January 29, 2021

Mr. Simon Kinneen, Chairman
North Pacific Fishery Management Council
1007 West Third, Suite 400
Anchorage, AK 99501

RE: Comment on Agenda Item C4 (Crab PSC)

Dear Chairman Kinneen, Council Members, and Advisory Bodies:

The Alaska Bering Sea Crabbers (ABSC) is a trade association representing independent crab harvesters who commercially fish for king, snow (opilio), and Tanner (bairdi) crab with pot gear in the Bering Sea and Aleutian Islands Crab Rationalization Program. We appreciate the opportunity to comment on Agenda Item C4 – Crab PSC – Initial Review.

As several of our crab stocks are at low levels, we as an industry are concerned and want to be proactive in helping crab stocks recover. We appreciate that the North Pacific Fishery Management Council (Council) is analyzing an action on crab prohibited species catch (PSC) limits to bring them to their lowest limit when directed crab fisheries are closed. Our comments today build on our comment letters from the December 2019 Council meeting and from the May 2020 CPT meeting which are incorporated by reference.

The action in front of the Council in February on crab PSC is a narrow action as far as bycatch reduction. However, it carries important policy implications and some biological benefits. The action does not change existing PSC limits or ranges for crab but does change the management response when crab stocks are at low enough levels, generally of legal males, to close the directed fishery but overall abundance is not low enough to lower PSC limits. This action shows that the management system values the directed fishery enough to conserve the stock and allow more abundant small crab to grow to larger sizes to again support a directed fishery and larger bycatch by reducing bycatch or PSC limits when the directed fishery closes.

- **ABSC encourages the Council to select Alternative 2 as their preliminary preferred alternative with the minor clarification identified by Council staff, noted below, and move to final action at the Council's earliest convenience.**

As noted in the analysis on p.15, the Council is asked to clarify their intent for the Tanner PSC limits under Alternative 2. ABSC agrees with the interpretation used in the analysis that if the directed Tanner fishery is closed, the Tanner PSC limit would be the lower of the lowest two Tanner PSC limit formulas specified in regulation at 50 CFR 679.21(e)(1)(ii)(A) and (B) (excerpt below with highlights for emphasis). This is in line with the intent of the action. We understand that, for analysis purposes to keep it simple, only the second lowest PSC limit was used as it is a fixed number. We recommend the description of Alternative 2 be revised to mirror the interpretation in the analysis described on p.15. Suggested language is provided in redline below.

(A) The following table refers to the PSC limits for C. bairdi that you must follow in Zone 1:

When the total abundance of *C. bairdi* crabs is ...	The PSC limit will be ...
(*1*) 150 million animals or less	0.5 percent of the total abundance minus 20,000 animals
(*2*) Over 150 million to 270 million animals	730,000 animals
(*3*) Over 270 million to 400 million animals	830,000 animals
(*4*) Over 400 million animals	980,000 animals

(B) This table refers to the PSC limits for *C. bairdi* that you must follow in Zone 2.

When the total abundance of C. bairdi crabs is ...	The PSC limit will be ...
(*1*) 175 million animals or less	1.2 percent of the total abundance minus 30,000 animals
(*2*) Over 175 million to 290 million animals	2,070,000 animals
(*3*) Over 290 million to 400 million animals	2,520,000 animals
(*4*) Over 400 million animals	2,970,000 animals

Alternative 2: Reduced PSC limits for BSAI trawl CDQ and non-CDQ groundfish fishing when the corresponding directed crab fishery is closed.

When no Crab Rationalization Program individual fishing quota (IFQ) is issued in a season for BBRKC, bairdi, or opilio, set the crab PSC limit for that stock at the lowest abundance-based level. As described in regulation at 50 CFR 679.21(e)(1), the PSC limits for the groundfish fisheries would be as follows under this alternative when the directed crab fishery is closed:

- *Bairdi Zone 1 – the lower of (1) 0.5% of total abundance minus 20,000 animals or (2) 730,000 animals*
- *Bairdi Zone 2 – the lower of (1) 1.2% of the total abundance minus 30,000 animals or (2) 2,070,000 animals*
- *BBRKC Zone 1 - 32,000 red king crab*
- *Opilio - 4.350 million animals*

ABSC believes this action is important not only from a policy perspective to better balance the impacts of fishing on a stock and help promote directed fisheries but also from a biological perspective. Crab stocks are benthic, slow moving creatures with episodic recruitment paired with patchy spatial distribution where they are known to school and ball up. Given this, when mature male abundance is low enough to close the directed fishery but total abundance, such as from females and smaller males, is high due to a recruitment event, this is the important time to reduce pressure on the stock to allow those male crab to grow bigger and again support a directed fishery. If bycatch continues to put pressure on these episodic crab recruitment events, it could be having a disproportionate effect and decrease the likelihood these crab grow to sizes for a directed fishery. In other words, the marginal changes proposed by Alternative 2 in this action could be enough to increase the likelihood of directed fisheries being open and, therefore, not a marginal but a beneficial impact to the directed fishery.

While this action is narrow and the analysis notes that it would only create marginal, limited changes, they are important changes nonetheless by shifting the incentives to more actively avoid crab bycatch. For example, we've seen in recent years that trawl activity is happening right on top of where our directed crab fisheries are occurring. This PSC action could be enough to shift them off of areas where crab are schooled.

- **From the crab scientists and SSC, it would be helpful to better understand whether the premise is true for crab that reducing all fishing impacts on more abundant small crab will help them grow to sizes targeted by the directed fishery.**

The crab stock assessment authors went through an exercise recently to better understand the impacts of bycatch on the stocks as described in the analysis in Section 3.4.6.1 and in Appendix 4. This sensitivity analysis was informative work and showed that the amount of bycatch would have to be substantially higher than current observed levels to impact the stock. As we described below, that potential exists in unaccounted for unobserved fishing mortality paired with consideration of population dynamics for crab.

There is an important component that this sensitivity analysis approach does not take into account. Turning back to the biology of crab with patchy distribution and episodic recruitment events, some areas and times of bycatch may have higher impacts on the crab stock. Therefore, a more conservative and proactive approach may need to be taken for crab.

For example, in the crab essential fish habitat (EFH) work, both the CPT and the Council's analysis flagged an area of disproportionate fishing impacts on key Bristol Bay red king crab (BBRKC) spawning grounds. The analysis notes concern over a small, localized area with high fishing impacts having an impact on the overall health of the BBRKC stock due to fishing impacts far exceeding the 10% EFH threshold at over 50% (Section 3.4.3, 3.4.12 from Fishing Effects on EFH, Apr 2017). This was flagged years earlier in a Council discussion paper on EFH for BBRKC from 2012, highlighting concern over habitat impacts and fishing impacts from unobserved fishing mortality from pelagic and non-pelagic trawl and offering several suggestions to help keep the BBRKC stock sustainable, including protections for southwestern Bristol Bay (Section 7.2, NMFS/Council Discussion Paper, Jan 2012). More recently, information from Daly et al 2020 points to the importance of this area in Southwestern Bristol Bay for key life stages of crab and larval advection.

However, the Council has not taken action to protect that area in southwestern Bristol Bay and the stock from high fishing impacts and instead has watched BBRKC march on a downward trend for over 10 years and now approaching overfished thresholds. The State, on the other hand, has taken some proactive measures affecting the directed fishery ratcheting down our TAC every year, by adding buffers to set more conservative TACs, and by closing the eastern Tanner fishery this year, in part, due to concern over BBRKC bycatch in the directed Tanner fishery. Yet, the BBRKC PSC limit is not at it's lowest possible level as a conservative measure to protect the stock when it is at levels where every pound of bycatch in other fisheries is deducted from the directed fishery harvest. When you look at that on a per pound value, each pound of directed fishery harvest is worth more than the pound of bycatch, and yet the Council is choosing pounds of bycatch instead due to their inaction.

Section 3.4.6 of the analysis on the crab PSC action highlights unobserved fishing mortality (UFM) as an unaccounted for source of bycatch mortality. This is an important note with potentially big implications for crab stocks. In addition to what is provided in the Council analysis, ABSC has conducted a literature review and provided additional information in the attached paper on "*Unobserved and Unaccounted Mortality of Crab Bycatch in Alaska's Bering Sea and Aleutian Islands*." The Magnuson-Stevens Fishery Conservation and Management Act National Standard 9 on bycatch defines unobserved mortality as "*fishing mortality due to an encounter with fishing gear that does not result in capture of fish (i.e., unobserved fishing mortality)*" (50 CFR 600.350(c)(1)). Based on the literature review in the attached paper along with known information on areas fished, gear on the bottom, locations of crab, and handling mortality by gear type, we suspect the impact of this unobserved mortality has the potential to be significant, particularly from mobile gears like pelagic and non-pelagic trawl gear, due to the benthic nature of crab species and their inability to quickly move out of the way. This unobserved mortality is currently unaccounted for in total mortality estimates for stock assessments or in bycatch/PSC management and we know the number is greater than zero. From recent studies described in the white paper, 95-99% of crab in the path of trawl gear go under the footrope escaping capture and some portion of those likely die after contact with the fishing gear. Given this number compared to what is observed as bycatch, the potential for unobserved mortality of crab could be millions of additional pounds of dead crab bycatch.

- **From the scientists, the Crab Plan Team, and the SSC, we ask that a proxy for unobserved mortality be developed based on existing information for use in the upcoming 2021 stock assessments and management cycle and that further research be identified to better inform those estimates. In addition, we ask that more information be considered on the effects of fishing on crab EFH, including Southwestern Bristol Bay, and on the impact of encounters with fishing gear when crab stocks are molting, mating, or at other vulnerable life stages throughout the year.**

While this unobserved fishing mortality is an important issue to be addressed moving forward, it should not slow down or change the current crab PSC action in front of the Council at this meeting. Rather, it is flagged as a piece of missing information in our understanding of fishing impacts to the crab resource that should be addressed.

In conclusion, for the crab PSC action in front of the Council, we support Alternative 2 and encourage the Council to move toward final action.

Thank you for your consideration.

Sincerely,

Jamie Goen
Executive Director
Alaska Bering Sea Crabbers
absc.jamie@gmail.com

ATTACHMENT – unobserved mortality white paper

Unobserved and Unaccounted *Mortality* of Crab Bycatch in Alaska's Bering Sea and Aleutian Islands: A White Paper

(Working Draft - January 2021)
for North Pacific Fishery Management Council meeting

Alaska Bering Sea Crabbers

Abstract

This paper highlights that unobserved or post-encounter fishing mortality, the mortality from crab after coming in contact with but not caught in fishing gear, is not currently included in total mortality estimates for stock assessments or considered in bycatch management. Juvenile and adult crab are benthic animals, living in an environment where they are susceptible to interactions with fishing gear on or near the seafloor. Unlike many species of fish, crab are slower moving organisms and have an inability to evade or quickly move out of the way of fishing gear. It's well known that there are interactions with fishing gear taking place on the seafloor that doesn't result in catch yet impacts crabs with a mortality rate greater than zero. Ultimately, all sources of fishing mortality should be considered and implemented in stock assessments and fisheries management, including unobserved or post-encounter mortality of crab stocks, as noted in the Magnuson-Stevens Fishery Conservation and Management Act. These unobserved mortality estimates should also consider the impact of encounters with fishing gear when crab stocks are molting, mating, or at other vulnerable life stages. While impacts from all fishing gear should be evaluated, we are concerned that the impacts from pelagic and non-pelagic trawl may be significant for crab given their time on bottom, the amount of the gear on the bottom, and the area fished. With some of these economically important crab stocks approaching all-time low levels of abundance and facing closures, an estimate of unobserved mortality should be put in place immediately for upcoming management cycles using available information until additional research can be carried out to refine those estimates, as needed.

Introduction

Alaska is home to some of the most productive large marine ecosystems in the world, including the Bering Sea, a vast area of almost 2.6 million square kilometers. This third largest semi-enclosed sea in the world has one of the most extensive continental shelves. These nutrient-rich waters provide favorable habitats for a host of marine birds, mammals, fish, and crustaceans that are of international and domestic importance. In particular, this Bering Sea ecosystem supports more than 450 species of fish, crustaceans, and mollusks. A variety of economically important species including salmon, crab, and flatfish species along with Pacific cod (*Gadus macrocephalus*), Pacific herring (*Clupea pallasii*), Pacific halibut (*Hippoglossus stenolepis*), walleye pollock (*Gadus chalcogramma*), and sablefish (*Anoplopoma fimbria*) has provided the cornerstones of Alaskan fisheries over the past half century. These commercial fisheries in Alaska's Bering Sea and Aleutian Islands (BSAI) are among the most productive in the United States (ranking first by volume and second by value), contributing 58% of the total US seafood landings (5.45 billion lbs), accounting for approximately $1.8 billion in value (NOAA 2018). Alaska crab harvest is valued at approximately $240M first wholesale value (ASMI 2020). Many of these commercially targeted species co-exist in overlapping ranges with the same benthic habitat. In some cases, this is beneficial for fishers targeting multi-species and using trawl gear with mobile, widespread nets to maximize their efforts and ultimately their catch. However, with trawl gear, it's difficult for fishers to exploit one species in this multi-layered ecosystem and as a result there are incidental catches of non-target and non-marketable species, called bycatch. Other gear types that are more selective, like pot gear and hook-and-line, have bycatch, too. In US fisheries, policy requires managers to account for mortality of all fished species, including target catch, bycatch, and prohibited species catch (PSC).

Turning to crab, of significant importance to the sustainable management of BSAI crab stocks is understanding the life history of these crabs, including all sources of mortality. There are many different sources of mortality, including natural mortality and fishing-related mortality. Some mortality sources are better understood and estimated than others. Sources of mortality and management's current level of understanding and incorporation of such, can be found in Table 1.

Few studies have explored natural mortality of crab stocks in the Bering Sea, leaving managers with more uncertainty than sound knowledge. Predation (Halflinger and McRoy, 1984), competition for resources (Armstrong et al., 1998) and ecosystem factors (Fedewa et al., 2020; Szuwalski et al., 2020) all affect natural mortality.

Fishing mortality can be broken down into different categories, some are easier to track and quantify than others. Landings from the directed fishery, also called retained catch, generate the most accurate accounting of fishing mortality. This includes all retained catch, or crab landed and processed, including deadloss (retained catch that dies en route to the processor). However, some of the species encountered during fishing are not retained and are discarded as bycatch. Some, but generally not all, of those discards subsequently die as a source of fishing mortality known as discard mortality or bycatch mortality. Bycatch mortality is estimated for both directed and non-directed fisheries, informed from discard mortality studies (Stevens 1990; Stoner et al., 2008; Yochum et al., 2015). Though not exact, this research still produces a best estimate of how we understand and document discard mortality on discarded crabs from different fisheries. There is another, more obscure source of fishing-related mortality that is poorly understood (Rose et al., 2013) and not represented in stock assessments and management- unobserved mortality. Unobserved mortality, for the purpose of this paper, is defined as: *any mortality imposed on a species by an encounter with fishing gear that does not result in capture*. Unobserved fishing mortality presents a large data gap and difficult source of mortality to quantify.Crab species are particularly vulnerable to this type of mortality because they are benthic species that cannot move quickly out of the way of fishing gear. These interactions on the seafloor between crab and fishing gear, in particular, widespread trawl nets, foot ropes and chains, large mesh net sections prior to cod end, sweeps and doors, have unknown effects, especially during molt cycles when crabs are particularly vulnerable (Donaldson and Byersdorfer, 2005).

Unobserved mortality has been on the North Pacific Fishery Management Council's (NPFMC) radar for some years now with a few projects focused on addressing the issue and attempting to quantify a number, a rate, or an estimate of crab interacting with fishing gear yet never coming to the surface (Hammond et al., 2013; Rose et al., 2013). Now more than ever, fisheries managers need to account for all sources of mortality on Alaska's BSAI crab stocks, especially to include unobserved mortality, given stock status, environmental uncertainty, unknown habitat designations, and continued fishing pressure.

Several stocks are persisting at low levels or overfished, with the iconic Bristol Bay red king crab at historic low levels potentially approaching an overfished status.

All sources of crab mortality must be accounted for and used in stock assessments and fisheries management, including unobserved or post-encounter mortality of crabs remaining on the seafloor after contact with fishing gear. This paper highlights the shortcoming of the current crab stock assessments and bycatch management by pointing to the need for estimates of unobserved crab mortality, particularly in the trawl fleet, using the best available science, and where science does not exist, reasonable proxies. Furthermore, future research should be identified to further quantify these effects with more certainty, as needed. In summary, our main goals in this paper are to:

1. Identify sources of fishing mortality and previous efforts towards understanding unobserved mortality on crab species.
2. Highlight that unobserved mortality is currently unaccounted for in BSAI crab stock assessments and bycatch management when we know it is greater than zero.
3. Call for a proxy to be used in the upcoming management cycle, along with identifying further research to better quantify unobserved mortality across all sectors and the impacts on BSAI crab stocks.

Background

Crab are a historically iconic and economically, as well as a culturally, important species in Alaska. Commercial harvest of red king crab (RKC, *Paralithodes camtschaticus*) dates back to the 1930s followed thereafter by directed fisheries for snow (*Chionoecetes opilio*) and Tanner (*Chionoecetes bairdi*) crab in the 1960s. The fishery was initially prosecuted by a mostly foreign fleet but shifted to domestic fishery in the early 1970s via the Magnuson-Stevens Fishery Conservation and Management Act (MSA). Retained catches for RKC peaked in the 1980s with snow and Tanner catches peaking in the 1990s. However, harvests dropped sharply for these stocks shortly after peak harvest levels were reached. Simultaneous to the directed fisheries, crab were being caught as bycatch in other non-directed fisheries and population abundance has remained at relatively low levels over the last two decades compared to what was seen in the 1970s.

In 2005, the BSAI Crab Rationalization (CR) Program was implemented. This CR Program is a “voluntary three pie cooperative” program which allocates BSAI crab resources among harvesters, processors, and coastal communities. The CR Program was designed to address conservation, social, economic, and management issues associated with the previous over-capitalized derby fishery, as well as increase the safety of crab fishermen by ending the race for fish. The Program issued harvest quota shares to vessel owners (License Limitation Program license holders) and captains, as well as processor quota shares to processors, based on historic participation to protect investment in and reliance on the fisheries. Program components include quota share allocation, processor quota share allocation, individual fishing quota and individual processing quota issuance, quota transfers, use caps, crab harvesting cooperatives, protections for Gulf of Alaska groundfish fisheries, an arbitration system, monitoring, economic data collection, and cost recovery fee collection. One of the goals of the Program was bycatch reduction and the Program delivered by ending TAC overages, reducing capacity, increased soak times, and improved deck sorting and handling techniques to reduce mortality (Council 2017).

Fishery stock assessment surveys are an important part of monitoring the status of commercially targeted crab stocks, as well as understanding environmental shifts and ecological considerations. Accounting for mortality also remains paramount for sustainable management priorities. There are, however, many different sources of mortality (Table 1), including fishing-related mortalities and natural mortality. Natural mortality is identified as a research priority for crab as all Alaskan stocks are considered tier-3 stocks or higher (NPFMC) and relatively few targeted studies exist to determine natural mortality for crab in the Bering Sea (Szuwalski, SAFE 2019).

Fishing mortality has multiple layers, some easier to quantify than others. Fishing mortality from retained catch in the directed crab fishery is the largest documented source of mortality for BSAI crab stocks. Discard mortality from the directed fishery is the next largest documented source of mortality (that we know of) after retained catch. Discard of crab in groundfish fisheries has been highest in the yellowfin sole trawl fishery, and decreases down through the flathead sole trawl fishery, Pacific cod bottom trawl fishery, and rock sole trawl fishery, respectively. Bycatch in fisheries other than the groundfish trawl fishery has historically been relatively low, except for some years in the pot cod fisheries where it has been higher.

Unobserved fishing mortality is the next layer of fishing-induced mortality yet presents the largest data gap, and most difficult source of mortality to quantify, for BSAI crab species. For the purposes of this paper, unobserved mortality or post-encounter mortality is defined as the mortality imposed on a species by an encounter with fishing gear that does not result in capture. Currently, unobserved mortality for BSAI crab stocks is not included in total mortality estimates and may be imposing substantial constraints on status assessments and the sustainable management of crab stocks. In other words, this potentially very important component of total mortality is estimated to be zero, which is widely agreed to not be the case. In an effort to account for all sources of mortality for BSAI crab stocks and in order to comply with the MSA National Standard 9 which includes unobserved mortality in the definition of bycatch (underlined for emphasis below), a proxy for unobserved mortality should be used for BSAI crab stocks until further research can be completed to inform a better estimate.

> *50 CFR 600.350*
>
> *(c) Definition—Bycatch. The term “bycatch” means fish that are harvested in a fishery, but that are not sold or kept for personal use.*
>
> *(1) Inclusions. Bycatch includes the discard of whole fish at sea or elsewhere, including economic discards and regulatory discards, and <u>fishing mortality due to an encounter with fishing gear that does not result in capture of fish (i.e., unobserved fishing mortality)</u>.*

<u>Estimating Fishing Mortality for Crab</u>

Understanding the relationship between fishing interactions and crab mortality have been the focus of multiple studies over the past few decades. A 1987 study conducted by Stevens established discard mortality rates for three commercial crab species (snow, Tanner and RKC) in the groundfish trawl fishery. Results from studies were subsequently implemented into Alaska’s fisheries management and subsequent discard mortality rates are assumed to be 80% for trawl fisheries and 50% for non-directed fixed gear fisheries (pot and hook-and-line), and 25-32% for directed BSAI crab fisheries. These rates account for differences in gear and handling procedures used in the various fisheries. For all crab assessments, the discard mortality rates are applied for all species across the board per respective fishery. Since the initial study carried out by Stevens that implemented the assumed discard mortality rates that are still being used today in some estimates, other studies have been executed to further elucidate the effects of trawling impacts on crab mortality but have fallen short of identifying anything for implementation by management. Armstrong et al. (1993) states "Effects of direct bycatch on the stock are obscured by lack of evidence on indirect effects of trawling, including crushing of crab and degradation of juvenile habitat" in their paper to assess trawl closure zones for RKC and essential habitat for juveniles. Murphy et al. (1994) conducted a survey to identify research priorities for RKC, and the results identified the primary need for future work to "Determine handling and gear effects on crab health/mortality" which in part, has been explored, yet today there still remain large data gaps (Zheng and Siddeek, 2020 BBRKC SAFE). In 2006, Broadhurst et al. published a literature review, to date, of all the primary studies (n=80) that have estimated collateral, unaccounted fishing mortalities across multiple regions and fisheries and identified these six key causal factors of unobserved mortalities; 1) avoiding, 2) escaping, 3) dropping out of the gear during fishing, 4) habitat destruction or subsequent 5) predation and 6) infection from any of the above.

The National Marine Fisheries Service (NMFS) Resource Assessment Conservation Engineering (RACE) program has dedicated years of research in efforts to investigate fishing-induced mortality and mitigate the effects of trawl gear on the seafloor. Conservation engineering, as it relates to fisheries science, is the research and development process to bring new and innovative techniques to commercial fishing operations that reduce bycatch and other unintended effects on non-target components of the marine ecosystem (Rose et al., 2010). A 2007 North Pacific Research Board (NPRB) project working on modified sweeps to observe, in part, the effects on crab mortality rates by the different components of a groundfish trawl configuration. These studies, among others over the years, focused on determining methods for and quantifying delayed mortality in Alaskan trawl-caught (and discarded per requirements) crab (Stoner et al., 2008; Rose et al., 2013; Yochum et al., 2015). Furthermore, researchers have coupled these studies with efforts to identify injuries sustained to crab passing underneath trawl footropes (Rose et al., 1999) and survival rates of crab interacting with trawl sweeps (Hammond et al., 2013 and Rose et al., 2013). All of these studies have brought to light that mortality rates on crab range from low to high and vary by species, by area of the gear encountered (e.g., footrope, bobbins, discs, etc.), time of year (particularly crab molting cycle), and a host of other variables. All of these studies allude to unobserved mortality from fishing gear. However, they all fail to estimate an unobserved encounter rate or unobserved mortality estimate for crab that interacts with the gear but is not retained in the net.

Trawl selectivity, when it comes to crabs, is a large unsolved part of this equation. Nguyen et al (2014) used cameras to observe snow crab interactions with trawl footropes and concluded that 95% of crab that encountered the gear, went underneath the footrope while the remaining 5% went over it, likely to be caught in the net. A 2010 pilot project estimated between 98-99.5% of crab escaped through the footrope and forward section of the net, therefore not getting caught in the net (unpublished data, C. Rose, AFSC). These two studies show an incredibly large percentage of crab interact with mobile fishing gear and remain on the seafloor. In the absence of encounter rate estimation, other methods to address impacts could be very informative. Bottom contact (i.e., time fishing gear is on the seafloor) is a factor for the impacts from trawl gear. Non-pelagic trawl (NPT) gear, also called bottom trawl, is, by design, on the seafloor near 100% of the time, although not the entire span of the gear is in contact with the bottom. For example, Lomeli et al (2019) demonstrated the ability to raise up to 95% of a West Coast groundfish bottom trawl sweeps off the bottom by 6 cm, similar to NPT gear modifications implemented in Alaska groundfish fisheries. Pelagic trawl gear, also called midwater trawl, amount and duration of seafloor contact, on the other hand, is difficult to quantify (Engaas et al., 2001). We know the gear hits the seafloor because benthic dwelling species and structures like crab, corals, and sea whips are part of the catch that's brought up in the codend. Estimating the amount of this seafloor contact, particularly the proportion of the trawl's nominal operating width in contact with the seafloor, has been limited to anecdotal knowledge derived from interviewing fishermen who use these trawls. Past methods and criteria to evaluate the effects of fishing on essential fish habitat (EFH) have resulted in a wide range of estimates for the time the gear is on bottom for pelagic trawl. Anecdotal information indicates the pelagic trawl fleet is likely on bottom or near bottom at times in attempts to lower the head rope depth in the water column to avoid salmon and herring bycatch, and small pollock that tend to congregate higher in the water column, and to increase the catch of larger more valuable pollock that tend to be on or near the bottom.

Recent spatial reviews of available information identify important overlap of known crab populations with pelagic and bottom trawl activity. Rose et al (2014) estimates commercially targeted crab species inhabit 85-90% of the seafloor area swept by the trawl sectors. Pelagic (pollock) and non-pelagic (pacific cod and flatfish) trawl fishing efforts (Figure 1) and pacific cod pot fishing efforts (Figure 2) have significant known overlap with adult RKC, adult Tanner and adult snow crabEFH (Figures 3-5), not to mention the remaining widespread juvenile and larval populations. These maps show an overlap in crab populations with both pelagic and non-pelagic trawl activity. Some informative work has been done mapping bycatch of crab with these fisheries (NPFMC discussion paper (MacLean, Jul 2019) and ABSC public comment to CPT, Sep 2020). Some area closures were put in place as an effort to mitigate habitat disturbance and subsequent mortality from non-directed fisheries. Trawl area closures (Figure 6), particularly the Red King Crab Savings Area and the Pribilof Island Habitat Conservation Area, are examples of zones that are closed to bottom trawling in efforts to minimize fishing pressures. However, spatially attributed rates of unobserved mortality may remain higher in certain areas, but it's difficult to determine the effectiveness of areas closed to non-pelagic trawling that are left open to pelagic trawling when we know that pelagic gear often interacts with the seafloor. Alternatively, there may be areas that are closed that would produce lower rates of overall mortality if they were to be open and other areas closed to better protect crab due to their seasonal movement and movement with changing bottom temperatures. What is missing is the true impact of bycatch with estimates of unobserved fishing mortality left out of the picture. In looking at these maps, overlaid with crab populations and distribution, the range and impact of unobserved mortality from trawl gear has a potential to be quite large.

Ultimately, all sources of fishing mortality must be considered and implemented in stock assessments and fisheries management, including unobserved or post-encounter mortality of crab stocks remaining on the grounds after contact with fishing gear. While some of these economically important stocks are approaching all-time low levels of abundance and facing closures, an estimate of unobserved mortality must be put in place in future management cycles using available information until additional research proposals are developed and carried out to refine those estimates, as needed. These estimates should also consider the impact of encounters with fishing gear when crab stocks are molting, mating, or at other vulnerable life stages.

Conclusion

Scientists and researchers for decades have been working diligently to better understand unobserved mortality of crab resulting from interactions with fishing gear but escaping capture by the gear. The impact that unobserved fishing gear interactions have on crab stocks is unknown and potentially significant. We can say for certain that there are, in fact, interactions resulting in immediate and delayed unobserved mortality for crab, yet this is not accounted for in the science or management process.

Unobserved fishing mortality, from trawl impacts in particular, has the potential to be quite large on crab stocks in the BSAI. This is especially true due to the high percentage (95-99.5%) of crab estimated to encounter fishing gear components and passing beneath the net avoiding capture (Figure 7). We know at least a portion of the non-pelagic trawl gear is in contact with the seafloor near 100% of the time and covering a large area of the Bering Sea shelf that overlaps with BSAI crab stocks. The actual time pelagic trawl gear is on the bottom is less well known. Estimating the amount of this seafloor contact, particularly the proportion of the trawl's nominal operating width in contact with the seafloor, has been limited to anecdotal knowledge derived from interviewing fishermen who use these trawls.

Studies using gear directly comparable to Alaska pelagic trawls, and identifying the resulting effect of gear contact with the seafloor, are lacking. By regulation, these trawl configurations must not use bobbins or other protective devices, so footropes are small in diameter (typically chain or sometimes cable or wrapped cable). Therefore, their effects may be similar to other footropes with small diameters (i.e., shrimp or Nephrops trawls). However, these nets have a large enough mesh size in the forward sections that few, if any, benthic organisms that actively swim upward would be retained in the net. Thus, the interaction and impacts are unobserved as benthic animals that were found in other studies to be separated from the bottom and removed by trawls with small-diameter footropes, as evident bycatch would, in these cases, return to the seafloor passing through as they contact forward sections of the Alaska pelagic trawls (BSAI Crab FMP, October 2011). For non-pelagic trawl gear, bottom contact has been greatly reduced with the use of raised sweeps (Rose et al., 2013, Lomeli et al., 2019) but no estimates for unobserved mortality exist. The extent that the raised sweeps have lowered observed mortality can be estimated but the extent these gear modifications have lowered unobserved mortality remains unknown.

Maps identifying crab EFH are available (Adult Summer EFH Maps Habitat associations, biological associations, predator/prey associations, and life histories of crabs in the BSAI King and Tanner Crab FMP; as presented to NPFMC April 2017) (Figures 3-5). These should be used in conjunction with maps showing trawl fishing effort, for example, to show spatial overlap and then used to show bottom contact using a proxy for non-pelagic and a higher proxy for bottom trawl. Estimating a proxy for unobserved crab mortality for each gear type is an important first step before identifying any field studies to be conducted. Although some crab recapture net studies have been conducted with non-pelagic trawl raised sweep fishing gear, unfortunately, those studies didn’t address unobserved crab mortality. Further, the studies did not capture the numbers of crab in the cod end compared to the numbers of crab in the recapture nets as this was not a focus for those studies (codends were left open).

In addition to the temporal and spatial fishing impacts, it is important to consider the impact of encounters with fishing gear when crab stocks are molting, mating, or at other vulnerable life stages. To date, data on crab shell condition have not been collected by groundfish observers and may prove difficult as soft shell crab tend to fall apart in fishing gear and are expected to have at or near 100% mortality. The available information on the life history and molting cycles of BSAI crab are incomplete at best. BSAI crab are generally thought to have a spring molt. Red king crab are likely molting between January-July with Tanner and snow January-May (Donaldson, W., Byersdorfer, S., 2005). Although, this can vary, for example, with young snow and Tanner crab molting several times in a year. Similarly, reports on mating vary. For example, red king crab studies report a variety of mating windows, generally in the spring, but covering January-September (Donaldson, W., Byersdorfer, S., 2005). It is clear within the context of accounting for sources of crab unobserved mortality from fishing impacts that imprecise temporal and spatial molting information for Bering Sea crab stocks warrants further attention.

Discussion

Alaska is home to some of the most pristine and iconic crab products in the world. A booming industry that supplies 10% of Alaska's seafood ex-vessel revenue while providing hundreds of jobs (McDowell Group, 2020). However, BSAI crab stocks generally fluctuate broadly, some are at historical lows, crab fisheries are closed for some species, and rebuilding plans are in place for several overfished stocks. BSAI crab research and management is difficult and managers require every bit of data to maintain a sustainable and productive fishery, especially in a changing climate.

While there are not yet estimates for unobserved crab mortality, we do know that trawling in the BSAI is being conducted every year over a large area and with much of this activity in contact on the seafloor in areas of crab EFH. Further, a number of BSAI trawl fishery resources remain underutilized and some growth in trawl fishery effort is expected. Until proxies for the factors identified in this paper are developed and unobserved mortality is accounted for, bycatch of BSAI crab should be considered an underestimate. Tanner and Bristol Bay RKC are examples of stock declines that would benefit from further protective measures while determining the extent and effect of unobserved mortality in the BSAI and how this may be contributing to the decline in crab biomass.

All sources of fishing mortality should be accounted for and estimated for use in stock assessments and fisheries management, including unobserved or post-encounter mortality of crab stocks remaining on the grounds after contact with fishing gear. An estimate should be developed for use in upcoming management cycles using available information, while additional research proposals should be developed to refine those estimates, as needed. This white paper highlights some areas for further research to better inform estimates on unobserved mortality in both the pelagic and bottom trawl fisheries in the BSAI, such as studies to quantify seafloor contact for the pelagic trawl sector. However, until further research is available, conservative proxies are needed now for stock assessments to better estimate the total mortality on crab stocks and for improved bycatch management. Finally, more information on the impact of encounters with fishing gear when crab stocks are molting, mating, or at other vulnerable life stages throughout the year are needed.

References

Alverson, D.L., Freeberg, M.H., Murawski, S.A., Pope, J.G., 1994. A global assessment of fisheries bycatch and discards, in: FAO Fish. Tech. Paper. pp. 1–233.

Armstrong, D.A., Wainwright, T.C., Gregory, C., Dinnel, P.A., Andersen, H.B., 1993. Taking Refuge From Bycatch Issues: Red King Crab (*Paralithodes camtschaticus*) and Trawl Fisheries in the Eastern Bering Sea. Canadian Journal of Fish and Aquatic Science, Volume 50.

Broadhurst, M.K., Suuronen, P., Hulme, A., 2006. Estimating collateral mortality from towed fishing gear. Journal of Fish and Fisheries, issue 7, p 180-218.

Donaldson, W., Byersdorfer, S., 2005. Biological Field Techniques for Lithodid Crabs, Biological Field Techniques for Lithodid Crabs. Alaska Sea Grant, University of Alaska Fairbanks. https://doi.org/10.4027/bftlc.2005

Engaas, A., Ona, E., Ramberg, K., 2001. In situ determination of bottom trawl ground gear contact. ICES CM 2001/Q:07

Fedewa, E.J., Jackson, T.M., Richar, J.I., Gardner, J.L., Litzow, M.A., 2020. Deep-Sea Research Part II Recent shifts in northern Bering Sea snow crab (*Chionoecetes opilio*) size structure and the potential role of climate-mediated range contraction. Deep. Res. Part II 104878. https://doi.org/10.1016/j.dsr2.2020.104878

Fisheries, F.O.R., n.d. Ecosystem Approaches for Fisheries.

Garber-yonts, B., 2019. Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Gulf of Alaska and Bering Sea/Aleutian Islands Area.

Lomeli, M.J.M., Wakefield, W.W., Herrmann, B., 2019. Evaluating off-bottom sweeps of a U.S. West Coast groundfish bottom trawl: Effects on catch efficiency and seafloor interactions.

Hammond, C.F., Conquest, L.L., Rose, C.S., 2013. Using reflex action mortality predictors (RAMP) to evaluate if trawl gear modifications reduce the unobserved mortality of Tanner crab (*Chionoecetes bairdi*) and snow crab (*C. opilio*). Marine Science.

Mullowney, D.R.J., Baker, K.D., 2020. Size-at-maturity shift in a male-only fishery : factors affecting molt-type outcomes in Newfoundland and Labrador snow crab (*Chionoecetes opilio*). https://doi.org/10.1093/icesjms/fsaa164

Murphy, J.T., 2020. Climate change, interspecific competition, and poleward vs. depth distribution shift: Spatial analyses of the eastern Bering Sea snow and Tanner crab (*Chionoecetes opilio* and *C. bairdi*). Fish. Res. 223, 105417. https://doi.org/10.1016/j.fishres.2019.105417

North Pacific Fishery Management Council, 2010. Ten-Year Program Review for the Crab Rationalization Management Program in the Bering Sea/ Aleutian Islands, 2017. North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

Truong X. Nguyen, Paul D. Winger, George Legge, Earl G. Dawe, Darrell R. Mullowney, 2014. Underwater observations of the behaviour of snow crab (Chionoecetes opilio) encountering a shrimp trawl off northeast Newfoundland. Fisheries Research, Volume 156, Pages 9-13, ISSN 0165-7836. https://doi.org/10.1016/j.fishres.2014.04.013.

Rose, C.S., Hammond, C.F., Stoner, A.W., Eric Munk, J., Gauvin, J.R., 2013. Quantification and reduction of unobserved mortality rates for snow, southern Tanner, and red king crabs (*Chionoecetes opilio, C. bairdi*, and *Paralithodes camtschaticus*) after encounters with trawls on the seafloor. Fish. Bull. 111, 42–53. https://doi.org/10.7755/FB.111.1.4

Stevens, B.G., 1990. Survival of King and Tanner Crabs Captured by Commercial Sole Trawls. Fish. Bull. 88, 731–744.

Stoner, A.W., Rose, C.S., Munk, E.J., Hammond, C.F., Davis, M.W., 2008. An Assessment for Two Alaskan Crab Species, Tanner Crab (Chionoecetes bairdi) and Snow Crab (C. opilio), Based on Reflex Impairment. Fish. Bull. 106, 337–347.

Yochum, N., Rose, C.S., Hammond, C.F., 2015. Evaluating the flexibility of a reflex action mortality predictor to determine bycatch mortality rates: A case study of Tanner crab (*Chionoecetes bairdi*) bycaught in Alaska bottom trawls. Fish. Res. 161, 226–234. https://doi.org/10.1016/j.fishres.2014.07.012

Tables and Figures:

Table 1: Sources of mortality on Bering Sea and Aleutian Islands (BSAI) crab stocks. Natural mortality is the most poorly understood source of mortality that is included in stock assessments and accounting. Retained catch and deadloss in directed BSAI crab fisheries have the most accurate accounting of mortality, followed by discard mortality in the directed and non-directed fisheries which is estimated. Unobserved mortality in both directed and non-directed fisheries is unknown, unaccounted for and not included in stock assessments.

BSAI Crab Mortality Source	Included in Assessments	Accounting	Catch or Bycatch	Status	Applies as PSC	Estimate Used
Fishing Mortality						
Target Crab Fisheries						
Retained Landed	YES	Documented	Catch	1	NA	
Deadloss	YES	Documented	Catch	1	NA	
Discard Mortality	YES	Observed/Estimated	Bycatch	2	NO	25-32%
Unobserved Mortality	NO	Unknown	Bycatch	3	NO	
Other Fisheries Pot						
Discard Mortality	YES	Observed/Estimated	Bycatch	2	NO	50%
Unobserved Mortality	NO	Unknown	Bycatch	3	NO	
Other Fisheries Hook-and-Line						
Discard Mortality	YES	Observed/Estimated	Bycatch	2	NO	50%
Unobserved Mortality	NO	Unknown	Bycatch	3	NO	
Other Fisheries Trawl						
Discard Mortality	YES	Observed/Estimated	Bycatch	2	YES	80%
Unobserved Mortality	NO	Unknown	Bycatch	4	NO	
Natural Mortality	YES	Estimated	NA	5	NA	

Status	Description
1	Accurately accounted from at dockside record keeping and reporting
2	Encounter estimates from observer coverage, mortality experimentally estimated, published
3	Unknown, unacounted for, but likely low due to nature of gear footprint
4	Unknown, unacounted for, but likely high due to nature of gear footprint
5	Poorly understood, variable sources, not documented per species, variable per assessment

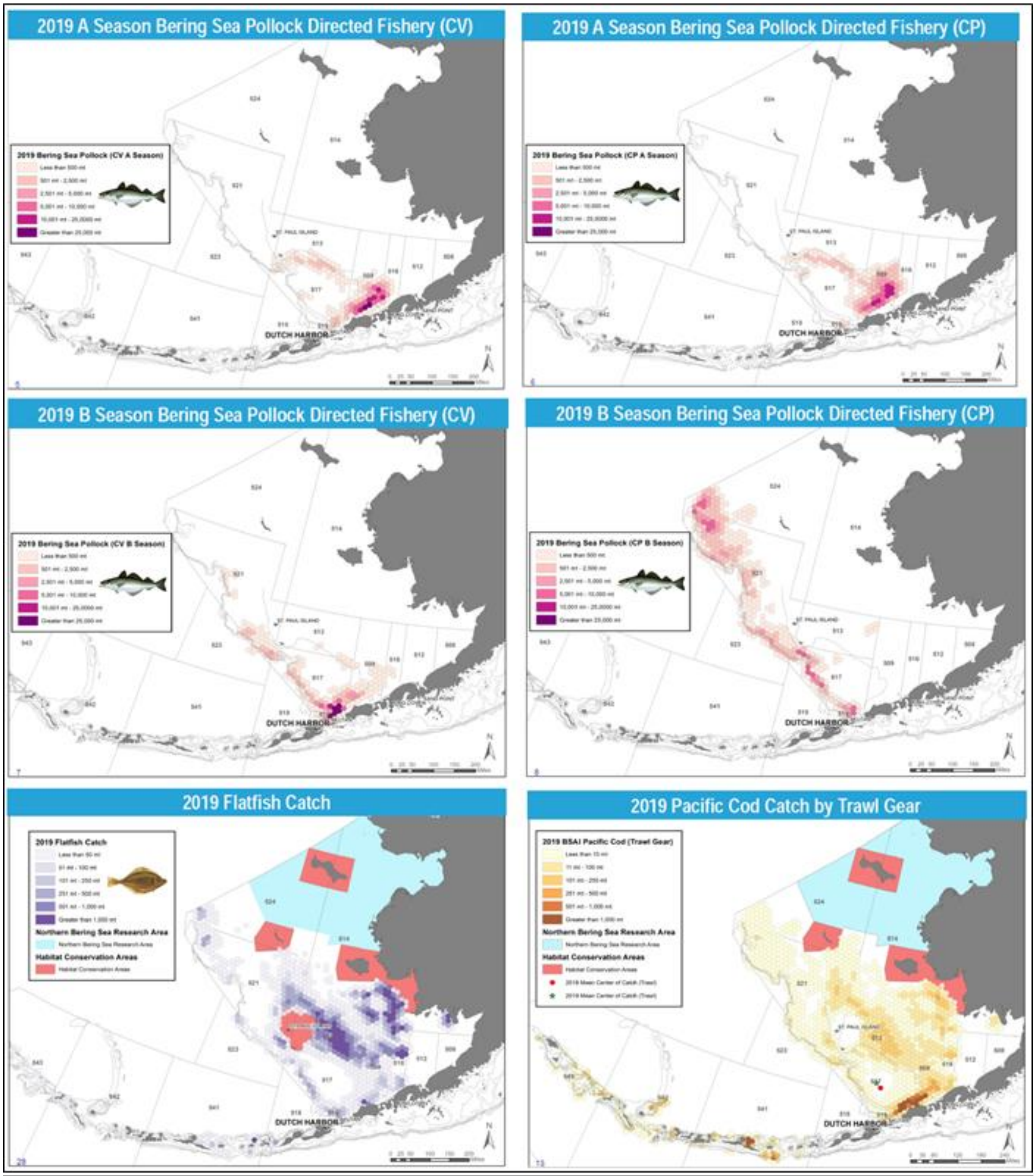

Fig 1. The 2019 Bering Sea and Aleutian Islands (BSAI) inseason management report shows area of A and B season catch by catcher vessels (CV) and catcher processors (CP) in the directed fishery. Similar area maps presented for flatfish and Pacific cod catch by trawl gear.
(https://www.fisheries.noaa.gov/alaska/commercial-fishing/fisheries-catch-and-landings-reports-alaska)

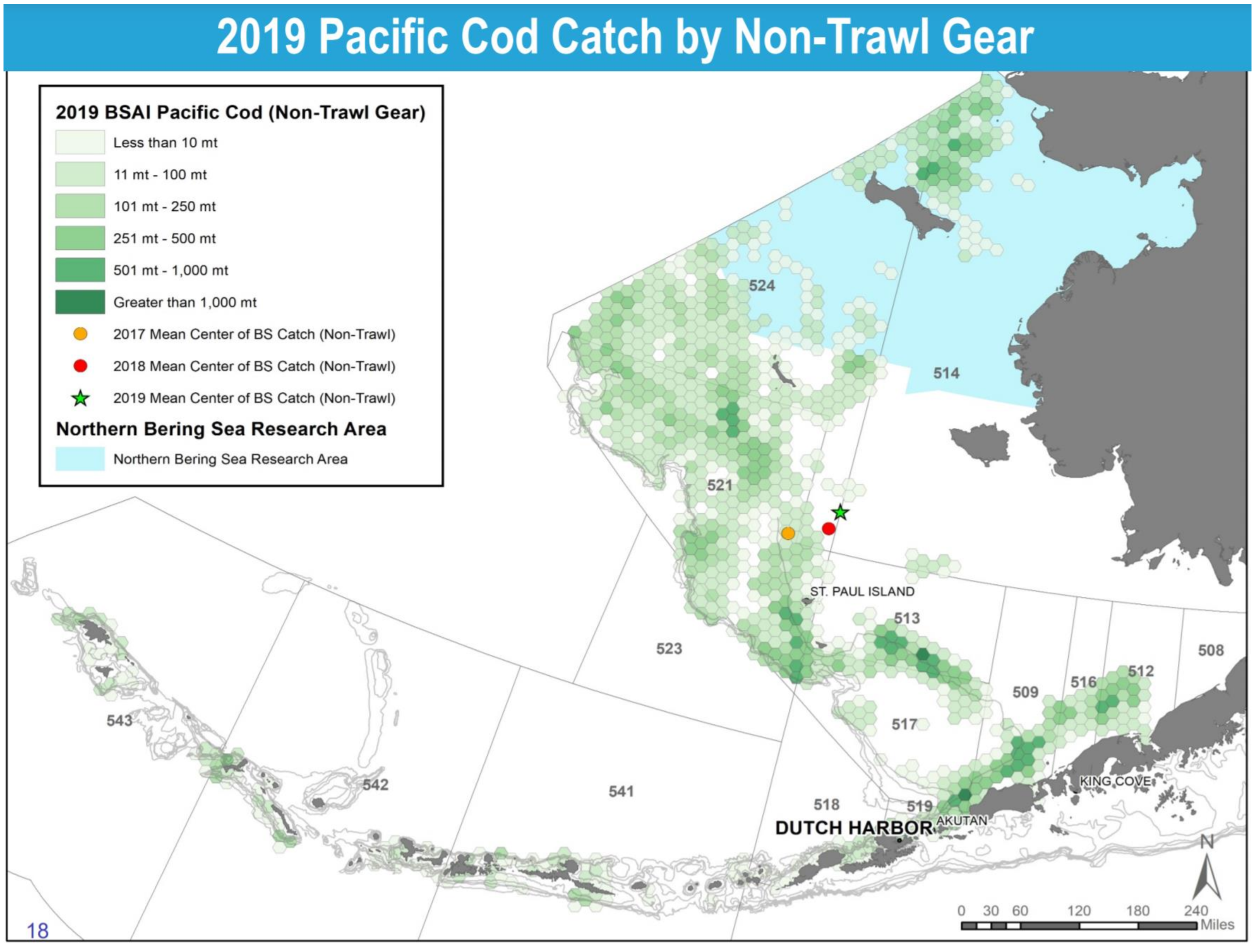

Fig 2. 2019 Bering Sea and Aleutian Islands (BSAI) Pacific cod catch by non-trawl (hook and line, pot and jig) gear. Catch was landed much throughout the southern bering sea, and along the Western Bering Sea shelf to the exclusive economic zone and North of St. Lawrence Island. Highest density areas of catch are reported north of Unimak pass and Unimak Island (south of the red king crab savings area) and around St. George Island of the pribilofs (outside the Pribilof Island Habitat Conservation Area) (https://www.fisheries.noaa.gov/alaska/commercial-fishing/fisheries-catch-and-landings-reports-alaska)

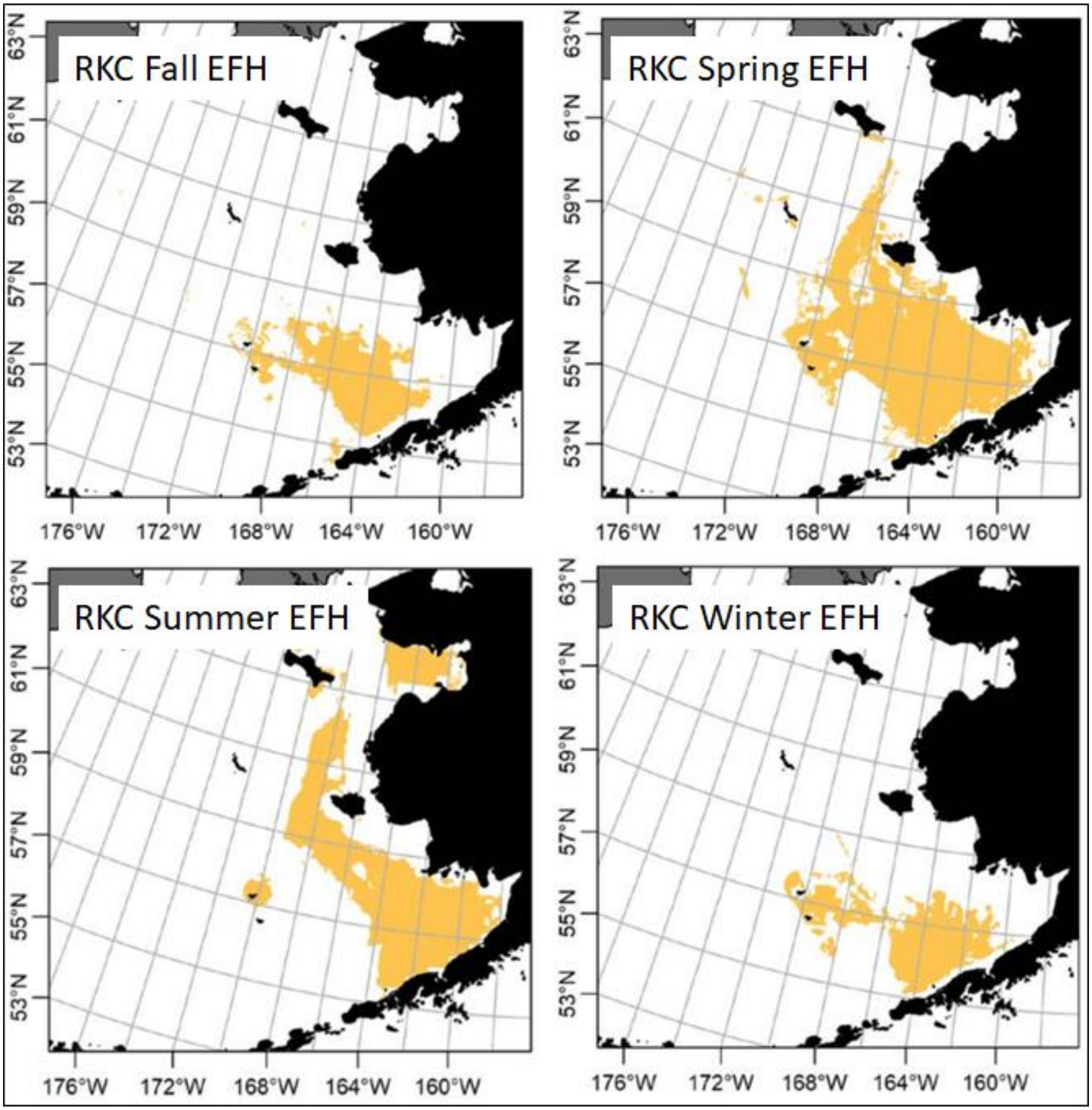

Fig 3. Adult red king crab essential fish habitat. Populations are concentrated towards the southern portion of their range during fall and winter seasons and are more widely spread out (North and West) during spring and summer. The general distribution area for this life stage, located in bottom habitats along the nearshore (spawning aggregations) and the inner (0 to 50 m), middle (50 to 100 m), and outer shelf (100 to 200 m) throughout the BSAI wherever there are substrates consisting of sand, mud, cobble, and gravel.
(https://www.fisheries.noaa.gov/management-plan/bering-sea-aleutian-islands-king-and-tanner-crabs-management-plan)

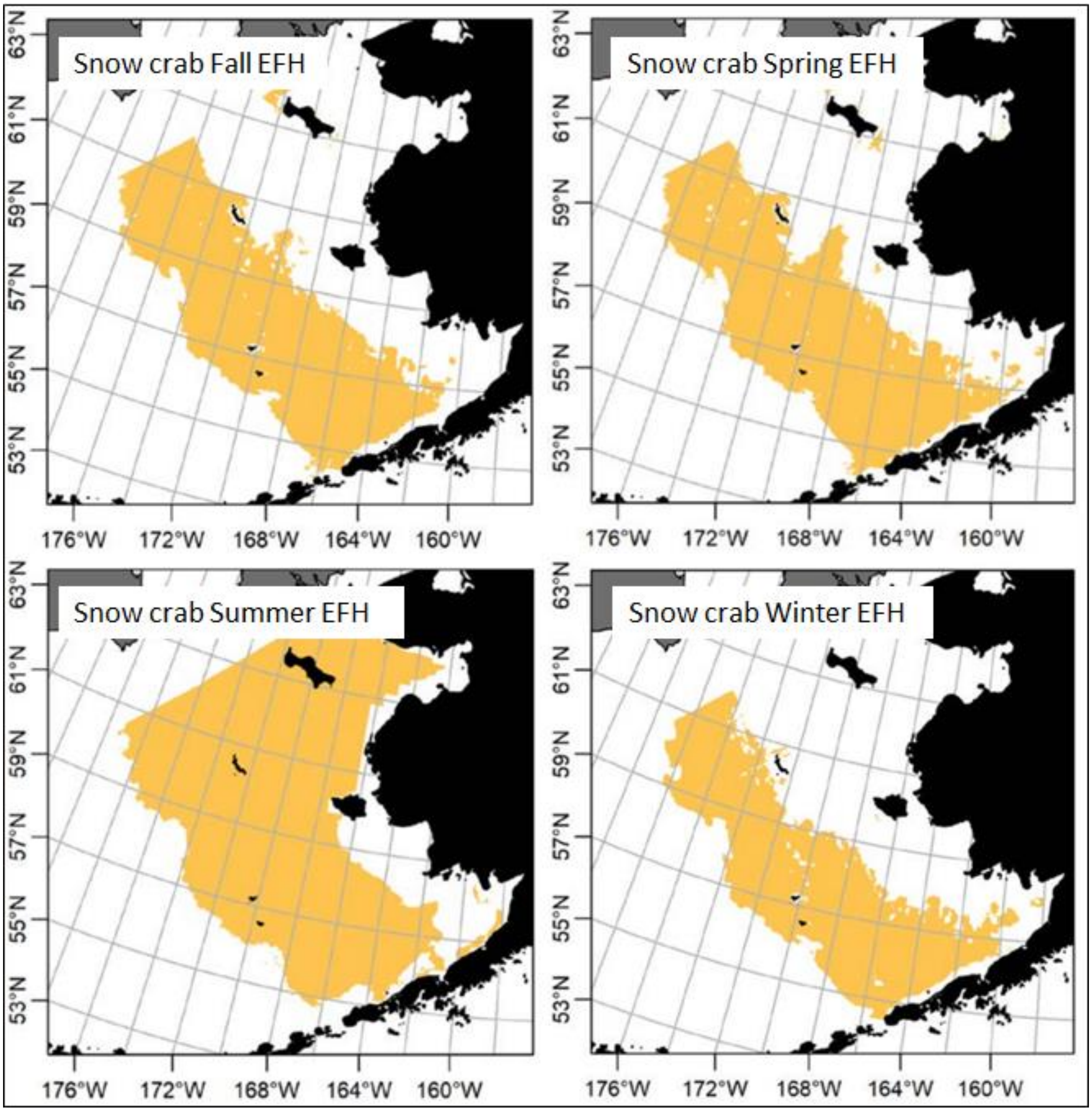

Fig 4. Adult snow crab essential fish habitat is wide-spread throughout most of the Bering Sea. The general distribution area for this life stage, located in bottom habitats along the inner (0 to 50 m), middle (50 to 100 m), and outer shelf (100 to 200 m) throughout the BSAI wherever there are substrates consisting mainly of mud.
(https://www.fisheries.noaa.gov/management-plan/bering-sea-aleutian-islands-king-and-tanner-crabs-management-plan)

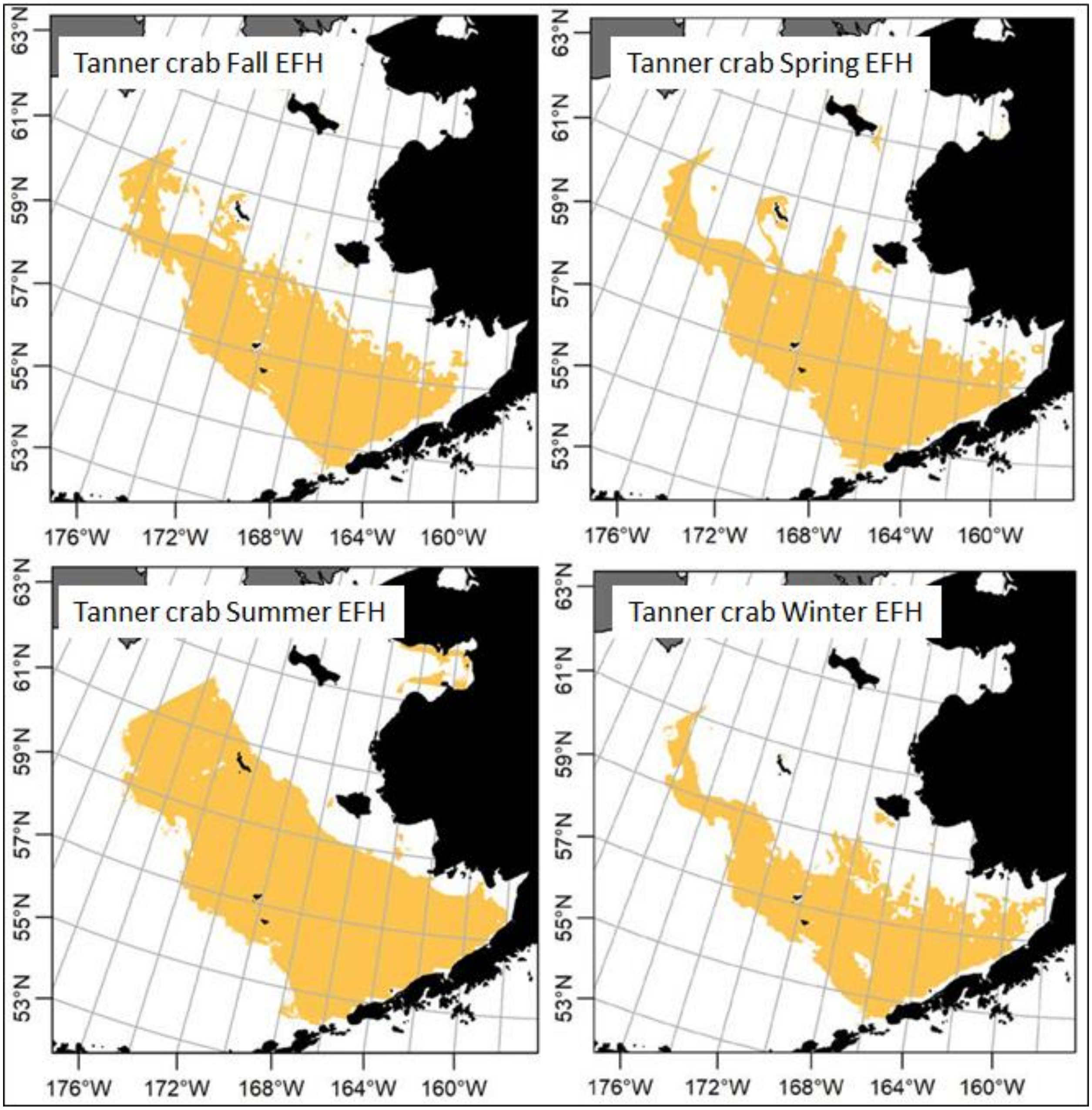

Fig 5. Adult Tanner crab essential fish habitat is wide-spread throughout the Bering Sea, similar to snow crab, except range does not expand into Norton sound like summer snow crab populations. The general distribution area for this life stage, located in bottom habitats along the inner (0 to 50 m), middle (50 to 100 m), and outer shelf (100 to 200 m) throughout the BSAI wherever there are substrates consisting mainly of mud.
(https://www.fisheries.noaa.gov/management-plan/bering-sea-aleutian-islands-king-and-tanner-crabs-management-plan)

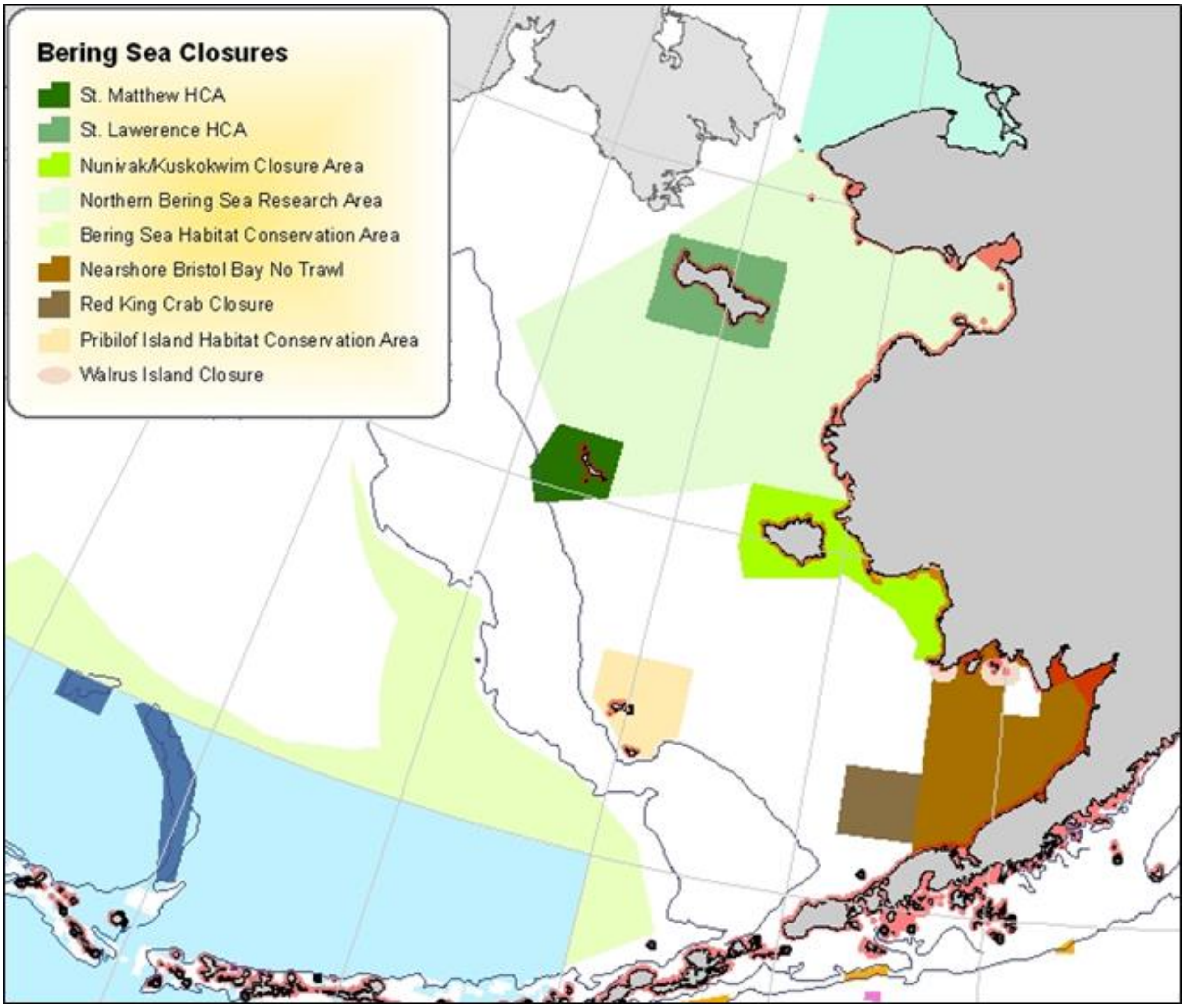

Fig 6. Some area closures have been permanently closed to groundfish trawling to reduce potential adverse impacts on sensitive habitat and to protect benthic invertebrates and enhance habitat. https://www.npfmc.org/habitat-protections/

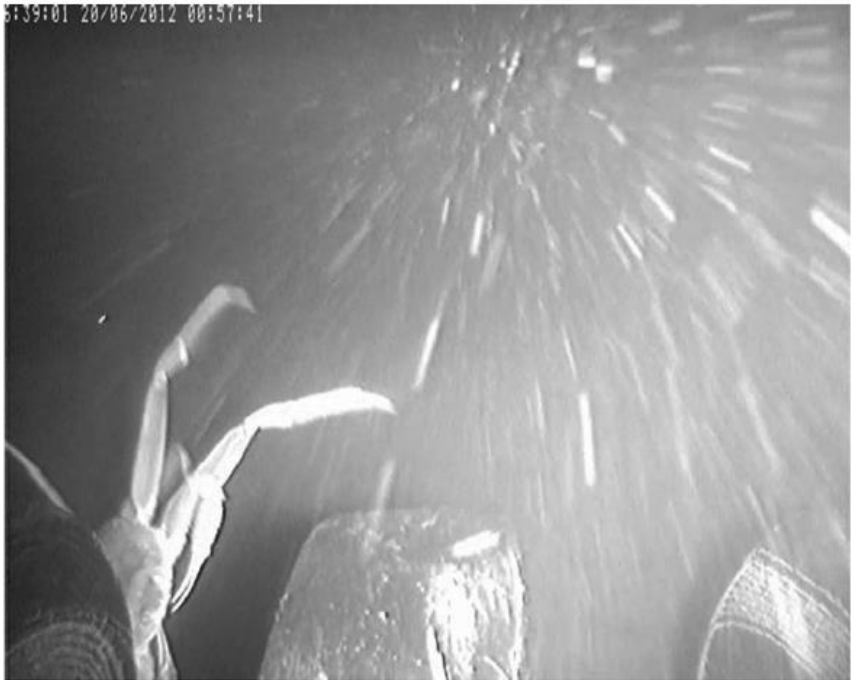

Fig 7. Video cameras placed on the footrope of a trawl net in a study by Nguyen et al., 2014 enabled biologists to observe the interactions and impacts of trawl components with snow crab. Video review revealed 95% of crab interactions resulted in crab going beneath the footrope.