, adopted a different excluder design and made adjustments to significantly increase Chinook escapement. The two following years the trials led to, when considering the confidence intervals, statistically the same (Storm Petrel) or significantly lower Chinook escapement performance; the nadir for Starbound in 2019, and 2021 being the significantly lower performance year for the Destination.

For the Storm Petrel, the initial year had the highest nominal rate of Chinook escapement although confidence intervals around results for each year generally suggest that adjustments simply didn't improve performance. The most surprising result for our lower HP category vessel was that the slow-downs done in 2021 didn't result in any improvements in Chinook escapement. This was quite unexpected because for first two years of the research the video footage revealed significant numbers of Chinook at the point of egress but failing to escape at the end of hauls. Another less common but still notable observation was Chinook coming forward during haul-back in Years 1 and 2 that didn't actually escape. For both situations, the short slow-downs seemed to be the best way to increase escapement but they just didn't produce that result. Perhaps they were insufficient in duration? Nor did they result in an increase in pollock escapement which was what the vessel's captain feared would be the inevitable cost of increased Chinook escapement.

From NPFRF's collective experience with salmon excluder testing and development (including Mr. Gruver's significant experience with salmon excluder design), one of the most counterintuitive results was for the Destination. In Year 3 that vessel performed the testing with a "zero-overlap" approach to an O/U excluder. That excluder clearly offered salmon the most accessible escapement pathway of any O/U excluder tested to date. And yet the Year 3 results showed what is likely to be a significantly lower Chinook escapement rate than the two earlier years using excluders with "less-aggressive" designs for reducing salmon catches.

For the Starbound, the adjustments made were certainly logical and informed steps to increase escapement from the initial result. The discussion of results for that vessel above reports two possible explanations for why the 2019 results were dramatically lower than for either of the other two years. The failure to achieve increases in escapement rates with each step was itself a surprise but most puzzling was that 2019 showed 9% escapement (compared to over 30% for the other years). And the cause of pollock and presumably salmon moving nearly passively through the excluder section remains a significant mystery.

Table 5: Escapement rates of salmon and pollock loss rates by vessel and EFP year [6].

VESSEL	YEAR	SALMON			POLLOCK			
		Cod-end (Number)	Escapes (Number)	Total Escape %	Cod-end (MT)	Escapes (MT)	Total Loss %	# Tows Tested
STORM PETREL	2018A	140	93	39.91%	331.8	6.1	1.81%	8
	2019A	65	36	35.64%	687.4	4	0.58%	11
	2021A	26	12	31.58%	697.03	1.04	0.15%	12
DESTINATION	2018A	80	38	32.20%	889.5	11.6	1.29%	11
	2019A	90	40	30.77%	877.2	6.6	0.74%	12
	2021A	78	14	15.22%	808.9	9.3	1.14%	11
STARBOUND	2018A	620	281	31.19%	2735.05	5.4	0.25%	30
	2019A	188	19	9.18%	2791.7	26.2	0.93%	27
	2020A	27	15	35.71%	2969.6	39.4	1.63%	26

There can be multiple reasons for failure to attain improvements through iterative adjustments in the process used for this EFP. Year-to-year variability of salmon encounter rates may have played a role in the escapement rates. The wider confidence intervals around median escapement do suggest that this variability affected escapement rates to some extent and we have attempted to take that into

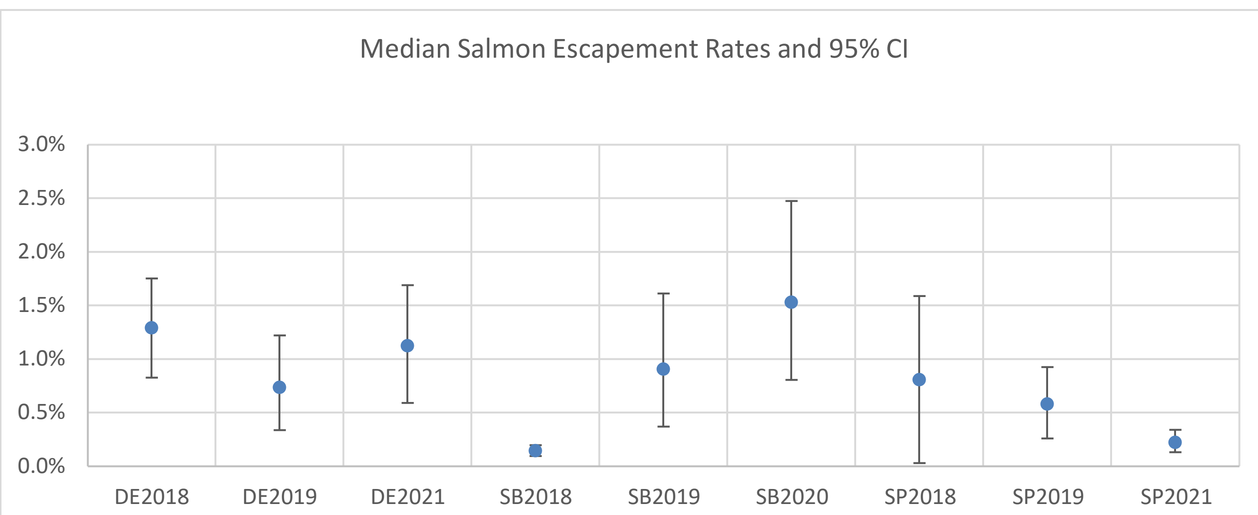

Figure 24: All median salmon escapement rates and 95% confidence intervals for all vessels and years.

[6] Results for Starbound are for three consecutive seasons starting in 2018. Due to a failure in data storage device our results for the Destination and Storm Petrel are for 2018, 2019, and 2021) were lost.

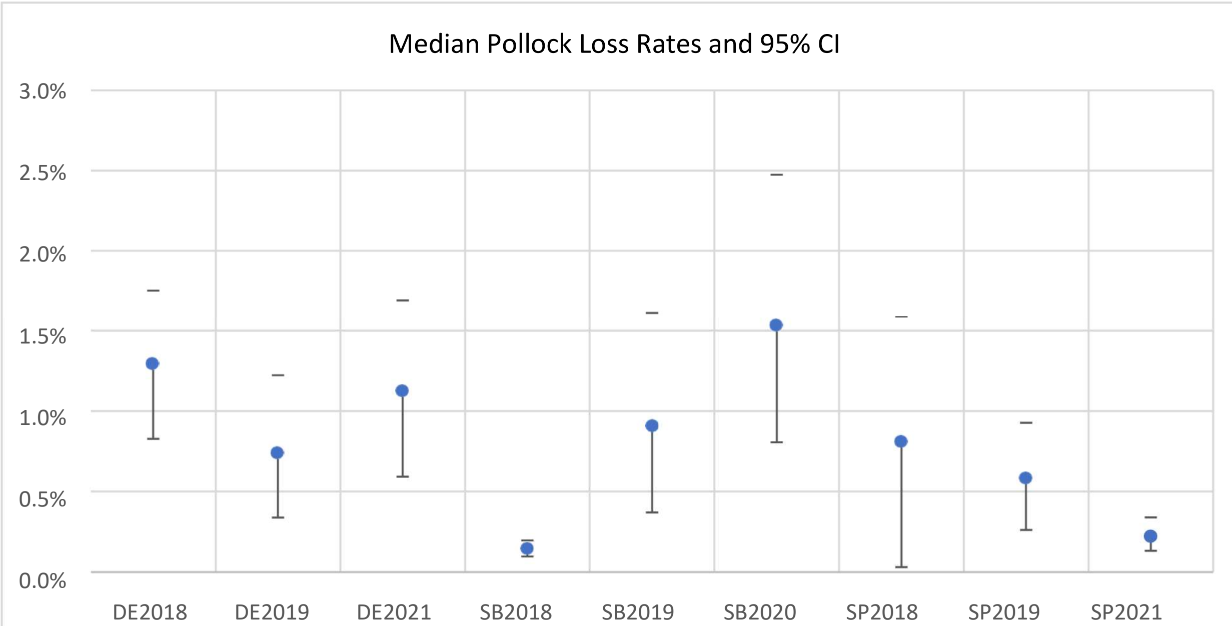

Figure 25: All median pollock loss rates and 95% confidence intervals for all vessels and years.

consideration in our explanation of what occurred (e.g. there was a nominal increase in escapement in Year 3 for Starbound but that increase is not likely to be significant because confidence intervals for 2018 and 2020 overlap). Spatial distribution of Chinook salmon in any given year and the degree salmon overlap with areas of concentrations of pollock varies widely and salmon distribution in any given year is likely to be patchy. While we endeavored to use communications between EFP vessels and vessels outside the EFP to find areas with higher concentrations of Chinook, and used Sea State data to locate hotspots as well, there is still an element of randomness and chance that is outside of the control of *in situ* research.

It is certainly possible that the adjustments made to the excluders at each stage did not, in fact, improve the design and may have inadvertently reduced the effectiveness of the design in some way. Those involved with the project provided their best expertise and advice before the commencement of the project and after reviewing the footage and results at each stage. Trawl gear is inherently a difficult gear to master, as it is difficult to observe the behavior of the gear and the response to salmon and pollock in its entirety. Fully understanding the complex dynamics of a piece of trawl gear and how adjustments affect the gear is a difficult task. The challenges of this type of research are acknowledged by other experts in the field also pushing forward improvements to excluder design[2]. Behavioral and design mechanisms affecting escaping are poorly understood, and even through our endeavors to systematically test escapement, a high level of variability is still present in our results.

Taking a more independent approach, the most likely explanation for our results is that we don't really

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[7] Yochum, N., Stone, M., Breddermann, K., Berejikian, B. A., Gauvin, J. R., and Irvine, D. J. 2021. *Evaluating the role of bycatch reduction device design and fish behavior on Pacific salmon (Oncorhynchus spp.) escapement rates from a pelagic trawl*. Fisheries Research, 236: 105830. https://doi.org/10.1016/j.fishres.2020.105830.

understand what factors incorporated into excluders or what conditions in nets during winter pollock fishing affect the chances that Chinook will use an excluder. Is it the towing speed and amount of relative water flow? Is it the amount of pollock moving through the net along with the salmon? Is it the relative amount of light, haul duration, or other myriad factors or combinations of them? If so, then how?

The next section addressing Objective 2 of this EFP describes our efforts to examine other factors given what we understood about how to account for them when we set out to examine covariates of factors affecting Chinook escapement with salmon excluders. It was anticipated that this effort would help to answer these important questions.

Objective 2:

Collect data to help identify factors affecting excluder performance

NPFRF's second objective was to collect data during the excluder trials to advance the collective understanding of factors affecting Chinook salmon escapement rates. For this part of the study, NPFRF explained that our previous efforts in this area were of limited success due to recognized shortcomings in data available to examine factors/conditions affecting escapement. These factors are frequently referred to as "covariates" by analysts.

As examples of data limitations, our application noted that a key factor affecting Chinook escapement rates might be the relative amount of pollock passing through the excluder section of the net along with Chinook salmon. Attention to this factor's possible role came originally from talking to fishermen who have used excluders during winter pollock fishing and felt they were less effective when catch rates of pollock were higher. Escapement affected by congestion was also apparent from NPFRF's review of video collected during earlier EFPs where congestion in the excluder section often does seem to affect a salmon's ability to access the escapement pathway.

To assess how pollock catch rates could affect Chinook escapement, NPFRF's previous analytical efforts compared "average" pollock catch rates per haul (groundfish catch per haul divided by minutes of haul duration) and Chinook escapement rates to see if there was a relationship. Using average catch rates was the best that could be done analytically given the available data, but this could well have overlooked what might actually affect the chances of escapement. Specifically, from experience looking at headrope sounder images, fishermen know that pollock catch is rarely a steady flow into the net and sometimes most of that catch occurs in a small fraction of the duration of the haul. A better way to examine how pollock catch rates affect salmon escapement would likely be to evaluate the instantaneous amount of pollock passing through the excluder section of the net at the time salmon were in that section. Recognizing this, our EFP set out to do just that and methods were developed to do this in a manner thought to be adequate.

Another factor expected to be of importance was the relative speed of water flow in the net. Past efforts to look at how speed or water flow affected salmon escapement rates compared "towing speed" (speed over bottom measured by GPS) relative to escapement rates per haul. But this ignored what was potentially the most important aspect of how water flow affects escapement: the amount of water flow determined in part by direction of the tide relative to the vessel's course. Towing speed and tide direction can work together, against each other, or create a myriad of effects on flow rate/direction if the vessel is towing at an angle to the direction of the tide. The combined result of how these effects translate through net meshes is the environment that salmon face as they attempt to move forward in the section of the excluder leading out of the net. The type of mesh (e.g. hexagonal or diamond mesh), the size of mesh, and the taper of the net where the excluder is installed also affect water flow, and so all potentially affect a salmon's ability to escape.

To better understand how water flow affects escapement, our EFP application noted that research underway at the time of our application by Memorial University's Marine Institute (MUMI) in Newfoundland could allow us to better assess how water flow rates affect Chinook escapement. MUMI was at that time evaluating a commercially available water flow meter to see if it provided consistent and accurate flow rates in trawl nets. At that time their preliminary assessment using models of trawl nets deployed in a flume tank suggested that the device could potentially provide reasonable rates of flow. While they were optimistic the device would provide this important information, they also planned to do actual validation in towed fishing nets in actual trawl fishing conditions.

Other potential sources of covariate factors that might better explain Chinook escapement rates discussed in the EFP application were relative amount of light at fishing depth. Relative amount of light includes ambient and artificial light from the study's cameras. Lastly, the vessel's activity (e.g. normal towing, turning, hauling back) at the time of escapements was included in our list of factors felt to be linked to Chinook escapement rates.

To evaluate these covariates, our plan was to collect information/data with synchronized time-stamps during the haul so that we could evaluate how factors varied individually and jointly during a haul. These could then be examined to evaluate whether some or all of them were correlated with times Chinook escapements occurred. The expected product of this would be an analysis of which factors or combinations of them best explained escapement rates for Chinook seen in our data from Objective 1.

Unanticipated limitations to covariate study design

It is important to flag that a critical assumption made in the design of this Objective 2 study was that Chinook escapements were essentially (more or less) a one-step process that occurred in a fairly short and/or consistent timeframe. This assumption was based on past tracking of salmon escapements with cameras located primarily at the escapement portal(s) of flapper and O/U excluders. Our study of factors affecting escapement added cameras installed aft of the excluders' weighted (or weighted and floated) mesh panels. These were intended to provide data on amount of pollock moving through the net, but they also revealed something unexpected about how Chinook salmon used the escapement pathway and this new information complicated our study design. Specifically, having cameras at both ends of the escapement pathway revealed that some Chinook took considerable time to move from the aft edge of the excluder's mesh panels up into the hood. And some also hesitated for considerable periods of time at the point(s) of egress at the edge of the escapement portal(s). This at times took approximately 20-30 minutes, or even longer.

This new information was apparent only when there were limited amounts of pollock in the escapement pathway and water clarity allowed the aft cameras tracking pollock in the excluder section to also see salmon moving forward. The time-stamps on the salmon escapement cameras and the pollock tracking cameras allowed video reviewers to track what was likely to be the same fish for some elongated escapes, but this was only possible when there was one salmon in the escapement pathway, or just a few salmon of distinctly different size.

Overall, however, it is important to understand that the only time we could observe that a subset of the salmon escaped over a longer-than-expected duration was when there were relatively few pollock in view, water clarity allowed for viewing an extended distance, and there were limited numbers of salmon in the area at the time. We know that we were able to track a subset of the salmon this way because we know the overall number of escapes per haul and thus the few seen through the tracking from the aft camera represent only a fraction of the whole. Ultimately, we don't know anything about how long it took for salmon to escape when the view did not allow for us to track them from aft of the excluder panels.

This new information, unfortunately, exposed a flaw in our study design to evaluate relative amount of pollock in the excluder section as a factor affecting salmon escapement rates. In retrospect, had we known that some escapements cover a fairly long duration, we would have attempted to collect data on whether a salmon was able to start the process of moving up into the hood as this was probably what was affected by the relative amount of pollock in the net at that time. Collecting data on when salmon started the escapement process, however, would have been challenging given that our ability to see them when large amounts of pollock are in that section of the excluder is quite limited. Perhaps additional cameras located in this area or cameras looking from the side instead of the top would have enabled more success, but consistently seeing salmon when there are dense amounts of pollock is likely to be unsuccessful.

Another unfortunate outcome was that the researchers at Memorial University evaluating the promising new water flow meter inside trawl nets found that the device was not reliably able to measure water flow in trawl nets during real fishing conditions at sea. This brought home the underlying difference between measuring flow in the controlled environment of a flume tank compared to the more dynamic environment inside a trawl net in the marine environment. Upon getting this unfortunate update, we considered other means of tracking flow. Alternative devices were suggested but upon further consideration none of these were deemed to have much potential to function correctly in trawl nets. Key in coming to this conclusion was the underwater video segments of pollock (and clouds of euphausiids etc.) pouring into a Bering Sea net under normal pollock fishing conditions. We provided these to various researchers proposing different devices to gauge water flow in a trawl net and this led them to reconsider their recommendations. These video clips also included the normal effects under typical Bering Sea wave/swell conditions influencing the nets towed by pollock vessels in winter.

All of the above complicated our ability to follow the methods we originally proposed for assessment of factors affecting escapement rates for Chinook. Regardless, we report below on our efforts and attempted adjustments, the data we collected, and our revised methods to analyze the data we collected. This part of the report may present valuable information to help future research refine ways to look at the important issue of understanding covariates affecting Chinook escapement with salmon excluders.

Data Collection Methods for Covariate Analysis

Indexing relative amount of pollock passing through excluder section during EFP tows

Originally the idea for systematically tracking how much pollock was moving through the section just aft of the excluder panels was to use a recording echo-sounder device. The device would run off battery power that would be contained within the housing, such as the recording wide-beam sonar NMFS' RACE Division provided to NPFRF in our earlier efforts to understand how funnel and tunnel excluder designs using square mesh affected the shape of the back end of a pollock net. After consulting staff at AFSC's RACE Division, we learned that they do not have a recording echosounder along the lines of the recording sounder they provided to us years ago.

We also talked to several companies that supply sonar and other sensing equipment, but they were unable to provide a recording echosounder/sonar/imaging system meeting our requirements for use that far back in a trawl net (beyond the range of the power supplied to the headrope sounder). One company recommended using a live video camera installed in this area such as the ones used by many catcher processor trawl vessels in recent years. Those cameras draw power and transmit data from a dedicated winch and cable system separate from the normal third-wire net sounder in use on most pollock vessels. These systems are known to be effective but are costly to install.

Given video was deemed to be the only practical way to provide data on relative amount of pollock in the excluder section of the net, recording video cameras would probably be the most cost-effective approach for our study, particularly where NPFRF already had additional underwater camera systems with light, camera/data storage, and battery contained in a sealed tube system allowing data downloading and charging. The advantage to an echosounder, however, would have been that the data might have been in a digital format that would not have required human review. But lacking any available recording echosounders, we adjusted the plan to include human review of the pollock flow video data.

The cameras dedicated to recording the flow of catch moving through the excluder were mounted in the aft section of the excluder facing forward (Figure 26 and Figure 27). This orientation allowed the video reviewer to use the continuous time-stamped images from the terminal edge of the flapper to quantify and characterize the amount of catch moving through the excluder section during each haul.

Video analysis for each haul started when the excluder took shape at the start of the tow (which was considered the start of fishing). For the review, every 30 seconds the video was paused and the number of fish in the frame were counted and recorded (see Figure 28 for examples). If the pollock within the viewing frame sampled at the 30-second interval was too dense for the video reviewer to discern the number of individual fish or if fish were up against the camera lens blocking the view, then the reviewer advanced the video forward from the 30 second interval until the view was sufficient for counting pollock within the field of view.

At two different stages of the review of the pollock flow video data we had meetings with Dr. Dayv Lowry (WDFW), and Dr. Noëlle Yochum (AFSC RACE Division) who agreed to provide technical assistance for our efforts to collect and analyze covariate data. Both scientists have extensive experience with video review for fish behavior and accounting for differences in catch rates and performance with gear modification testing. Their advice was critical to our ability to develop systematic methods to account for the amount of pollock in the excluder section and solutions to unanticipated challenges (e.g. salmon escapement not a one-stage process but occurring over a fairly long period of time in some cases).

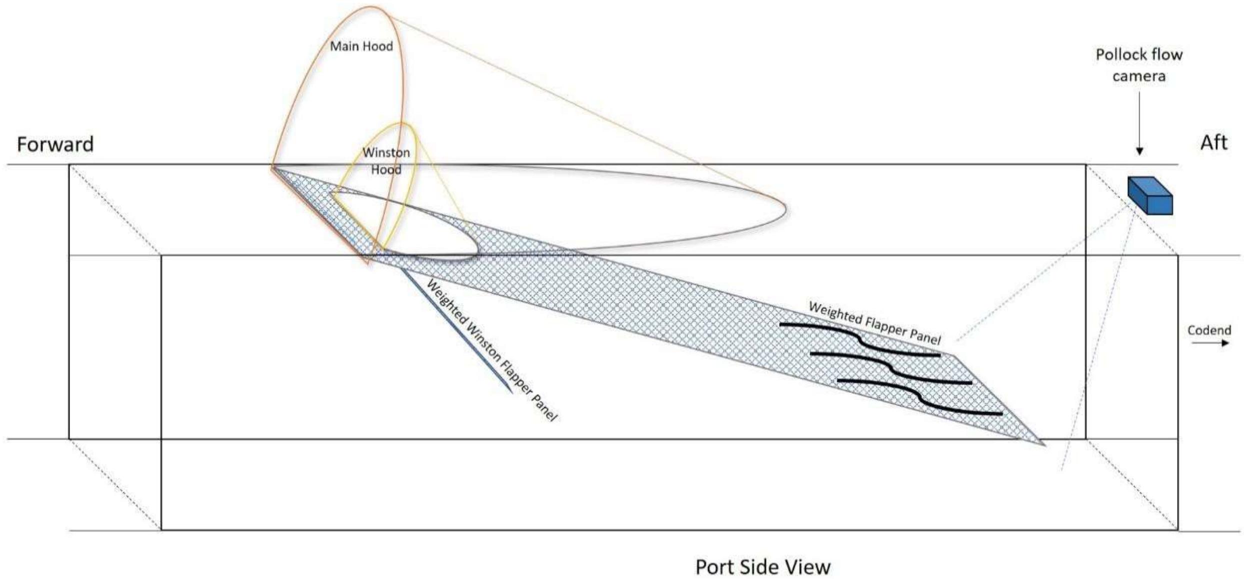

Figure 26: The pollock flow camera placed inside on the top sheet of the Winston Flapper excluder behind the hood, near the

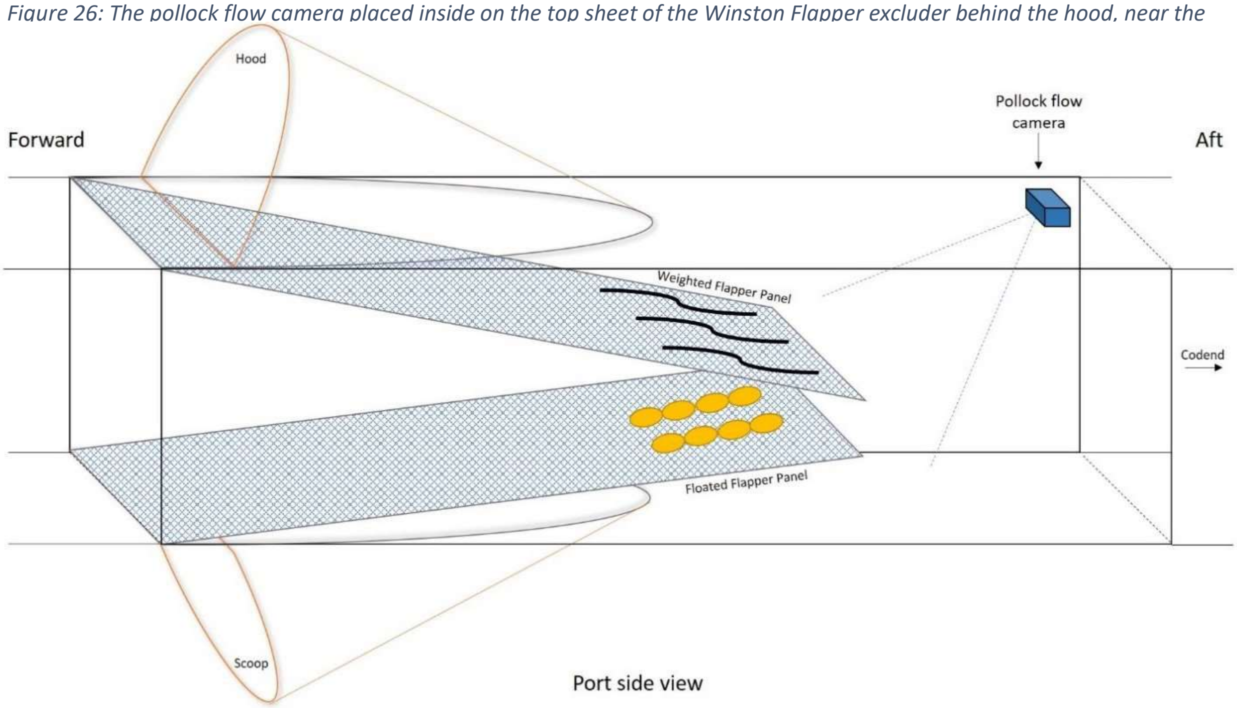

Figure 27: Example clips from the time-stamped video collected by the pollock flow camera.

Figure 28: The pollock flow camera placed inside on the top sheet of the O/U excluder behind the hood, near the excluder seam, facing forward. The camera was angled downward.

One challenge for systematic accounting of pollock was that water clarity/light at times changed the area of view during some tows. This effectively changed the amount of area that could be seen and at times made it possible to account for pollock in a larger area. Not accounting for this would tend to inflate the amount of pollock passing through the net at these times. To avoid this, our experts recommended that the reviewers use a set number of net meshes to frame the area of view to allow it to remain as constant as possible. This approach worked well to standardize the area. If the field of view was less than the area inside the framed set of meshes, the reviewer advanced the video to the closest frame where accounting could view the entire framed-off area. This typically occurred mostly from pollock being up against the camera lens itself, or so close that the light reflected off the fish obscured the field of view.

Effects of the relative amount of light on salmon escapement

Our investigation of effects of light on salmon escapement rates originated from feedback received in the excluder workshops prior to the commencement of this EFP. A belief by many in the pollock industry was that Chinook salmon are attracted to light, so adding light to the salmon excluder should increase escapement. No systematic information was available to evaluate this assumption and given many in the industry were gearing up with different versions of supplemental lights with the expectation of increasing escapement, it was important to try to evaluate whether we could detect the effects of degrees of light on escapement rates.

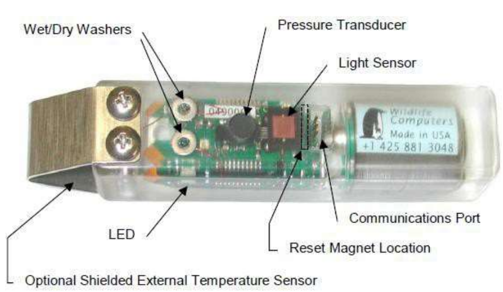

Figure 29: Wildlife Computer MK9 archival tag.

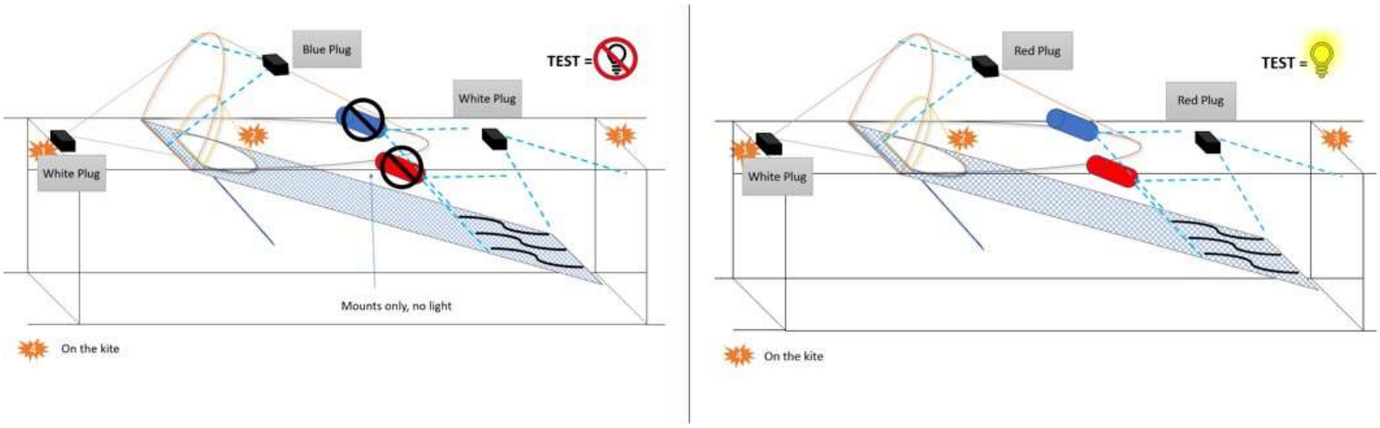

*Figure 30: Schematic showing position of cameras, types of lights used for those cameras (designated as white [**no light**], red [**high light**], or blue [**low light**]), and whether the tube lights were on our off to test a low-light environment compared to a high-light environment and how it corresponded to salmon escapement.*

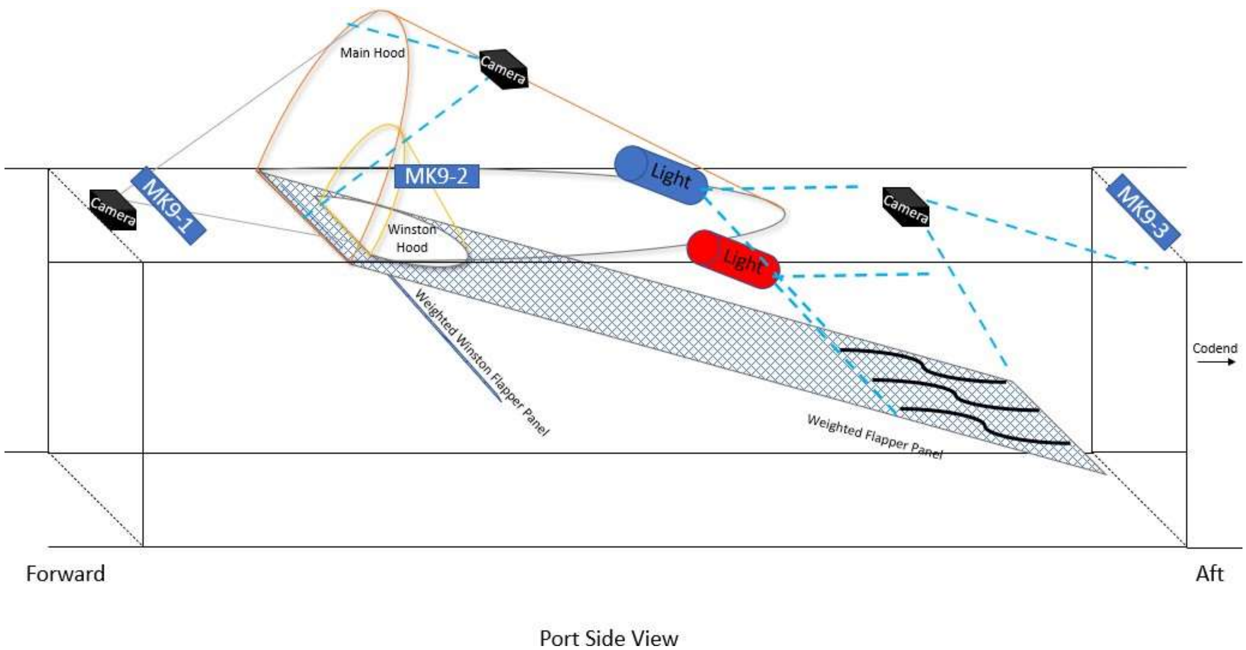

Figure 31: Schematic of MK9 placement and cameras and lights for the 2019 Starbound tests.

In 2019, data collection on all three vessels included light sensors. The light sensors were Wildlife Computer MK9 archival tags (Figure 29) borrowed from AFSC's Dr. Yochum. They are small and easily attached to the net, and then once submerged they sample and store depth and relative light- level. These sensors were attached to the excluder in locations where we expected salmon to perform important behaviors like swimming out of the catch and escaping (Figure 30 and Figure 31). The relative light-level data was time-stamped and recorded continuously for the entire tow.

Light proved to be a challenging covariate to observe given that our salmon excluder work involved testing with lighted cameras to account for escapement rates. Essentially, we were evaluating the combination of ambient (in winter where ambient light is quite limited) and artificial light in the excluder section. Evaluation of the effects of light on escapement rates would likely be more straight forward if differences in ambient natural light alone were the treatment variable. There was no way to do this, however, because without the artificial lighting to track escapement the most important objectives of the research would not be accomplished.

It is worth noting that earlier in NPFRF's efforts to test excluders, recapture nets were used to account for escapement rates. This avoided the influence of light from tracking escapement but included the effects of recapture nets on salmon escapement. Many in the pollock industry thought that adding a secondary net on the outside of the excluder itself greatly affected escapement rates for salmon and pollock. Another solution here might have been to use infrared light or a fast-updating sonar unit that might allow for differentiation between pollock and salmon escapes. Based on our understanding, salmon behavior is not affected by these. Unfortunately, equipment to account for escapement under these alternative approaches was not available for our work.

Another challenge we had with the MK9 sensors was that they were not sufficiently rugged for the testing environment on pollock vessels in A-season fishing conditions. The 3D-printed housings unfortunately bent or in some cases broke apart when exposed to ambient conditions and forces during our winter tests. We had some back-up sensors, but over time as some of the units failed, we had insufficient numbers to cover all the desired locations for measuring light levels for the second and third vessel in the testing line up.

Accounting for vessel activity as a factor affecting escapements

To account for differences in escapement rates when EFP vessels were turning or hauling back the net relative to normal towing speed in a straight line, the EFP field project manager arranged for the captain and mate of each EFP vessel (whoever would be in command of the vessels at different times during the tests) to record vessel activities during hauls. Each was provided a form where they could record the EFP haul number, net deployment time, start and end time of turns, start of haul-back, and end of net retrieval time. We did not include the vessel master's estimate of the time the net started fishing (was sufficiently deployed for fish to start entering the excluder section of the net) because we were able to determine that with our recording cameras. Likewise, for turns and haul-backs, the video cameras and time-stamps were useful for making sure the vessel master's noted times were accurate. This is because the effects of a turn or the start of a haul-back are detectible from the video footage soon after they occur because the shape of the net and the change in tension on the net meshes becomes obvious from the video.

Analytical methods for evaluation of effects of covariate factors on escapement rates

Our original plan for covariate data analysis in our EFP application stated that various statistical approaches to covariate data analysis used in similar studies would be used. We learned from the additional camera deployments, however, that instantaneous factors such as amount of pollock in the excluder section, relative amount of light, and specific vessel activity were not directly relatable to salmon escapements. Certainly, some of the Chinook salmon escapes were within a short period of time of the factors we tracked, but for many of the escapes the conditions we tracked had occurred 20-30 minutes before the actual time of the escapement. We considered lagging the recorded escape time, but this would be arbitrary because our ability to estimate average escapement time for salmon was higher when there were fewer pollock in the viewing area. We really have no information about how long it took salmon to escape during periods of high pollock density inside the excluder section of the net.

In recognition of this unforeseen limitation to our approach and data collection methods, we followed the advice of our experts in video review and fish behavior assessment to do an exploratory analysis. This involved creating a timeline for tows where the covariate data was collected reliably. On this timeline we decided to note the times salmon escapes occurred and we blocked off a five- minute period centered around the actual time of escapement. We then overlayed our covariate data onto this haul-specific timeline. This afforded a way of examining if any specific factor of interest seemed to explain when escapes occurred. This was informative to some extent, as what was clear is that escapes in the bracketed five-minute periods don't appear to be consistently related to any of the factors for which we collected data. We did consider putting brackets of 30 minutes around escape times, but this would essentially be arbitrary and would blunt level of precision used for the covariate data collection.

The timeline plots shown in Figure 33 - Figure 55 (Appendix 1) are for the Destination and the Storm Petrel in 2019 alone. Data on our covariate factors were collected in 2018 and 2019 EFP seasons but our efforts in 2018 can definitely be described as affected by a steep learning curve and adverse conditions.

Cameras were installed to collect data to track the amount of pollock aft of the excluder in both 2018 and 2019 during Storm Petrel's EFP tests. Our efforts in 2018 ceased after just a few hauls for safety reasons. Storm Petrel can only use its aft net reel during EFP test fishing because the on-deck conveyor belt system required for volumetric accounting of groundfish catch necessitates that the forward net reel cannot be used. Haul-backs with the aft net reel require the Storm Petrel's crew to fasten the net to the vessel with spectra holding straps. This is to prevent the situation where our project manager would be in the process of recovering the camera inside the net when the vessel surges forward but the cod-end is still in the water, thereby creating considerable force on the holding straps. Such as situation would present a considerable risk for a crew member or project manager being pulled overboard while inside the net. To avoid this situation, we opted to drop placements of cameras aft of the excluder on Storm Petrel in 2018. We did make these placements in 2019 due in part to a better system for securing the net during camera placements and relatively better weather conditions during Storm Petrel's part of the EFP in 2019.

Cameras were deployed on the Starbound in 2018 and 2019 to track pollock flow but success in this endeavor was quite low despite several adjustments to the camera placement locations and light settings for the cameras. The unanticipated challenge was that the dimensions of the excluder section of the Starbound's net are much larger than for catcher vessels. This results in the locations where a camera needs to be to be able to view the entire area of interest often exceeding the viewing distance of the cameras given the water clarity conditions.

Collection of data on the amount of pollock flowing through the net was done on the Destination in 2018 and 2019 but 2018 data were deemed to be largely unusable due to the stormy conditions during the Destination's testing period in 2018 and poor water clarity that results for a period of days and sometimes weeks following each storm that came through. Several rounds of adjustments in the camera locations were made to attempt to get sufficiently clear views for gauging the pollock catch rates with reasonable accounting precision. Unfortunately gaps within a haul due to a learning curve with the use of the new cameras for this work and the relatively low visibility lowered the utility of the data for the 2018 data.

Our attempt to review the data for at least gauging pollock catch led to the finding that many of the segments where visibility was poorest were likely when most of the pollock catch occurred. Bottom line was that the images at these times were not clear enough to allow accurate accounting as per our proposed methods. For 2019 not only were conditions better but our experience in 2018 led to adjustments in camera light settings, camera battery charging procedures, and camera location adjustments that solved many of the problems encountered in 2018.

Figure 33 - Figure 55 (Appendix 1) shows the 2019 plots for Destination and Storm Petrel displaying the number of pollock in the field of view at 30 second intervals and the vessel activity occurring at the same time. Plots in Figure 33 - Figure 55 show when Chinook escapes occurred (bracketed into five-minute intervals) and corresponding number of pollock in 30 second intervals and vessel activities (in continuous intervals).

Discussion of degree to which instantaneous amount of pollock and vessel activity may explain Chinook escapements

Reviewing the data from the 12 Destination and 11 Storm Petrel 2019 hauls Appendix 1, Figure 33 - Figure 55) where we were able to adequately track pollock moving through the nets we see that the five-minute windows around Chinook escapements do not appear to be particularly correlated with the amount of pollock moving through the excluder section of their nets. In some of the plots there does appear to be at least a weak negative relationship between sections of the haul with high numbers of pollock in the excluder section of the net and lack or relatively few Chinook escapements but for other hauls there really is no apparent pattern or correspondence between the two.

Reviewing the haul-specific relationship is admittedly fairly tedious but we included it here in case some hauls showed a clear relationship but others did not, perhaps allowing us to make some inferences about why that was the case. To look at the relationship more comprehensively we aggregated the numbers of pollock in the 30-minute intervals for all tows in the timeline plots for the two vessels into bins and overlayed binned numbers of Chinook escapements (Figure 32). This illustrated what we expected from looking at the individual haul data in term of Chinook escapes occurring in nearly evenly across all the levels of pollock per minute. One observation that may be

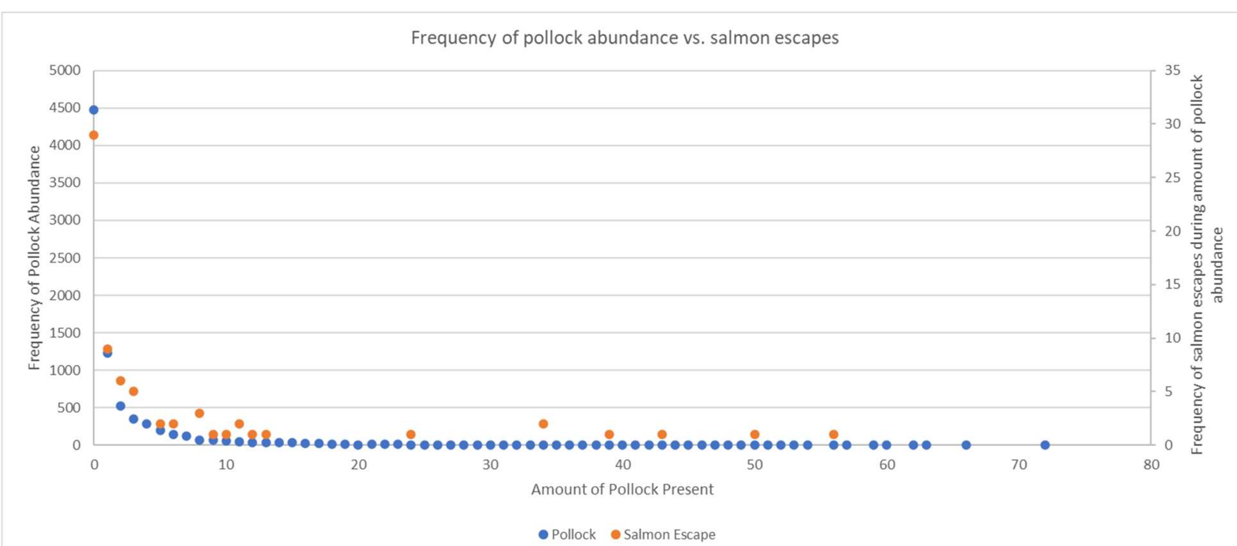

Figure 32: Frequency of pollock abundance verses salmon

meaningful from the aggregated/binned data is that at the highest level of pollock numbers in the field of view do not correspond to any times when Chinook escapements occurred.

An additional aspect seen in the data shown in Figure 32 is that most of the Chinook escapes occurred when amounts of pollock in the excluder area were relatively low. This may also suggest a negative relationship between escapement and amount of pollock in the excluder section of the net. But caution needs to be applied before we make any strong inferences from the information in Figure 33 - Figure 55. One important thing to keep in mind here is that salmon may enter the net in the water column as the net is being set to a higher degree than pollock. If this is the case, then salmon may be moving back through the net before the pollock on some hauls. This would suggest that the relationship is not one where Chinook escapement is somehow thwarted or occurring at a lower rate due to higher relative abundance of pollock in the excluder section. Instead, salmon may simply be ahead of the pollock. Likewise, for Chinook that come back to the excluder section after passing that area on their way back through the net (something that video reviewers see commonly during haul-backs) this is likely to be a time when lower number of pollock are seen in the excluder section. This would probably be best explained by Chinook being better swimmers and more able to preserve energy to move forward when the water flow slows down during haul-back than pollock are generally capable of.

As we attempt to think about possible relationships between instantaneous amounts of pollock and Chinook escapements seen in Figure 33 - Figure 55, the overriding limitations to our data collection needs to be kept in mind. The expected relationship was that large amounts of pollock in the excluder section would reduce opportunity for Chinook to escape. But some of the salmon escapements occurred considerably later than the time that these fish were directly affected by the congestion of pollock at the aft end of the excluder's mesh panels.

As was noted in the introductory section, we would ideally have been able to collect data on the instantaneous amount of pollock and compare to the time that salmon passing back through the net actually started the escapement process by moving out of the flow of fish in the excluder section into the pathway forward. That would likely have been a more logical way to compare how escapement was affected by the instantaneous amount of pollock in the excluder section of the net. But our methods did not collect that information because we don't have a way to reliably observe salmon in the presence of relatively large amounts of pollock in the area of interest. Another confounding element in observing the Chinook escapement process in the presence of different amounts of pollock is that salmon that appear to start the escapement process don't always escape (we observed many falling back and continuing back in the net). Even those that do escape take varying amounts of time to accomplish the entire escapement process and there is really no way to time the process for individual salmon when there are multiple fish in the excluder's escapement pathway.

Finally, and even more confounding, is that there are salmon that appear to make little or no effort to escape as they move back in the net, but then some of these salmon move forward later on in the haul. It is unlikely that pollock at the time of escapement affect the chances of escapement for salmon that move forward later on in the haul. But the relative amount of pollock in the excluder section when they first moved back through that area may well have affected their chances of using the excluder at that time.

Ultimately the take-home message here is that attempting to explain how amount of pollock in the excluder section affects Chinook escapement rates is, from our experience anyway, not a straightforward undertaking. That said, many pollock fishermen are convinced that excluders that provide a better opportunity for Chinook to find the pathway on their way back the first time are likely to be more effective at reducing Chinook bycatch. Pollock fishermen also think that the better an excluder creates room for salmon to get out of the congestion from the flow of pollock, the better the excluder will achieve selectivity. Our attempt to examine the underlying relationships that are embedded in the thinking expressed by fishermen was simply not successful in examining the underlying mechanisms adequately.

Figure 33 - Figure 55 also provide information to examine how vessel activity (and amounts of pollock) are related to salmon escapes. Just as with the data presented on the instantaneous amount of pollock, we see that Chinook escapes occur during fishing, during haul-backs, and to some extent during vessel turns. To some extent the amount of pollock in the excluder section seems to be affected by the vessel activity more predictably than the Chinook escapements. This makes sense because turns and haul-backs would likely be times when the amount of pollock in the excluder section would tend to be lower than when the net is being towed at full towing speed. But just as we describe above, the vessel activity may trigger Chinook to start the escapement process but ultimately if the escapement process takes more than just a few minutes then tracking how vessel activity affects times of escapements may not be the best way to look at effects of what the vessel is doing. For example, a turn may be what entices a salmon to move forward after passing the excluder section originally, but may not actually escape until after the turn when the vessel resumes full towing speed for fishing.

To some extent, vessel activities that involve less water flow (turns and haul-backs) may be better explained by the methods in our study. This is because turns and haul-backs occur over longer periods of time relative to 30-second intervals of pollock moving through the excluder section. That said, however, the timeline plots show as many salmon escapements during fishing (full towing speed) as during turns and haul-back. This suggests that we cannot say anything conclusive about different vessel activities contributing to Chinook escapement rates with the limitations to our study design and the fact that some salmon take relatively long periods of time to complete escapements. Ultimately, turns and haul- backs affect water flow and perhaps direct and accurate measurements of flow in the net (when instruments that can do that reliably are available) will be a better way to understand how vessel activities affect escapement rates.

Finally, we had originally set out to include data on the concurrent amount of light in our examination of factors affecting Chinook escapements. Unfortunately, the data on relative amount of light (combination ambient and artificial) with the sensors we used essentially showed very little change in light at fishing depths during any of the hauls shown below. This is probably because daylight hours are short in winter and the amount of ambient light at fishing depth in winter months is minimal, whether it is daytime or nighttime. For this reason, we opted to look at light as a threshold factor to examine the number of Chinook escapes occurring on daylight versus nighttime hauls in the EFP for the three vessels (determined using the time for sunrise and sunset). These data are presented in Table 6 below.

As can be seen in Table 6, for the Destination and the Starbound the fraction of daylight versus night Chinook escapements is nearly evenly split between day and night and was similar for the two vessels. The Storm Petrel had a much larger fraction of its escapements during nighttime. The reasons for Storm Petrel’s larger fraction during nighttime are puzzling because light sensors showed almost no difference in light levels at towing depths for each vessel whether fishing during night hours at the surface or during the day.

Table 6: Comparison of salmon escapes during daylight hours and nighttime hours for all three vessels.

	Destination	Starbound	Storm Petrel
Sum of salmon escape	38	11	36
Escapes during daylight	22	6	8
% escapes during daylight	57.9%	54.5%	22.2%
Escapes during darkness	16	5	28
% escapes during darkness	42.1%	45.5%	77.8%
***B lit**		2	
% escapes lit		18.2%	
***B unlit**		9	
% escapes unlit		81.8%	

Summary of findings from our study of covariate factors affecting Chinook escapements

As described in our introduction to Objective 2 for the EFP, we encountered several challenges to what we set out to do. We learned from having multiple cameras tracking the aft and forward section of the excluders for escapement that some salmon take considerably longer to complete the process of escapement than we originally understood. This created significant challenges because our methods assumed that tracking instantaneous amounts of pollock in the aft end of the excluder's mesh panels would be reasonably effective way to understand how congestion created by pollock affects Chinook escapement rates. While our efforts allowed us to recognize that the process was different for some salmon, we were unable to adjust data collection based on the time salmon started the escapement process due to inability to reliably make that determination for salmon starting the process when large quantities of pollock were present. Even if we had found a camera angle that would have allowed for that determination, we still would not have been able to relate this to actual escapements (some salmon start the process but turn back or fail to escape and are recovered in the forward section of the excluder above the mesh panels at haul-back).

The inability to track escapements and water flow in the net was perhaps the most disappointing aspect of this part of the study. When we proposed to look at this factor, we were confident that the instruments to do so reliably would be available. Having a systematic and accurate way to gauge water flow in a trawl net *in situ* as opposed to a flume tank will be especially important to understand how vessel activity affects escapement rates as well. This is because instead of simply assuming a turn or haul-back creates lower or at least different water flow levels, data to measure and understand how great these differences are (including the effects of tide flow and direction) will finally be available. We remain confident that for excluders of the type tested in our EFP (requiring Chinook to swim up and forward to differing degrees), accurate recording of water flow will ultimately be very important for understanding rates of escapement.

Our discussion of the degree to which Objective 1 was achieved underscored that adjustments intended to improve escapement rates for each HP class of the pollock fishery indicated that a better understanding of what makes salmon excluders actually work was needed. While adjustments and tweaks were made to excluders at each stage based on what fishermen and net designers with decades of experience thought would work, we didn't see the linear improvement we expected. This underscores the need to dig in further to understand factors that actually affect excluder performance. We are hopeful that by recounting what we attempted to do to understand covariates this information will be useful to other researchers that follow our work. Ultimately this information is critical to making real improvements to excluder performance for reducing Chinook salmon bycatch.

Acknowledgements:

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We thank Dr. Noelle Yochum of the NMFS' Alaska Fishery Science Center for scientific and technical advice and her willingness to loan equipment for our fieldwork. We also thank Dr. Dayv Lowry, formerly of the Washington Department of Fish and Wildlife, for advice on collecting and analyzing underwater video. Next, we wish to acknowledge Bridget Mansfield and Anne Marie Eich of the NMFS Alaska Regional Office for their help in development, approval, and modification of the exempted fishing permit. Without their willingness to take on this additional work we would not have been able to do the research (or continue when we hit unforeseen obstacles).

We thank Susie Zagorski for her work on the vessels as field project manager from 2018-2020 and her data review work throughout. And I personally want to thank Brianna Bowman King, co-author of this report, for her willingness to take over Susie's field project manager role when Susie had other work obligations.

We also want to express our appreciation to all the NMFS observers who stepped in as sea samplers on each EFP field season.

On the pollock industry side, we especially thank John Gruver for his enduring and tireless commitment to design work on salmon excluders for this and earlier salmon excluder EFPs. Mr. Gruver has from the beginning been willing to put his own ideas into flume tank models and actual excluders. And he has patiently worked with pollock fishermen interested in doing the same. We also want to express our appreciation to Caitlin Yeager, cooperative manager for the Alyeska Seafoods Cooperative, for her assistance each year with logistics in Dutch Harbor and Seattle. Caitlin's efforts to find ways to circumvent numerous challenges from the Covid outbreak in Dutch Harbor in 2021 were truly exemplary. We especially thank the three EFP captains (Acacio Domar, Jeff Garrison, Shawn Raymond, and James Buskirk) and their crews who provided safe and effective testing platforms and diligently followed our testing protocols while providing helpful input at each stage. Finally, we thank Dan Martin and Dave Irvine, two Bering Sea pollock captains who worked shoreside and at-sea during this EFP to help us troubleshoot problems.

All of you mentioned above stepped up to make this project as successful as possible and we want to express our sincere gratitude.

Appendix 1

Destination

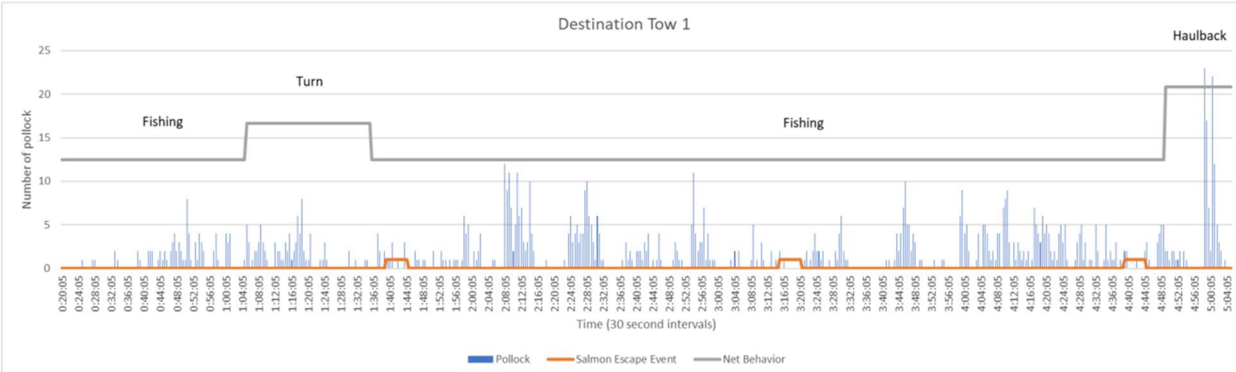

Figure 33

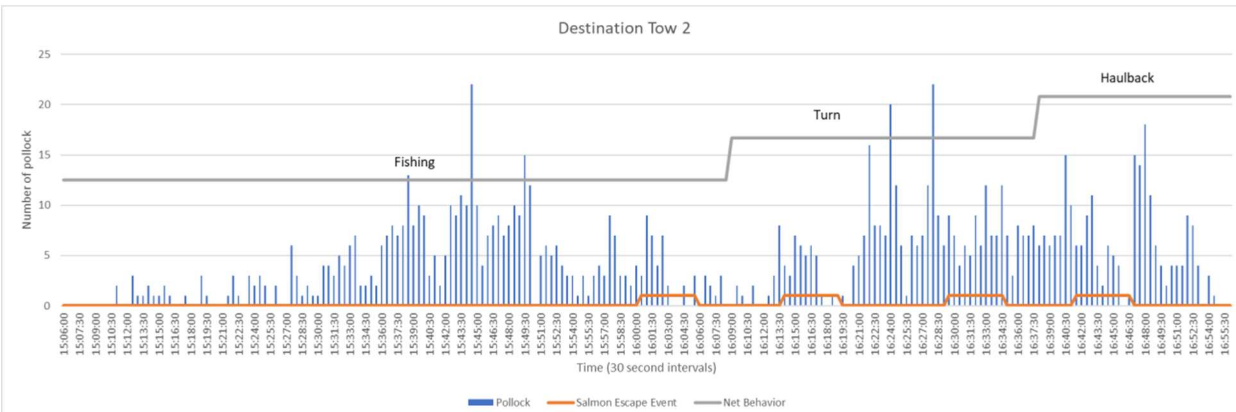

Figure 34

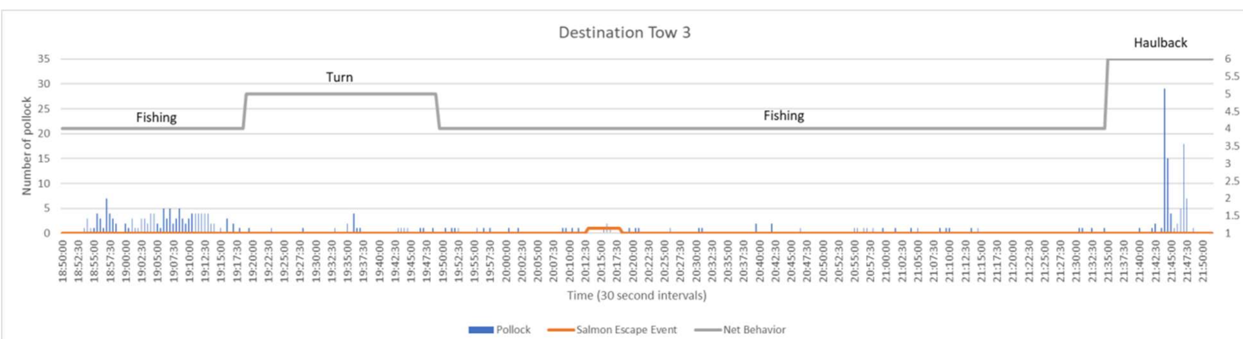

Figure 35

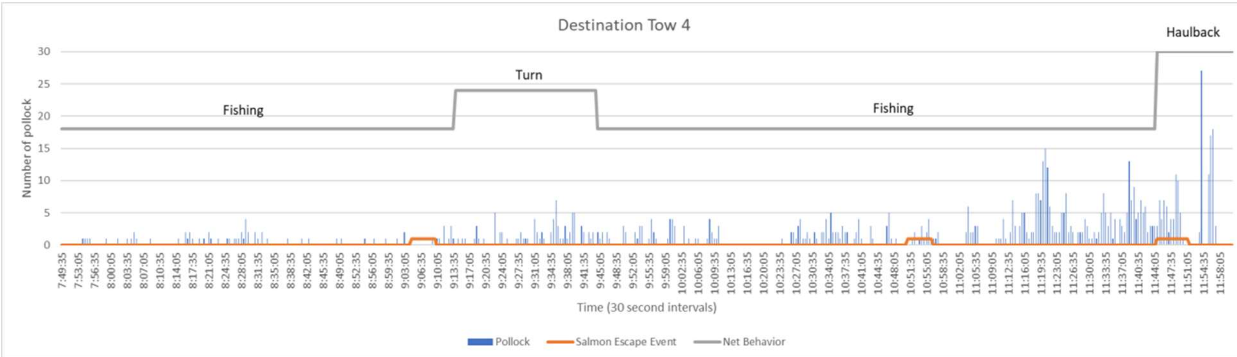

Figure 36

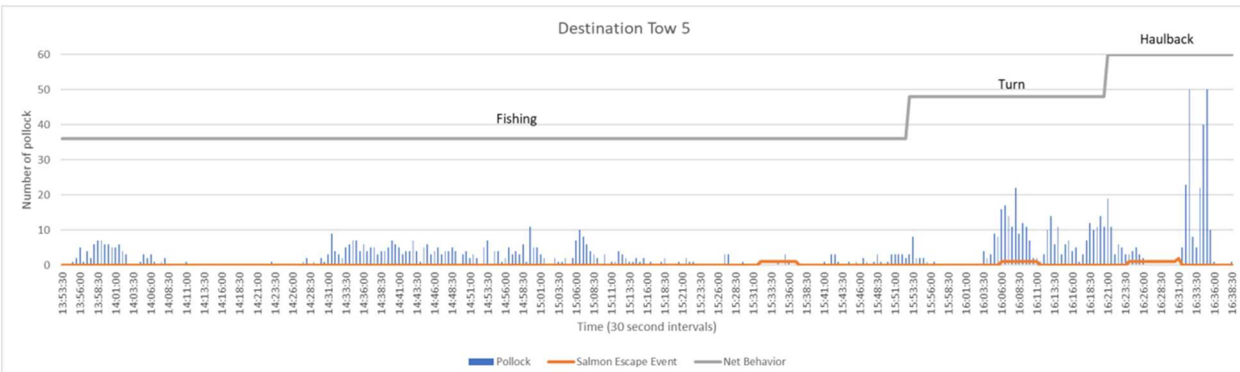

Figure 37

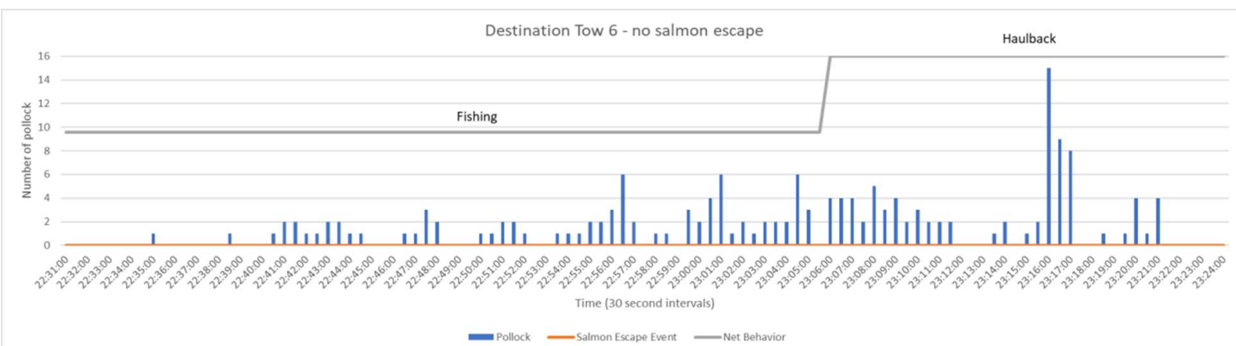

Figure 38

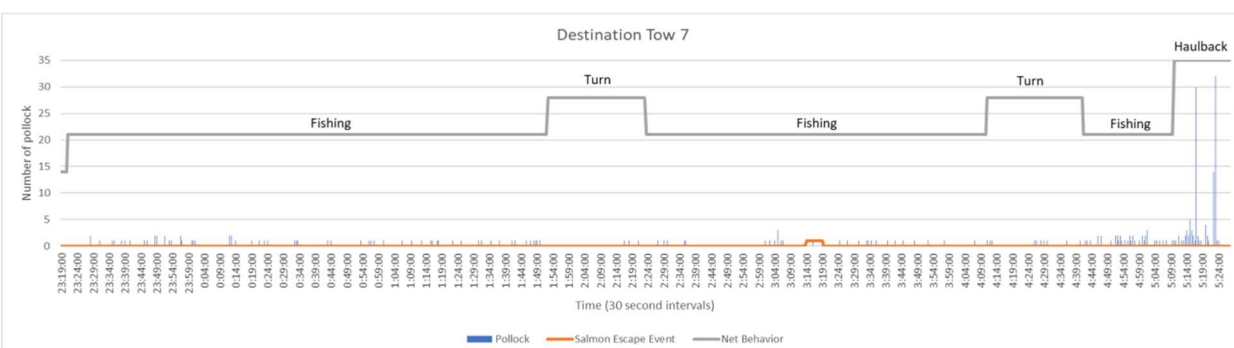

Figure 39

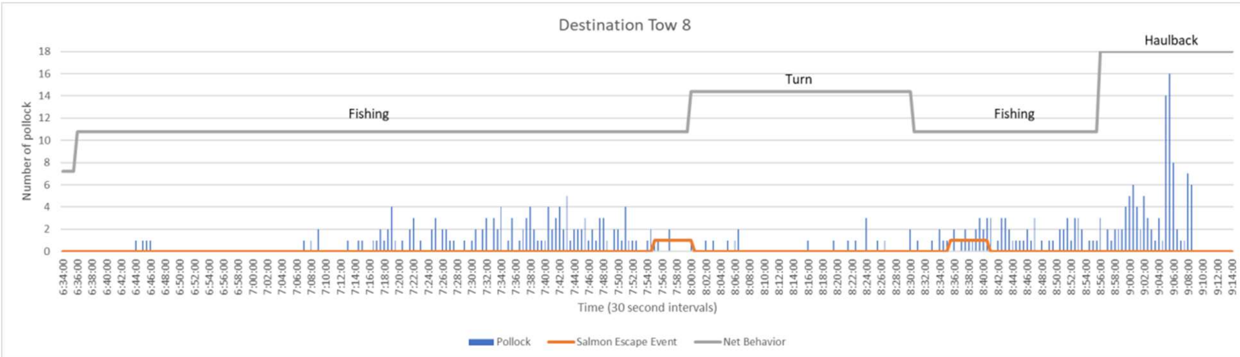

Figure 40

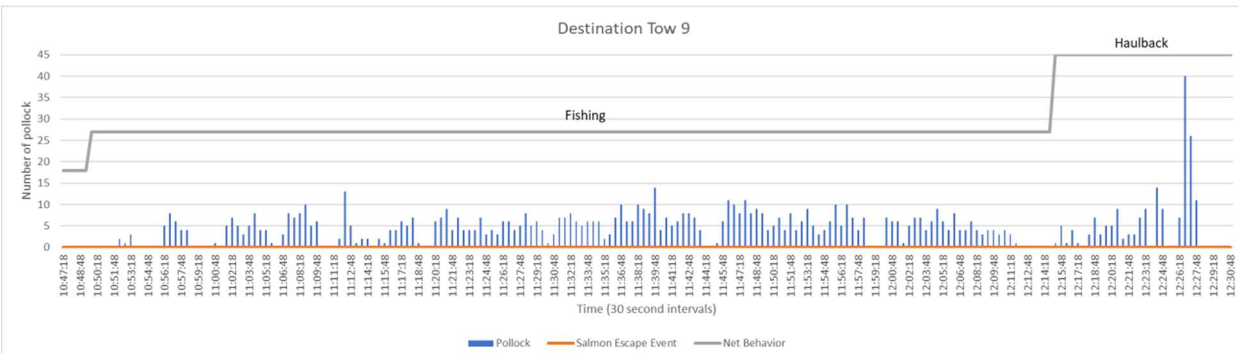

Figure 41

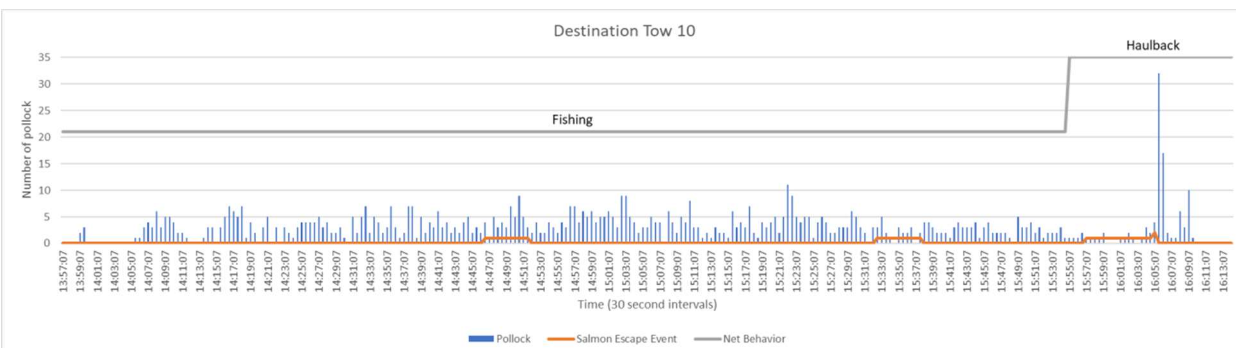

Figure 42

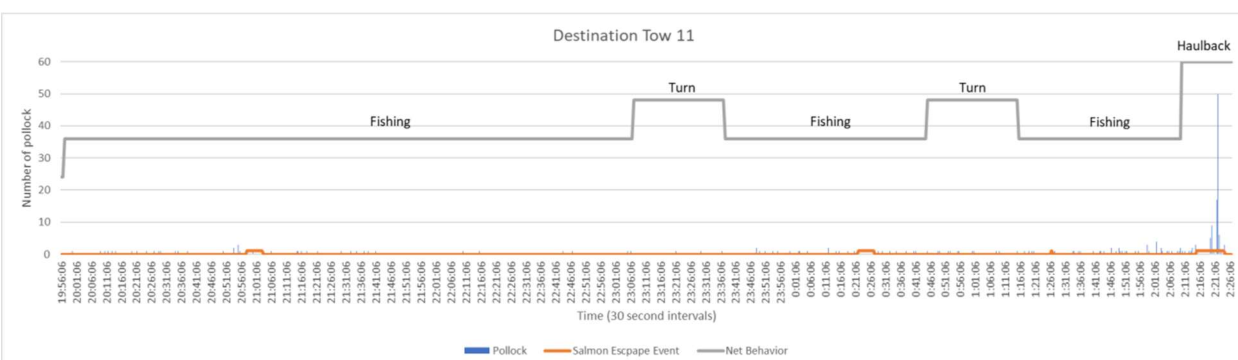

Figure 39

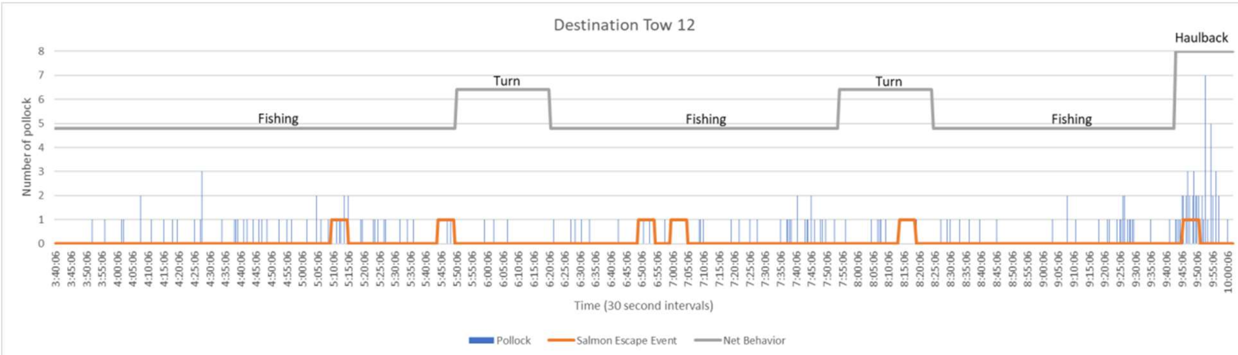

Figure 44

Storm Petrel

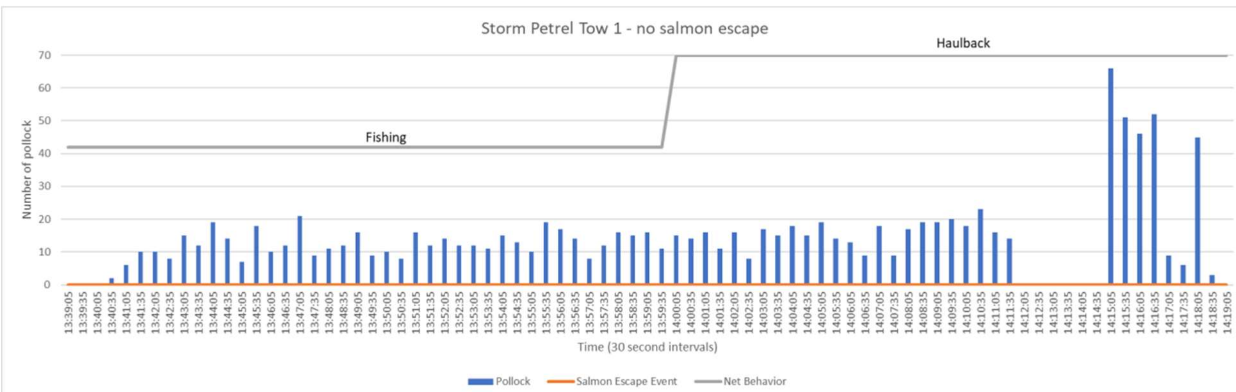

Figure 45

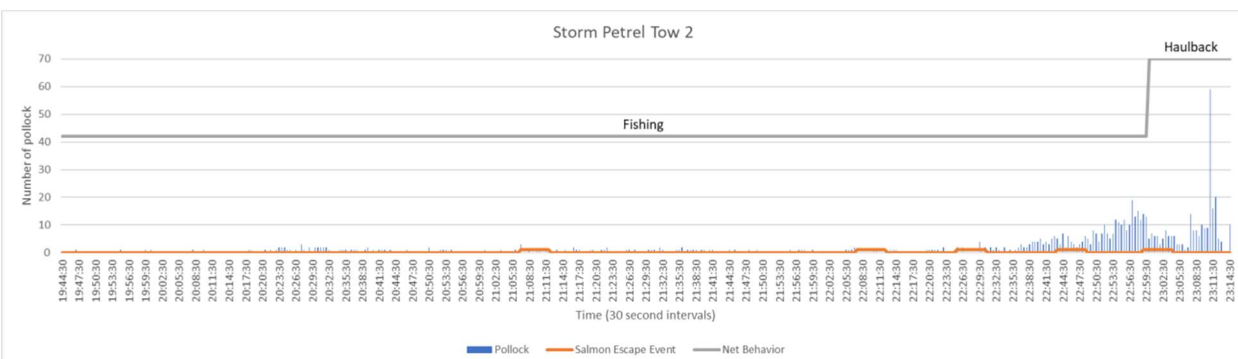

Figure 46

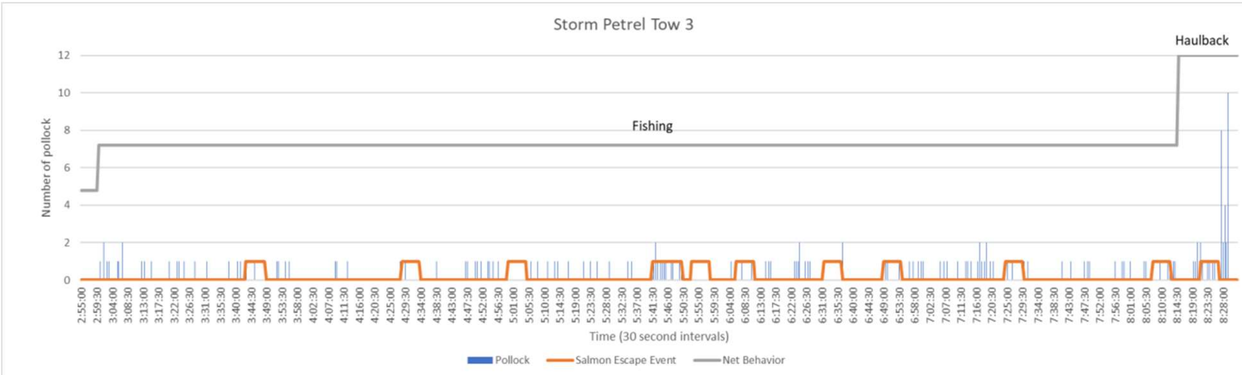

Figure 47

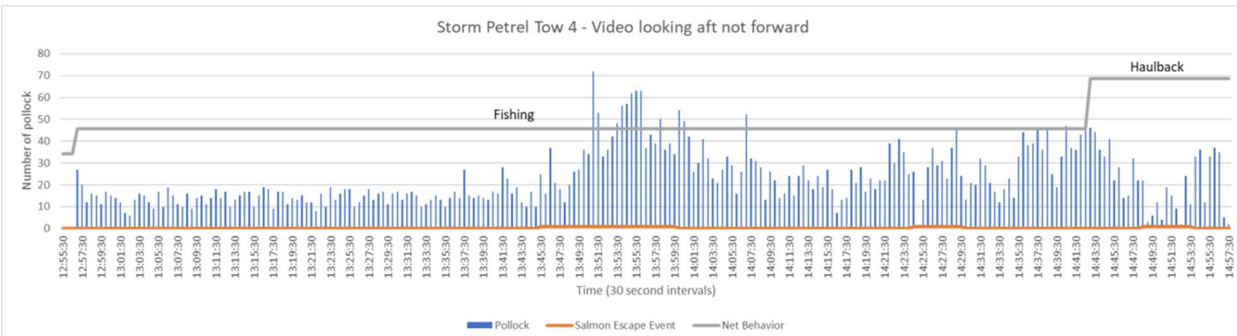

Figure 48

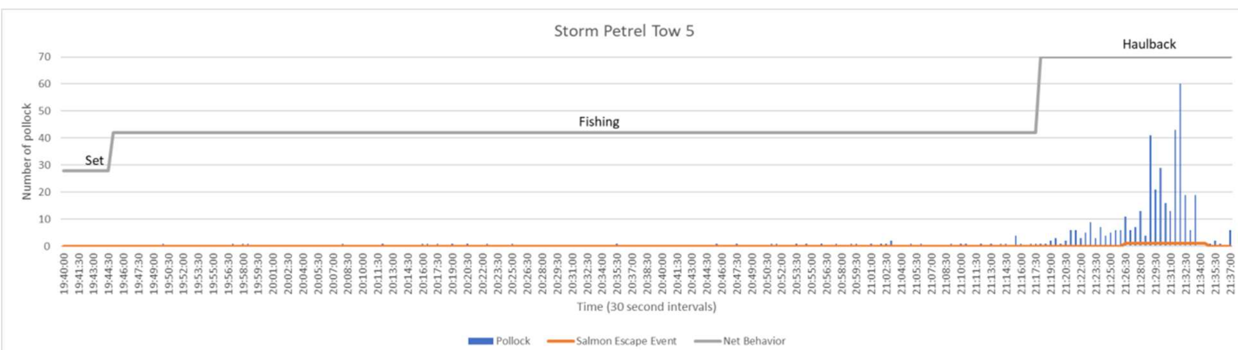

Figure 49

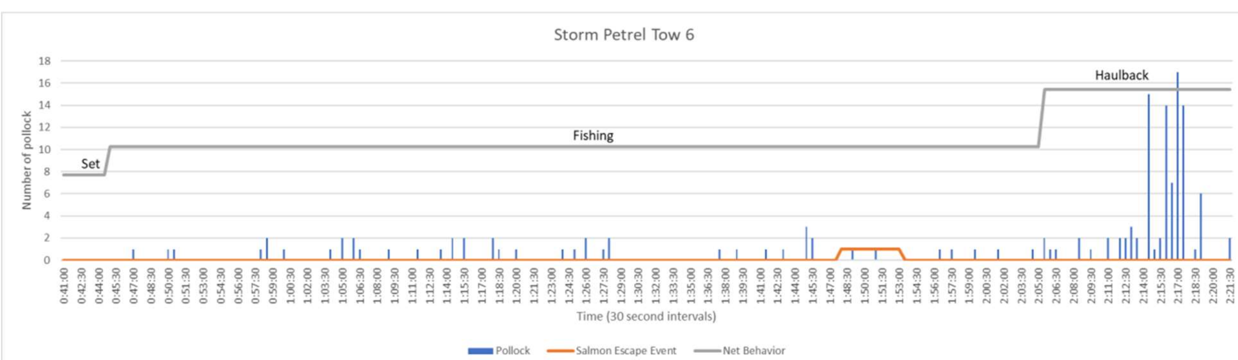

Figure 50

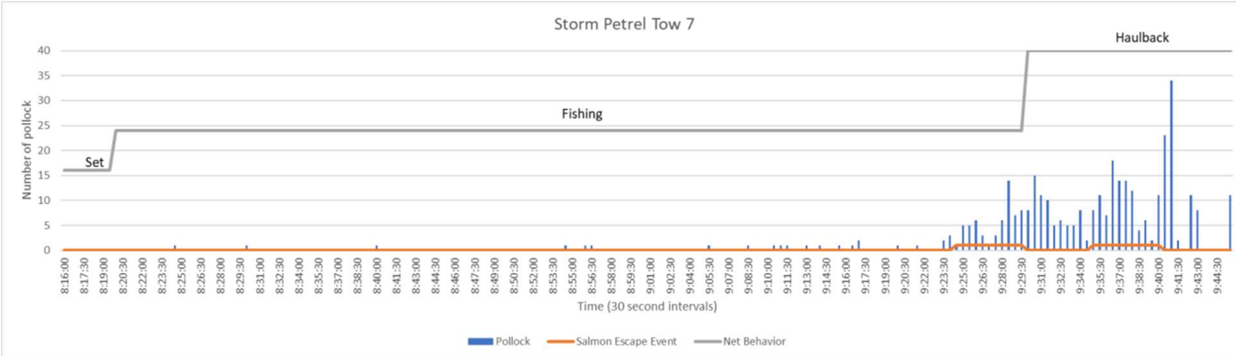

Figure 51

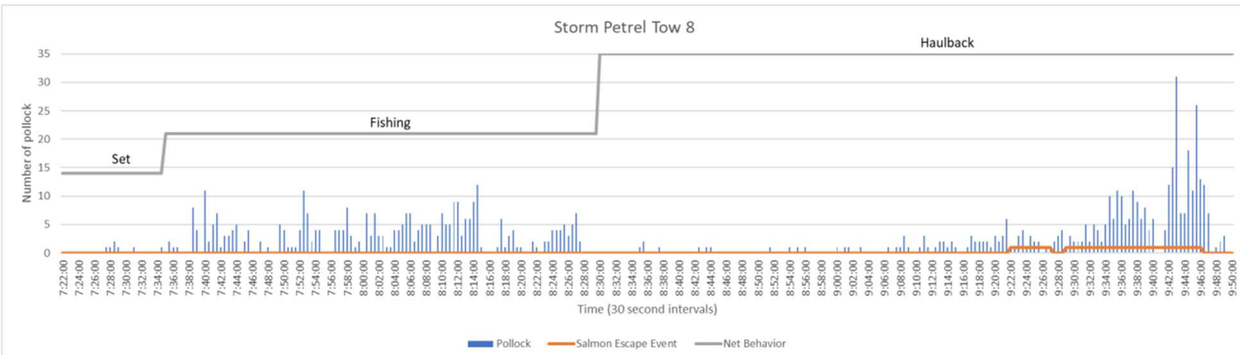

Figure 52

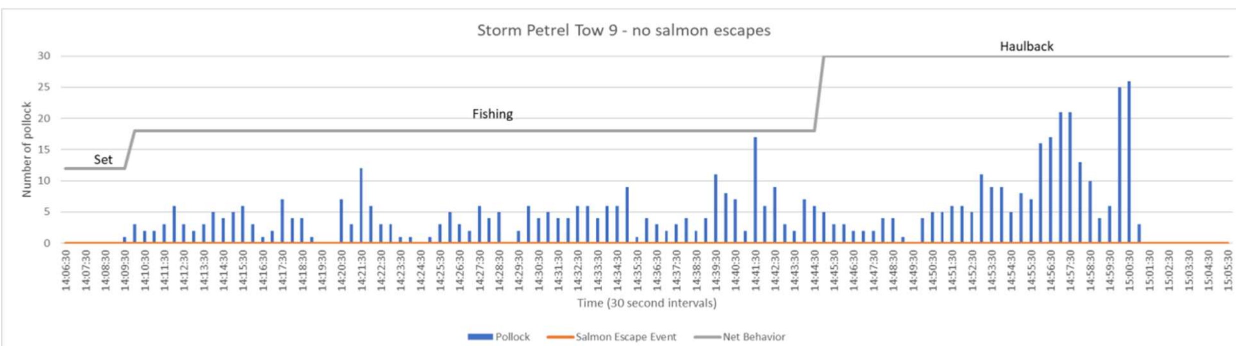

Figure 53

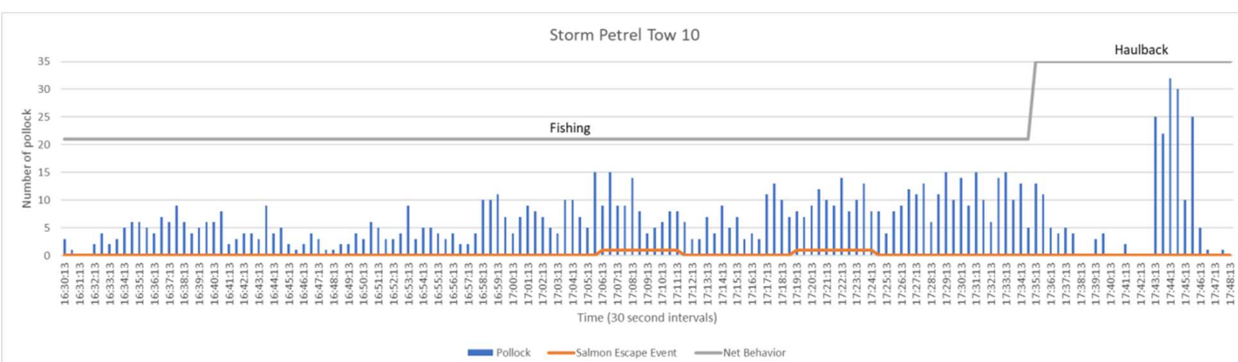

Figure 50

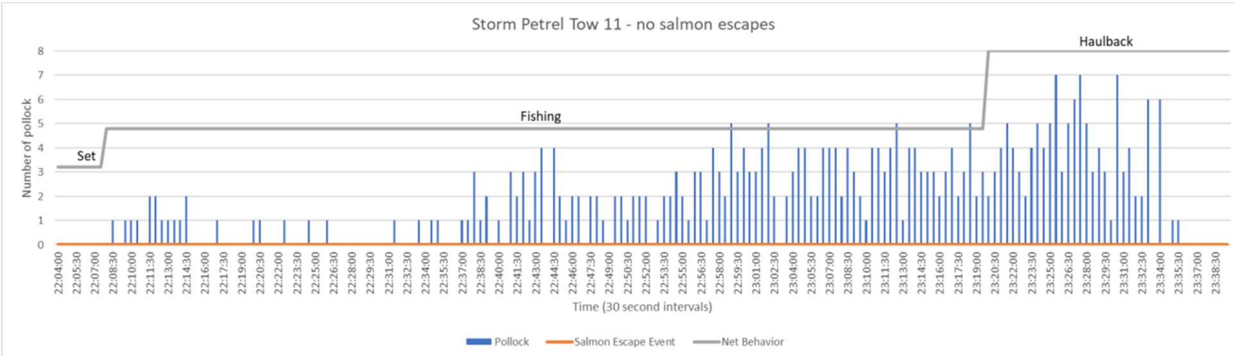

Figure 55

Appendix 2: EFP catches by year

Total Harvest by Year without jellyfish included

Species	2018 (mt)	2019 (mt)	2020 (mt)	2021 (mt)	EFP Total (mt)	% of Total
Pollock	2130.559	2446.884	2521.063	1589.710	8688.215	98.9%
Pacific Cod	6.114	23.745	30.587	6.720	67.166	0.8%
Flathead Sole (FHS)	4.875	4.097	1.664	0.334	10.970	0.1%
Skate	0.417	1.427	0.697	0.242	2.783	0.0%
Squid	2.155	0.000	0.002	0.000	2.157	0.0%
Northern Rock Sole (NRS)	0.016	0.546	0.966	0.444	1.972	0.0%
Kamchatka Flounder	0.060	1.408	0.000	0.000	1.468	0.0%
Alaska Skate	0.350	0.452	0.320	0.000	1.122	0.0%
Arrowtooth Flounder (ATF)	0.333	0.602	0.102	0.022	1.059	0.0%
Rex Sole	0.781	0.178	0.071	0.041	1.070	0.0%
Pacific Ocean Perch (POP)	0.799	0.000	0.088	0.000	0.887	0.0%
Big Skate	0.000	0.802	0.000	0.000	0.802	0.0%
Eelpout	0.665	0.000	0.000	0.000	0.665	0.0%
Octopus	0.600	0.000	0.000	0.000	0.600	0.0%
Lumpsucker	0.270	0.117	0.015	0.025	0.427	0.0%
sablefish	0.400	0.000	0.001	0.000	0.401	0.0%
yellowfin sole	0.000	0.065	0.299	0.000	0.364	0.0%
Shark	0.151	0.195	0.000	0.441	0.787	0.0%
Thornyhead	0.263	0.000	0.000	0.000	0.263	0.0%
Dover Sole	0.000	0.238	0.000	0.000	0.238	0.0%
Greenland Turbot	0.176	0.000	0.000	0.000	0.176	0.0%
Sculpin	0.001	0.142	0.000	0.003	0.145	0.0%
Pacific Herring	0.011	0.000	0.061	0.004	0.076	0.0%
Dusky Rockfish	0.002	0.052	0.000	0.000	0.054	0.0%

Lantern Fish	0.003	0.047	0.000	0.000	0.050	0.0%
Sea Star	0.021	0.011	0.000	0.000	0.032	0.0%
Eulachon	0.027	0.000	0.000	0.000	0.027	0.0%
Lancet Fish	0.027	0.000	0.000	0.000	0.027	0.0%
Alaska Plaice	0.000	0.002	0.017	0.000	0.019	0.0%
Starry Flounder	0.000	0.000	0.008	0.000	0.008	0.0%
Aleutian Skate	0.006	0.000	0.000	0.000	0.006	0.0%
Grenadier	0.005	0.000	0.000	0.000	0.005	0.0%
Sand Lance	0.005	0.000	0.000	0.000	0.005	0.0%
Bering flounder	0.000	0.003	0.000	0.000	0.003	0.0%
Poacher	0.000	0.000	0.002	0.000	0.002	0.0%
Misc.	0.000	0.002	0.000	0.000	0.002	0.0%
Northern Rockfish (NRF)	0.000	0.001	0.001	0.001	0.003	0.0%
Spiny Dogfish	0.000	0.002	0.000	0.000	0.002	0.0%
Snailfish	0.001	0.000	0.000	0.000	0.001	0.0%
Prowfish	0.000	0.000	0.000	0.007	0.008	0.0%
Atka Mackerel	0.000	0.000	0.001	0.000	0.001	0.0%
Total	**2149.092**	**2481.019**	**2555.965**	**1597.994**	**8784.070**	**100.0%**

Appendix 3: Pollock Weights by Tow

Vessel	Year	Trip	EFP Haul	Vessel Haul	Catch Rate (mt)	Total Catch (mt)	Total Pollock (mt)	Pollock Average Weight (g)
DE	2018	1	1	28	404.6	100.79	100.78	662
DE	2018	1	2	29	164.6	134.78	134.75	673
DE	2018	1	3	30	168.8	94.95	94.94	742
DE	2018	2	4	31	34.9	61.53	61.51	538
DE	2018	2	5	32	23.2	60.42	60.38	581
DE	2018	2	6	33	34.9	68.54	67.34	559
DE	2018	2	7	34	34.2	73.88	73.71	581
DE	2018	2	8	35	75.6	67.72	67.69	540
DE	2018	3	9	36	24.6	76.78	76.03	507
DE	2018	3	10	37	25.5	68.8	66.77	531
DE	2018	3	11	38	25.1	85.64	85.61	535
DE	2019	1	1	24	13.3	58.17	54.05	773
DE	2019	1	2	25	48.7	74.43	73.11	753
DE	2019	1	3	26	24.5	66.8	63.55	824
DE	2019	1	4	27	24.1	93.36	88.37	802
DE	2019	1	5	28	35.3	87.12	87.09	764
DE	2019	1	6	29	73.3	74.41	74.41	818
DE	2019	2	7	30	13.3	77.49	76.87	771

DE	2019	2	8	31	34.7	80.78	76.99	788
DE	2019	2	9	32	59.8	83.06	81.66	734
DE	2019	2	10	33	31.4	62.05	61.67	789
DE	2019	2	11	34	12.4	77.7	74.99	823
DE	2019	2	12	35	11.3	68.22	64.48	826
DE	2020	1	1	4	18.6	68.14	59.83	840
DE	2020	1	2	5	54.5	67.23	67.23	763
DE	2020	1	3	6	14.1	65.33	59.82	814
DE	2020	1	4	7	14.5	79.77	79.57	787
DE	2020	2	5	8	20.5	24.21	24.13	864
DE	2020	2	6	9	11.6	80.51	80.5	808
DE	2020	2	7	10	13.8	27.9	27.3	759
DE	2020	2	8	11	89.8	76.33	72.57	807
DE	2020	2	9	12	134.4	100.77	98.86	765
DE	2020	2	10	13	127.7	83.02	82.62	761
DE	2020	2	11	14	166.9	108.45	108.45	773
DE	2020	2	12	15	23.2	93.71	93.68	NA
DE	2021	1	18	13	64.9	76.95	76.73	608
DE	2021	1	19	14	38.1	92.59	92.59	875
DE	2021	1	20	15	40.5	93.03	93.03	776
DE	2021	1	21	16	20.7	52.49	50.79	504
DE	2021	1	22	17	15.4	66.95	65.77	453
DE	2021	1	23	18	23.3	74.07	71.56	505
DE	2021	2	24	19	14.8	59.83	58.96	623
DE	2021	2	25	20	30.4	84.36	84.34	724
DE	2021	2	26	21	79.7	75.87	75.85	805
DE	2021	2	27	22	25.8	76.19	76.14	622
DE	2021	2	28	23	29.4	71.97	71.97	754
DE	2021	2	29	24	94.8	63.18	63.17	754
SP	2018	1	1	1000	13.4	37.85	37.84	587
SP	2018	1	2	1001	7.4	30.41	30.25	587
SP	2018	2	3	1002	3.6	29.48	29.32	586
SP	2018	2	4	1003	99.2	48.63	48.63	570
SP	2018	2	5	1004	141.6	55.75	53.9	618
SP	2018	2	6	1005	13.5	31.4	30.04	467
SP	2018	2	7	1006	73.1	53.7	52.99	550
SP	2018	2	8	1007	98.6	48.8	48.8	501
SP	2019	1	1	20	155.8	77	76.48	775
SP	2019	1	2	21	23.1	75	73.12	811
SP	2019	1	3	22	11.1	58	57.79	810
SP	2019	2	4	23	42.3	71	70.82	797
SP	2019	2	5	24	46.8	74	72.71	890
SP	2019	2	6	25	52.2	74	72.45	854
SP	2019	2	7	26	25.8	30	30	870

SP	2019	3	8	27	87.7	80	79.71	789
SP	2019	3	9	28	67.8	39	39	800
SP	2019	3	10	29	56	69	68.6	823
SP	2019	3	11	30	40.3	47	46.74	857
SP	2020	1	1	27	NA	71.9	63.85	704
SP	2020	1	2	28	NA	51.02	50.52	706
SP	2020	1	3	29	NA	78.31	75.76	756
SP	2020	1	4	30	NA	30.16	29.87	693
SP	2020	2	5	31	NA	65	60.33	594
SP	2020	2	6	32	NA	84.2	82.57	586
SP	2020	2	7	33	NA	76	71.31	621
SP	2020	2	8	34	NA	49.88	47.72	666
SP	2020	3	9	35	NA	56.4	54.71	630
SP	2020	3	10	36	NA	86	85.8	634
SP	2020	3	11	37	NA	70	69.99	681
SP	2021	1	3	6	25.5	62.46	44.48	767
SP	2021	1	4	7	24.4	54	51.48	785
SP	2021	1	5	8	71.5	69	69	781
SP	2021	1	6	9	27.4	66	65.89	636
SP	2021	2	7	10	72.4	60.28	60.13	828
SP	2021	2	8	11	36.9	63.2	63.17	414
SP	2021	2	9	12	24	75	69.44	869
SP	2021	2	10	13	16	45.18	43.24	906
SP	2021	3	11	14	26.7	63	62.84	829
SP	2021	3	12	15	22.3	72.6	70.5	555
SP	2021	3	13	16	33	71.4	64.94	765
SP	2021	3	14	17	10.2	33	31.92	635
SB	2018	0	1	134	9	45.32	44.8	761
SB	2018	0	2	135	20	106.57	106.12	616
SB	2018	0	3	136	17.8	96.64	95.95	732
SB	2018	0	4	137	13	84.78	84.15	741
SB	2018	0	5	138	22	139.05	138.32	748
SB	2018	0	6	139	10.9	90.31	88.24	734.8
SB	2018	0	7	140	13.1	30.08	29.18	788.65
SB	2018	0	NA	141	167.7	109.69	108.62	580
SB	2018	0	NA	142	125.5	104.59	101.64	600
SB	2018	0	NA	143	70.3	105.39	99.62	600
SB	2018	0	NA	144	57.7	92.39	91.47	550
SB	2018	0	NA	145	22.1	119.28	113.21	470
SB	2018	0	NA	146	43.7	104.19	101.2	530
SB	2018	0	NA	147	78.3	108.26	107.7	580
SB	2018	0	NA	148	47	104.95	103.27	560
SB	2018	0	NA	149	82.6	105.98	104.25	510
SB	2018	0	NA	150	95.9	95.89	94.95	460

SB	2018	0	NA	151	130.9	98.18	97.78	540
SB	2018	0	NA	152	42	106.39	106.07	500
SB	2018	0	NA	153	128.8	107.3	106.23	600
SB	2018	0	NA	154	83.3	88.85	88.67	544
SB	2018	0	NA	155	121.7	101.42	100.26	550
SB	2018	0	NA	156	134.6	94.25	91.88	520
SB	2018	0	NA	157	158.6	100.45	99.02	494
SB	2018	0	NA	158	22.6	97.04	86.36	660
SB	2018	0	NA	159	159	103.37	102.71	500
SB	2018	0	NA	160	168.8	104.1	101.52	590
SB	2018	0	NA	161	#VALUE!	NA	NA	NA
SB	2018	0	NA	162	#VALUE!	NA	NA	NA
SB	2018	0	8	163	21	52.67	46.58	559
SB	2018	0	9	164	7	30.44	30.11	642
SB	2018	0	10	165	8.3	41.15	40.78	692
SB	2018	0	11	166	14	55.31	54.88	638
SB	2018	0	12	167	28.3	120.04	111.78	652
SB	2018	0	13	168	29.7	62.45	62.2	670
SB	2019	0	AFA1	1	22.5	96.65	93.36	810
SB	2019	0	CDQ2	2	73.1	94.91	94.44	800
SB	2019	0	AFA3	3	40.9	104.83	103.21	720
SB	2019	0	AFA4	4	74.9	115.9	114.46	790
SB	2019	0	AFA5	5	180.1	113.92	113.63	760
SB	2019	0	AFA6	6	184.5	116.32	115.97	760
SB	2019	0	AFA7	7	90.5	111.88	111.1	780
SB	2019	0	AFA8	8	67.8	110.62	110.21	760
SB	2019	0	AFA9	9	28.3	104.55	102.79	810
SB	2019	0	AFA10	10	48.6	125.33	123.25	820
SB	2019	0	CDQ11	11	91	116.82	115.02	800
SB	2019	0	AFA12	12	29	128.87	127.22	810
SB	2019	0	AFA13	13	16.8	95.85	91.98	820
SB	2019	0	AFA14	14	18.5	103.08	96.85	830
SB	2019	0	CDQ15	15	39.1	97.21	96.17	800
SB	2019	0	CDQ16	16	35.7	117.29	116.09	780
SB	2019	0	AFA17	17	77.2	120.96	120.66	740
SB	2019	0	AFA18	18	34.9	105.05	103.8	760
SB	2019	0	AFA19	19	8.1	43.84	40.55	740
SB	2019	0	AFA20	20	40.1	106.69	104.61	770
SB	2019	0	AFA21	21	35.2	120.22	116.99	750
SB	2019	0	AFA22	22	15.8	41.09	39.3	750
SB	2019	0	CDQ23	23	56.5	104.56	103.33	760
SB	2019	0	1	24	25.5	88.5	85.47	720
SB	2019	0	2	25	45.7	118.05	116.5	790
SB	2019	0	3	26	35.9	104.22	101.86	780

SB	2019	0	4	27	98.8	93.13	92.63	770
SB	2019	0	5	28	51.7	86.01	85.45	820
SB	2019	0	6	29	39.2	103.17	101.52	810
SB	2019	0	7	30	22.1	76.53	74.73	810
SB	2019	0	8	31	60.7	120.77	120.22	810
SB	2019	0	9	32	28.3	107.44	103.92	820
SB	2020	0	AFA1	30	83.7	124.17	122.89	760
SB	2020	0	AFA2	31	41.2	120.15	118.14	690
SB	2020	0	AFA3	32	60.2	114.09	113.3	700
SB	2020	0	AFA4	33	84.9	142.41	138.9	680
SB	2020	0	AFA5	34	114.8	115.29	112.62	710
SB	2020	0	AFA6	35	38.4	168.28	150.29	750
SB	2020	0	CDQ7	36	27.7	111.85	110.09	700
SB	2020	0	AFA8	37	67.3	116.53	114.54	720
SB	2020	0	AFA9	38	49.4	118.09	115.44	710
SB	2020	0	AFA10	39	65.7	167.31	165.77	700
SB	2020	0	CDQ11	40	66.1	108.43	107.37	700
SB	2020	0	AFA12	41	90.5	132.74	128.07	720
SB	2020	0	AFA13	42	91.7	117.93	116.78	690
SB	2020	0	AFA14	43	101.5	155.46	154.39	700
SB	2020	0	AFA15	44	15.4	59.96	59.59	700
SB	2020	0	AFA16	45	24.8	87.06	84.75	760
SB	2020	0	AFA17	46	64.4	113.7	113.11	760
SB	2020	0	AFA18	47	92	116.79	115.24	780
SB	2020	0	1	48	247.4	106.82	105.87	720
SB	2020	0	2	49	104.3	105.39	103.74	710
SB	2020	0	3	50	86.5	84.6	82.29	770
SB	2020	0	4	51	47.4	103.83	102.4	740
SB	2020	0	5	52	18.5	108.32	104.83	720
SB	2020	0	6	53	55.5	120.98	119.29	680
SB	2020	0	7	54	183.7	126.6	125.54	720
SB	2020	0	8	55	88.6	112.28	111.12	780
SB	2020	0	9	56	96.2	96.74	96.15	720