Bristol Bay Red King Crab Information

Discussion Paper

April 2022[1]

1 Introduction and Background

In October and December 2021, the North Pacific Fishery Management Council (Council) tasked staff to prepare a discussion paper that provides the best available information on four topics related to Bristol Bay red king crab (BBRKC).[2] The Council's motions are responsive to an ongoing decline in the BBRKC stock, culminating in the State of Alaska's inability to open a directed fishery for the 2021/2022 season. After review of this paper, the Council may request further analysis, develop alternatives to recommend actions that fall under its authority, or initiate dialogue with other management agencies at its own discretion. No action is required by statute and this document is not part of a mandated program or allocation review.

Staff has reordered the four topics in the final December 2021 motion so that the information presented in this paper flows logically and the background information provided in each section contributes to the understanding of the following sections to the extent possible. The four topics, as ordered in this paper, are described here in the Council's words:

[1] Prepared by: Sam Cunningham (NPFMC) and Kelly Cates (NMFS AKRO SF)
[2] The December 2021 motion appended a fourth topic to the previously passed October motion.

1. Provide the best available information on Bristol Bay red king crab molting/mating annual cycle and how the seasonality of this overlaps with fisheries and the effects these interactions may have.
2. Evaluate boundaries used for the BBRKC survey, stock assessment, PSC limits, and directed fishery.
3. Provide the best available information on bottom contact by pelagic trawl gear and the impact it may have on BBRKC stocks.
4. Summarize mechanisms used in other council managed fisheries to create flexible, responsive spatial management measures for all gear types and how they might be applied to protect BBRKC.

The 2021 NMFS eastern Bering Sea bottom trawl survey ("trawl survey") results were consistent with a trend of decreasing BBRKC biomass (Zacher et al. 2021). The 2021 mature female abundance estimate was 25% less than in 2019. While the abundance of female red king crab (RKC) has been low in recent years, 2021 was the first year since 1995 that the mature female abundance fell below the established threshold in the State of Alaska's harvest strategy to allow a directed fishery in Registration Area T (see Figure 3-1). The length-based abundance estimate was 7.9 million mature female RKC in 2021, which is below the threshold of 8.4 million (Zheng et al. 2021). As a result, the directed fishery was closed for the 2021/2022 season.

Estimated mature biomass increased in the mid-1970s and then decreased precipitously in the early 1980s (Figure 1-1). Abundance increased from the mid-1980s until about 2007. Mature females were estimated to be roughly four times more abundant in 2007 than in 1985; mature males were roughly twice as abundant in 2007 than in 1985. Abundance has steadily declined since 2010 (Zacher et al. 2021). The projected mature male biomass in 2021 is less than 50% of the peak value (2002) during the last 40 years. Estimated mature female biomass has been at a low level during the four most recent years. Since 1984, recruitment has only been above the long-term historical average in six years, with the most recent above-average year occurring in 2005 (Zheng et al. 2021).

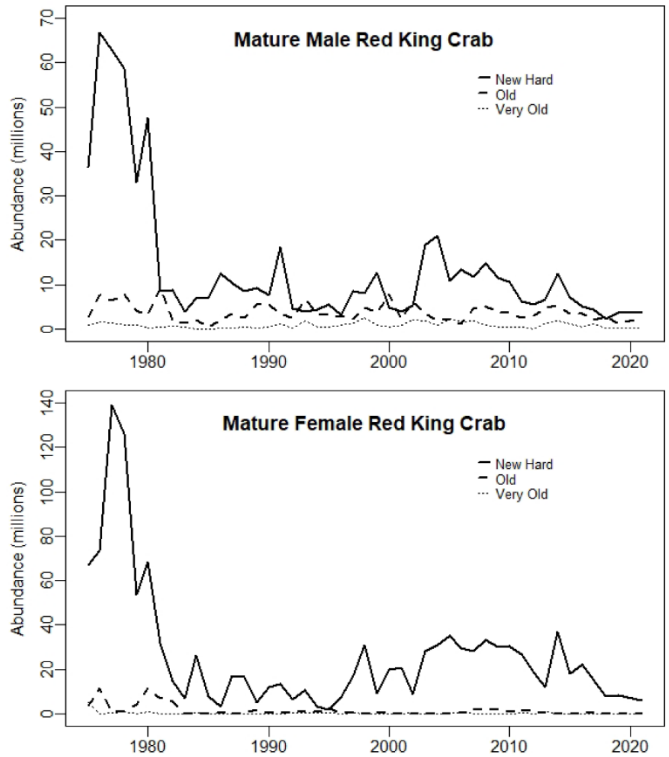

Figure 1-1 Time series of mature male (≥120 mm CL) and female (actual maturity) Bristol Bay red king crab abundance by shell condition, 1975-2021 (Zacher et al. 2021).

The Council has recently reviewed several analyses related to the abundance of BBRKC. The Council considered adjusting Bering Sea and Aleutian Islands (BSAI) groundfish trawl PSC limits for BBRKC, snow crab, and Tanner crab in February 2021 (NPFMC 2021a), and an emergency rule request for a northward expansion of the Red King Crab Savings Area (RKCSA) in December 2021 (NPFMC 2021b). The Council did not pursue action following those analyses but has closely monitored the stock and requested this discussion paper as a platform to contemplate actions that might address the fishery and its stakeholders, as bounded by the Council's authority. Whereas previous analyses focused on a specific topic or action alternatives, this paper looks broadly at what information is available on several requested topics. The topic areas include BBRKC biology, stock assessment, interaction with gear from other fisheries and flexible management options.

2 Item 1: BBRKC Molting and Mating

Red king crab (RKC) mate when they enter shallow waters (<50 m) where males grasp females just prior to female molting, after which the eggs are fertilized and extruded on the female's abdomen. Adult females brood thousands of embryos (43,000 to 500,000 eggs) underneath their tail flap for 11 months before they hatch. Hatching generally occurs in April but embryo development can be delayed in cold years (Chilton et al. 2010).[3] When embryos are fully developed they hatch as swimming larvae but are susceptible to the movements of tides and currents. Cooler water temperatures slow larval development

[3] For example, colder than average bottom temperatures in 2020 may have delayed peak hatch timing to June. This supposition is based on the fact that 2020 bottom temperatures were colder than 2006-2007 bottom temperatures when Chilton et al. (2010) noted that survey stations sampled in May had high numbers of mature females still brooding embryos fertilized the previous season (Fedewa et al. 2020).

rates and can increase mortality due to spending more time in a vulnerable state and increased offshore transport into ecosystem areas where larvae are less likely to mature to juveniles (Loher and Armstrong 2000). After feeding on plant and animal plankton for two to three months and undergoing body changes with each molt, they settle into their benthic life stage. Young-of-the-year crab occur at depths of 50m or less. They are solitary and need high relief habitat or coarse substrate such as boulders, cobble, shell hash, and living substrates such as bryozoans and stalked ascidians. Between the ages of two and four years there is a decreasing reliance on habitat and a tendency for the crab to form pods consisting of thousands of crabs. Podding generally continues until four years of age (about 65 mm carapace length (CL)) when the crab move to deeper water and join adults in the spring migration to shallow water for spawning, and then to deep water for the remainder of the year. Mean age at recruitment into the fishery is 8-9 years (Crab FMP), though "adult phenology" is described as 5-6+ year (Fedewa et al. 2020[4]).

King crab molt multiple times per year through age-3 after which molting is annual. At larger sizes, king crab (especially males), may skip molt as growth slows. Females grow more slowly and do not become as large as males. In Bristol Bay, 50% maturity is attained by males at 120 mm CL and by females at 90 mm CL (about 7 years). Within days to weeks after molting, RKC shells begin to harden. RKC are particularly vulnerable during their molting phase where it takes 74.2 days for the carapace to reach 90% of maximum hardness (Stevens, 2009). During this time, RKC are at increased risk of predation and harm from contact with fishing gear. Molting crab are not feeding so they do not enter baited pots.

Specific to BBRKC, the best information available to the analysts indicates that the mating season primarily occurs from January to March for primiparous (individuals bearing first offspring) RKC females and from April to June for multiparous RKC females. Mating occurs at the same time as molting for mature females. Molting times for mature males are not as well described as for mature females. Mature males are thought to molt once during the March to May period, whereas juvenile crab may molt several times per year as they grow and can molt at different times during a year. Large juveniles generally molt during the spring. Overall, the molting period for BBRKC ranges from January to June (Pers Comm J. Zheng, ADFG; see also Table 2a in Fedewa et al. 2020).

Larval advection is an important process for recruitment in benthic invertebrates as the supply of settlement-competent larvae to a given area typically depends upon larval hatch that occurs elsewhere. For species with long larval pelagic duration, substantial transport distances may occur before reaching the settling stage (Shanks 2009). As such, variable rates of connectivity and retention can result in large-scale population trends. Recent studies have assessed how predicted settlement success varied through changes in larval pelagic duration and oceanographic circulation patterns, demonstrating that shorter advective distance was associated with warmer conditions, causing higher rates of local retention relative to cold conditions (Daly et al. 2018 & 2020). This is contrary to earlier models which presumed that most larvae hatched in southwest Bristol Bay were advected offshore away from good habitat whereas larvae hatched in central and nearshore Bristol Bay were retained in or advected to good habitat along the Alaska Peninsula. These results suggest that contemporary spatial distributions can supply settlement-competent larvae to nurseries along the Alaska Peninsula and that, under certain conditions, larvae may reach the Pribilof Islands when hatched from southwest Bristol Bay. Larvae released from regions other than the western Unimak area did not reach the Pribilof Islands in the Daly et al. (2020) study, suggesting disconnection of the Pribilof Islands from the present-day Bristol Bay red king crab population.

Recruitment variability is not fully understood for Bering Sea crab stocks. The nearshore area in southwest Bristol Bay was hypothesized as having historically (i.e., prior to 1980) been the most important spawning ground for BBRKC. More recently the nearshore grounds north of Unimak Island and the Black Hills have been hypothesized as the population's most important hatching ground for

[4] A useful summary of red king crab biology and the Bristol Bay ecosystem is provided in the most recent Ecosystem and Socioeconomic Profile of BBRKC (Fedewa et al. 2020).

supplying recruits to the population because the predicted location of settling post-larvae after dispersal corresponds with favorable nearshore benthic habitat (Armstrong et al. 1986; Armstrong et al. 1993; Evans et al. 2012; Haynes 1974; Hebard 1959; Hsu 1987; Loher 2001). Additional areas of BBRKC preferred habitat are in the RKCSA and the Nearshore Bristol Bay Trawl Closure Area (NBBTCA), which was created to protect juvenile RKC. These closures were first established under emergency rules in 1995 (60 FR 4866) and then implemented under BSAI Groundfish FMP Amendment 37, effective in 1997 (61 FR 65985). The Secretarial Review Draft of the EA/RIR for Amendment 37 notes that the 1996 RKCSA closure, adopted by NMFS's inseason authority to run from January 1 through March 31, was extended through June 15 "to protect red king crab during the molting and mating period" (NPFMC 1996) The RKCSA is currently in effect year-round, but the Agency's rationale at the time was a documented acknowledgement of the molt/mate season as it was then understood.

RKC distributions vary over both seasonal and interannual time scales due to ontogeny (speed of development from egg to adult), seasonal reproductive cycles, and variable environmental factors (Zacher et al. 2018). Decadal-scale temperature trends can also lead to shifts in distribution of benthic species, including RKC (Mueter and Litzow 2008). The Bering Sea oscillates between warm and cold temperature regimes, largely driven by sea ice extent (Stabeno et al. 2012). In cold years, with greater sea ice extent and later ice retreat in the spring, a pool of cold bottom water (< 2°C; called the "cold pool") persists in the southeastern Bering Sea throughout the summer and into fall until vertical mixing occurs (Stabeno et al. 2012). In contrast, the cold pool is farther north in warm years, and bottom waters in the southeastern Bering Sea are several degrees warmer (Mueter and Litzow 2008; Stabeno et al. 2012). Cold and warm years can affect both the recruitment success for BBRKC and the area to which they recruit. Northerly shifts in stock distribution are generally associated with both warmer temperatures and high Pacific Decadal Oscillation values during the summer (Loher and Armstrong, 2005; Zheng and Kruse, 2006). Fall distributions during the BBRKC fishery tend to contract to the center of Bristol Bay during warm years (Zacher et al. 2018). The effect of variable recruitment areas and seasonal distribution may influence which crab are available to the parts of the eastern Bering Sea summer trawl survey that are used in the stock assessment (see Section 3, "Boundaries"). A tagging study on the winter movements of BBRKC is currently underway and is described in Section 3 (see Figure 3-8).

3 Item 2: BBRKC Boundaries

The Council requested an evaluation of four specific boundaries that pertain to BBRKC. Those are the boundaries that define: (1) the sampling areas used in the NMFS summer eastern Bering Sea trawl survey, (2) the areas used to develop the BBRKC stock assessment, (3) the area within which groundfish trawl bycatch accrues to the Zone 1 red king crab PSC limit, and (4) the ADFG registration area that bounds the directed fishery for BBRKC (Area T). Depending on the management or assessment purpose that is being pursued, these boundaries might be synonymous or slightly offset due to the ADFG/NMFS co-management of crab and the difference in ADFG statistical areas and NMFS reporting areas (see Appendix 1).[5]

This paper uses map overlays where possible to describe how boundaries are used, where there is consistency across purposes, and what adjustments are made when there is not consistency.[6] Because the

[5] Appendix 1 shows the EBS trawl survey grid stations overlaid on ADFG statistical areas. The survey grid is 20 nm x 20 nm squares. ADFG areas are based on latitude and longitude, thus their size/area change lightly with latitude. ADFG areas are roughly 30 nm x 30 nm in the Bering Sea.

[6] This paper is responsive to SSC comments from February 2021: "Stock areas used in the assessment do not align with the crab PSC management areas. The implication is that crab caught as bycatch from outside of the stock area (area used in the stock assessment) would accrue towards the PSC limit but would not explicitly be included in total removals in the assessment. These amounts are likely small and are likely more of an issue for BBRKC than Tanner

RKC PSC limit boundary (Zone 1) is part of this Council request, this section is the place where staff have included historical data on PSC, PSC rates, and groundfish basis catch.

The context for this Council request is the coincidence of lower survey abundance data for red king crab in the Bristol Bay stock assessment area, the State of Alaska's inability to open a directed BBRKC fishery for the 2021/2022 season, and preliminary survey evidence that red king crab are moving north into areas that are not included in the BBRKC assessment and directed fishery management.

The purpose of this section is strictly informational and does not presuppose that the Council is looking to recommend changes to boundary lines – the direct authority over which lies with other management entities with the exception of the Zone 1 PSC boundary. For example, the State of Alaska has authority over directed fishery management boundaries; any changes to Registration Area T would require action by the State. The Crab FMP currently adopts the State management areas and stock definitions used in the BBRKC assessment. Even though the Crab FMP gives authority to the State, it should be noted that Federal regulations describe where BBRKC individual fishing quota can be harvested (§ 680 Table 1). Having consulted with NMFS and NOAA OLE staff, the analysts' current understanding is that if the State establishes different boundary lines but the Federal government does not modify regulations then BBRKC IFQ could not be retained outside of the area currently defined for the rationalized fishery.

This section also describes various Council-established boundaries that are not listed in the Council's motion but affect where and/or when various types of groundfish trawl fishing may occur. Those include the RKCSA, the Red King Crab Savings Subarea (RKCSS; also known as the "10-minute strip" on the southern end of the RKCSA), the NBBTCA, and the Northern Bristol Bay Trawl Area (also referred to as the Togiak subarea) that lies within the NBBTCA but is open to trawling for part of the spring.

Finally, this section informs the Council about timely cooperative crab tagging research on the location of RKC outside of the time-window of the EBS Trawl Survey. That work will supplement the crab and groundfish-bycatch fishery data that currently augment the survey to better understand seasonal stock distribution.

3.1 Survey and Assessment Boundaries

The NMFS EBS trawl survey has been conducted annually since 1968. Haul-level data for BBRKC are available back to 1975, which is the point at which the assessment model originates. The trawl survey is used to collect data on the distribution and abundance of RKC.[7] Surveyed mature female abundance and effective spawning biomass are used for stock assessment, setting Zone 1 trawl PSC limits (described below), and the State of Alaska's determination of a directed BBRKC fishery. In general, the assessment is based on data from Area T.

The BBRKC stock assessment incorporates data from the trawl survey as it overlaps Area T, retained and discarded catch in the Area T directed fishery, and crab PSC in Bering Sea groundfish fisheries. Figure 3-1 overlays the trawl survey grid on ADFG Area T, showing 2021 survey estimates of RKC. The inclusion of crab PSC data from groundfish fisheries in the assessment is complicated by the fact that NMFS reporting areas and ADFG statistical areas are not identical (see Appendix 1). AKFIN has

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or snow crab, given the smaller stock area relative to the fishery footprint. To clarify this issue, the SSC recommends a map be added that overlays the stock areas used in the assessment, crab PSC areas, and state management areas."

[7] There are four identified stocks of red king crab: Bristol Bay, Pribilof Islands, Norton Sound, and Western Aleutian Islands. Stock assessments are done annually for Bristol Bay and Norton Sound, and triennially for Pribilof Islands and Western Aleutian Islands.

provided the assessment authors with approximated crab PSC data occurring within the State management boundary dating back to 1991.

RKC PSC in groundfish fisheries is estimated in two ways: one to inform the stock assessment and the other to monitor the Zone 1 PSC limit. The PSC estimation that is used to monitor the groundfish trawl limit is denominated in the number of crab and is drawn from the NMFS reporting areas that comprise Zone 1. While the Zone 1 PSC limit was established to protect the BBRKC stock, the areas that accrue to the limit are not synonymous with the BBRKC stock area as defined in the assessment (Figure 3-1). The PSC estimation that informs the stock assessment is denominated in weight and is based on catch in ADFG statistical areas, and thus is more aligned with the State's management boundary (Area T); however, this requires a data adjustment for statistical areas on the northern and southern borders of the State area.

When setting the BBRKC harvest limit, the State of Alaska uses both the raw area-swept abundance estimates from the trawl survey and model-based estimates that account for parameters like recruitment, growth, and gear selectivity. Including additional trawl survey stations in the assessment would affect both raw area-swept data and create a new set of model-based estimates.

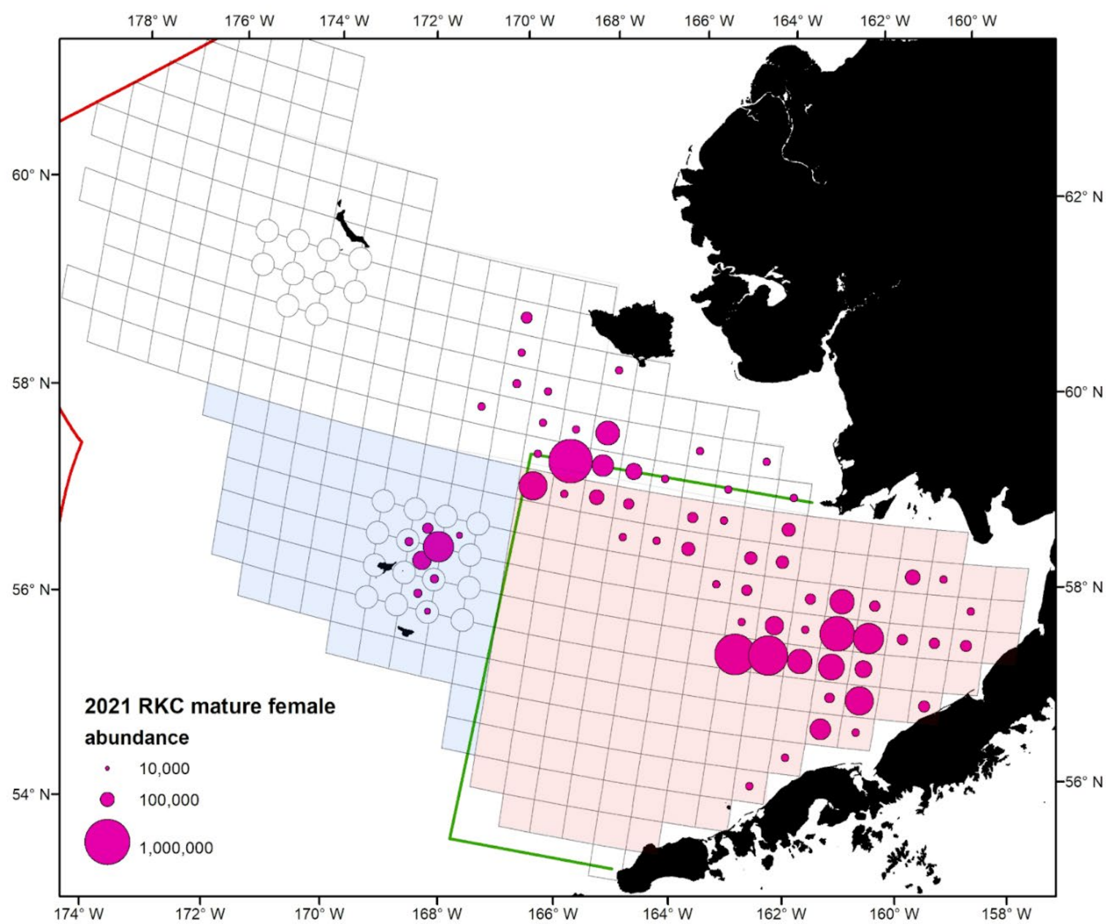


Figure 3-1 Mature female 2021 survey area-swept estimates. Grid corresponds to eastern Bering Sea summer bottom trawl survey stations; green line is the ADFG Bristol Bay management district (Area T). Survey stations included in the BBRKC stock assessment indicated by pink; survey stations included in the Pribilof Islands RKC assessment indicated by blue. Crab in white boxes are classified as "unstratified" and do not get included in any stock assessment. (Source: B. Daly, ADFG. February 2022)

Figure 3-2 illustrates where the pollock trawl fishery has occurred in recent years and overlays that data on where RKC were encountered in the region of the 2021 EBS trawl survey that is used in the BBRKC stock assessment. The analysts focus on the pollock fishery because the Council specifically requested information about the interaction of pelagic gear trawling and RKC, which is further explored in the following section. The survey CPUE data shown in the figure reflect the 2021 trawl survey. Survey CPUE – e.g., high value of 3,307 – is given in units of the estimated number of crab per square nautical mile (total number of crab in a survey haul divided by area swept by the haul). The stock assessment extrapolates survey results over the entire management area to estimate the total abundance of the BBRKC stock, but the figure shown here has no extrapolation.[8]

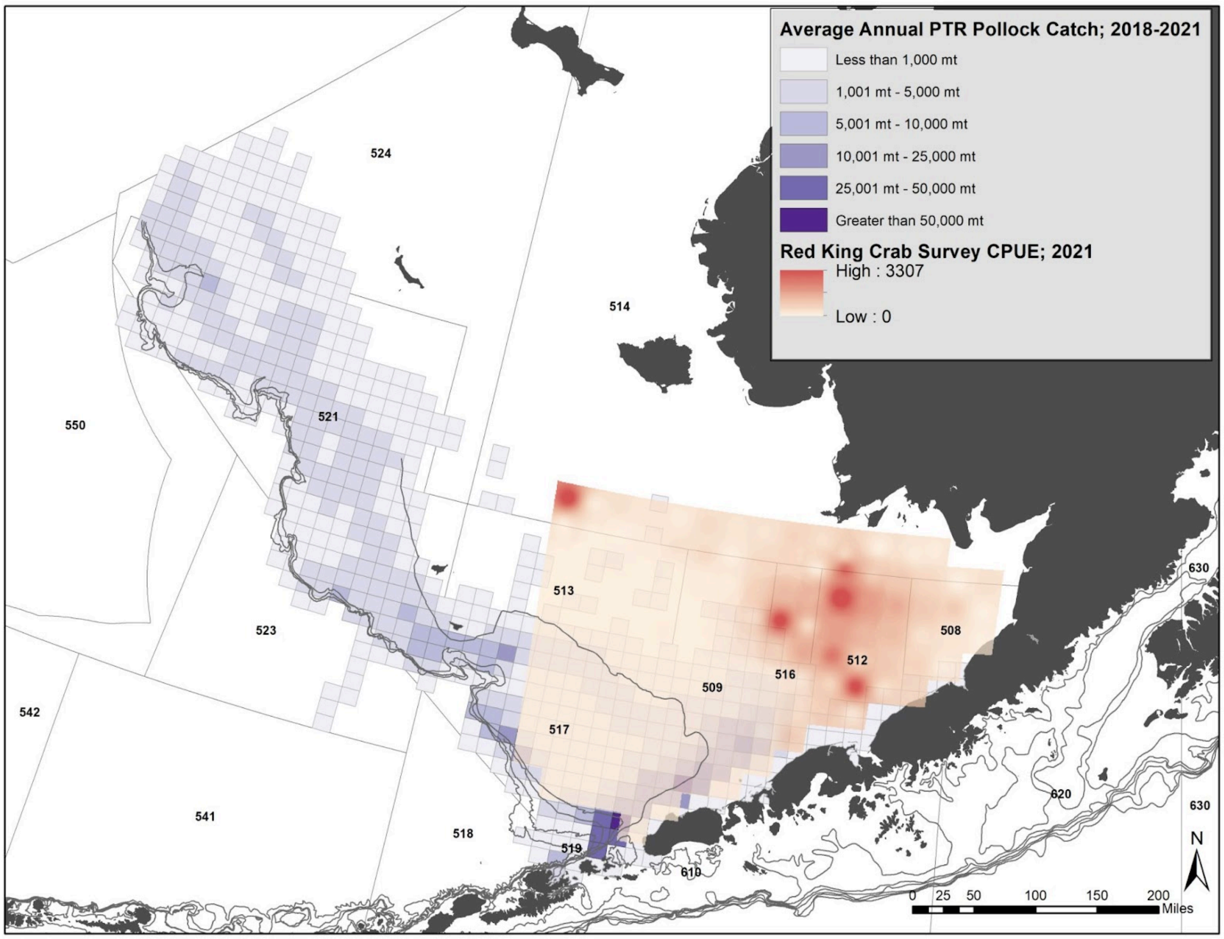


Figure 3-2 2021 EBS trawl survey red king crab CPUE (red scale) overlaid on average annual Bering Sea pelagic trawl pollock catch (by ADFG statistical area; purple scale), 2018-2021 (Source: J. Keaton, NMFS AKRO; NMFS Catch In Areas Database, March 2022)

[8] NMFS has resurveyed portions of the BBRKC area in certain years to better assess mature female abundance. In 1999, 2000, 2006-2012, and 2021 NMFS resurveyed the northern portion of the survey area about six weeks after the standard survey because a high proportion of females had not yet molted or mated when sampling initially occurred. More large females were found in the resurveys, presumably because mature females were not available to the standard survey (Zheng et al., p.12).

3.2 Red King Crab Distribution

The most recent available survey data suggest that the distribution of RKC could be shifting to the north. Slides 27-32 of an AFSC presentation to the Council's Crab Plan Team given in September 2021 identifies a "Northern District" that lies outside of the area included in the BBRKC assessment (Litzow et al., 2021).

The science on RKC in this area is not settled as to whether those unstratified crab contribute to the Bristol Bay or Norton Sounds stocks. The 2021 surveyed abundance estimates for the Northern District were largely influenced by one survey station (Figure 3-1). Relative to the past, the annual estimate of immature males in the Northern District was the second highest since 1975 and mature females in that area were at a peak. Figure 3-3 shows a marked increase in Northern District mature females in 2021; mature female estimates were up in 2014 as well but the 2021 increase was different because it occurred in the context of lower estimates overall. Legal male abundance in the Northern District was not remarkable but the survey stations with the highest legal male density were towards the north of the area shown in pink in Figure 3-1 (Litzow et al., 2021).

Litzow et al. plot the center of the surveyed stock distribution (centroid) for BBRKC in 2021 compared to all years since 1975 (Slides 31-32, referenced above). The 2021 center of distribution for both males and females of the combined Bristol Bay and Northern District was at or near the most northern latitude observed since 1975, whereas the directed fishery catch center of distribution has remained relatively stable (Figure 3-4). While some evidence suggests population distribution occurs farther north at lower population abundance levels (Figure 3-5), distribution is likely linked to environmental conditions such as temperature, with crab moving north when temperatures are higher (Figure 3-6; Loher and Armstrong 2005). As noted below, finding more crab in the Northern District does not necessarily mean that the crab have migrated there. Chilton et al. (2010) found that colder bottom temperatures (i.e., strong cold pool years) moved the location of larval release closer to shore. Nearshore larval release has been associated with dispersal to the north and release around Amak Island has been associated with dispersal and recruitment in Bristol Bay.

The signal that the center of distribution is farther north could be reflecting any of several different stories: crab in the southern portion of the BBRKC assessment area are doing less well – for whatever reason – or the crab are moving northward in response to environmental factors. The stock could be shifting north because the crab are physically moving, because larvae dispersal is occurring in areas that advect to more northern latitudes, or because the crab in the southern portion of the area are dying and thus are not available to the survey. Figure 3-4 shows that the directed BBRKC fishery has tended to remain in place in terms of latitude, likely due to proximity to ports and processing facilities. The Council may consider whether incorporating additional crab into the assessment – via the inclusion of northern survey stations – might increase local exploitation on the southern end of the stock that is either depleting or fleeing. There are uncertainties about whether the mature female crab surveyed in the Northern District are genetically contributing to the population in the southern portion of the BBRKC management area. From a management perspective, the Council should also consider the fact that these unstratified crab could be a part of one fishery that is rationalized (Bristol Bay) and one that is not (Norton Sound).

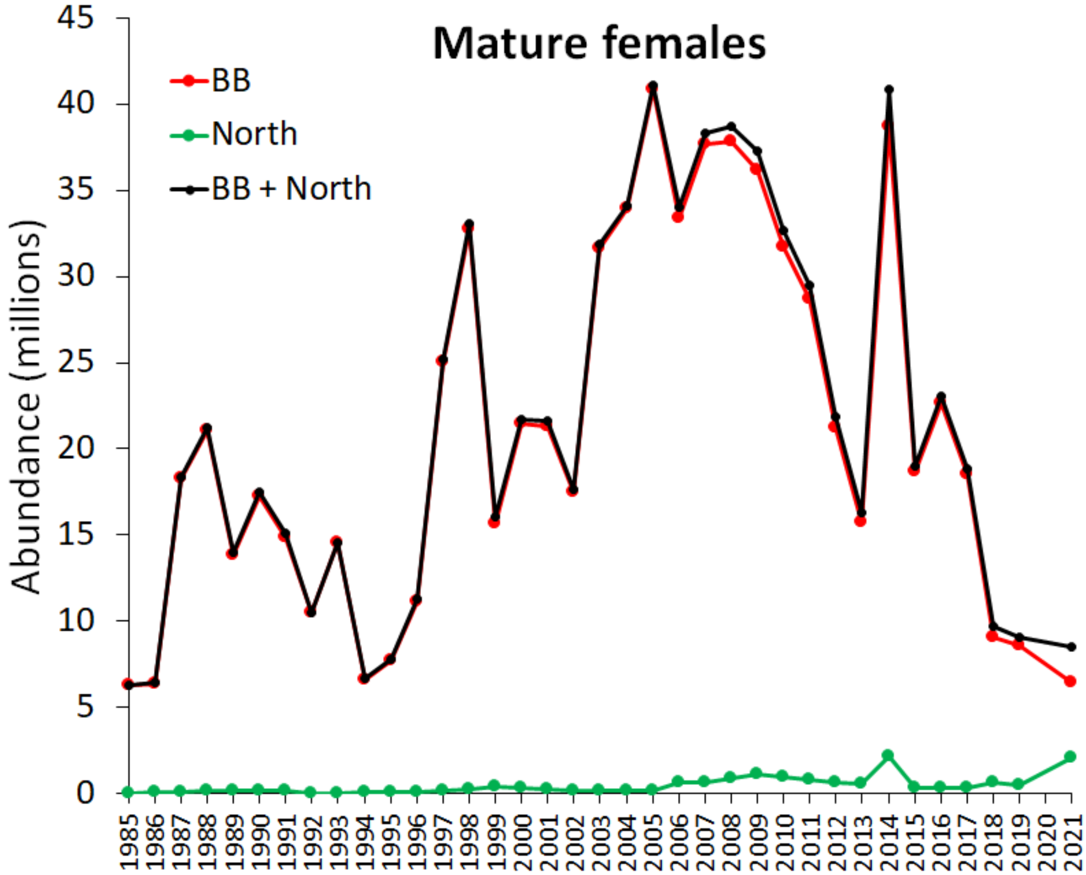


Figure 3-3 Eastern Bering Sea summer bottom trawl survey area-swept abundance estimates for mature females in Bristol Bay, Northern District, and combined from 1975 to 2021.

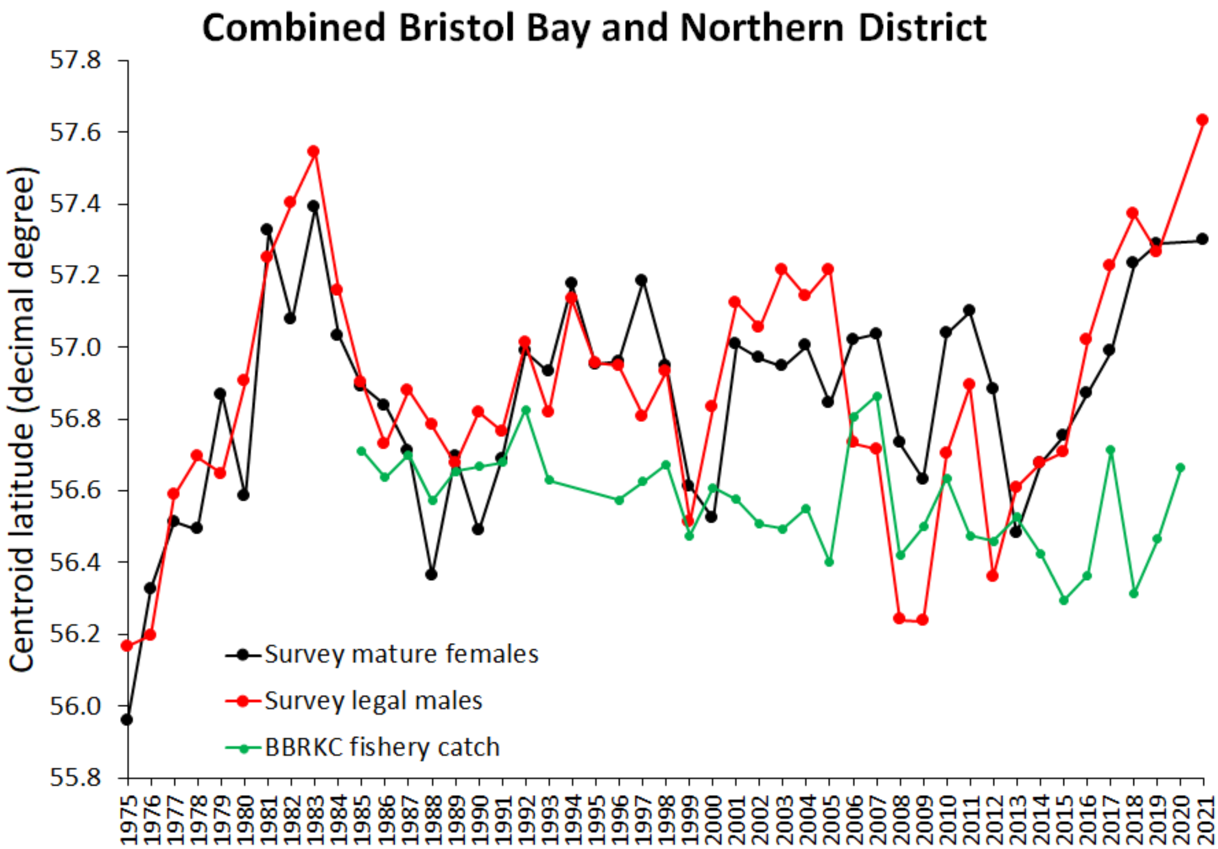


Figure 3-4 **Legal male (red line) and mature female (black line) weighted center of distribution latitudes for eastern Bering Sea summer bottom trawl survey data for Bristol Bay and Northern Districts combined. Fishery catch weighted centers of distribution latitudes are shown for comparison (green line).**

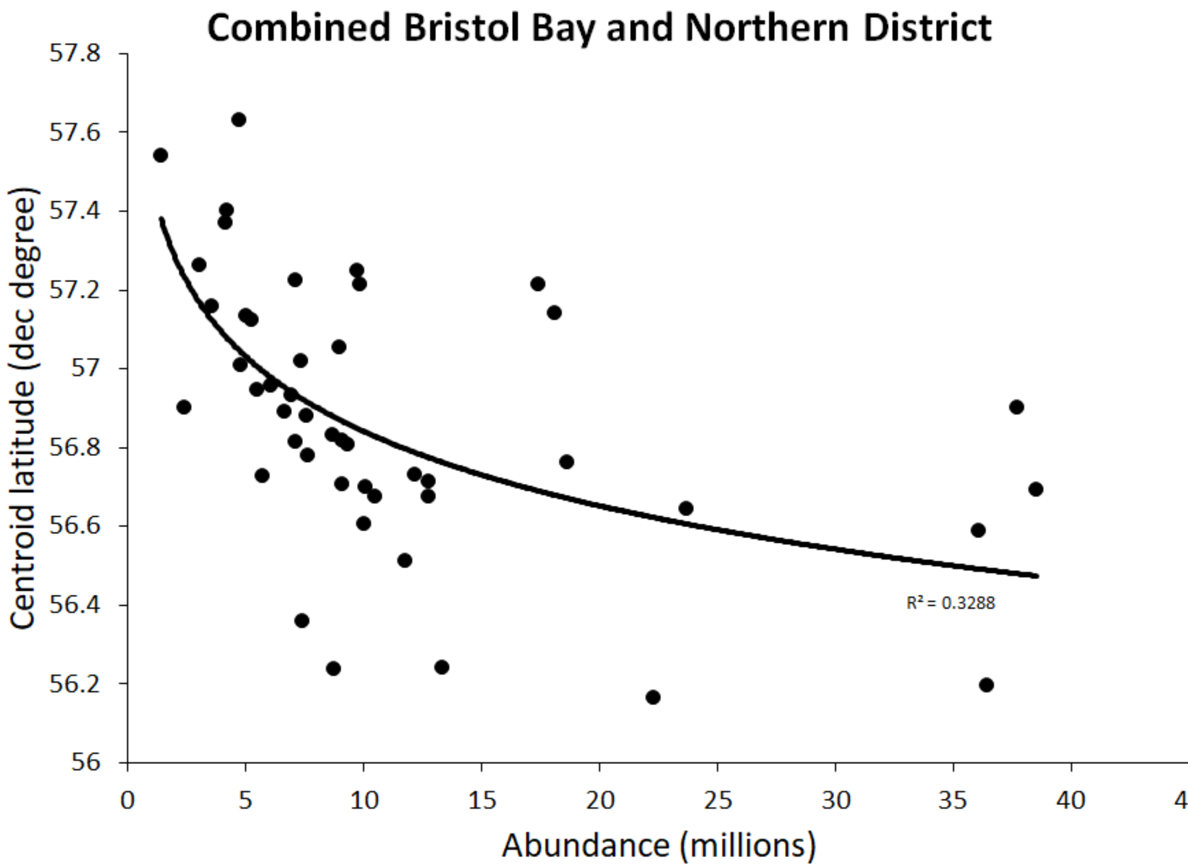


Figure 3-5 Legal male weighted center of distribution latitudes by abundance levels for EBS summer bottom trawl survey data (Bristol Bay and Northern District combined). Each point represents one year of trawl survey data.

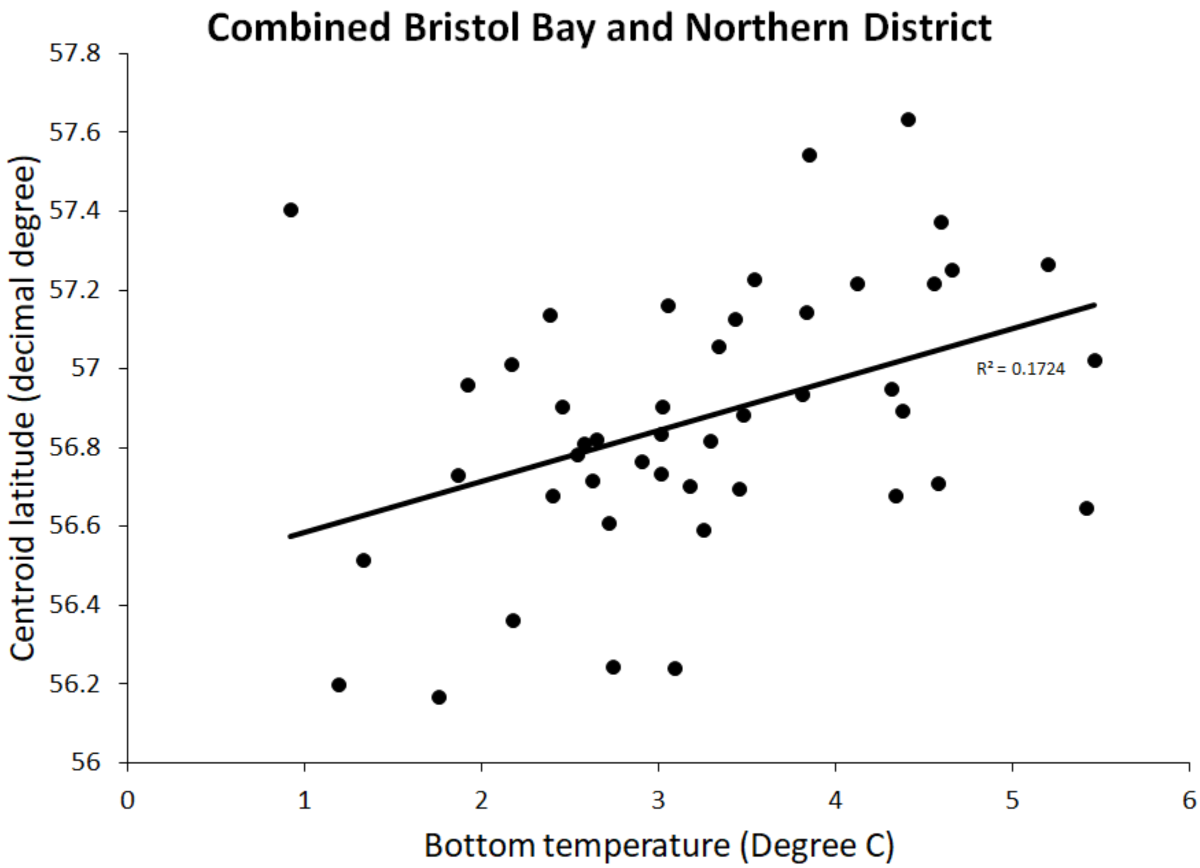


Figure 3-6 Legal male weighted center of distribution latitudes by mean summer bottom temperature for EBS summer bottom trawl survey data (Bristol Bay and Northern District combined). Each point represents one year of trawl survey data.

3.3 Other Boundaries

The RKCSA is closed to non-pelagic trawling year-round. The RKCSS is a 10 nm strip on the southern boundary of the RKCSA that NMFS may be open to non-pelagic trawling if a GHL fishery for BBRKC has been established for the crab season leading into that NMFS calendar fishing year.[9] The RKCSS was originally established to allow for productive rock sole fishing in years when the RKC biomass is sufficient. The subarea is limited by a subapportionment of the total Zone 1 RKC PSC limit that is set annually in harvest specifications and may not exceed 25% of the Zone 1 PSC limit. The RKCSA/SS were fully implemented as year-round areas in 1997 after having been in place as partial-year closures under emergency rule in the prior year (BSAI FMP Amendment 37; 61 FR 65985, Dec. 1996). At its inception, the area closure was designed to protect the stock and habitat during molting and mating periods. The final EA/RIR for Amendment 37, referencing data from 1993 to 1995, stated that the RKCSA would cover 40% of males and 30% of mature females in the BBRKC stock, with the western portion of the area composed almost entirely of males (NPFMC 1996). For the context of this discussion paper, the reader should note that pelagic trawl gear is allowed within the closure areas. As discussed in the following section of this paper, pelagic gear is known to contact the seafloor.

[9] See BSAI Groundfish FMP Section 3.5.2.1.3 and § 679.22(a)(3) for RKCSA; § 679.21(e)(3)(ii)(B) for RKSSA.

The NBBTCA is closed to all trawling year-round, except for a subarea near Togiak that is open to trawling from April 1 through June 15 each year (Figure 3-7).[10] The rationale for closing this area to trawl gear is the protection of juvenile RKC habitat. The subarea that is open in the spring is prosecuted for flatfish by non-pelagic trawl vessels, as evidenced by the lack of pelagic trawl impacts mapped in Figure 4-1 through Figure 4-3. Under a voluntary agreement with the Togiak community, the non-pelagic trawl sector ceases fishing in the subarea one week earlier than the regulatory closure (June 7) to minimize interactions with halibut.

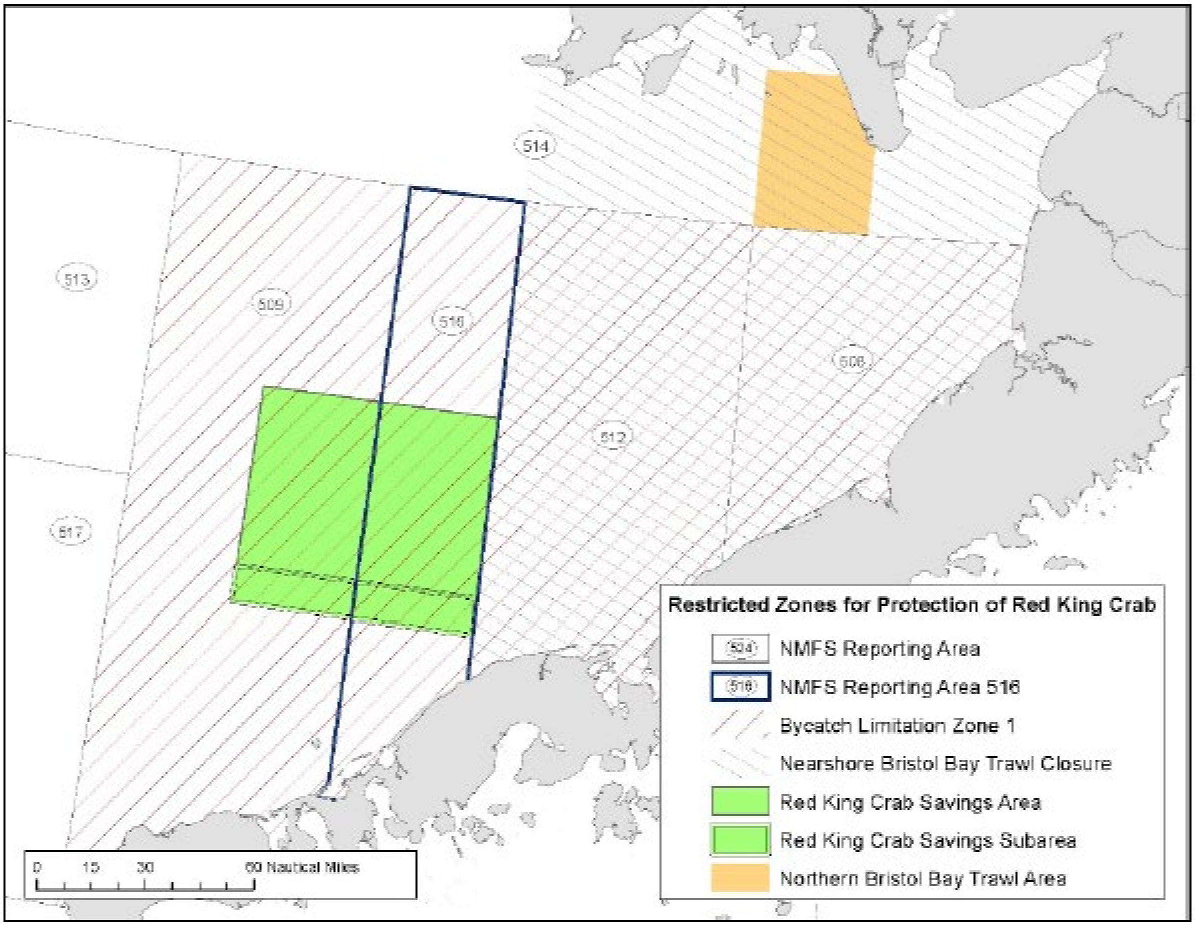


Figure 3-7 Bycatch limitation Zone 1 and trawl closure areas in the Bristol Bay region. NBBTCA includes the areas east of NMFS Area 516. Orange box denotes the "Togiak" area that is open to trawling from April 1-June 15.

Another area designation that affects when certain types of trawling can occur is the Catcher Vessel Operational Area (CVOA).[11] Unless directed fishing for CDQ pollock, catcher/processor vessels may not fish in the CVOA during the pollock B Season (June 10 through November 1). The CVOA overlaps Bycatch Limitation Zone 1 by two degrees of longitude (between 165 W and 163 W) and south of 56 N latitude (see Figure 2 to Part 679). Given that only non-CDQ CP vessels are restricted, this time/area closure does not preclude interactions between trawl gear and RKC.

[10] See FMP Section 3.5.2.1.4 and § 679.22(a)(9).
[11] See FMP Section 3.5.2.1.5 and § 679.22(a)(5).

3.4 Zone 1 Red King Crab Trawl PSC Management and Historical Data

Table 3-1 and Table 3-2, below, report the trawl PSC limits and PSC estimates for RKC in Zone 1.[12] The Zone 1 PSC limit for RKC is set in harvest specifications based on criteria established in regulation at § 679.21(e)(1)(i) and is described in Section 3.6.2.1.1 of the BSAI Groundfish FMP (Zone 1 depicted in Figure 3-18 of the FMP, and elsewhere in this paper). The criteria are the estimated abundance of mature females and the effective spawning biomass. The total Zone 1 PSC limit is 197,000 crab if the number of mature females is greater than 8.4 million and the effective spawning biomass is greater than or equal to 55 million lbs. The limit is 97,000 crab if mature females are greater than the 8.4 million threshold and the effective spawning biomass is between 14.5 and 55 million lbs. The limit is 32,000 crab if mature females are below the 8.4 million threshold or effective spawning biomass is less than or equal to 14.5 million lbs. The Zone 1 PSC limit was reduced from 197,000 to 97,000 in 2012 as a result of effective spawning biomass falling below the 55 million lbs. threshold. The number of mature females also went down in 2012, but did not fall below 8.4 million. The Zone 1 PSC limit remained at 97,000 from 2012 until 2022. This year, based on 2021 survey data, the PSC limit is 32,000 crab. Mature female abundance was estimated at 6.432 million crab and effective spawning biomass was estimated at 25.120 million lbs. (87 FR 11641). The reduction in the PSC limit is the result of falling below the mature female abundance threshold of 8.4 million crab.

Each year, the total Zone 1 PSC limit is apportioned to the CDQ PSQ reserve (10.7% of the limit), the Amendment 80 sector (A80), and the BSAI Trawl Limited Access sector (TLAS). CDQ PSQ can be used for directed fishing with any gear type. Part of the total limit that would have been apportioned to A80 is not apportioned to any sector or gear and remains unused; this was part of the designed implementation of the Amendment 80 program. The TLAS limit applies to all trawling by non-A80 vessels, including both pelagic and non-pelagic gear. The TLAS limit is subapportioned to three directed fishery categories for purposes of in-season PSC monitoring and management: yellowfin sole, Pacific cod, and a combined category consisting of pollock, Atka mackerel and “other” species (“other” includes skates, sharks and octopuses). That third fishery category generally encompasses the fishing that occurs with pelagic trawl gear.

When a Zone 1 RKC PSC limit is reached (see Table 3-1), NMFS closes directed fishing with non-pelagic trawl gear for that species category. For example, if TLAS reaches the PSC limit for the Pacific cod directed fishery (2,954 crab in 2021; 975 crab in 2022) then Zone 1 would be closed to non-pelagic trawling in the directed fishery for Pacific cod. Pacific cod could still be retained up to the MRA when fishing with non-pelagic gear in the directed fishery for yellowfin sole. If TLAS reaches the PSC limit for the pollock/Atka/other category (197 crab in 2021; 65 crab in 2022) the directed fishery for that category is closed for non-pelagic trawl gear. This closure may not directly impact where vessels fishing for pollock can fish because pollock vessels use pelagic gear, Atka mackerel are not targeted in Zone 1, and directed fishing for “other species” (skates/shark/octopus) is never open. The pollock fishery is treated differently – i.e., it is already not permitted to use non-pelagic gear and thus it is effectively not subject to non-pelagic trawl closures. This specific handling of the pollock/Atka/other category went into effect under FMP Amendment 57. The Council’s purpose and need for Amendment 57 was focused on bycatch minimization and the action also included PSC limit reductions for halibut, RKC, opilio crab, and Tanner crab.

[12] Though different than a PSC limit, and thus not directly requested as part of this discussion paper, the analysts note a different limit on trawl catch of crab in the BSAI and GOA pollock fisheries. Regulations at 679.7(a)(14)(i) define the BSAI Trawl Gear Performance Standard. This regulation makes it unlawful for a vessel participating in the directed fishery for BSAI pollock to have 20 or more crabs with a carapace width of more than 1.5 inches (38mm) at any particular time. This regulation can be enforced by the NOAA Office of Law Enforcement (OLE).

Comparing Table 3-1 and Table 3-2, it is evident that the Zone 1 PSC limits in place prior to 2022 have not been reached. However, the lower limits in place for 2022 would have been reached in some of the years since 2010, resulting in an area closure for non-pelagic trawl gear. Examples are A80 in all years except 2015 and 2018, CDQ in 2020, and TLAS Pacific cod in 2011. The TLAS pollock/Atka/other category – which best aligns with the Council's motion as it regards pelagic trawl gear – would not have met the 2022 Zone 1 PSC limit of 65 RKC in any year. Sixty-five animals is a small number of any species in the context of trawling, and it is easy to imagine that this limit could be met but, as noted above, reaching the limit would not directly require vessels targeting pollock to move out of Zone 1.

The groundfish basis weights for the Zone 1 PSC estimates shown in the TLAS Pollock/Atka/Other column of Table 3-2 ranged from 88,000 mt to 513,00 mt during the 2010 through 2021 period, meaning that the number of estimated RKC PSC per ton of groundfish is near to zero. Groundfish basis weight is the denominator used to calculate a PSC rate (number of crab per metric ton of groundfish). In terms of groundfish production in that segment of the TLAS, harvest within Zone 1 averaged roughly 277,000 mt annually for the whole period, and roughly 427,000 mt annually for the five most recent years (range of 343,000 to 513,000 mt). Zone 1 harvest in other fishery categories was lower in volume than the pelagic trawl sector. The A80 sector averaged 84,000 mt of groundfish annually since 2010 (54,000 mt in the five most recent years), and the non-pelagic TLAS category (Pacific cod, yellowfin sole, and other flatfish) averaged 21,000 mt (22,000 mt in the five most recent years). The A80 sector's PSC rate was around 0.30 to 0.40 RKC per mt of groundfish, and the rate for the non-pelagic portion of the TLAS category was around 0.06 to 0.10 RKC per mt.

Table 3-1 Zone 1 red king crab prohibited species catch limits for trawl gear, 2010-2022

Year	A80 Limit	A80 Not Allocated	CDQ	TLAS Pollock/Atka/Other	TLAS Pacific Cod	TLAS Yellowfin	TLAS Total	Total
2010	98,920	23,204	21,079	400	6,000	47,397	53,797	197,000
2011	93,432	28,692	21,079	400	6,000	47,397	53,797	197,000
2012-2021	43,293	16,839	10,379	197	2,954	23,338	26,489	97,000
2022	14,282	5,555	3,424	65	975	7,700	8,739	32,000

Table 3-2 Zone 1 red king crab prohibited species catch estimates for trawl gear, 2010-2021

Year	A80	CDQ†	TLAS Pollock/Atka/Other	TLAS Pacific Cod	TLAS Yellowfin	TLAS Other Flatfish	Total
2010	54,479	779	22	0	0	0	55,280
2011	31,304	3,634	0	1,971	1,366	0	38,276
2012	24,164	2,605	3	0	102	123	26,996
2013	22,537	2,425	15	0	69	140	25,186
2014	26,586	1,457	0	85	92	0	28,220
2015	12,615	62	0	51	6	20	12,754
2016	21,442	430	6	547	842	58	23,325
2017	27,143	3,722	39	280	3,626	245	35,055
2018	9,799	1,936	14	199	778	12	12,739
2019	20,775	2,051	18	466	1,604	119	25,033
2020	32,474	6,301	9	175	3,034	762	42,755
2021	16,397	1,867	17	25	892	0	19,198

Source: NMFS Alaska Region Catch Accounting System, data compiled by AKFIN in Comprehensive_PSC.
† CDQ red king crab PSC is reported for trawl gear only.
Note: "TLAS Other Flatfish" shows PSC that occurred on trips (CV) or hauls (CP) where the target assigned by NMFS CAS based on predominant species caught does not fit the three categories for which a PSC limit is apportioned (e.g., rock sole, flathead sole, plaice). These CAS "targets" likely occur in the directed fishery for yellowfin sole. Accruing this crab PSC to an apportioned limit has not previously been an issue due to the large gap between historical TLAS yellowfin sole PSC limits and use, but with lower limits in effect in 2022 NMFS could reasonably accrue this PSC to the yellowfin sole category. NMFS would use its knowledge of the fishery and the activity of the vessels on which PSC occurred to accrue PSC accurately.

The amount of PSC that can be taken by non-pelagic trawl gear in the Red King Crab Savings Subarea (RKCSS; shown in Figure 3-7) is restricted by a limit set annually in harvest specifications that cannot exceed 25% of the total Zone 1 limit (§ 679.21(e)(3)(ii)(B)(2)). From 2012 through 2021, for example, this meant that non-pelagic gear could not take more than 24,250 RKC in the RKCSS (limit set at 25% of 97,000). However, when the BBRKC stock is insufficient for the State of Alaska to establish a GHL fishery in the previous year NMFS and the Council will not specify a PSC limit for the RKCSS and thus NMFS closes the subarea to directed fishing with non-pelagic gear. This is the case for 2022.[13]

For comparison to trawl bycatch of RKC in Zone 1, Table 3-3 reports estimated crab discard mortality in the directed fishery for BBRKC that takes place in State Registration Area T. ADFG estimates total discards by summing estimated catch of females and males based on fishing effort multiplied by sex-specific observer catch-per-unit-effort (CPUE) data. All female catch is discarded and male discards are estimated as the remainder after subtracting retained catch from total male catch. Most discarded males are of sublegal size, though some legal-size males are discarded due to shell condition or if they are very close to the legal size threshold. Estimated discard mortality is calculated by applying a 20% "handling mortality rate" to total discards.[14] Reliable discard estimates are available back to 2005 when the fishery was rationalized and observer data improved. The table shows that total discards are greater than retained catch in most years, but not all. On average, retained catch was about 80% of the number of discarded crab, though the annual range varied from 42% (2018) to 185% (2012). In the three most recently reported years when there were fewer crab retained (2018-2020), discards outweighed retained catch by a greater margin, perhaps reflecting that the fishery was sorting through a higher relative proportion of sublegal males.

[13] See final rule for implementing 2022/23 BSAI harvest specifications: Table 15 in 87 FR 11626, March 3, 2022.
[14] The 20% handling mortality rate for red king crab within the directed fishery is lower than mortality rates applied to red king crab caught in the Tanner crab fishery (25%), fixed-gear fisheries (50%), and trawl fisheries (80%).

Table 3-3 Estimated discards, discard mortality, and retained catch (number of animals) in the directed BBRKC fishery, 2005-2020 (Source: B. Daly, ADFG. March 2022. Pers. Comm.)

	Female discards	Male discards	Total discards	Discard mortality	Male catch (retained)
2005	1,682,031	3,181,024	4,863,056	**972,611**	2,763,147
2006	221,623	1,572,174	1,793,797	**358,759**	2,502,786
2007	731,651	3,498,460	4,230,111	**846,022**	3,162,287
2008	662,313	3,772,206	4,434,519	**886,904**	3,066,286
2009	350,730	3,118,571	3,469,302	**693,860**	2,556,645
2010	470,492	2,321,052	2,791,545	**558,309**	2,409,952
2011	118,511	1,338,976	1,457,486	**291,497**	1,298,023
2012	46,511	590,033	636,545	**127,309**	1,175,752
2013	409,457	908,106	1,317,563	**263,513**	1,272,273
2014	275,901	1,704,433	1,980,333	**396,067**	1,525,581
2015	801,260	1,107,517	1,908,777	**381,755**	1,526,974
2016	432,824	946,875	1,379,699	**275,940**	1,281,194
2017	233,063	730,783	963,846	**192,769**	997,214
2018	591,898	910,903	1,502,801	**300,560**	629,907
2019	151,967	813,686	965,653	**193,131**	548,516
2020	64,575	662,986	727,561	**145,512**	455,262
Average	452,800	1,698,612	2,151,412	430,282	1,698,237
Median	380,094	1,223,246	1,648,299	329,660	1,411,802

3.5 Stock Distribution: Logbook and Tagging Studies

The Alaska Fisheries Science Center, ADF&G, and the Bering Sea Fisheries Research Foundation (BSFRF) have collaborated to develop and test tagging techniques for BBRKC that will contribute to the understanding of stock distribution and movement patterns outside the summer trawl survey period. These methods have included the use of pop-up satellite tags, traditional spaghetti tags[15] and acoustic tags. Each tagging method has different strengths in terms of cost, deployment duration, recovery method, and tag retention through the molt. Initial efforts focused on mature males, examining crab movement from summer into fall, when the directed crab fishery begins. Tagging results are currently being analyzed and prepared for publication. Thus far, results for males show similar patterns in fall distribution compared with fishery-derived data. One published study of fishery data utilized logbooks to track legal males in the fall months of 2005 through 2016 (Zacher et al., 2018). The purpose of the logbook study, and winter tagging studies that are ongoing, is to fill the information gap on where RKC are distributed outside of the summer survey season. Zacher et al. found that, on average, roughly 60% of commercially caught BBRKC were harvested in areas that are closed to all trawling (e.g., NBBTCA) or non-pelagic trawling (RKCSA) but that percentage fluctuated based on temperature regime. RKC were found farther south, towards the Alaska Peninsula, in cold years but tended to cluster in the middle of Bristol Bay in warm years. The study authors noted that "it is difficult to evaluate the placement of no-trawl zones, because most crab bycatch occurs in trawl fisheries during winter when crab distributions are unknown."

More recent tagging efforts have focused on the winter and early spring when BBRKC distributions are less well understood. The winter/spring period is of particular interest because of increased expected interactions with trawl fisheries at the same time that crab are mating and molting. In November 2021,

[15] "Spaghetti tags" are a piece of tough plastic that is attached to an animal. The tag has an identification code that a person can report when the tag is retrieved.

pop-up satellite tags were placed on both mature male and female RKC in Bristol Bay. Tags released from male crab in January 2022 and will release from females later in spring 2022, which is set to approximate the timing of larval hatch and mating. The timing on both releases is required to ensure tags release before crabs molt and either before/after sea ice is expected in Bristol Bay. Figure 3-8 shows the movement of male crab from fall into winter based on the first pop-up satellite tag results from the ADFG/NMFS/BSFRF study.

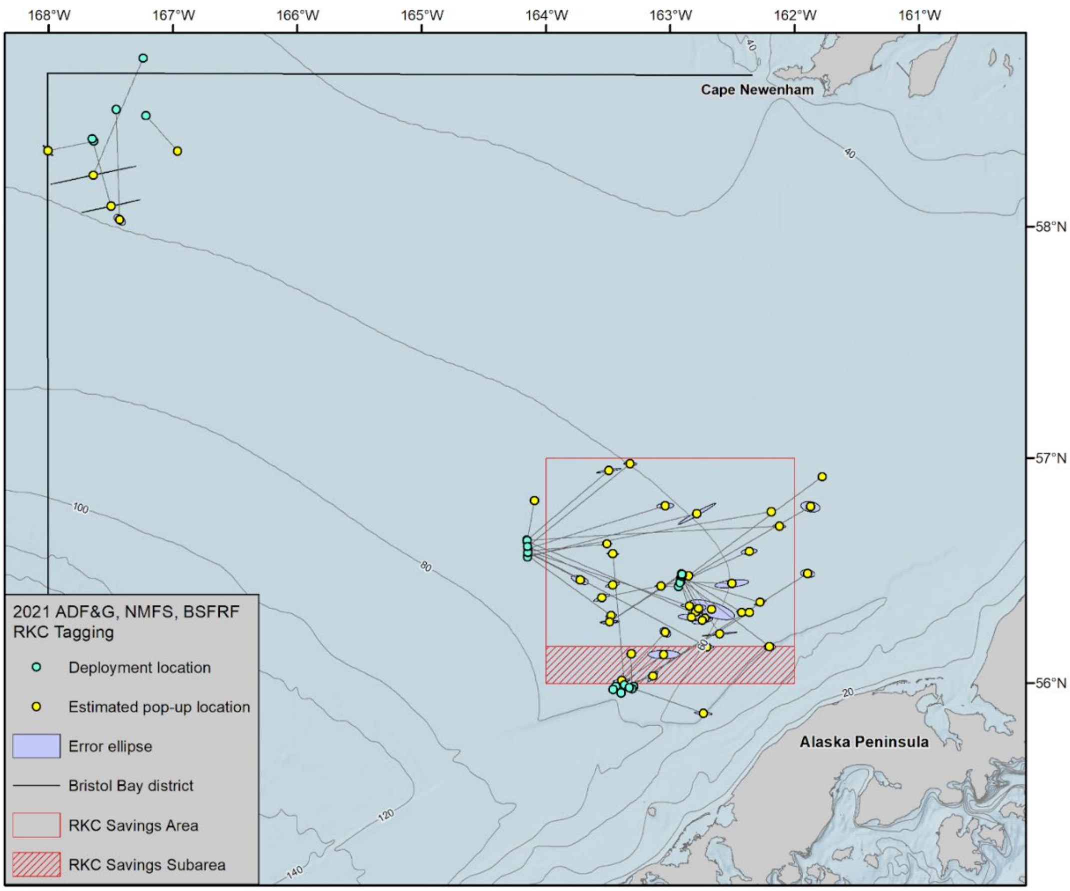


Figure 3-8 Fall-to-winter 2021/22 male red king crab tagging results in Bristol Bay (Source: B. Daly, ADFG. March 2022. Pers. Comm.)

4 Item 3: Bottom Contact by Pelagic Trawl Gear

The Council asked staff to provide the best available information on bottom contact by pelagic trawl (PTR) gear and the impact it may have on the BBRKC stock.[16] This is a complex topic on which the best available science continues to progress. For the following discussion, the analysts stipulate two facts that

[16] "Pelagic trawl" gear is defined in regulation (679.2) as a trawl that has no discs, bobbins or rollers, which are elements of non-pelagic trawls that elevate gear off the seafloor. Pelagic trawls cannot have chafe protection gear attached to the footrope or other lines. The physical aspects of the gear, as is noted by onboard observers or enforcement officers, is what determines whether a vessel may directed fish for pollock or trawl in areas closed to non-pelagic gear (e.g., RKCSA). The term "pelagic" is sometimes used informally to describe the midwater pollock target in NMFS Catch Accounting System (CAS) data as it relates to catch/bycatch estimation. This paper strictly adheres to the definition of pelagic that describes the physical gear, thus the data included reflects all pollock trawling regardless of whether classified in CAS as midwater or bottom pollock targets.

are known to fishery participants and are documented in work reviewed by the SSC: pelagic trawl gear contacts the seafloor, and pelagic trawling is synonymous with the pollock fishery.[17] The fact that pollock trawls in the eastern Bering Sea contact the seafloor is not surprising given that the area is relatively shallow, flat, and has the type of substrates that trawl gear can generally withstand – as compared to areas off the shelf, around the Aleutian Islands, or in the Gulf of Alaska. Also, trawl operators may fish close to the bottom of the water column at times to minimize bycatch of salmon species that are higher up or to increase pollock catch rates if the target fish are near the bottom, thus reducing the total towing time required to meet the harvest target.

The Council's request entails two questions that are highly related but not identical. The first question – where and how often pelagic trawl gear is contacting the seafloor in the Bering Sea – can be, and has been, studied empirically. That work builds upon earlier estimates that were based on the conventional wisdom of gear designers and vessel operators; much of that work was done in service of the Essential Fish Habitat (EFH) EIS which itself has undergone iterative reviews and refinements for several decades. Nevertheless, PTR is the most complex gear for which to estimate bottom contact and event-level data are in relatively short supply. As a result, the best efforts to quantify area-wide bottom contact are model-based, using contact parameters that are estimated for types of fishing events that are being described at increasingly specific levels as work progresses. The second question – what impact pelagic gear contacting the seafloor has on BBRKC – requires a connection to be made between gear-on-bottom and both the benthic habitat of RKC and bycatch (observed and unobserved). That connection is the crux of the issue and will not be fully answered here. The best available information can accurately capture where PTR has occurred since 2003 but the ability to draw a conclusion about stock impacts would require the knowledge of where RKC were during the trawl season and the shell condition of those crab as it relates to the molt/mate cycle.

The analysts wish to make clear that the direct and indirect impacts of PTR, or trawl gear in general, is not presumed to be the sole driver of the decline in the BBRKC stock that has been ongoing since around 2007 (Figure 1-1) and has recently come to a head with the closure of the 2021/22 directed fishery. Trawling that contacts the seafloor is assuredly one of the factors that challenge the BBRKC stock; other factors to account for include directed crab fishing, the effect of other groundfish gear types, and BBRKC stock dynamics as influenced by the changing ecosystem. Ecosystem factors and their effects, as currently understood, were described in the two previous sections of this document (see also Fedewa et al. 2020).

The end of this section acknowledges that other modes of fishing could impact BBRKC and the stock area (Section 4.5), but this paper is largely focused on pelagic trawling to be responsive to the Council's request. A more expansive look at the effects of fishing would be found in the Council's EFH review documents, where cumulative fishing effort across all gear types is mapped while accounting for dynamic changes in the ocean environment (the most recent update on this work is found in Olson et al. 2022; Feb. 2022 SSC Agenda Item D5).

[17] From 2010 through 2021, 99.98% of groundfish caught with pelagic trawl gear was in the pollock "target" fishery as classified by NMFS Catch Accounting System. Catch by the pelagic gear sector in other targets – Atka mackerel, Pacific cod, rockfish, flathead sole, rock sole, and yellowfin sole – accounted for only 3,725 out of roughly 15.2 million metric tons over the entire period. Those instances in the CAS likely result from outlier events or perhaps test fishing.
The Gear Limitations section of regulations (679.24(b)(4)) specifies that non-pelagic trawl gear may not be used to engage in directed fishing for pollock in the BSAI). The amount of time that a trawl footrope may be in contact with the seabed is restricted in any pelagic-trawl-only portion of the Gulf of Alaska (no more than 10% of any tow), but no such limitation is specified for the BSAI.

4.1 Estimated Bottom Contact

In responding to the Council's request, this paper presents novel outputs that were produced using the data that underlie the Fishing Effects (FE) model, though in a different application. The FE model uses spatially-explicit data (gear tracks) dating back to 2003 to estimate cumulative impacts on benthic habitat while accounting for the nature of the seafloor substrate and its ability to regenerate (Smeltz et al., 2019). FE utilizes parameters that translate gear tracks to estimated bottom contact; these parameters have been reviewed by the SSC, most recently in February 2022 (see Appendix 2 in Olson et al. 2022). Here, the same Vessel Monitoring System (VMS) pelagic trawl tracks that inform FE are plotted to give the best possible accounting for where pelagic trawl gear contacts the seafloor in the Bristol Bay region. The reader should note that estimated bottom contact is not directly equivalent to RKC bycatch or impacts on the ability of BBRKC to reproduce and recruit into the fishery.

Figure 4-1 through Figure 4-4 were produced by the Fisheries, Aquatic Sciences & Technology (FAST) Lab at Alaska Pacific University (APU).[18] Figures FR1 through FR3 depict the nominal area swept by PTR gear as modified by the bottom contact parameters that are used in the FE model, described below the figures. The base unit of measure is the monthly area swept per 5-kilometer grid cell, which has been averaged across years (Figure 4-1) or across seasons annually (Figure 4-2 and Figure 4-3). Estimated PTR bottom contact is cumulative. For instance, a hypothetical grid cell that registers 25 km^2 of swept area does not indicate that every square kilometer in the cell was subject to bottom contact by PTR; rather, that cell would indicate that cumulative total estimated bottom contact on a monthly basis amounted to more than 25 km^2. A grid cell that registers 20 km^2 of swept area also does not indicate that 80% of the grid cell was contacted; in many cases, vessel tracks are overlapping.

Figures Figure 4-2 and Figure 4-3 depict 19-year seasonal averages for what is, approximately, the pollock A and B seasons. Figure 4-2 includes January through May and Figure 4-3 includes June through November. The darker color scale in those figures relative to Figure 4-1 is a function of averaging seasonal totals versus monthly totals. FR1 plots the 19-year average of all months' (Jan-Nov) total swept area from 2003-2021 (e.g. 11 monthly averages over 19 years). Figure 4-2 and Figure 4-3 take the seasonal value of swept area in each year and average those values across years – in other words, each Jan-May or June-Nov time period is a unit that is then averaged over 2003-2021. The reader should focus on the story that the maps tell about where the pollock fishery occurs seasonally, in the context of other information known about the BBRKC stock, rather than the absolute values depicted.

A selection of year/month-specific maps using the same methodology is attached as Appendix 2. Though more intensive to interpret due to the number of months in the analyzed period, those maps allow the interested reader to see past the effect of averaging across years or seasons over a period of many years.

Figure 4-4 shows estimated PTR bottom contact by area (directed BBRKC fishery area, PSC Zone 1, RKCSA, and RKCSS) in relation to the BSAI pollock seasons. Seasonal bottom contact data are of interest because RKC are understood to be molting and mating during the A Season, though their specific location relative to the PTR fishery is uncertain. The time step for each plotted point on the x-axis is one month so, whereas the first three figures show monthly or seasonal averages compressed over years, Figure 4-4 allows the reader to look at swept-area estimates for individual months in isolation. In most years, the peak of estimated swept-area occurs at the beginning of each season (left hand side of grey/white vertical bands); this accords with a general understanding of when the pollock fishery is most heavily prosecuted.

[18] F. Restrepo, APU FAST Lab. March 2022. Personal Communication.

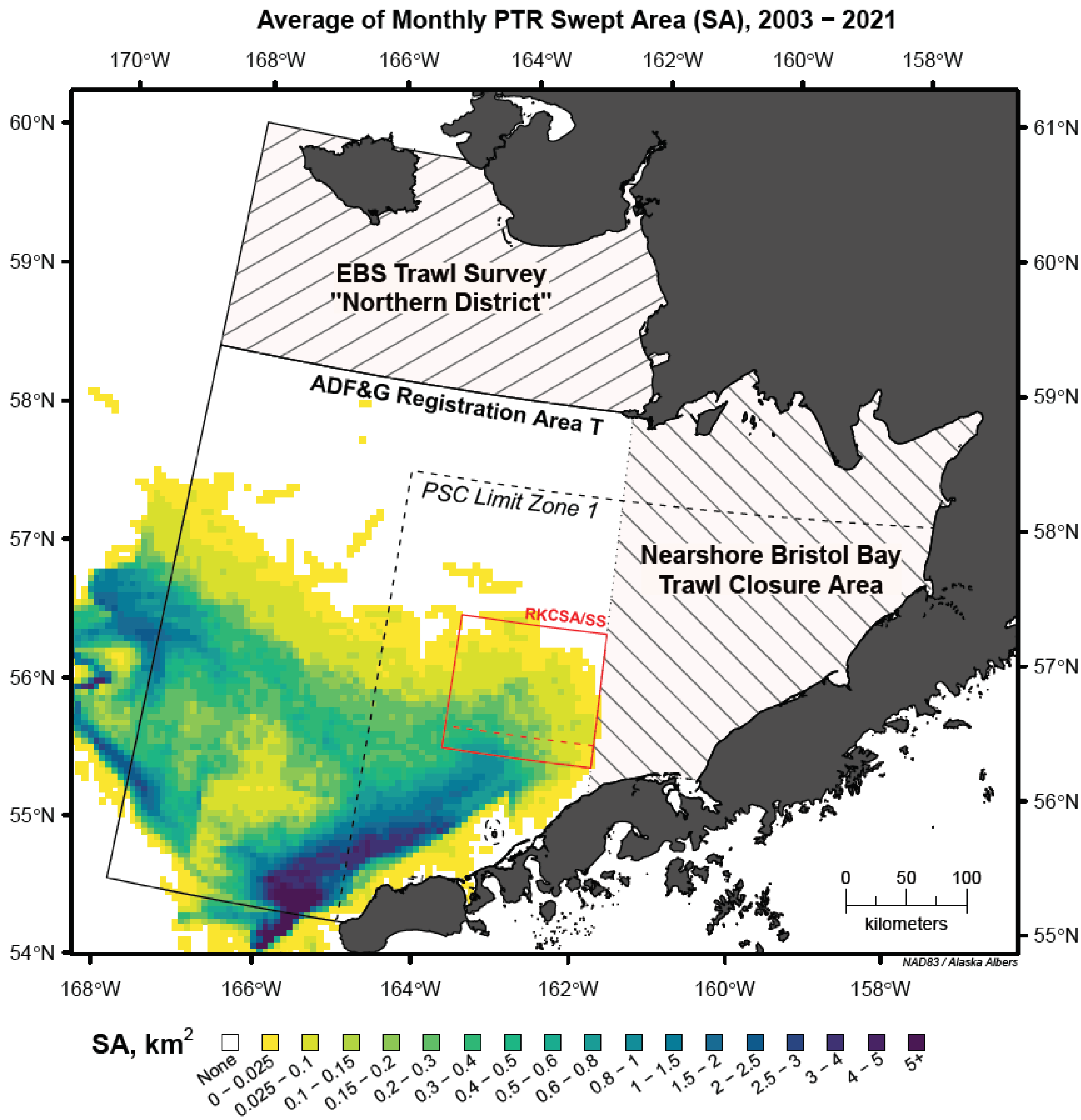


Figure 4-1 **Estimated pelagic trawl swept area (SA) in the eastern Bering Sea. 5 km grid cells represent SA by month, averaged across all pollock fishery months (Jan-Nov) in available years, 2003-2021. (Source: APU FAST Lab)**

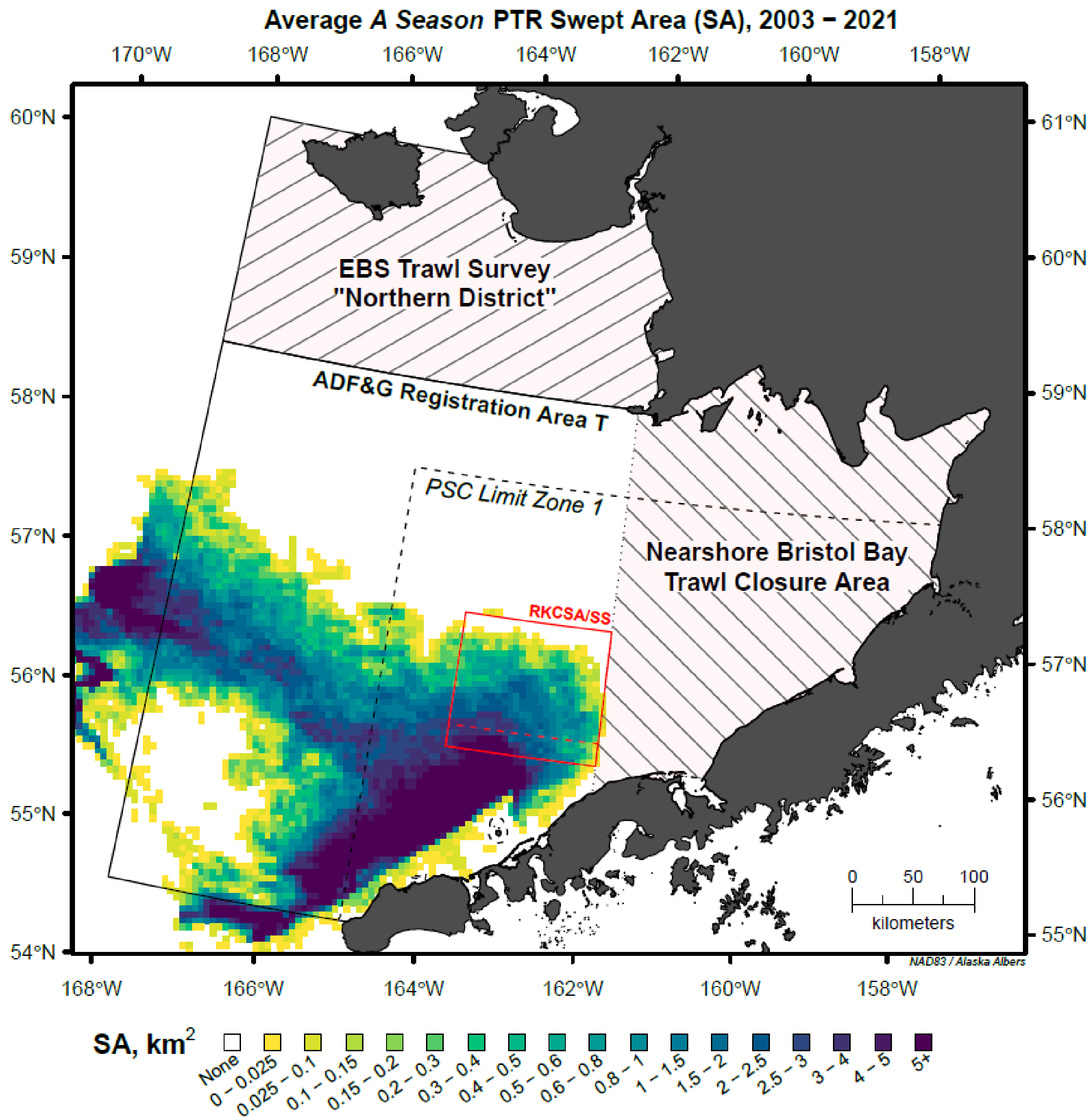


Figure 4-2 **Estimated pelagic trawl swept area (SA) in the eastern Bering Sea. 5 km grid cells represent SA by pollock "A season" (Jan-May), averaged across all available years, 2003-2021. (Source: APU FAST Lab)**

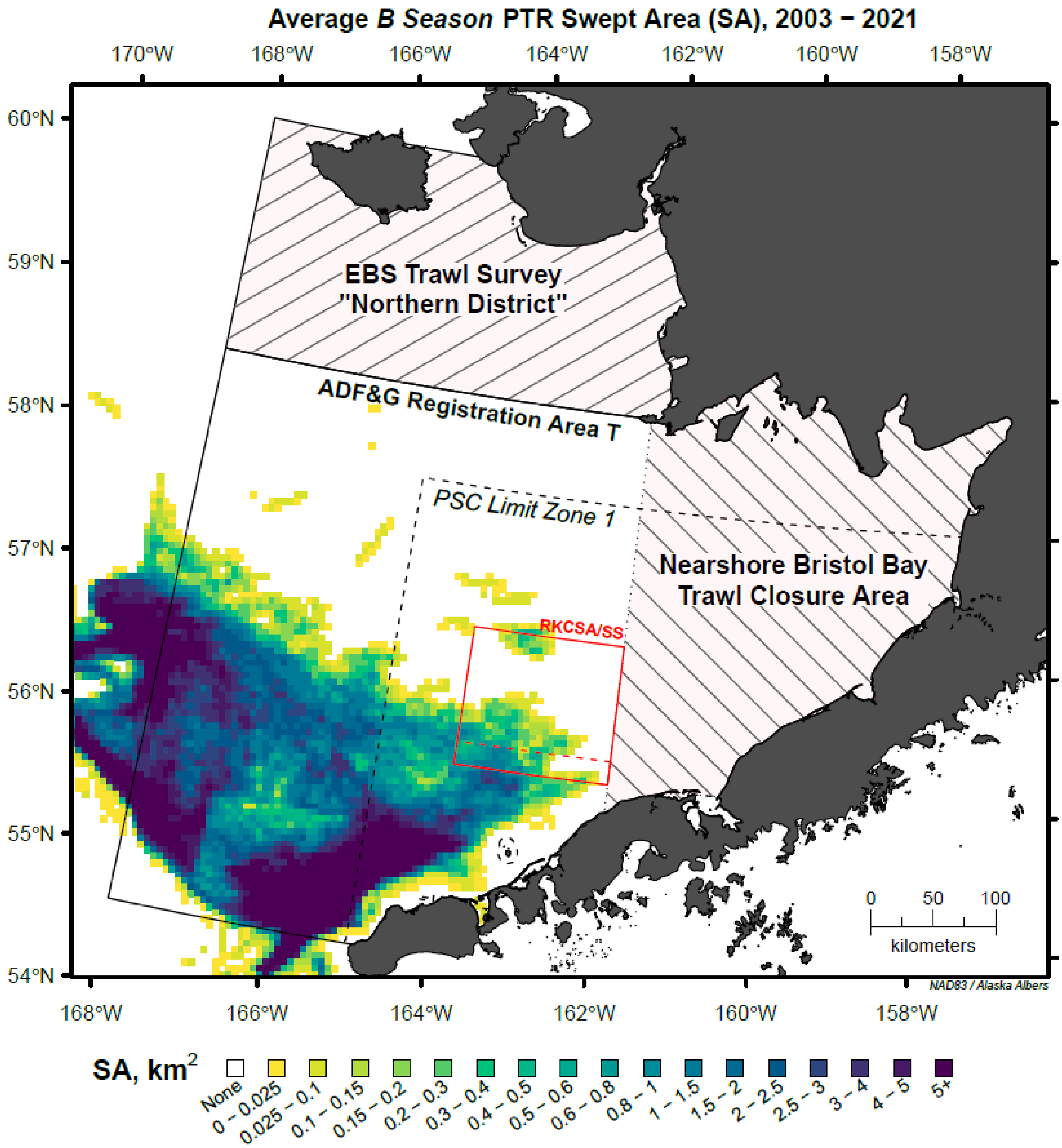


Figure 4-3 Estimated pelagic trawl swept area (SA) in the eastern Bering Sea. 5 km grid cells represent SA by pollock "B season" (June-Nov), averaged across all available years, 2003-2021. (Source: APU FAST Lab)

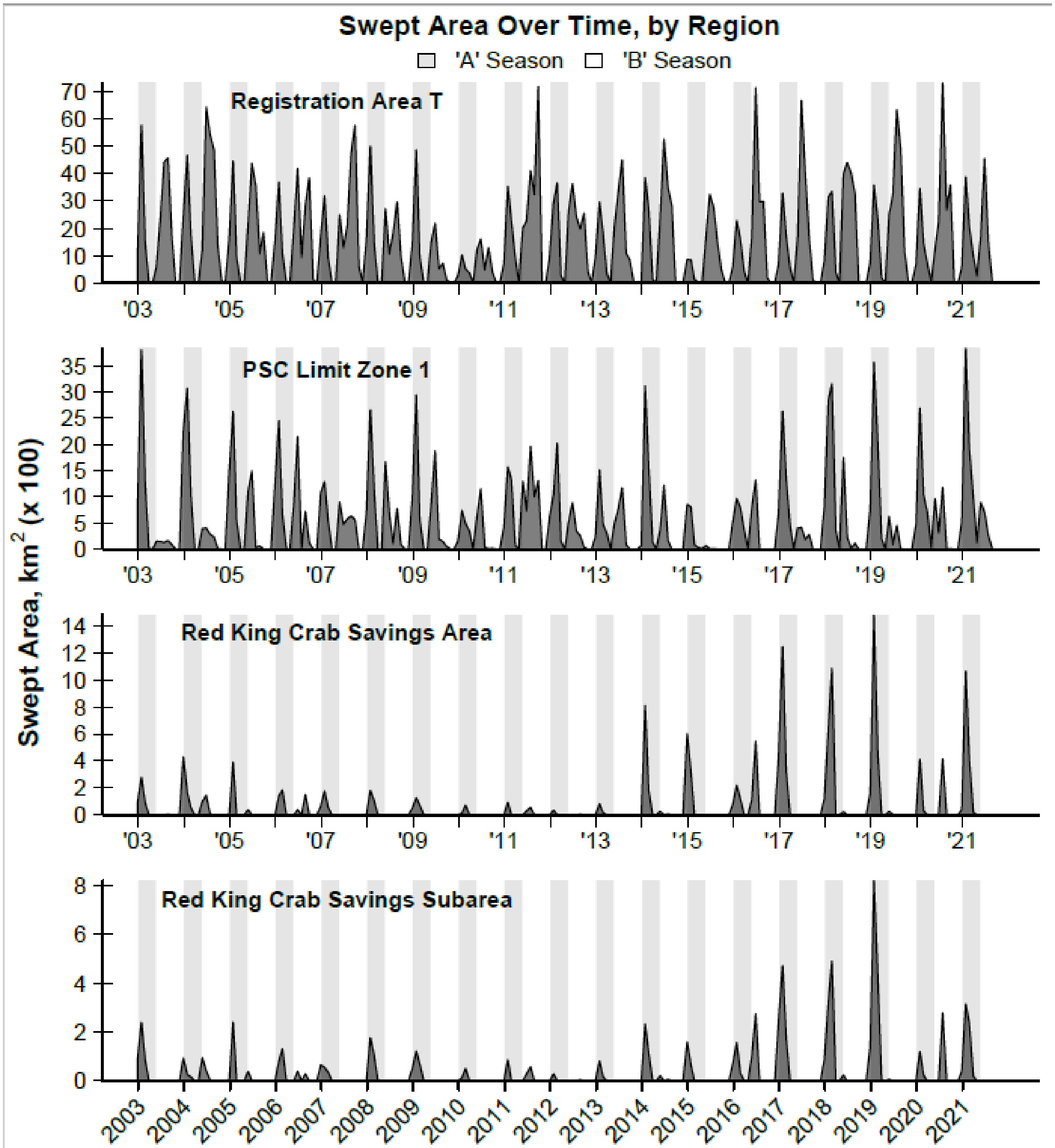


Figure 4-4 Estimated pelagic trawl swept area within four management areas of interest, by month (x-axis), 2003-2021. Grey and white vertical bands represent the pollock "A season" (Jan-May) and "B season" (June-Nov). Note the difference in y-axis scale across the four areas. (Source: APU FAST Lab)

The bottom contact for each trawl tow used to estimate fishing intensity in the FE model itself is calculated by multiplying the distance fished by an estimate of the width of trawl/seafloor contact. Contact width estimates used in these plots break down individual pelagic trawl events by fishery, the target assigned by NMFS Catch Accounting System (CAS) – e.g., midwater-pollock versus bottom-pollock/all others – FMP area, season (A/B), vessel type (CP/CV), vessel length (partly as a proxy for horsepower or other towing characteristics), and ocean depth in the grid cell where the tow occurred. Both trawl width during operation (nominal width) and the proportion of that width in contact with the seafloor (contact adjustment) vary across fishing situations. Maximum trawl width was derived based on direct input from gear manufacturers. Nominal widths were calculated as a proportion of maximum trawl width for each vessel class and then further adjusted for event-level effects that can affect net spreading – e.g., depth, season, and day vs. night. Finally, the adjusted nominal width is multiplied by the contact adjustment that is indexed for trawl height values estimated from fishing depths and seafloor depths as recorded in vessel logs.

The contact adjustment for a Bering Sea pelagic trawl CV tow is drawn from a range spanning 0.2 to 0.6 with a median of 0.4. In other words, actual bottom contact would be estimated at a value between 20% and 60% of the raw area swept, where raw area swept is a function of tow length and adjusted nominal width. The contact adjustment for pelagic CPs is drawn from a higher range. During the A Season the contact adjustment for CPs is drawn from 0.7 to 0.9, reflecting an assumption that pelagic gear is on bottom at least 70% of the time. During the B Season the range is from 0.8 to 1.0.

The adjustment parameters were developed by the FE model authors in consultation with trawl fleet representatives prior to the model's use in the 2016 Essential Fish Habitat (EFH) analysis. Contact adjustments do not assume that the on-bottom trawl path is the entire width of the trawl's wing-tip spread. In the absence of direct measurement of contact width during fishing operations, the investigators estimated the bottom-contacting proportion of the net by augmenting industry knowledge with data on bycatch of benthic species at different times in the year (as correlates to the depth of area-fished) and trawl height (distance between the headrope and the ocean depth, reported by observers). Bycatch presence and trawl height reports are imprecise measures of the proportion of pelagic trawl widths contacting the seafloor, but it was noted that bycatch increased and trawl height decreased from the A season to the B season and as ocean depth increased. The investigators noted several reasons that nominal width might vary with fishing depth, seasons, or times, and thus result in a higher or lower bottom contact estimate – holding trawl height and fishing depth the same. Trawl nets being fished deeper require longer lines so the cables do not restrict the width as much as they would if the net is fishing closer to the sea surface. Fishing in harsher conditions (e.g., A season) may also put more tension on cables and thus restrict spreading. Also, vessels fishing at night might be more likely to keep the net off the bottom and thus would use less line and allow for less spread.

Another source of the distinction in bottom contact percentages estimated for CVs and CPs came from the proportion of tows where the trawl height was at a level where contact with the seafloor was low, medium, or highly probable based on the estimates of the normal vertical operating opening of the pelagic trawl nets used in each fleet. In other words, CPs had a greater percentage of tows where the distance between the headrope and the seafloor was such that bottom contact had a greater probability (C. Rose. Personal communication, Jan. 2022).

4.2 Related Research: Ecosystem Indicators

Alaska Fisheries Science Center researchers have reached out to the authors of this paper to note that data products similar to the swept-area estimates shown above could support the development of a fishing effects indicator for inclusion in the Bristol Bay RKC Ecosystem and Socioeconomic Profile (ESP).[19] The most recent BBRKC ESP – September 2020 – is available as Appendix E to the BBRKC SAFE Report. The ESP is a useful reader reference for summary information on the relevant ecosystem conditions, stock dynamics, fishery participation, production, and market values.

A quantification of the spatiotemporal overlap of RKC populations and fishing gear could provide an indicator that highlights potential RKC vulnerabilities and communicates stock-specific concerns to

[19] E. Fedewa. 2022. Personal communication.

managers and stakeholders. Future refinement of a fishing effects indicator could, for example, assess the impact of multiple gear types, and utilize ongoing BBRKC satellite tagging efforts to characterize spatial overlap between winter fisheries and BBRKC distributions during the molt-mate season.

4.3 Related Research: Bottom Contact for Pelagic Trawl Gear

This subsection briefly summarizes two master's thesis projects conducted at Alaska Pacific University's FAST Lab.

Zagorski (2016) addresses the pollock industry's ability to develop trawl gear that complies with regulations prohibiting the use of the elevating discs, bobbins and rollers that are common in non-pelagic trawls while efficiently capturing pollock near the seafloor, avoiding salmon, crab, and halibut, and minimizing adverse impacts on benthic habitats. The author cites previous work noting that adult pollock aggregate on or near the seafloor – particularly during the daytime – that pelagic trawls are not optimal for capturing pollock near the seafloor, and that variable seafloor contact increases the potential for benthic impacts. The North Pacific Research Board (NPRB)-funded field research partnered FAST Lab with NOAA and AFSC to quantify the benthic impact of six modified footrope configurations: one that complies with pelagic gear regulations and five that do not. Raised footropes were achieved using floating line material (as opposed to chains) and a range of spacing, weights, and bobbins. Results were gathered with bottom contact sensors on the footrope, cameras, and imaging sonar to assess measures of benthic impact like trawl tracks and downed sea whips. The study found that modified footropes were effective at elevating the groundgear resulting in reduced impact of pelagic gear on benthic organisms. Some of the tested modifications could be implemented under current regulations while others (e.g., bobbins) would require changes. Additional work would be required to understand whether these modifications would be effective for capturing target species while avoiding bycatch (e.g., non-pollock groundfish, halibut, and crab). The final report for this project entitled "Assessment of the benthic impacts of raised groundgear for the eastern Bering Sea pollock fishery" was submitted to the NPRB in August 2016.[20]

King (2019) evaluated methods to quantify the footrope-seabed interactions of pelagic trawls. Building on the Zagorski (2016) work, this effort focused on developing technological and analytical tools to gather event-level information on bottom contact and seafloor clearance of pelagic trawls. During a NMFS-AFSC conservation engineering research charter, contact and clearance data were gathered at 1 or 5 second intervals by multiple accelerometer-based tilt sensors placed at 5 points across the footrope span. The investigators found that (1) bottom contact was less than expected by the vessel master, (2) contact was highly variable along and across the tow path even when the vessel operator was attempting to keep the gear "hard on the bottom" for the purpose of the experiment, and (3) the center of the footrope had higher clearance (less contact) than the inner and outer wings. This study shows that a technological solution to collect more granular data and estimate bottom contact of the footrope is possible but there are complications that remain to be resolved. Namely, the tilt sensors must be attached and removed from the gear during set and haul back to avoid damage to the sensors and the net thereby limiting their broad use during commercial operations. The analyses employed in this study are currently being refined for submission to a peer-reviewed journal. In general, this work demonstrates that if practical for broad deployment, bottom contact sensors could enhance assessments of fishing impact on benthic habitat and species by providing within-tow data on ground contact and clearance including its variability. Currently, estimates of contact are made at the gear-level (i.e. proportion of nominal swept area by gear type) and rely on assumptions based on key, isolated studies and perceptions of fishery participants. The state of knowledge on bottom contact is such that gains can be made even if the technology is deployed without full fleet coverage or precision estimates. One substantial advancement that could be made is better

[20] Rose C.S., Harris B., Zagorski S., Hammond C., Sethi S. and McEntire S. 2016. Assessment of benthic impacts of raised footrope for the Eastern Bering Sea pollock fishery. NPRB Project 1319 Final Report. 60pp.

understanding the variability of bottom contact within and between tows. As noted in the description of the gear parameters used in the Fishing Effects model and the PTR area-swept estimates provided in this paper, bottom contact estimates are based on adjustment parameters that cover a broad range of fishing events that fall within a certain category (e.g., CP/CV, target, season, vessel size). As noted throughout this discussion paper, estimated bottom contact is a key component of quantifying fishing impacts on the benthos but estimated contact is not synonymous with the amount of impact to crab or the level of adversity posed.

4.4 Unobserved Crab Mortality from Trawl Gear

Fishing activities lead to crab mortality in ways that are not directly observed. This includes both post-release mortality of discarded crab (which is estimated through a discard mortality rate) and crab that are never captured by fishing gear but die due to gear interactions or sustained damages that cause delayed mortality. The potential for unobserved mortality of crabs that encounter bottom trawls but are not captured has long been a concern for the management of groundfish fisheries in the Bering Sea (Witherell and Pautzke, 1997; Witherell and Woodby, 2005). Unobserved mortality is not accounted for in crab stock assessments and is not accrued towards trawl PSC limits.

Rose (1999) – in a paper studying the injury rates of RKC that passed under non-pelagic trawl footropes – provided the following introductory statement: “The inability to accurately estimate unaccounted mortality does not preclude its consideration in management and fishing decisions. Unfortunately, the lack of information on unaccounted mortality means that those participating in such decisions have to combine and weigh a mixture of related knowledge, opinions, and suppositions to substitute for conclusive facts. This can be a source of considerable dispute and reservations about the ultimate decisions.” A short overview of research on unobserved crab mortality by non-pelagic gear is provided later in this subsection. Since the time of that writing, the Council has taken action to address crab mortality by raising non-pelagic trawl gear off the seafloor in a variety of ways. However, those tools are not available under the pelagic gear specifications in Federal regulation that apply to all Bering Sea pollock trawls. Unobserved mortality impacts for pelagic gear remain in the realm of informed supposition based on related knowledge.

The topic of unobserved mortality was most recently addressed in a Council analysis when crab PSC limits for trawl fisheries were reviewed in February 2021 prior to taking no action (see Section 3.4.6 and Appendix 4 in NPFMC 2021a). The SSC’s February 2021 report noted that including any future estimation of unobserved crab mortality (from both groundfish and directed crab fishing) in a stock assessment would require extensive evaluation to understand how the assessment’s parameters for factors like catchability, natural mortality and reference points would be affected. The SSC noted that “unobserved mortality is a source of both assessed and unassessed uncertainty throughout the history of the assessments (e.g., currently attributed to natural mortality), and that the ABC/TAC buffers in place are an appropriate process to account for sources of uncertainty that cannot be explicitly described in the assessment.” Finally, the SSC supported further research on the topic by industry and NMFS and encouraged consideration of this source of uncertainty when setting harvest buffers.

The trawl PSC limit analysis (NPFMC 2021a) identified improving the understanding of the seasonal and spatial distribution of crab, crab bycatch, and crab in various shell conditions as important pieces to a better understanding of the unobserved impact of gear interactions. The PTR area-swept maps provided in this paper – Figure 4-1 through Figure 4-4 – do not allow for an estimation of unobserved mortality – just as they do not allow for an enhanced estimation of observed mortality – because they are not mapped onto seasonal crab distribution and shell condition. Nevertheless, as noted above relative to a potential ESR indicator, this new work advances the effort by showing where PTR is likely contacting the seafloor in the Bristol Bay region during the pollock A and B seasons.

Appendix 4 to the trawl PSC limit analysis (NPFMC 2021a) includes a sensitivity analysis conducted by the BBRKC stock assessment author in response to the Crab Plan Team's request to better understand potential stock impacts from theoretical unobserved fishing mortality levels. The author recreated the preferred 2020 stock assessment model but increased the input level of trawl and fixed-gear bycatch biomass by amounts ranging from 100% to 1,000%. The author found that the model's terminal mature male biomass (MMB) and OFL levels did not change much if bycatch biomass was doubled or increased by a lesser amount (decrease < 3% of MMB compared to no change in bycatch). Increasing the bycatch biomass by 500% reduced the model's terminal MMB to decrease by 14% or more, with the author noting that the change could be much larger in some years throughout the model's run.

Published studies on the impacts of trawl gear on crab have generally focused on non-pelagic gear, including studies in the Bering Sea and in the shrimp fishery off the east coast of Canada. Studies have utilized bottom and wing recapture nets to collect impacted crab that would not have ended up in the trawl net, cameras to visualize crab that were avoiding the trawl net, and even submersible camera-equipped vehicle dives to compare damage to crabs before and after trawling in an area. The obvious limitation of referencing studies of non-pelagic gear is that the studies were assessing mortality reduction tools that are not permitted the pelagic trawls that are specified in regulations for the Bering Sea pollock fishery.

Rose (1999) cites an earlier study (Donaldson 1990) as a "preliminary estimate" of the rate of unobserved crab injuries, wherein RKC were tethered to the seafloor, a trawl net was towed over the area, and divers attempted to recover the crab. Of 169 crab, 21% were captured in the net, 46% were recovered by the divers, and 33% could not be located. While only two of the 78 recovered crabs were injured, Rose noted the ambiguity posed by the fate of the unrecovered crabs relative to the sample size. An unpublished video study (Rose 1995) found that sweep diameter was the main factor in whether crab could escape over the sweep (note that sweeps were not elevated during this period). The study was not able to determine the frequency, nature, or severity of injuries to crabs that went under the sweep. The Rose (1999) study in Bristol Bay used a recapture net to assess injury rates to crab that pass under different types of footrope. Eight experimental tows yielded injury rates of between 5% and 10% of the recaptured crab.

Subsequent work by Rose et al. (2013) provided estimates of the unobserved mortality rates of crabs swept over by trawl gear common to bottom trawl fisheries in the Bering Sea. This research demonstrated that mortality rates varied by crab species (red king, Tanner, and snow) but depended mainly on that part of the trawl system crab encountered. Additionally, reduction of crab mortality rates by altering specific gear designs showed that gear modifications, such as raised sweeps, can mitigate unobserved mortality. The finding was that mortality was much higher for crab that passed under the footrope (particularly the wing section) than for crab that were struck by the sweeps that herd flatfish. One supposition was that effective herding can reduce overall crab mortality because it reduces the amount of footrope-swept area needed to catch the same number of flatfish. This study used an assessment method[21] onboard the vessel to predict the delayed mortality of recaptured crab that would have been impacted by the trawl but not captured by normal fishing. The study also evaluated crab caught in a control net where they did not encounter the trawl gear (footrope, sweeps) to adjust observed mortality rates for the effects of capture and handling. The study results were that the experimental trawls produced more mortalities of RKC than either snow or tanner crab, which was expected due to their larger, less flat body shape. The raw mortality rate for RKC that passed under the footrope wing was the highest, at 32%. The study concluded that RKC estimated unobserved mortality rates, adjusted for the area swept by each trawl component (i.e., footrope center, wing, and sweep) were reduced to 6% when sweeps were elevated, which is now required for BSAI non-pelagic trawls.

[21] Reflex Action Mortality Predictor (RAMP); see Davis and Ottmar (2006) and Stoner et al. (2008).

The remote-video study of shrimp trawl interactions with snow crab off St. Mary's Bay in southeastern Canada only assessed areas swept by the trawl footrope (Dawe et al. 2007). The study did not collect a large sample of direct post-trawl observations but did not report any dead crab in the trawl corridor or crab with carapace damage. The authors note that the study area has a soft mud substrate and that a similar early study (Schwinghamer et al. 1998) did observe dead crab in a dense sand substrate on the northern Grand Bank. The study did not find a reduced density of snow crab in the trawled bays after trawling occurred. However, the study concluded that intensive trawling could increase crab leg-loss by about 10%.

A trawl-mounted video study in the same part of Canada looked at how snow crab physically reacted to shrimp bottom trawls (Nguyen et al. 2014). This study was also limited to the footrope portion of the trawl, and concluded that about 54% of observable crab interacted with the footgear (e.g., elevating discs, spacers, or chains). The majority of video-observed crabs actively responded to the approaching trawl and tried to escape. The study was unable to estimate the severity or likelihood of mortality after passing under footgear. This study, and references to herding in Rose et al. (2013), highlights the relevance of crab shell condition to susceptibility to unobserved trawl mortality. In a time/area where crab are likely to be in a soft-shell condition and less mobile, unobserved mortality rates could be higher than the ranges estimated in the studies available.

The primary reason for the decline in the BBRKC stock, if there is one, is not clearly understood. While there are likely many interacting factors including crab movement and environmental shifts (including shifts identified prior to the BBRKC decline in the late 1970s), some researchers have highlighted unobserved trawl mortality – historically if not currently (Dew and McConnaughey 2005; Dew 2010). Those researchers contend that the BBRKC brood stock had a high site fidelity to an area in southwest Bristol Bay that was the region's first no-trawl zone, known as the Bristol Bay Pot Sanctuary, but that subsequent management measures allowing trawl gear in that area resulted in high unobserved mortality. Further, relatively low numbers of trawl BBRKC bycatch today could be the result of historical mortality. Researchers with different views note that BBRKC crab abundance declined precipitously before trawl gear was permitted in the Pot Sanctuary (i.e., prior to 1982; see Witherell and Pautzke, 1997). While it is not possible to make a definitive conclusion and whether or not one believes that trawling was the principal cause of the BBRKC stock decline dating to the late 1970s, it remains possible that trawling could have impacted RKC rebuilding over the decades since then.[22]

4.5 Bottom Contact by Other Gear Types

Though it is not part of the Council's direct request, this paper briefly acknowledges that types of gear other than pelagic trawls contact the seafloor and may affect BBRKC in ways that are not captured by observed crab bycatch mortality data. The nominal gear width values in the gear parameter table of Olson et al. (2022) provides a measure by which to compare gears. However, similar to the information presented about PTR, those parameters are intended for the study of habitat disturbance and do not tell the reader anything about the time/area collocation of these gear types and BBRKC.

The nominal gear widths for trawls in the BSAI and GOA range from 50 m to 259 m. BSAI pelagic trawls ranged from 50 m to 175 m and BSAI non-pelagic trawls ranged from 90 m to 259 m. GOA pelagic trawls ranged from 50 m to 100m and GOA non-pelagic trawls ranged from 55 m to 193 m. Certain categories of non-pelagic trawling have bottom contact adjustments of 1.0 (assumed bottom contact) but others, where trawl sweeps are raised and fishing gear is elevated by bobbins, have contact adjustments as low as 0.27 (27% of nominal area swept being contacted).

[22] J. Zheng (ADFG). 2022. Personal Communication.

By comparison, the nominal widths used in the FE model for pot gear and hook-and-line gear is listed at 5.6 and 6 meters, respectively. The benthic impacts of fishing gears other than trawl and dredges (i.e., scallop gear) has been less studied. When updating the gear parameter table in 2022, Olson et al. cited a hook-and-line longline study from Australia (Welsford et al. 2014) and a sablefish longline-pot study from British Columbia, Canada (Doherty et al. 2017). The hook-and-line study identified line shear and hooking that could impact structure-forming invertebrates. Such impacts might relate to crab as they rely on structure for safety after molting. The average lateral line movement in Welsford et al. was 6.2 meters, and virtually all lateral movement occurred during deployment or retrieval. The documentation behind the FE gear parameter table noted that lateral line movement can result from currents or from captured fish. Bycatch of sessile benthos (e.g., sponges, corals) are sometimes observed in the Alaska longline fishery so it is known that seafloor interactions do occur. The longline-pot study (Doherty) noted that hauling speed and direction, combined with environmental factors like depth, slope, and current affects a pot's footprint. The BC pot study was assessing conical pots that are significantly smaller than most Bering Sea crab pots but similar to smaller groundfish pots (e.g., sablefish). Doherty estimated the mean bottom-contact area for a 54-inch pot at $53m^2$, or roughly 36 times its static footprint of 1.47 x 1.47 meters. The longline-pots were observed to drag for between 0.4 and 5.9 minutes when hauling. For comparison, Doherty et al. specifically cites Alaska king crab pots as having a roughly 2.4 x 2.4 meter size. The analysts note that the effect of pot dragging would greatly depend on hauling conditions and also note that less dragging would be expected for pots that are not connected to one another by a groundline.

Alaska weathervane scallops are fished with towed dredges that directly impact the seafloor. There is only one scallop area in the Bering Sea; it is relatively small and lies directly north of Unimak Island, which places it inside the boundaries of interest in this paper (i.e., ADFG Area T, trawl PSC limit Zone 1, and the parts of the summer trawl survey that are included in the BBRKC stock assessment. The Bering Sea scallop area has not been widely fished in recent years due to a parasite that emerged during the 2014/15 season. A small amount of scallop fishing occurs occasionally but only as part of the parasite and stock monitoring efforts that the scallop cooperative undertakes. No scallop fishing occurred in the area in the 2020/21 season due to the quality impacts of the parasite, high fuel costs, and the logistical impacts of COVID-19. The primary scallop vessel that had fished the area in past years is reported to be geared for other fisheries.[23]

5 Item 4: Flexible Spatial Management Measures

Fishing for groundfish by U.S. vessels in the U.S. Exclusive Economic Zone (EEZ) of the BSAI is managed by NMFS according to the FMP for the Groundfish Fishery of the Bering Sea and Aleutian Islands Management Area (BSAI FMP). The BSAI FMP was prepared by the Council under the Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. 1801, et seq.) (Magnuson-Stevens Act), and is implemented by regulations governing the U.S. groundfish fisheries at 50 CFR part 679.

The FMP for the Commercial King and Tanner Crab Fisheries (Crab FMP) in the BSAI was approved by the Secretary of Commerce on June 2, 1989. The FMP establishes a state/federal cooperative management regime that defers crab management to the State of Alaska with federal oversight. State regulations are subject to the provisions of the FMP, including its goals and objectives, the Magnuson-Stevens Act National Standards, and other applicable federal laws.

Various management measures have been implemented in the Bering Sea to protect RKC. These measures consist of PSC limits and area closures, such as the RKCSA and the NBBTCA. In the December motion, the Council asked for an exploration of available flexible spatial management

[23] Sources for this paragraph: Scallop FMP Figures 3 & 4 (pp.29-30), and R. Woodruff, ADFG (2021).

measures that may benefit BBRKC. The analysts examined management options within Alaska, as well as from other regions. The options examined fell into three primary categories: inseason management, incentive approaches, and time and area closures. The following discussion will consider each of these categories and offer examples of possible strategies under each. The analysts also offer several examples of management considerations that might benefit BBRKC but are not “spatial” in nature.

5.1 Inseason Management

Federal regulations provide NMFS with the authority to make inseason management adjustments for directed groundfish fishing (679.25(a)). Inseason adjustments can include season closures, extensions or openings in all or part of a management area; modification of the allowable gear in all or part of a management area; adjustment to TAC or PSC limits; or interim closures of statistical areas to directed fishing for specific groundfish species. The authority for these actions is reiterated in BSAI Groundfish FMP Section 3.8.1 "Flexible Management Authority -- Inseason Adjustments". The FMP text makes clear that inseason interventions by NMFS are a necessary tool to manage groundfish harvest or PSC limits that were specified based on the best available information at the time but may be subject to changes in the state of the fishery or a prohibited species that become known from events within the fishery as it proceeds or from new scientific survey data. If a groundfish harvest or PSC limit was set too high or too low prior to the fishery commencing, then prescribed closures could lead to conservation concerns or forgone economic benefits. The FMP states: "The Council finds that inseason adjustments are accomplished most effectively by management personnel who are monitoring the fishery and communicating with those in the fishing industry who would be directly affected by such adjustments." The FMP lists the types of information that NMFS must consider in determining whether an inseason adjustment is required.

That said, the FMP goes on to acknowledge that NMFS managers are constrained in their choice of management response in several ways. First, data on catch/bycatch rates might not be timely enough to implement effective closures or to determine whether a rate-spike is reflecting natural variability or "dirty fishing". Second, NMFS is subject to procedural requirements to consider "least restrictive" measures and then -- in most cases -- go through the process of publishing notice of proposed adjustments in the Federal Register with a comment period. And third, when applicable, NMFS must coordinate inseason adjustments with the State of Alaska to assure uniformity of management in State and Federal waters. In recognition of some of the limitations of NMFS's ability to take inseason action on bycatch, the FMP allows for the Secretary of Commerce -- after consultation with the Council -- to implement measures that provide incentives to individual vessels to reduce PSC, with the intended effect of increasing the opportunity to harvest groundfish TACs before PSC limits are reached (BSAI Groundfish FMP Section 3.6.4).

5.2 Incentive Approaches

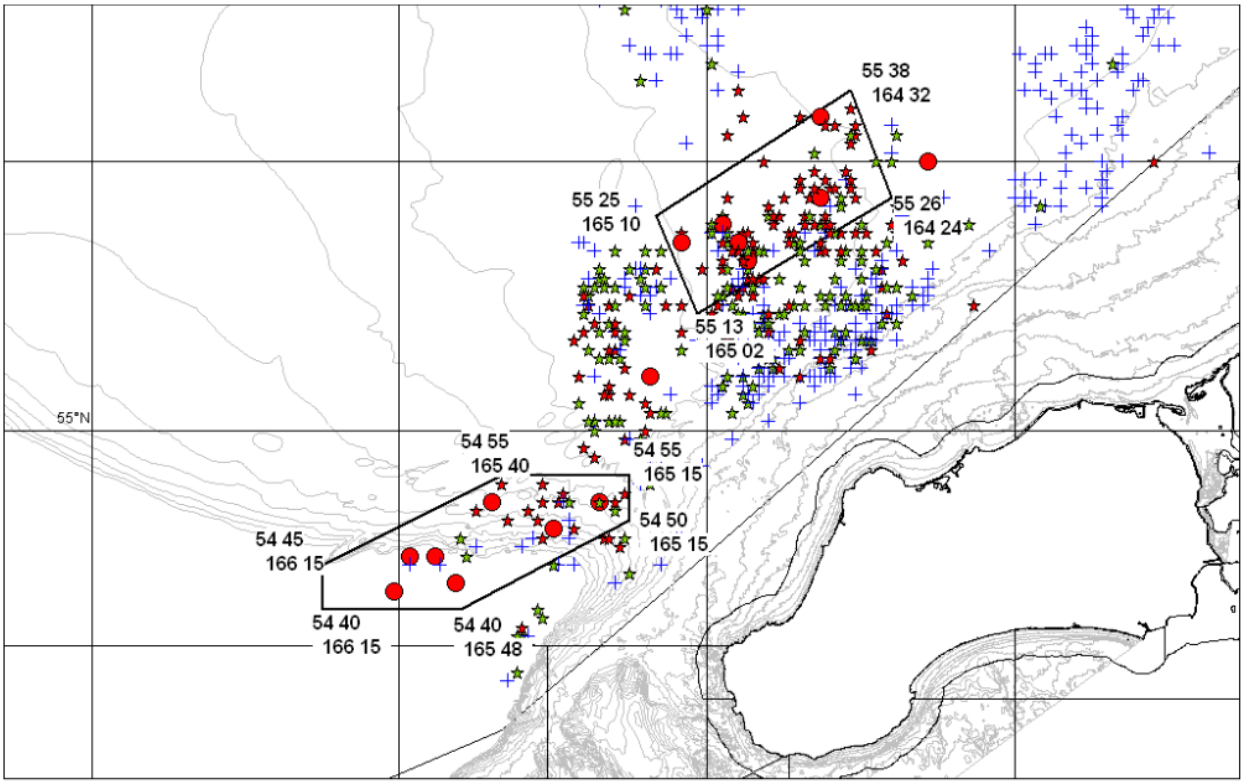
One example of an incentive approach in the BSAI, albeit with a complex history that is not likely to be duplicated, is the management of salmon bycatch in the BSAI pollock trawl fishery. Chinook and chum salmon bycatch in the pollock fishery was managed by triggered area and/or time closures that predate the Congressional implementation of the American Fisheries Act (AFA). In 2001 and 2002 AFA participants began voluntarily implementing a flexible management approach to chum and Chinook salmon bycatch, respectively, known as the "rolling hotspot system" (RHS, described below). Participants utilized RHS to reduce the likelihood that area closures would be triggered, having noted that CDQ pollock fishing – which was not subject to the same area restrictions – was finding clean fishing in times/areas for which non-CDQ vessels were often finding themselves barred. In 2006 and 2007 exempted fishing permits issued by NMFS allowed RHS participants to fish in the triggered-closure areas. Starting in 2008, NMFS has approved Inter-Cooperative Agreements (ICA) that exempt RHS participants from chum/Chinook closure areas.

The purpose of the RHS exemption (Amendment 84) was to reduce bycatch through the RHS while other management measures were being developed. Through subsequent actions (Amendments 91 and 110), triggered closure areas were effectively replaced by Incentive Plan Agreements (IPA) under which participating cooperative members utilize real-time third-party spatial catch/bycatch data management and internal accountability measures to minimize bycatch with dynamic tools while remaining under various forms of an overall PSC cap on Chinook salmon. IPA participation, which currently covers the entire AFA fleet, alleviates the need for static spatial boundaries based on historical survey and fishery data that can be difficult to manage responsively. A triggered closure area for chum salmon still exists as a back-stop but, because the pollock fleet entirely operates under IPAs, closed areas are not currently the foundation of salmon bycatch minimization.

The RHS works by monitoring bycatch rates at the AFA-cooperative or vessel level and comparing them to a base rate. Basing performance on a rate is meant to incentivize bycatch avoidance at all levels relative to a PSC cap. Poor performers may be restricted in their fishing options and internally penalized, while all vessels benefit from timely information on areas with high bycatch rates so that they can fish productively under the cap (or their allocation of the cap). Fishing cooperatives may impose temporary area closures on their members. The efficacy of the program is reviewed annually by the Council. Figure 5-1 shows an example of a pollock cooperative's salmon bycatch monitoring that was presented to the Alaska House of Representatives Fisheries Committee in March 2017.

The Council will want to consider the extent to which a dynamic hotspot strategy could apply to RKC as it applies to salmon. Crab may not move throughout the ocean or commingle with target species in the same way that salmon do but the relative lack of knowledge about crab distribution throughout the year – and their susceptibility to bycatch mortality, i.e., molting and mating – might resemble the uncertainty that a trawl captain has when setting a net under a salmon cap or cooperative performance standard. A potential weakness of this approach lies in the incentives. The Zone 1 trawl PSC limit does not close the pollock fleet out of fishing areas. Given the low number of observed RKC bycatch in the pollock fishery (see Table 3-2), the incentive to implement a hotspot strategy through cooperatives might stem from social pressure more so than from the potential loss of directed fishing opportunities. While recent historical BBRKC PSC in the pollock fishery can be called "very low", the limit in harvest specs is also quite low – less than 100 crab. That is a reachable cap under any circumstances, and so it is conceivable that the pollock fleet would be willing to invest in additional measures if they believe those measures to be both necessary and effective.

The premise of a dynamic hotspot strategy is that static area closures can be sticky (difficult to change) and ineffective/inefficient if the closure set in regulation becomes out of step with the current state of the stock distribution. If event-level bycatch encounter rates are sufficiently uncertain, real-time data become very valuable and vessel operators pay more attention to predicting and interpreting bycatch than they pay to a closure area on a map.



Note: “Sea State” refers to a pollock cooperative’s third-party data manager.

Figure 5-1 Example of rolling hot spot monitoring: “High bycatch areas identified by Sea State” – from pollock industry presentation to Alaska House of Representatives Fisheries Committee, 3/9/2017. (Source: http://www.akleg.gov/basis/get_documents.asp?session=30&docid=13337)

Other incentive-based measures to minimize effects on bycatch species in Alaska tend to be structured around annual hard caps where performance to a low level of bycatch in one year provides an insurance-like buffer in the following year. One example of this is the Chinook salmon PSC limit for non-pollock and Rockfish Program trawl vessels in the GOA. The incentive to achieve a certain standard is closely linked to the economic penalty of having a season shortened or a PSC limit reduced. As noted above, the BS crab PSC limit for pelagic trawling does not directly entail a similar penalty. Moreover, the pelagic trawl sector’s subapportionment of Zone 1 crab PSC is set in harvest specifications and can be modified by NMFS under inseason authority; it is not a hard cap set in regulations and/or the FMP. Finally, while the effect of these GOA incentive structures is expected to be dynamic responses by the groundfish fleet – as left to their own individual or cooperative decisions – there is nothing about them that directly incentivizes spatial responses. A vessel operator could fish under this incentive-structured hard cap without changing where they fish, generally. In that sense, if the Council is hoping to keep certain gear types out of areas – with the areas themselves being the dynamic aspect – then this sort of example may miss the mark.

In the U.S. Pacific region, the Pacific Council and NMFS took steps to transition contour-based area closures protecting salmon from static zones to “routine inseason management tools” based on triggered thresholds. The offshore whiting fishery (CPs and motherships) uses a third-party data manager to disseminate catch and bycatch data at a fine spatial scale. Similar to the RHS program in Alaska, vessels voluntarily move away from bycatch and alert other vessels. Council action was required to institute spatial flexibility and transform bycatch hard caps to soft caps with reserves that can only be accessed when vessels participate in co-management through a Salmon Mitigation Plan process. One key to making this transition acceptable was providing publicly accessible data on catch and salmon bycatch in the whiting fishery (through PACFIN/PSMFC), as opposed to providing public information retrospectively through end-of-year reports.

Existing examples of incentive-based approaches to change fishing behavior that rely on real-time communication can be thought of as partnership approaches. As a category, they rely on collaboration, iteration, and trust. In most cases, it seems, the effectiveness of these programs depends on the existence of bycatch caps or triggered area closures that would restrict the fishery that needs to minimize bycatch. An example that turns the Bristol Bay fish/shellfish bycatch relationship on its head is the Atlantic scallop fishery off the U.S. east coast. The Atlantic Scallop FMP includes gear modifications and time/area closures to try to mitigate flatfish bycatch – specifically of yellowtail and windowpane flounder – in scallop dredges. In addition to bycatch limits and time/area closures, the scallop fishery partnered for several years with UMass-Dartmouth's School for Marine Science and Technology (SMAST) to develop a bycatch avoidance plan. The plan involved distributing flatfish and scallop survey data to the fleet prior to the fishery and then facilitating real-time communication to avoid flounder hotspots.

5.3 Time and Area Closures

Permanent Area Closures

Several permanent area closures already exist in the Bering Sea aimed at protecting RKC, such as the RKCSA to protect mature adult BBRKC and the NBBTCA to protect juvenile BBRKC habitat (December 16, 1996, 61 FR 65985). While the Council asked for flexible spatial management strategies and permanent area closures are by no means flexible, the Council may consider examining existing closure areas and deciding whether these areas should remain in the correct location, whether they should be moved, or if new closure areas are warranted.

Permanent closures are commonly used across U.S. regions to protect habitat or recovering stocks. Closures might apply to all fishing, certain gears, or vessels of a certain size. Closure areas might have exceptions. For example, the many closure areas of the New England region's Northeast Multispecies (groundfish) FMP – a trawl gear fishery – include "access areas" that allow the scallop fishery to access the scallop resource during specified seasons. The permanent closures are described here. The Western Pacific region is dominated by Marine National Monuments (under the Antiquities Act) and coral refuges, marine mammal protection areas, and permanent closures that apply only to certain gears or vessel sizes (under the Magnuson-Stevens Act). A map illustrating these closed areas is found here.

Seasonal Closures

Unlike permanent closures, seasonal closures seek to protect vulnerable species at strategic times during the year. Seasonal closures can be instituted for a variety of reasons including avoidance of times and areas with high bycatch, to prevent interference with recreational and subsistence practices, and to protect species during important biological times. Permanent area closures for RKC based on areas of high abundance of mature adult RKC and important habitat for juvenile RKC have already been instituted, therefore the analysts have focused this section on examples of seasonal closures to protect species during important biological times.

In Alaska, Area 516 of Zone 1 is closed to trawl gear from March 15 through June 15 (50 CFR 679.22(a)(2)). The seasonal extension of the closed area is intended to provide additional protection to RKC, especially females during molting and mating when their shells are soft and more vulnerable to damage by trawl gear. This measure is based on a 1988 scientific survey of RKC distribution, which indicates a significant movement of RKC, especially mature female animals into this area (May 4, 1989, 54 FR 19199).

In New England, the New England Northeast Multispecies FMP includes areas that are seasonally closed to protect groundfish. Those closures also prohibit fishing by non-groundfish gears that are capable of catching groundfish – i.e., scallop dredges. Examples include the Winter Massachusetts Bay Spawning Protection Area (Nov-Jan), the Spring Massachusetts Bay Spawning Protection Area (April 15-30), and the Gulf of Maine Cod Spawning Protection Area (April-June). Full details on those seasonal closures and exception categories are available here.

The analysts also offer an example of seasonal management that, while not a closure, does take into account biologically important times for a vulnerable species. Ensuring a steady supply of prey for a recovering population is important for a variety of reasons, especially for adult females with dependent young. For Steller sea lions winter is an especially demanding metabolic period and obtaining an adequate supply of food is critical to ensuring successful pregnancies. In order to maintain a consistent amount of prey, seasonal apportionments of important prey species such as Atka Mackerel and Pacific cod were created (May 8, 2003, 68 FR 203).

One might consider triggered-closures to be a subset of seasonal closures (although sometimes a season can be the remainder of the calendar year). In Alaska, hard cap PSC limits could be considered triggered closures. A management area could be closed to all fishing by a certain gear type or for a certain directed fishery. Examples include Chinook salmon PSC limits in the Gulf of Alaska pollock and non-pollock trawl fisheries (the pollock PSC limit is apportioned by management subarea), or the closure of BBRKC Zone 1 to non-pelagic trawl gear for certain directed fisheries. Non-trawl fisheries can be closed based on observed takes of protected seabird species. South of the Main Hawaiian Islands, there is a Southern Exclusion Zone that prohibits "deep-set" longline fishing after a certain number of interactions with False Killer Whales is met. The Western Pacific also has hard caps for interactions with sea turtles, seabirds, and Oceanic Whitetip sharks that trigger area closures. Some of those triggered area closures apply only to a certain part of the fishery, analogous to a gear type; for example, sea turtle interactions close the "shallow-set" component of the longline fishery.

In discussion of seasonal closures, it may also be worth consideration of seasonal openings. Seasonal openings can strike a balance between protection of one species while allowing full prosecution of fisheries during times when disturbance and bycatch would be at a minimum. An example in Alaska of a seasonal opening is in the NBBTCA where a portion of the closure area is open to trawling from April 1st to June 15th (December 16, 1996, 61 FR 65986). Harvest information indicates that allowing trawling in this area yields high catches of flatfish and low bycatch of other species. The April 1 to June 15 time period is allowed as a way to reduce bycatch rates of halibut, which move into the nearshore area in June. Sea ice generally prevents fishing operations in northern Bristol Bay before April 1.

Effective seasonal closure areas for BBRKC, would likely be most effective if applied to mature BBRKC females during molting and mating. A seasonal closure area could be based on summer trawl survey results that would indicate where large groupings of mature females are located. The weakness of that approach is the disconnect between the survey period, the fisheries, and molt/mate period. A different approach might use data on catch/bycatch in the first few weeks of a fishery to place a closure area. That approach may lack timeliness and could still subject crab in need of protection to a period of heavy fishing with gear that contacts the bottom. A third approach would be to set a fixed seasonal closure area using historical data on where mature females occurred. That approach would essentially be repeating the process that led to the RKCSA (which itself was a seasonal closure at first) and would also require an improved understanding of where crab are during the relevant fishing seasons and during molt/mate periods. As noted elsewhere in this paper, fixed-area closures are difficult to change once implemented, and they are not particularly responsive to stock distribution changes that might be predictable but occur on a slow scale (e.g., related to temperature regime shifts like the decadal oscillation) or that might be less predictable (e.g., the less well understood effects of climate change).

Rotational Area Closures

Rotational closures are area closures that shift spatially dependent on input data or predetermined criteria. These closures target specific vulnerable species, generally for a specific demographic of the population. One example of a rotational area closure is for Atlantic scallops, where juvenile scallops are protected with rotational closures in the Northeast and Midatlantic U.S. regions. Based on data from both NMFS and industry-led surveys, abundance, distribution and size of scallops are mapped in the Northeast Atlantic. Areas of predominantly smaller scallops are closed to directed fishing for scallop in order to allow these scallops the time to grow into a commercially valuable size. These closures are focused on protecting the scallop stock by restricting the scallop fishery itself rather than restricting other fisheries that may impact scallops.

If a similar strategy were used in the BS for BBRKC, the results of the BSAI NMFS Trawl Survey could be used to identify areas of vulnerable populations, which for BBRKC would likely be mature adult females. Additionally, efforts could be made to develop an industry-led survey that could improve the type and resolution of data collected on the spatial distribution of RKC in data deficient times of year, such as Fall/Winter. A winter survey would be particularly beneficial if sampling protocols were capable of finding molting crab, which do not typically enter pots and can be missed or damaged by trawl survey gear.

A different approach to rotational closure is to close an entire management area in alternating time periods – e.g., single or multiple years. Since 1978 the State of Hawaii has used rotational closures of one to two years in the Waikiki-Diamond Head Fishery Management Area (FMA) on Oahu, Hawaii to protect coral reef fish stocks. The effects were studied in 2006 (Williams et al.) and found that time-rotational closures were not effective, whereas stocks did improve in a neighboring permanent closure even though reefs were being overtaken by alien algae in both areas. The success of a species protected by a rotational closure likely has much to do with its life history characteristics and non-fishing impacts on the habitat (e.g., recreation tourism, which is not an issue in the Bering Sea).

Temperature Closures

Temperature closures can go into effect when temperature thresholds are surpassed and conditions are unsafe for certain species. These closures can go into effect to protect species when air or water temperatures are outside of normal thermal thresholds. Several examples of temperature closures are described below.

The first example was implemented by the Texas Parks and Wildlife Department and resulted in a temporary closure to saltwater fishing along parts of the Texas coast due to freezing weather conditions. In addition to killing game fish in shallow bay waters, a hard freeze can also cause surviving fish to congregate in a few deeper areas where they become sluggish and prone to capture, which was the main justification for implementing the closure. The second example occurred in Yellowstone National Park, when the park closed fishing to anglers, in order to protect fish that were experiencing unprecedented heat exposure and low river levels.

Another example of dynamic temperature-based fishery management is the TurtleWatch tool, created by Pacific Island Fisheries Science Center and available through NOAA OceanWatch.[24] No fishery closures are enacted through TurtleWatch but an up-to-date map tool is provided online that helps fishermen avoid ESA-listed loggerhead sea turtles. Most interactions with loggerheads occur during the longline swordfish fishery north of the Hawaiian Islands during the first three months of the year. The map provides a sea surface temperature contour in terms of latitude and longitude that shows areas to avoid. The warmer end

[24] See https://www.fisheries.noaa.gov/resource/map/turtlewatch; and https://oceanwatch.pifsc.noaa.gov/turtlewatch.html.

of the band indicates the southern boundary of the turtles' preferred temperature habitat (65.5°F) and the cooler end of the band (63.5°F) marks the northern edge of the temperature range in which more than half of observed fishery interactions have occurred. The data that inform the turtles' preferred habitat were gathered through capture-tag-release studies.

In Alaska, it is known that when air temperatures are very low, snow crab can instantly freeze and lose legs when hauled on deck. For crab that are brought on deck as bycatch, even though they are technically still alive and can regrow legs, this loss of legs would likely increase discard mortality rates. Not much is known about how freezing air temperatures affect RKC. The Alaska Bering Sea Crabbers (ABSC) industry group informed the analysts that they have submitted a preliminary proposal to NOAA's Bycatch Reduction Engineering Program (BREP) to place water temperature sensors on crab pots (as well as some more sophisticated data loggers that record water salinity and pH). The goal of the study is to do statistical analysis of retained and discarded crab under certain conditions; presumably, air temperatures could be recorded for each pot haul as part of the study protocol if viability is being assessed on deck.

5.4 Non-Spatial Management Considerations

The Council motion was specific in its request that options for flexible spatial management measures be examined. In exploring available options, the analysts noted management options that did not fit in the realm of spatial management but may be of interest to Council. The analysts did not do an in-depth analysis of these options; a brief summary is provided for each method.

Gear Modifications or Changes

Floating pots – Studies have been conducted on the feasibility of using floating pots to reduce bycatch of crab species. Studies conducted for cod fisheries have shown that floating pots greatly reduce bycatch of crab species and in some cases increased catch of targeted cod (Furevik et al. 2008. Marcella et al. 2016, Ovegard et al. 2011).

Slinky pots – Slinky pots are a lightweight, collapsible mesh pot that is easily stacked onboard vessels and is primarily used in Alaska waters to reduce depredation by marine mammals. Bycatch of crab in slinky pots has yet to be analyzed, although it has been theorized that due to how much the pots move, that crab may be deterred from entering the pot.

Modification of pots – Collaboration among several research groups has focused on cod pot modification to reduce RKC bycatch in recent years. The output of this collaboration has indicated several promising avenues to reduce bycatch. The lab and field results for RKC and pot cod trials so far support the concept that pot tunnel, ramp, and entry elements can change the way that cod and RKC are able to pass through gear panels and enter a pot. There were two gear variants that were expected to reduce crab bycatch, the 'sock' and the 'slick ramp' and both showed reduced passage for crab in lab results. However, there was evidence of lower cod CPUE and logistical challenges with the 'slick ramp' in field trials. The 'slick ramps' caught less cod in contrast to control pots and were not resilient on deck (tearing with use) and were omitted from further consideration after field trial reporting. Preliminary project results to date reflect lab and field summaries that support the use of 'socks' or 'sock variants' as the best likely method for reducing crab bycatch.[25]

Fisheries Executed in Tandem

Fisheries that require similar gear types and overlap spatially can be fished in tandem in order to reduce discards for each fishery. An example of this strategy in Alaska is how the opening date of the halibut

[25] Source: Comment letter provided to the Council by Bering Sea Fisheries Research Foundation, Alaska Bering Sea Crabbers, and Natural Resource Consultants, Inc. January 28, 2022.

season is taken into account when determining the opening date for sablefish. The stated purpose is to reduce bycatch and regulatory discards in the two fisheries (50 CFR 679.23(g)(1)).

This strategy may prove more challenging when dealing with RKC as there are additional layers of regulation involved. All BS rationalized crab fisheries have the same opening date (October 15) but have different regulatory closure dates set by the State for biological reasons. The crab fleet has previously asked the Board of Fish for the ability to retain multiple species of crab on the same trip citing less mortality of species they have IFQ/CDQ for, but little action has occurred mainly due to issues with processing capabilities, State catch accounting, and gear specifications for each crab fishery. That said, there are currently incidental catch allowances of Western Bering Sea Tanner crab, Bering Sea snow crab and Eastern Bering Sea Tanner crab in some other directed crab fisheries. When keeping incidental amounts of Tanner and snow crab in other directed crab fisheries, the vessel operator must have available IFQ/CDQ and the directed fishery for those incidental species must be open. There is currently no BBRKC retention allowed in other directed crab fisheries, likely due to the fact that legal sized RKC are not able to enter snow crab or Tanner crab pot gear because of RKC excluder devices. In addition, BBRKC directed fishery closes by State regulation on January 15 while Tanner and snow crab remain open. Any changes to the incidental catch allowances of crab in directed crab fisheries would need to be made by the Alaska Board of Fisheries. There is currently nothing in federal regulation to prohibit the retention of incidental crab species while directed crab fishing as long as there is available IFQ or CDQ.

An additional possibility that the Council may wish to consider is the retention of BBRKC while pot fishing for Pacific cod. That approach would face many regulatory challenges but might ultimately reduce discard mortality rates.

6 Contributors and Persons Consulted

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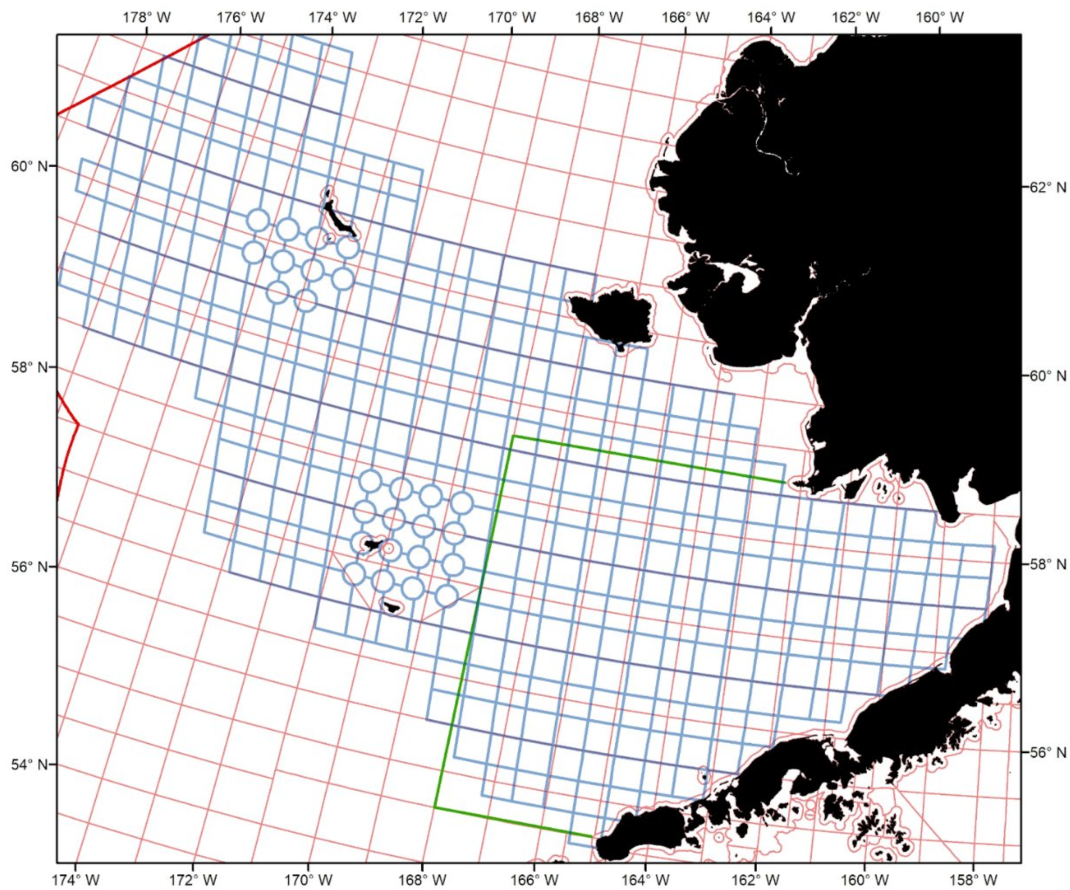
Appendix 1: Overlay of EBS trawl survey grid, ADFG statistical areas, and ADFG Registration Area T (BBRKC)

Figure shows EBS trawl survey stations in blue, ADFG statistical areas in red, and ADFG Registration Area T in green.



Source: B. Daly, personal communication. March 2022.

Appendix 2: Month-by-month mapping of estimated swept area for pelagic trawl gear (attached separately)