The evaluation of adverse impacts from fishing on crab essential fish habitat

NMFS and NPFMC staff discussion paper, January 2012

1 Introduction

In April 2010, the Council reviewed the summary report of the 5-year review of essential fish habitat (EFH) provisions. The report addresses new habitat information available since the last comprehensive review of EFH, documented in the 2005 EFH Environmental Impact Statement (EIS), and how it pertains to the EFH provisions of the Council's fishery management plans.

During the Crab Plan Team's review of EFH information pertaining to crab species, the Plan Team recommended that further analysis should be undertaken to evaluate fishing effects on crab stocks, and determine whether the conclusions reported in the FMP (and synthesized from the 2005 EFH EIS) are valid. Distribution of crab stocks, particularly red king crab, has changed since the analysis in the 2005 EFH EIS. Additionally, the Plan Team was concerned that the methodology used in the 2005 effects of fishing analysis may not adequately capture actual impacts of fishing on crab populations. Other parameters may need to be considered for crab stocks, such as the importance of spawning and larval distribution relative to oceanographic currents (pelagic habitat) for crab settlement. The conclusions in the 2005 EFH EIS may imply that more is known about the effects of fishing on the habitat needs and life history stages of crab (especially growth to maturity) than can be substantiated, based on research-to-date. Also, the Plan Team identified that recent shifts in the red king crab population distribution may mean that the spawning population is now present in an area in southwestern Bristol Bay that is also a location of intensive trawl fishing. Therefore the Crab Plan Team recommended further evaluation of the effects of fishing be undertaken.

Consequently, the Council asked staff to prepare a discussion paper to further examine the Crab Plan Team's recommendation to re-evaluate the effects of fishing on crab stocks. This discussion paper aims to provide clarification on the issues raised by the Plan Team with respect to the methodology that was used in the 2005 evaluation of fishing effects, and whether the appropriate parameters for crab stocks are included in that analysis (such as the importance of spawning and larval distribution relative to oceanographic currents for crab settlement). The paper focuses specifically on red king crab, as a case study, although a similar methodology is used for all crab species. The paper also looks at the importance of southwestern Bristol Bay for red king crab populations, and whether and how trawl fisheries in that area may be impacting the crab habitat. The paper evaluates existing crab protection areas in light of new information about shifting populations, and identifies some possible avenues for future Council action.

This discussion paper was originally presented to the Council in April 2011. At that meeting, the Council also received a presentation with more specific information about the area in southwestern Bristol Bay, southwest of Amak Island, the oceanographic currents that may mean that eggs released in this area have greater chance of survival through larval and juvenile life history stages, and the influence of the Bering Sea cold pool which affects when and where larvae from ovigerous females are more likely to be hatching in this area. As a result, the Council requested that the paper be revised to include the additional information on the importance of environmental variables and fishery removals on red king crab distribution in the Amak area, and the cumulative effects on red king crab habitat from other non-fishing sources and climate change. The Council also requested that the paper look at the efficacy of existing red king crab protection areas, such as the Red King Crab Savings Area and the Nearshore Bristol Bay Trawl Closure.

The discussion paper has been revised to address these issues to the extent possible. Additional information describing the importance of southwestern Bristol Bay and the role of environmental variables is included in Section 5.3; the bycatch interactions of groundfish fisheries in this area are included in Sections 4.2 and 5.4; and a description of existing closures is included in Section 5.5. A comprehensive analysis of the efficacy of these closures has not yet been undertaken, however, as staff with the necessary crab stock assessment experience have not yet been available for such an evaluation.

The final section, Section 7, describes some options for Council action on this issue. This discussion is a response to concerns raised by the Crab Plan Team during the EFH 5-year review in 2010. There are two issues that were raised: the general conclusions about the effects of fishing on crab EFH that were reached during the 2005 EFH EIS, and specific concerns about a habitat area important for red king crab. Regarding the first issue, the Crab Plan Team's initial concern was that the analysis concluded that some fishing effects on crab stocks were known, with which they disagreed. The Council should decide whether it is appropriate to initiate a re-evaluation of the effects of fishing on crab EFH as an outcome of the 2010 EFH 5-year review, or whether further research is needed to investigate these issues, which might be developed in preparation for the 2015 EFH 5 year review. Of note, the Crab Plan Team has not had an opportunity to discuss EFH since May 2010.

With regard to the second issue, habitat protection for red king crab, the discussion paper investigates the importance of larvae from ovigerous red king crab females hatching in southwestern Bristol Bay for boosting larval and juvenile survival. A habitat-based hypothesis is presented, but has yet to be empirically verified. The Crab Plan Team has expressed concern about groundfish fishery interactions with crab in this area both from habitat and bycatch considerations. Given this, the paper suggests several avenues that are available to the Council for possible action.

2 Current EFH description for red king crab

EFH descriptions are defined for by life history stage for managed species. The following information is available for defining EFH for red king crab:

BSAI Crab Species	Egg	Larvae	Early Juvenile	Late Juvenile	Adult
Red king crab	Inferred (from adult) – level 1	n/a	n/a	1	1

Level 1 means that distribution data are available for some or all portions of the geographic range of the species. At this level, only distribution data are available to describe the geographic range of a species (or life stage). Distribution data may be derived from systematic presence/absence sampling and/or may include information on species and life stages collected opportunistically. In the event that distribution data are available only for portions of the geographic area occupied by a particular life stage of a species, habitat use can be inferred on the basis of distributions among habitats where the species has been found and on information about its habitat requirements and behavior. Habitat use may also be inferred, if appropriate, based on information on a similar species or another life stage.

Methodology for existing EFH descriptions for crab stocks

EFH is described as 95 percent of the population where the species' life stage has been recruited to the survey, investigated through research, officially observed, or reported in a vessel catch log.
In addition to scientific information sources the description is based upon two significant fishery geographic information data resources: survey (Resource Assessment and Conservation Engineering Division [RACE]) and observer (NORPAC). For eggs and larvae, the EFH description was based on presence/absence data from surveys (AFSC RACE Matarese 2003). Under this methodology, for crab species, no EFH description was possible for these life history stages. An EFH description for eggs was inferred from the EFH description for egg-bearing female crab.

For adult and late juvenile life stages, each data set was analyzed for 95 percent of the total accumulated population for the species using GIS. EFH shape files were developed based on these data sets.
Fishery catch per unit of effort (CPUE) data from the NMFS observer database (NORPAC, 1990 to 2001), NMFS trawl survey data from RACE, 1987 to 2002, and, where appropriate, ADF&G survey data were analyzed to estimate the population distribution of each species. Where this information exists, the area described by these data is identified as EFH. The analyzed EFH data and area were further reviewed by scientific stock assessment authors for accuracy. Stock expert review ensures any outlying habitat areas not captured by the CPUE data are included and errors in the data or described EFH area.

Red king crab EFH description

The following is the EFH text description for red king crab, by life history stage:

Eggs
Essential fish habitat of the red king crab eggs is inferred from the general distribution of egg-bearing female crab. (See also Adults.)

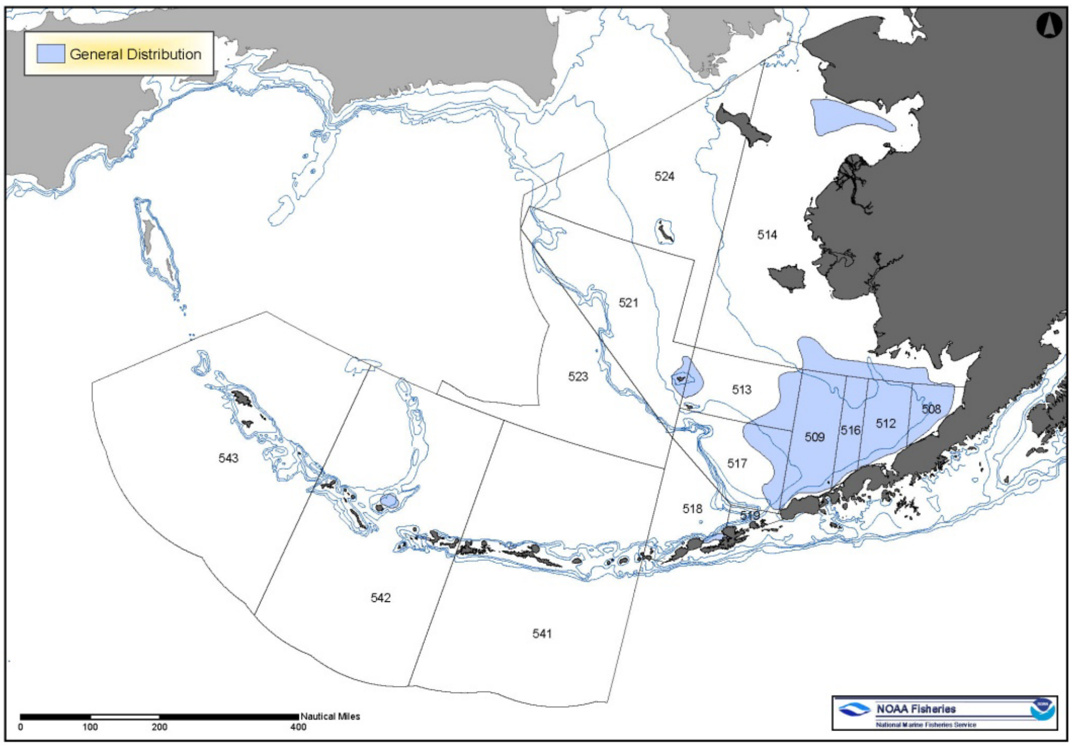
Larvae - No EFH Description Determined
Insufficient information is available.

Early Juveniles - No EFH Description Determined
Insufficient information is available.

Late Juveniles
EFH for late juvenile red king crab is the general distribution area for this life stage, located in bottom habitats along the inner (0 to 50 m), middle (50 to 100 m), and outer shelf (100 to 200 m) throughout the BSAI wherever there are substrates consisting of rock, cobble, and gravel and biogenic structures such as boltenia, bryozoans, ascidians, and shell hash, as depicted in Figure 1.

Adults
EFH for adult red king crab is the general distribution area for this life stage, located in bottom habitats along the nearshore (spawning aggregations) and the inner (0 to 50 m), middle (50 to 100 m), and outer shelf (100 to 200 m) throughout the BSAI wherever there are substrates consisting of sand, mud, cobble, and gravel, as depicted in Figure 1.

Figure 1 EFH Distribution map for BSAI red king crab, late juveniles/adults



3 Habitat needs for crab stocks

Crab species in the eastern Bering Sea have similar life history events. Females brood their embryos, which are released into the water column as larvae. The early life cycle of the king crab is illustrated in Figure 2. Mature red king crab females migrate into relatively shallow waters (< 50 m) in nearshore areas where they aggregate and release larvae, molt, mate, and extrude eggs (Armstrong et al., 1987; Stone et al., 1992; Stone et al., 1993, Loher and Armstrong 2005). Egg extrusion and larval hatching are relatively synchronous in red king crab and occurs every year (unlike blue king crab; Somerton and MacIntosh 1985). Adults have a much lower predation risk, so the ability of habitat to provide a predation refuge becomes less important as crab mature. However, because the crab are densely aggregated in these habitats and because of their soft shell condition, they are vulnerable at this critical period in their life history. Since the larvae from these females spend an extended period in the plankton (Figure 3) and are transported far from the release site, there may be particular areas, such as the western end of the Alaska Peninsula, that are disproportionately important, as larvae released there are more likely to end up in prime settling areas than are larvae released elsewhere, based on prevailing currents (Dew and McConnaughey, 2005). The spatial distribution of mature females prior to larval release and locations of crab larvae settlement may also be important for positive recruitment (Zheng and Kruse 2006). The benthic environment or habitat occupied by molting and mating crab differs from that occupied by mature crabs during the remainder of the year when they move offshore to soft substrates (Rodin 1989).

Figure 2 Early king crab life cycle

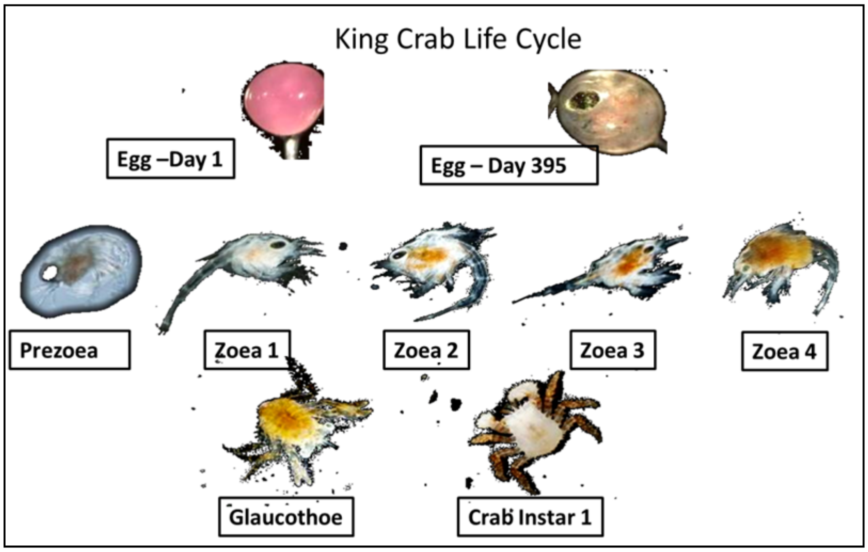
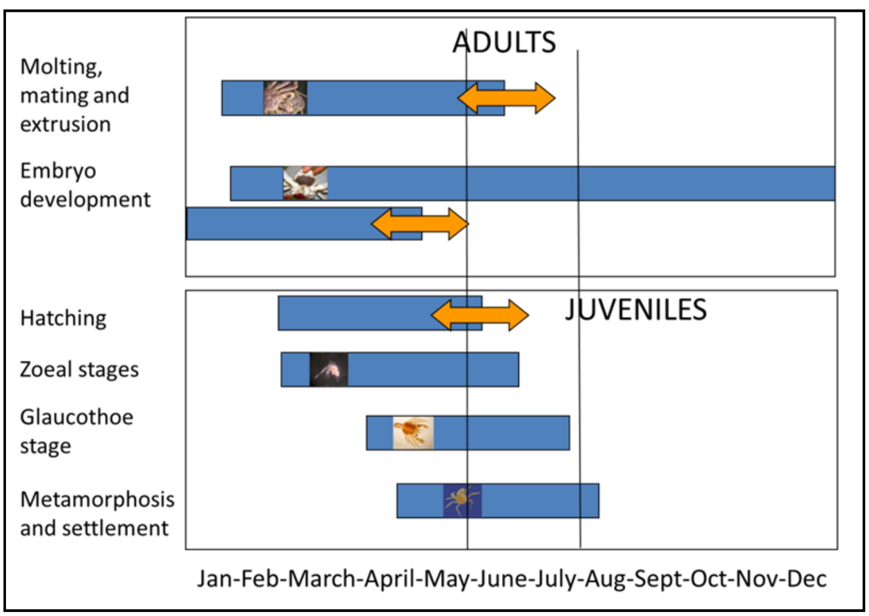


Figure 3 Timing of red king crab life history



Larval stage survival is likely dependent on environmental conditions and is tied to successful settlement. Crab larvae spend several months feeding in the pelagic habitat, except for golden king crab larvae which are likely benthic and do not feed. The habitat for larvae of all the crab species, except golden king crabs

(Shirley and Zhou 1997), is the pelagic zone, generally close to the surface. Larval stages are distributed according to vertical swimming abilities, the oceanographic currents, and mixing or stratification of the water column. Larvae, like many other zooplanktonic species, exhibit a diel vertical migration, probably to minimize predation risk during the day and maximize feeding at night (Armstrong et al., 1987; McMurray et al., 1984). The habitat is primarily defined by the physical characteristics of the water column, such as temperature and salinity, and each species has a tolerance range for these parameters (e.g., Shirley and Shirley, 1989). Temperature, salinity, vertical mixing, and upwelling can also influence food availability for the larvae, which can influence recruitment (Rosenkranz et al., 1998; Rosenkranz et al., 2001; Zheng and Kruse, 2000). Finally, current structure is very important in transporting larvae to suitable settling habitat or retaining larvae within a region (Rosenkranz et al. 1998, Rosenkranz et al. 2001). Larvae molt two to three times before metamorphosizing into a settling stage (glaucothoe for king crabs, and megalops for the *Chionoecetes* spp.).

Defining the environmental conditions important for larval survival is difficult, while settlement habitat requirements are better understood. The settling stage seeks and settles in suitable benthic habitat where they molt into the first crab stage. Young of the year red king crab require nearshore shallow habitat with significant cover that offers protection (e.g., sea stars, anemones, macroalgae, shell hash, cobble, and shale).

Juvenile populations are most likely limited by predation; thus, their habitat requirements are defined by their anti-predator strategy. Juvenile red king crab have been shown to prefer nearshore habitats of high complexity (Loher and Armstrong 2000). Red king crab juveniles are associated with both biogenic structure, such as sea stars, bryozoans, or tube worms for feeding and refuge (Dew, 1990; McMurray et al., 1984; Sundberg and Clausen, 1977), and non-biogenic structure, such as cobble or shell hash (Loher and Armstrong, 2000). However, many of these studies occur offshore while the age-0 juvenile crab, most likely representative of larval dispersion, are located in shallow areas closer to shore than most surveys.

4 Evaluation of the effects of fishing in the 2005 EFH EIS

The EFH EIS draws conclusions about the effects of fishing on crab habitat essential for four requirements (spawning, rearing, feeding, and growth to maturity). The following subsections provide information directly from Appendix B of the 2005 EFH EIS that pertains to red king crab.

4.1 Red king crab habitat linkages

Habitat effects on crab concern effects on prey and on living and non-living structures on and in the ocean bottom. Effects on the population due to bycatch in trawl fisheries are not included as a habitat effect. Direct effects due to bycatch mortality in trawl fisheries on crab populations were addressed in the PSEIS (NMFS 2004). The focus of the EFH EIS is on the linkages to fishing-induced impacts on habitat and their subsequent effects on spawning/breeding, growth to maturity, or adult feeding of red king crab.

Spawning/Breeding

Spawning and breeding success of crab species depends upon high egg-fertilization rate, successful transport of pelagic larvae to nursery areas, good environmental conditions, and survival to the adult stage. Egg fertilization success depends upon the size and number of mature male crabs (and hence the amount of sperm) available. The eggs are attached to the underside of females and carried for nearly a year before hatching. Transport of larvae depends upon environmental conditions, and survival depends upon the quantity and quality of nursery habitat and the presence of predators.

Settlement and nursery areas are important components of spawning success for crab species. In the southeastern BS, females remain in relatively shallow nearshore waters most of the year, whereas males move offshore into deeper water during the summer and fall, then return to shallower water for breeding in the winter and early spring (Loher 2001). The location of females hatching eggs and prevailing currents determine the general area where larvae settle. Settling larvae have moderate swimming capability and have some ability to choose the micro-habitat where they settle (Loher 2000). Suitable substrates for survival of settling larvae appear to be largely rock or cobble bottoms, or mussel beds (Stevens and Kittaka 1998).

Adult Feeding

From settling larvae to senescence, crabs dwell on the bottom and depend on benthic feeding. Red king crabs are omnivorous. Bivalves, barnacles, polychaetes, snails, Tanner crab, echinoids, and hydroids have been found in stomachs of red king crab from shallow waters near Kodiak during May and June (Feder and Jewett 1981). Juvenile red king crab near Kodiak have been observed to eat sea stars, kelp, sea lettuce, red king crab molt exuvia, lettleneck clams, mussels, nudibranch egg masses, and barnacles (Dew 1990).

Growth to Maturity

Early stage red king crabs seek out biological cover in which to hide. Survival at this stage depends upon availability of cover. After they reach a size exceeding 25-millimeter (mm) carapace length, red king crabs form pods, which consist of similar sized crabs of both sexes, and may contain hundreds to thousands of crabs. Pods of juvenile crabs form during the daytime, but disperse at night for feeding. As crabs grow, they move to deeper water in Bristol Bay where the substrate is mostly sand, silt, and mud.

4.2 Analysis of fishing impacts on crab EFH from EFH EIS and the 2010 EFH 5-year review

This section provides a brief comparison of the distribution of fishing intensity of pelagic and nonpelagic trawl gear as originally presented in the 2005 EFH EIS, and reanalyzed for the 2010 EFH 5-year review. Although overall fishing effort decreased over the more recent period, the Crab Plan Team noted that one discrete area of increase in nonpelagic trawl effort coincides with an area believed to be particularly important for recruitment success of the red king crab stock. This concern was an impetus for the current discussion paper.

In the 2005 EFH EIS, analysis of the effects of fishing on EFH applied a numerical model that provided spatial distributions of an index of the effects of fishing on several classes of habitat features, such as infauna prey and shelter created by living organisms. The specific index (Fujioka 2006), termed the Long-term Effect Index (LEI), estimated the eventual proportional reduction of habitat features from a theoretical unaffected habitat state, should the recent pattern of fishing intensities be continued indefinitely. Distributions of LEIs for each class of habitat feature were provided to experts on each managed species, to use in their assessment of whether such effects were likely to impact life history processes in a way that indicated an adverse change to EFH. Experts were asked to assess connections between the life history functions of their species at different life stages and the classes of habitat features used in the effects-of-fishing model. Then, considering the distribution of LEIs for each of those features, they were asked whether such effects raised concerns for their species. Experts also considered the history of the status of species stocks in their assessments.

In the 2010 EFH 5-year review (NPFMC and NMFS 2010), new information about the inputs to the model was evaluated, in particular the distribution of fishing intensity for trawl gear. The review provided a retrospective look both at changes before the 5-year period originally analyzed in the 2005 EFH EIS (1998-2002), as well as a look at shifts in intensity in subsequent years. This analysis, for nonpelagic trawl gear, is summarized below. The first set of maps shows *average annual intensity* for each period, fishery, and region. “Intensity”, for the purposes of this analysis, is defined as the proportion of the area swept by fishing effort assigned to a block relative to the total area of that block. For example, an intensity of 1.0 represents enough fishing effort to fully cover the block once, if it was spread evenly across the block. The data are presented for three five-year periods: 1993-1997 (Figure 4), 1998-2002 (which was evaluated in the original 2005 EFH EIS; Figure 5), and 2003-2007 (Figure 6). The mapping of changes in fishing intensity presented in this section is based on NORPAC observer data aggregated to 100km^2 blocks.

Figure 4 Bering Sea non-pelagic trawl average fishing annual intensity over the five-year period 1993 to 1997.

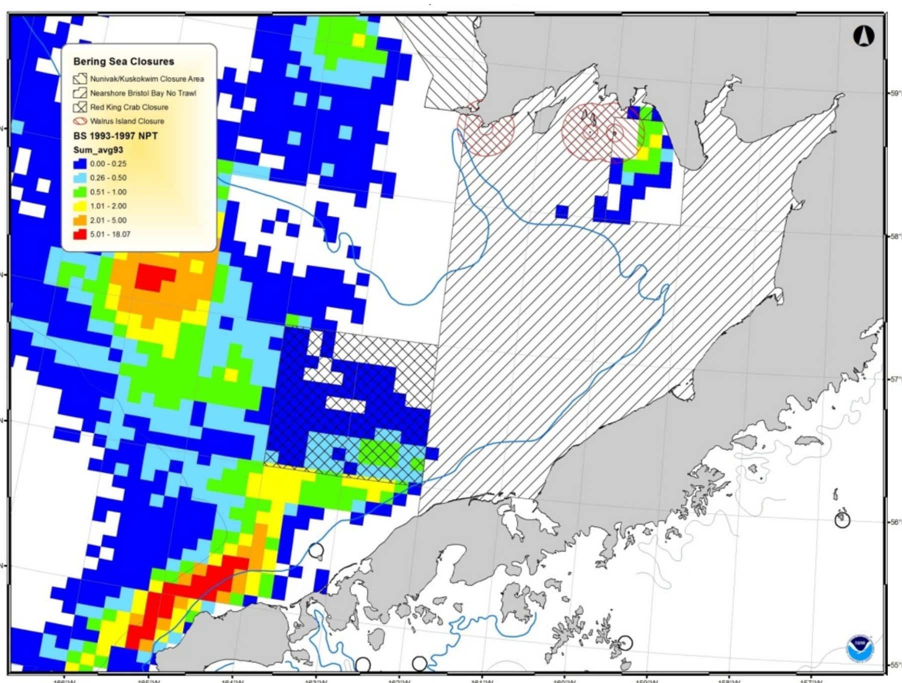


Figure 5 Bering Sea non-pelagic trawl average fishing annual intensity over the five-year period 1998 to 2002 (evaluated in the EFH EIS).

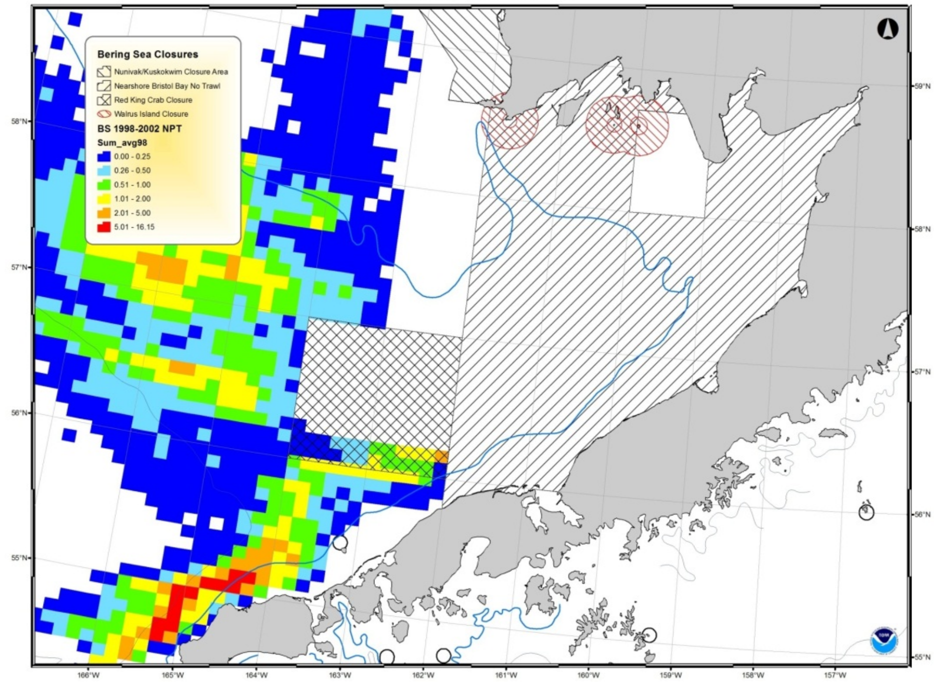
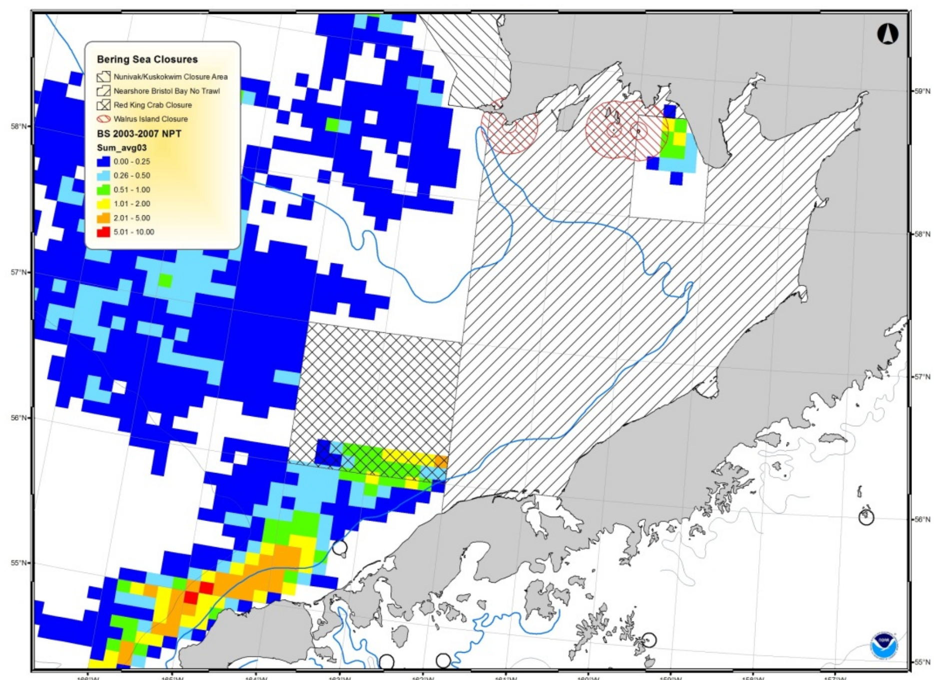


Figure 6 Bering Sea non-pelagic trawl average fishing annual intensity over the five-year period 2003 to 2007.



A second set of maps compares *change in intensity* between two five-year periods (1993-1997 versus 1998-2002 (Figure 7) and 1998-2002 vs 2003-2007 (Figure 8)). Positive values reflect increases in trawl intensity; while negative values reflect decreases in trawl intensity. The figures illustrate where fishing intensity changed moderately (intensity differences of 0.25 - 1) and strongly (>1). Together, the two sets of maps can be used to identify which areas may experience continuing high levels of effort (high intensity) every year, as these areas will not appear on the second set of maps due to a small change in effort between periods. Conversely, other areas may not appear to have high total intensity, but may show a larger marginal increase or decrease in effort, which will be apparent in the second set of maps. Supplemented with material from the EFH EIS, these maps are intended to provide an assessment whether the direction of shifts in fishing efforts is likely to be favorable or unfavorable to a particular species.

Figure 7 **Difference in Bering Sea non-pelagic trawl intensity between the five-year period analyzed in the EFH EIS (1998 to 2002) and the previous period (1993 to 1997).**

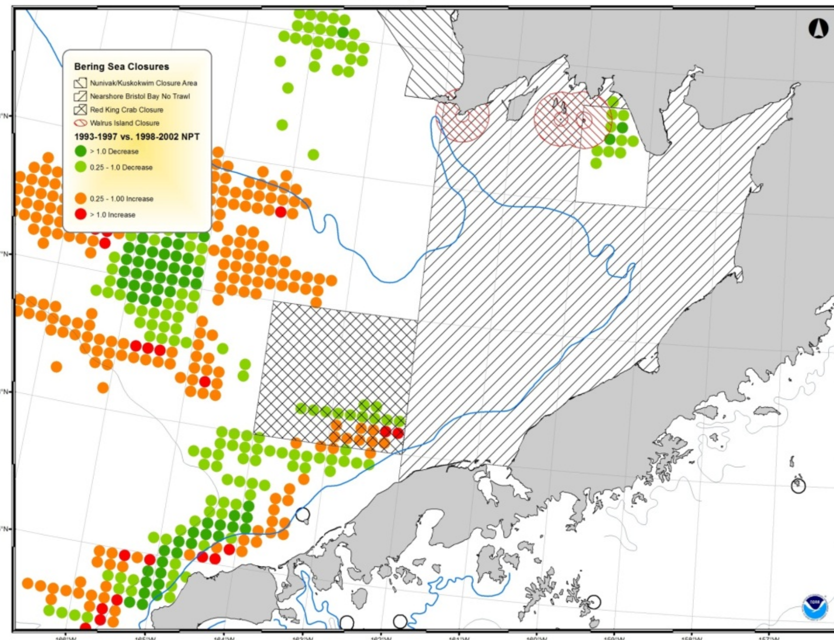
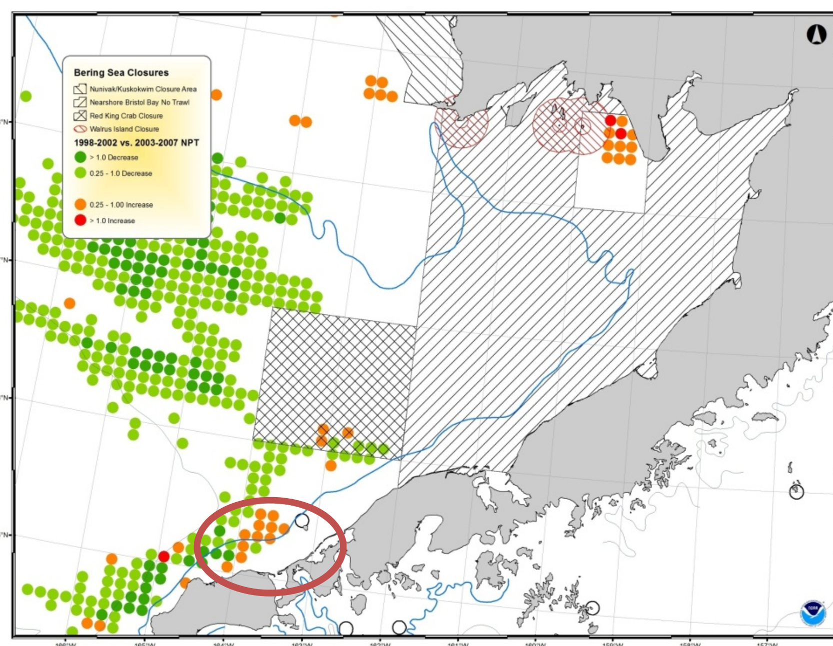


Figure 8 **Difference in Bering Sea non-pelagic trawl intensity between the five-year period analyzed in the EFH EIS (1998 to 2002) and the more recent period (2003 to 2007). The area circled, southwest of Amak Island, represent the potential area of concern discussed in this paper.**



The principal shifts in fishing intensity are summarized as follows:

> **1993-1997 vs. 1998-2002** (Figure 7): In 1998-2002, the central Bering Sea showed a pattern of higher intensity in non-pelagic trawling around a central area of lower intensity near the border of management areas 509 and 513. Decreases in fishing intensity occurred on the west side of the Nushagak Peninsula, off of Kuskoquim Bay, northeast of St George Island, and Pervenets Canyon to the far northwest. Intensity dropped in the area north of Akutan Island, Unimak Pass and Unimak Island, while there were increases on the southwest and eastern sides of that area.

> **1998-2002 vs. 2003-2007** (Figure 8): There has been no radical shift in the distribution of fishing intensity in the Bering Sea. The large area of the central Bering Sea that was subject to particularly high bottom trawl intensity in 1998 - 2002 received moderately lighter intensity from 2003 - 2007. Four principal areas were subject to increased bottom trawl intensity; 1) along the northwest border of the Pribilof Islands Habitat Conservation Zone, 2) off of Kuskoquim Bay, 3) along the southern border of the King Crab Protection Zone and 4). Most of the increases were moderate, though 2 of 8 blocks in the 4th area along the western side of the Nushagak Peninsula (inner Bristol Bay) had strong increases. The area of high intensity effort north of Akutan Island, Unimak Pass and Unimak Island remained a high intensity area. Many of the shifts within that area registered as moderate or strong changes because of the high absolute levels of fishing intensity.

The area that raised concern among the Crab Plan Team is indicated on Figure 8 with a circle. There were moderate increases in fishing intensity in the nearshore area southwest of Amak Island, north of the Alaska Peninsula. This is an area that is of concern for red king crab, as discussed in Section 5.3.

4.3 Conclusions about fishing impacts on crab EFH, and Crab Plan Team concerns

During the 2010 EFH 5-year review, the Crab Plan Team noted that the conclusions in the 2005 EFH EIS imply that more is known about the effects of fishing on the habitat needs and life history stages of crab (especially growth to maturity) than can be substantiated, based on research-to-date. The Plan Team's initial reaction was to change all "Minimal, temporary, or no effect" conclusions to "Unknown effect", however after deliberation, it was determined that this issue should instead be highlighted for the Council, so that a more deliberative analysis could be considered. The Plan Team was also concerned that the methodology for the 2005 EFH EIS focuses on benthic habitat only, while other parameters may need to be considered for crab stocks, such as the importance of spawning and larval distribution relative to oceanographic currents (pelagic habitat) for crab settlement. Although this concern is applicable to the assessment of all crab stocks, a particular example for red king crab was highlighted and is discussed later in this discussion paper (Section 5).

As an illustration, the FMP's conclusion about the effects of fishing on red king crab EFH, which resulted from in the 2005 EFH EIS analysis, is as follows:

Spawning/breeding	MT (Minimal, temporary, or no effect)
Feeding	U (Unknown effect)
Growth to maturity	MT (Minimal, temporary, or no effect)

Habitat Impacts Relative to Spawning/Breeding

There is only a small area of overlap between current female red king crab distribution and areas where trawling occurs. This overlap would only occur in the areas between about 162 and 163º W, where fishing effects are generally low. Male and female red king crabs migrate to nearshore waters generally less than 50 m deep to hatch their eggs and mate. North of Unimak Island, some of the high fishing effects area extends into waters less than 50 m deep; however, to the east, trawling generally occurs more than 50 m deep. The mating areas would experience little impact; however, trawling in deeper waters somewhat overlaps the migration route to mating areas.

Habitat Impacts Relative to Feeding

Changes in growth for Bristol Bay red king crab are unknown. Most of the distribution of red king crab is to the north and east of the high fishing effects areas.

Habitat Impacts Relative to Growth to Maturity

There are essentially no fishing effects in areas important to juvenile red king crab. All known juvenile rearing areas are currently protected by trawl closure areas. Growth per molt for BS red king crab showed no change between the late 1950s and the 1990s based on tag data (Council 2004). Molting probability during different time periods has been estimated in a stock assessment model; however, parameters are confounded by change with natural mortality, and it is difficult to assess the age of crab. Molting probability was estimated as higher in the 1950s and lower in the 1960s from tag data (Balsiger 1974). Model estimates of molting probability were higher in the 1970s than those from the 1960s tag data and have been lower since then (Council 2004).

4.4 Developing a better methodology for evaluating adverse impacts of fishing on crab EFH

To build upon previous analyses that assessed the available data on particular life history stages, future analyses should include modeling tools to extend the empirical data to probabilistic determinations of impacts on crab populations. The 2010, a CIE review of the Bristol Bay red king crab stock assessment model determined that a more descriptive understanding of the key temporal and spatial biological processes is necessary. Life history characteristics should include primiparous and multiparous mating locations and timing, hatching, larval period and movement, settlement period and location, growth at each stage, molt frequency and timing, time and size at maturity, and adult migration patterns. More specific understanding of these stages would promote a better understanding of habitat requirements and potential impacts of fishing on each stage. Such a conceptual model would help to interpret survey and model results as well as assess key bottlenecks in the life history to identify habitat fishery removal specific concerns.

An additional analysis to evaluate the adverse impacts of fishing would be to build upon the conceptual model approach to quantify potential losses as a result of management actions. This could occur in concert with a Management Strategy Evaluation with the existing stock assessment model or more directly applied to a specific life history parameter. To assess the impacts of fishing on adult female red king crab in southwestern Bristol Bay, a retrospective assessment of potential losses to reproductive fitness may lend insight into the relative importance of protecting habitat important for larval drift and subsequent recruitment into the important Bristol Bay habitat.

Lastly, and in concert with the above two approaches, a more detailed analysis of the importance of the physical environment on various stages of development is necessary to properly understand how temporally or spatially specific removals would impact a stocks. It is not, however, satisfactory to say that these influences are unknown and therefore the impacts are likely unimportant. Coupled bio-physical models to better understand the effects of temperature and currents on larval drift and the effects of changing the release site as a result of commercial removals would be an important step forward.

5 Distribution of the red king crab population and southwestern Bristol Bay

The Crab Plan Team identified a particular area in southwest Bristol Bay where the red king crab biomass is fluctuating, and where there has also been an increase in trawling activity in a recent 5-year period. This section evaluates the potential for adverse interactions of trawling on crab in this area, and whether any adverse interaction is likely to be from increased bycatch and mortality and/or adverse modification of habitat that is essential to increasing the red king crab population.

5.1 Changing distribution of red king crab throughout their range

The NMFS eastern Bering Sea bottom trawl survey collects data on the red king crab distribution in June each year (Chilton et al. 2011). This time period is in the middle of when red king crab molt and mate. In cold years the survey misses this event and in warm years collects crab just subsequent to this event (Chilton et al. 2010). Since the beginning of the survey, the abundance of adult female red king crab increased to a maximum 3,000 crab/nmi^2 in the late 1970s before declining rapidly in the early 1980s (Figure 10). Abundance remained at a lower mean except for recruitment events in 1988, 2000, and 2005. Female red king crab were located inside Bristol Bay during 1980-1987 and 1992-2006 (Zheng and Kruse 2006). From 1988-1991, the adult female distribution slightly shifted south but not near the maximum southern extent previously found in the 1970s. Loher and Armstrong (2005) hypothesized that a similar shift in inner Bristol Bay during the late 1970s and early 1980s was the result of increased bottom temperatures. In more recent years when the cold pool extended onto the Bristol Bay shelf area in 2006-2010, the summer distribution of ovigerous RKC had moved from the central area of Bristol Bay to the nearshore areas along the Alaska Peninsula (Zheng and Siddeek 2010, Chilton et al. 2010).

Changes in the seasonal variability and magnitude of bottom water temperatures impact the amount of benthic habitat available to crab species during critical life history stages. As an example, mature female snow crab distribution in the eastern Bering Sea shifted to the northwest EBS shelf concurrent with temperature decreases (Orensanz et al. 2004). To relate adult female abundance and potential influence of temperature on red king crab production, temperature was overlaid on the time series of CPUE (Figure 9). Peak mean CPUEs correspond with increases in warmer temperature suggesting a number of possible mechanisms. First, the survey may be missing adult crab during the colder year due to movement. Second, there may be a positive feedback in larval recruitment during cold years that produce large abundances of adult crab and an apparently negative feedback on larval survival in warm years. To look for corresponding differences in variability between temperature and adult abundance, the standard deviation of both were plotted with little evidence of a consistent relationship (Figure 11).

Figure 9 **Mean adult female red king crab CPUE across all stations in the Bristol Bay red king crab management area with dark bars representing warm years and light bars representing cold years from 1975 to 2010.**

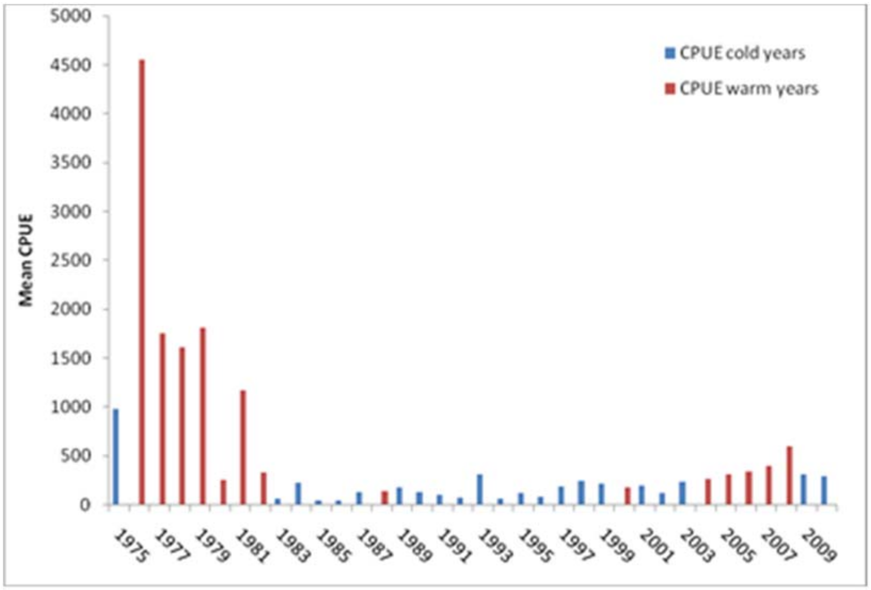
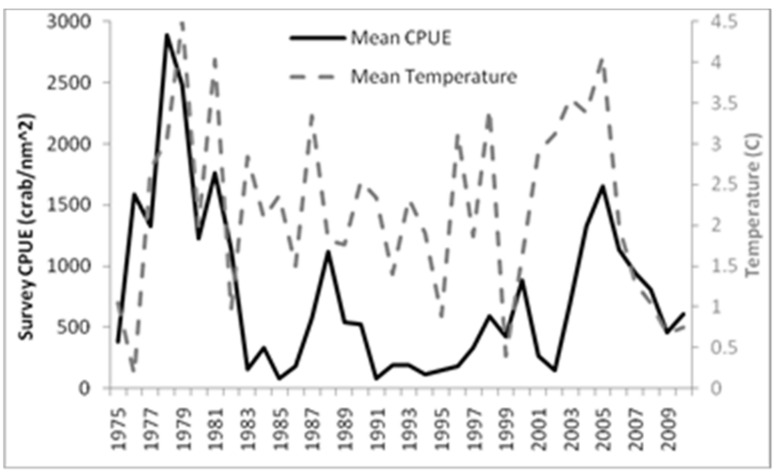


Figure 10 **Relationship of survey mean CPUE of adult female red king crab with mean temperature of all stations with positive red king crab abundance from 1975 to 2010.**



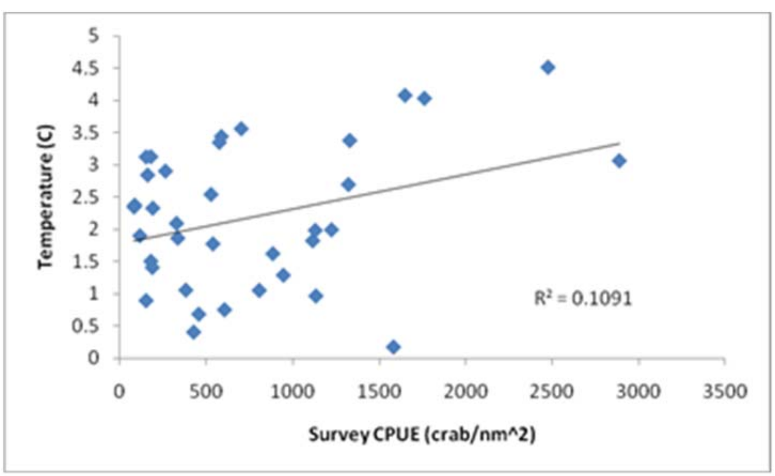
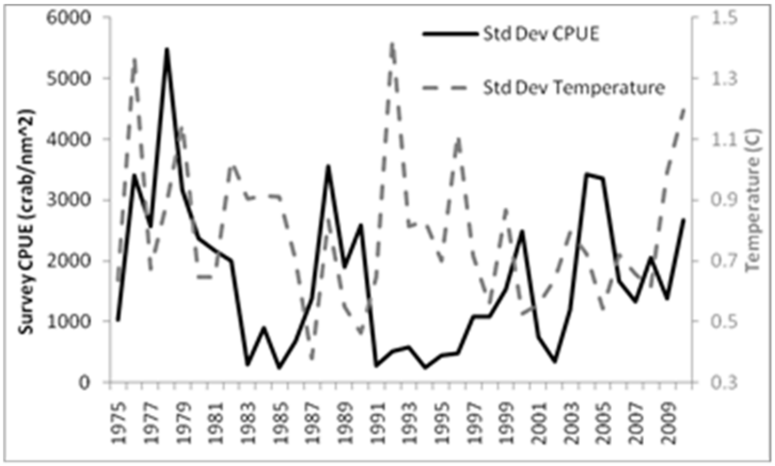
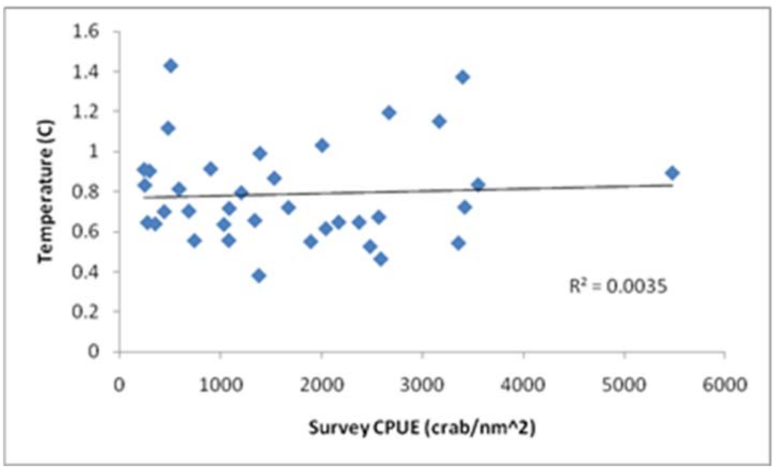


Figure 11 **Relationship of survey standard deviation of adult female red king crab CPUE with the standard deviation of temperature of all stations with positive red king crab abundance from 1975 to 2010.**





5.2 Role of environmental variables

Red king crab recruitment has been related to larger scale climate variability. As stated above, year class strength has been negatively correlated with temperature but weak relationships suggest that temperature alone does not account for all the variability in year class strength (Zheng and Kruse 2000). Additional environmental variables, such as the intensity of the Aleutian Low atmospheric pressure system, are positively correlated with year class strength (Tyler and Kruse 1996; Zheng and Kruse 2000). Variables affecting larval survival and dispersal are likely important for red king crab. As an example, in eastern Bering Sea Tanner crabs, warm seawater temperatures during gonadal development and embryo incubation coupled with northeast winds during the larval stages promote larval survival (Rosenkranz et al. 2001). Therefore, having an understanding of expected climatic variability is critical for forecasting crab behavior and identifying management efforts that may mitigate some of the effects. Predictions of climate forcing changes in the Bering Sea region include increases in air temperature, storm intensity, storm frequency, southerly wind, humidity, and precipitation (Barange and Perry 2009, Brander 2010, Hoegh-Guldberg and Bruno 2010). As a result, the Alaska Stream, Near Strait Inflow, Bering Slope Current, and Kamchatka Current are likely to affect changes in Unimak Pass inflow, the shelf coastal current, and the Bering Strait outflow. Figure 12 shows the currents important to red king crab larval dispersal in the western Bristol Bay region, and Figure 13 shows the variation in Bering Sea bottom temperatures from 2003-2011. These changes lead to uncertain impacts on red king crab larval habitat requirements; however, they highlight the importance of collecting baseline information to forecast impacts.

Figure 12 Current structure in the eastern Bering Sea shelf. Oceanographic mooring 2A (KC-2A) location depicted with a flag and the flow of the Alaska Coastal Current (ACC) from the Gulf of Alaska into the eastern Bering Sea is shown. (Adapted from Stabeno et al. 2001).

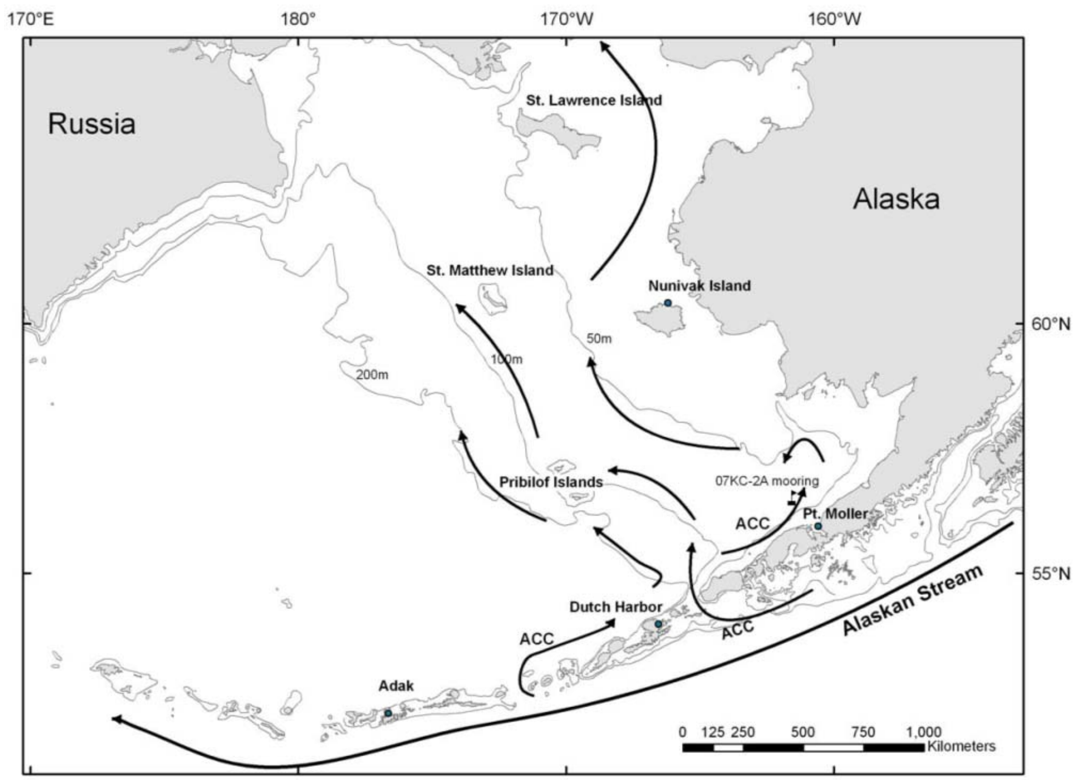
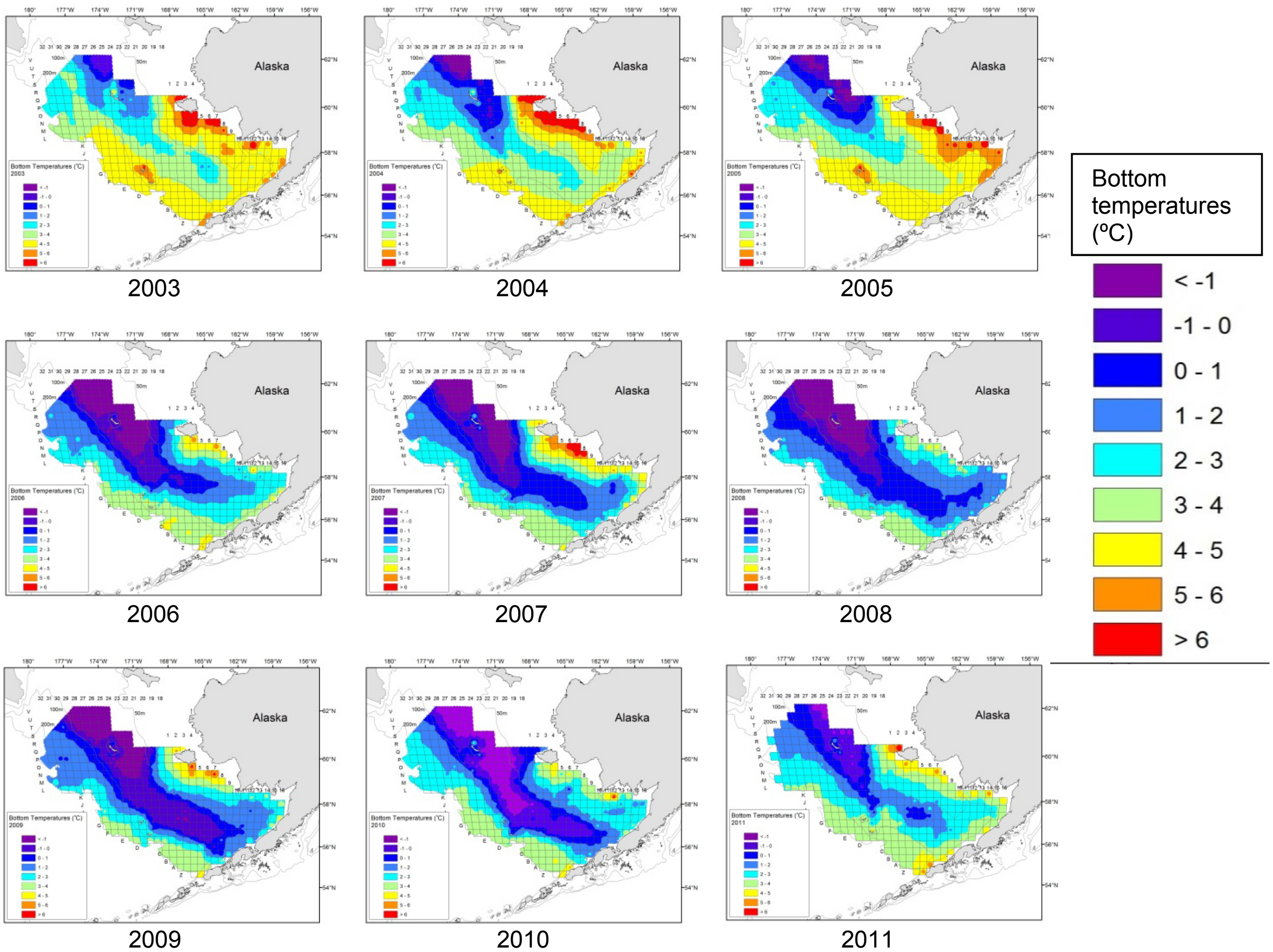


Figure 13 Bering Sea bottom temperatures, 2003 to 2011, from the NMFS Bering Sea bottom trawl survey.



5.3 Importance of southwestern Bristol Bay

The Bristol Bay red king stock assessment and the technical memo reporting on the results of the NMFS eastern Bering Sea bottom trawl survey described the increase of adult red king crab in the southwestern region of Bristol Bay. While the spatial distribution of red king crab fluctuates, a significant presence in this region has not been seen since the 1970s. Previous publications have commented on the likely importance of the region for larval release (Dew and McConnaughey 2005), however, mechanisms have not been developed further. In a recent publication regarding the effects of temperature in Bristol Bay on red king movement and molt-mate timing, the effects of the “cold pool” moving adult red king crab into the nearshore region and possibly laterally along the shore were discussed (Chilton et al. 2010). Figure 14 uses NMFS bottom trawl survey data to illustrate the temperature and distribution of crab in three years: 2001, a warm year; and 2009 and 2010, cold years. The figure illustrates that the crab are moving to stay out of the cold water. The survey occurs during the time that mature males and females are migrating in and out of the nearshore, to molt and mate, so the location of the cold water is affecting where they will go inshore, and pushing them to the southwest and north.

Data from the NMFS survey station B08, which is located just north of the Alaska Peninsula, southwest of Amak Island (Figure 18), substantiates the movement of crab southwest during the cold years. Figure 15 illustrates the mean temperature and the survey mean CPUE of adult female red king crab at survey station B08, from 1975 to 2010. The figure illustrates a clear relationship between temperature and crab abundance at this station, opposite from the general abundance trend for red king crab (Figure 10). This area in southwestern Bristol Bay serves as a refuge for crab, as they move away from the cold water.

Figure 14 Bering Sea cold pool extent, and distribution of red king crab in the Bering Sea bottom trawl survey.

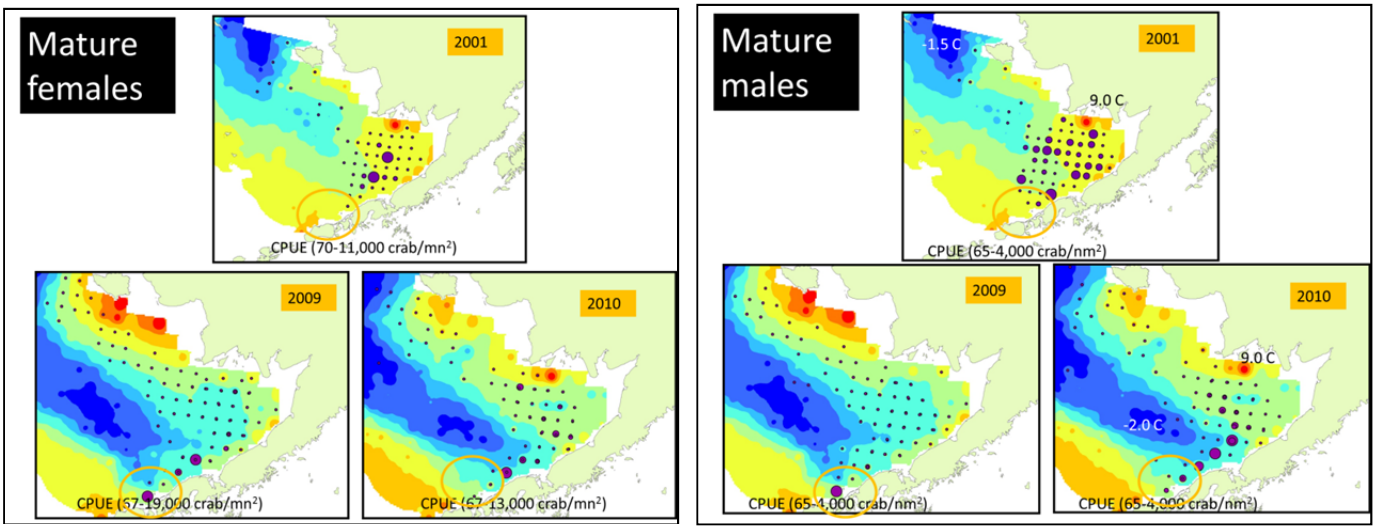
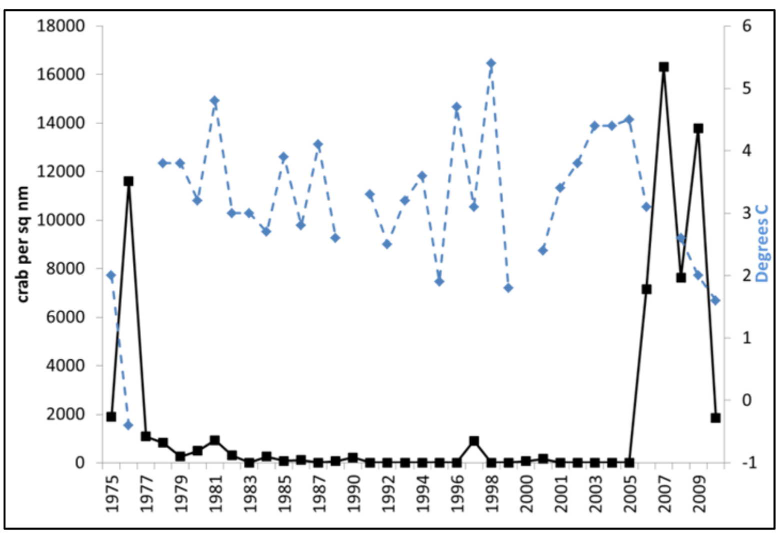


Figure 15 Relationship of survey mean CPUE of adult female red king crab with mean temperature at survey station B08, from 1975 to 2010.



The prevailing currents bifurcate in the area that has been identified, with one fork heading northwards and one fork heading into along the peninsula and into Bristol Bay. The larval stage of the crab is pelagic, and once they are extruded, the larvae drift with the current. Figure 16 confirms that as most of the crab larvae are in the surface water (0 to 5m), they would be likely to be advected into the Bay, rather than elsewhere to the north. The location where they are extruded along the peninsula, however, is likely to affect their ability to find appropriate habitat for settlement in the juvenile stage. Figure 17 illustrates a crude calculation of where settlement of the crab might occur, based on the initial location of extrusion. The nearshore current is estimated at 5 cm per second, and the average length of the pelagic stage is estimated at 45 days. Given these parameters, it is estimated that the larvae would travel 200 km before settling. In a cold year, if ovigerous crab are pushed into southwestern Bristol Bay, the crab larvae would have a high likelihood of settling in habitat that is favorable to juvenile survival, within Bristol Bay. In warm years, however, when the eggs are released further along the peninsula, the crab will be further north once they begin to settle, where the habitat may be less favorable to juvenile survival.

Figure 16 **Current patterns on the northern shore of the Alaska Peninsula, between 0 and 40 m depth.**

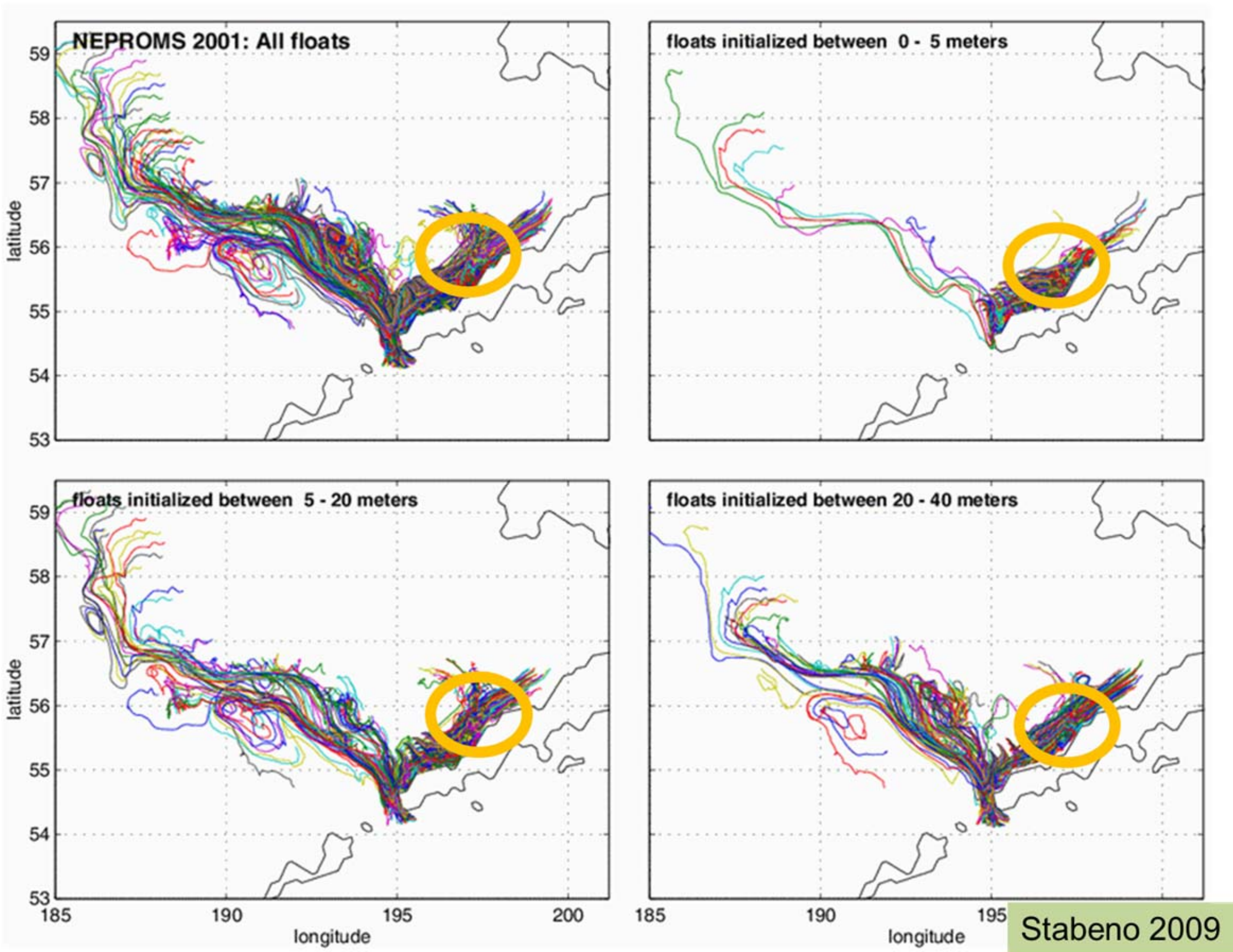
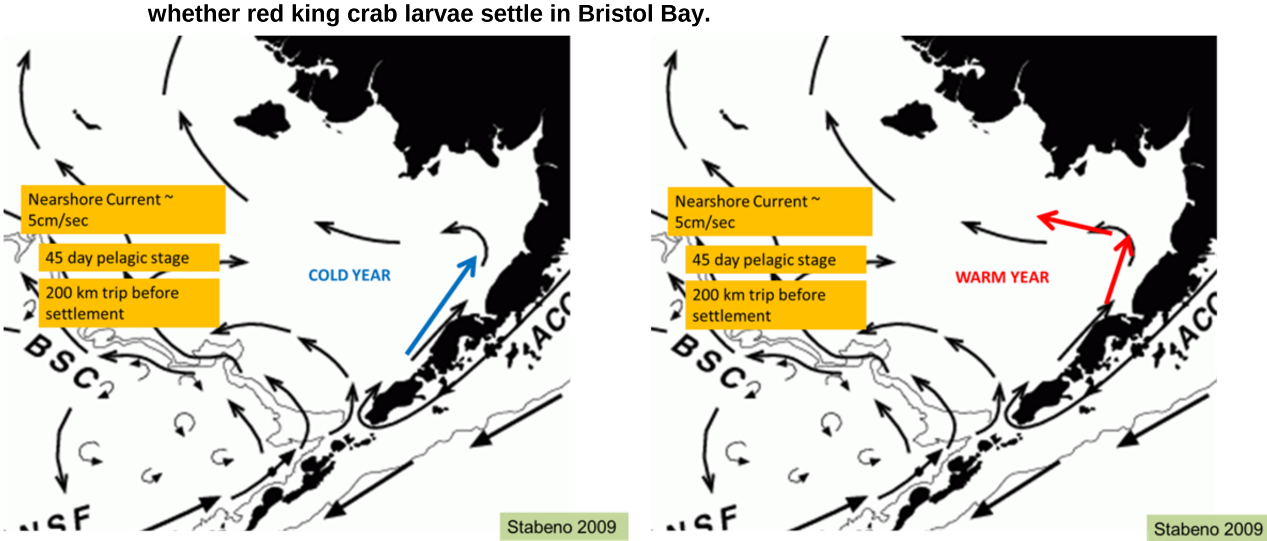


Figure 17 **Crude example of how the location of larval release and the prevailing currents might affect whether red king crab larvae settle in Bristol Bay.**



In 2011, an effort was undertaken by NMFS, in collaboration with the Bering Sea Fisheries Research Foundation (BSFRF), to survey red king crab further inshore, along the north of the Alaska Peninsula, to assess potential future recruits to the Bristol Bay red king crab stock. Figure 18 illustrates the 2011 nearshore study area. The shaded stations within the bolded study area are standard stations included in the NMFS trawl survey; nine additional stations were added inshore with the NMFS standard 83-112 trawl net, and a small mesh (nephrops) trawl net, operated by the BSFRF, made 93 successful tows within the area. 2011 was a warmer year in Bristol Bay, and warmer water was available all along the peninsula (Figure 19). Consistent with the theory, the surveys did not find any significant number of mature females in the general area, southwest of Amak Island, that is the subject of this discussion, neither in the standard survey stations nor in the additional nearshore stations (Figure 20). A follow-up survey is planned for 2012, which is predicted to be a cold year, and will provide an interesting counterpoint to these results.

Figure 18 NMFS trawl standard survey stations for the red king crab district (shaded), and the 2011 inshore red king crab study area (outlined in bold).

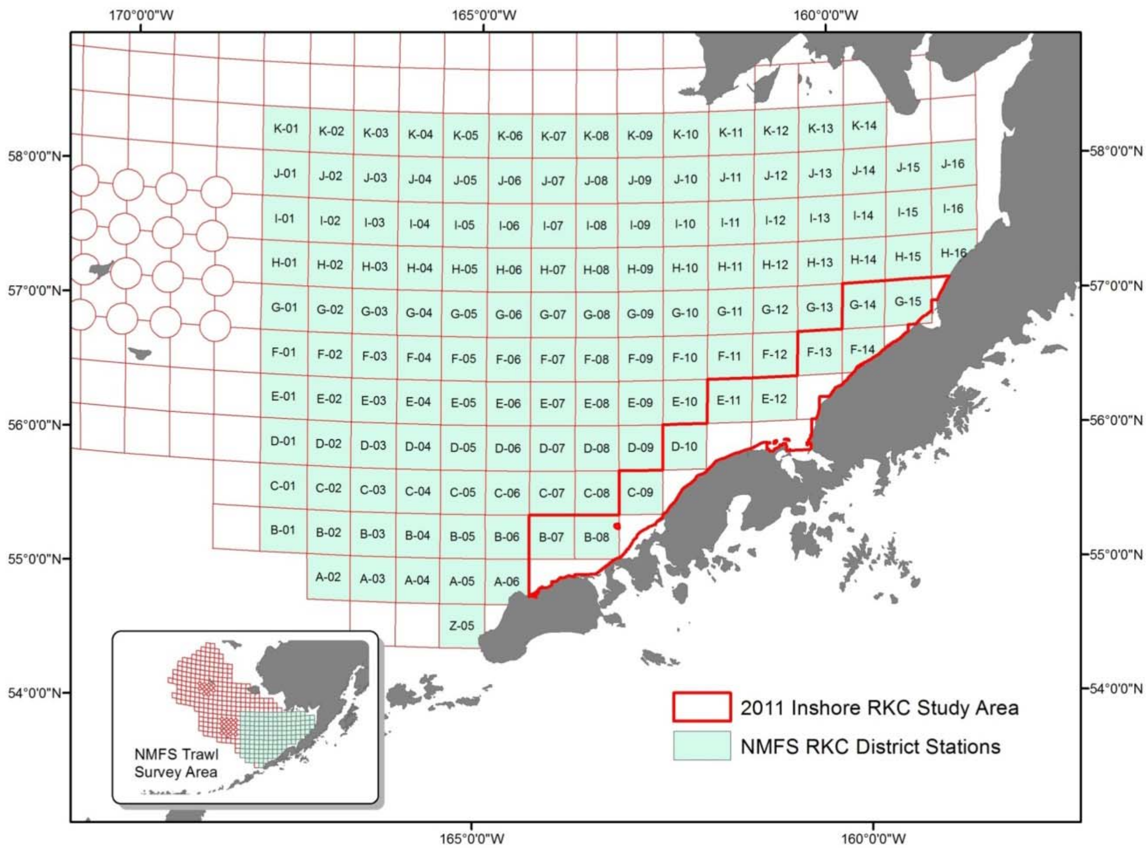


Figure 19 Bottom temperatures measured on the NMFS bottom trawl and BSFRF nearshore surveys, 2011

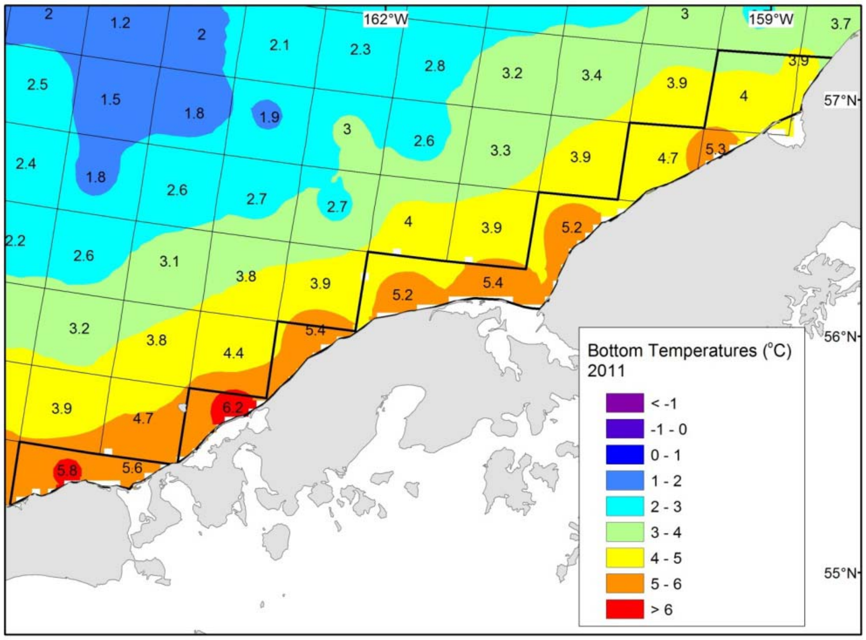
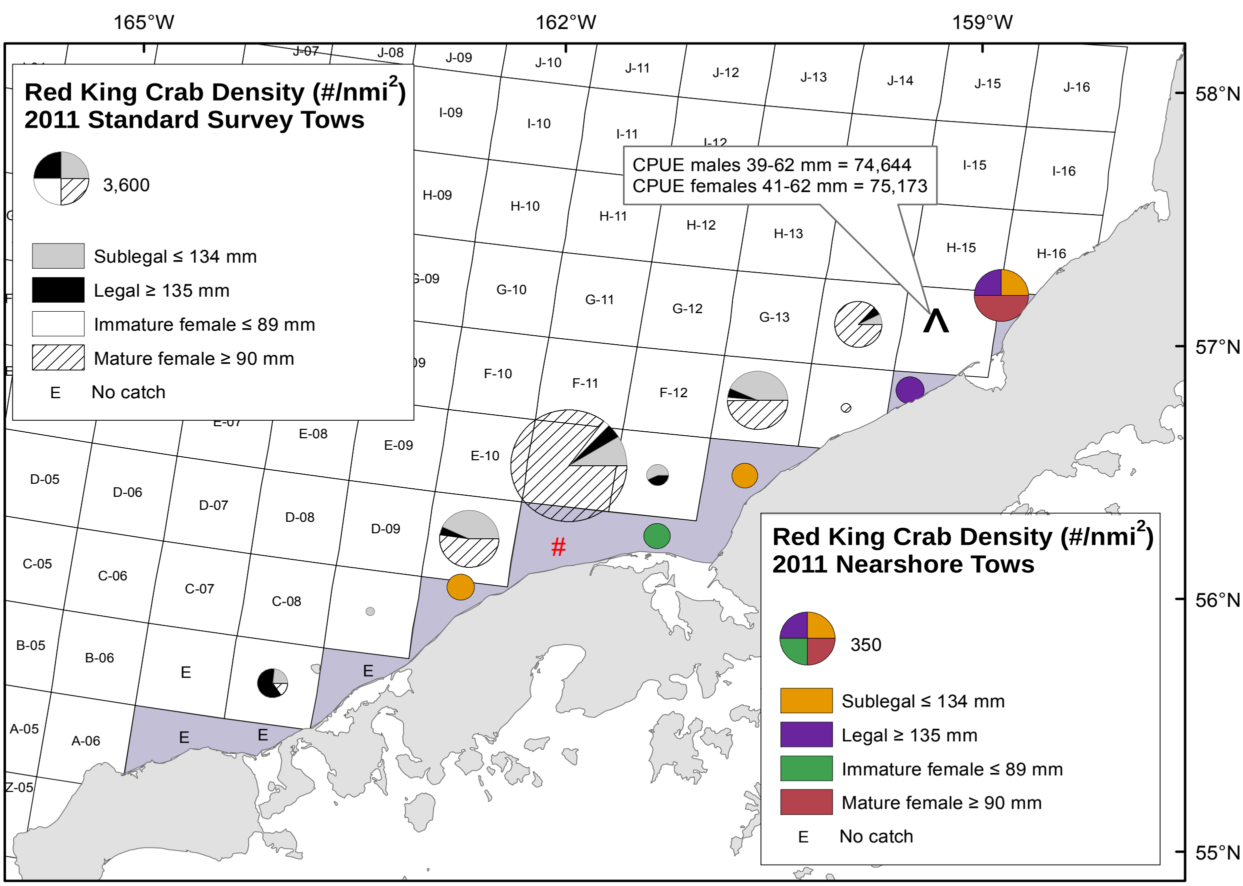


Figure 20 Density of red king crab (number of crab/nmi^2) in the NMFS bottom trawl survey within the 2011 red king crab study area, at standard and nearshore stations



The region to the southwest may be critical to providing the Bristol Bay red king crab stock with high recruitment events not observed since the 1970s. The specific delineation of this region will require a multivariate analysis of environmental variables and timing related to adult female movement associated with larval hatching, molting, and mating. To verify the importance of this region to positive recruitment in the Bristol Bay stock will require additional analyses on regional temperatures (affecting larval growth) and currents (affecting larval transport distance).

5.4 Bycatch interactions southwest of Amak Island

For purposes of this discussion paper, we have equated the area of concern, southwest of Amak Island, with ADFG statistical areas 635504, 635501, 635503, and 635431 (Figure 21). This is the area bounded by 55º30’ latitude to the north, 163º W. longitude to the east, 164º W. longitude to the west, and the Alaska Peninsula to the south. This statistical area encompasses the majority of the area in which increased trawl effort was noted by the Crab Plan Team during the EFH 5-year review (as illustrated on Figure 8). Only the southwestern-most orange dot is not included in the area outlined in red in Figure 21.

Figure 21 ADFG statistical area 635504, and areas inshore (statistical areas 635501, 635503, and 35431), outlined in red.

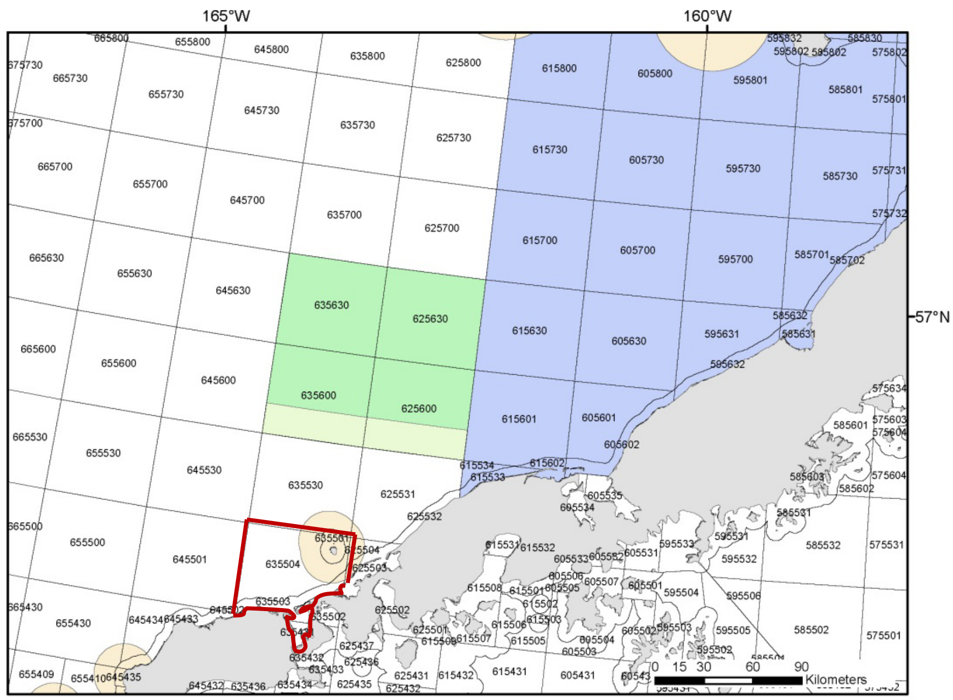


Table 1 identifies red king crab bycatch, by gear type, in the area southwest of Amak, and compares that with the total red king crab bycatch in the Bering Sea, for 2003 to 2011. Nonpelagic trawl vessels are responsible for the majority of red king crab interceptions in both areas. Looking specifically at the data for the area southwest of Amak, it is clear that the years of highest bycatch occur in the cold years in the Bering Sea (2006 to 2010), and that during the earlier warm years (2003 to 2005), bycatch levels in this area were very low to nil. The area is primarily used by trawl fisheries (nonpelagic and pelagic), although there is also some fixed gear effort in the area (for Pacific cod).

Table 1 **Observed red king crab bycatch in the area southwest of Amak Island (ADFG statistical area 635504 and inshore) and in the Bering Sea as a whole, by gear type, for 2003 to 2011.**

Year	Nonpelagic trawl		Hook and line		Pot		Pelagic trawl		Total for all gears	
	SW of Amak I.	Bering Sea	**SW of Amak I.**	Bering Sea	**SW of Amak I.**	Bering Sea	**SW of Amak I.**	Bering Sea	**SW of Amak I.**	Bering Sea
2003	*	48,169		8,117		31		39	*	56,356
2004		50,090		7,357		224		16		57,687
2005		66,165		8,416		1,367				75,948
2006	**134**	60,548		3,892		3,224	*	24	*	67,688
2007	**891**	66,833	*	5,358	*	8,020		4	**908**	80,215
2008	**3,026**	87,227	*	4,195	*	6,563	*	40	**3,179**	98,025
2009	**14,530**	73,842	*	4,740		540	**5**	32	*	79,154
2010	**1,949**	57,514	*	1,612		391		16	*	61,485
2011	**1,478**	42,579	*	2,935		2,398		4	*	47,916

Source: NMFS Comprehensive Observer Database, January 2012.
* = data is confidential

Table 2 focuses specifically on red king crab bycatch in the nonpelagic trawl fishery, in the area southwest of Amak Island. In addition to the annual bycatch, the table provides the total catch of groundfish by gear type, to demonstrate that the variation in bycatch levels is not an artifact of a dramatic shift in effort. The time period when red king crab are most vulnerable is during mating and molting, which occurs between March and June. In years where there is bycatch, and seasonal totals can be disclosed, between 12% and 23% of the red king crab bycatch is intercepted by the fishery during these months. On an annual basis, the rock sole fishery is primarily responsible for red king crab removals, as the target fishery distribution overlaps with the distribution of red king crab. The rock sole fishery, which is exclusively allocated to the Amendment 80 sector, has had 200% observer coverage since 2008, so the observed catch should represent the majority of nonpelagic trawl bycatch that is occurring in this area. Figure 22 through Figure 30 illustrate annual bycatch data graphically, mapping observed red king crab bycatch by nonpelagic trawl vessels for 2003 to 2011. In these figures, the area of concern, southwest of Amak Island, is outlined in red.

Table 2 **Observed red king crab bycatch and total groundfish catch in the nonpelagic trawl fishery, in ADFG statistical area 635504 and inshore, for 2003 to 2011.**

Year	Annual bycatch total	Observed total groundfish catch	Seasonal bycatch total for March to June	Seasonal total as % of annual total	Annual bycatch by target fishery			
					Rock Sole	Pacific Cod	Yellowfin Sole	Pollock
2003	*	8,372	*		*			
2004		14,723						
2005		14,059						
2006	134	11,359	*		*	*		
2007	891	11,895	207	23%	*	*		
2008	3,026	15,241	*		2,600	*		*
2009	14,530	5,625	1,702	12%	12,992	*		*
2010	1,949	8,319	329	17%	*		*	
2011	1,478	6,128	*na*		*	*		

Source: NMFS Comprehensive Observer Database, January 2012.
* = data is confidential
na = Seasonal data is not available in this discussion paper for 2011.

Figure 22 **Observed red king crab bycatch by nonpelagic trawl gear, 2003. The area outlined in red, southwest of Amak Island, represents ADFG statistical area 635504 and areas inshore.**

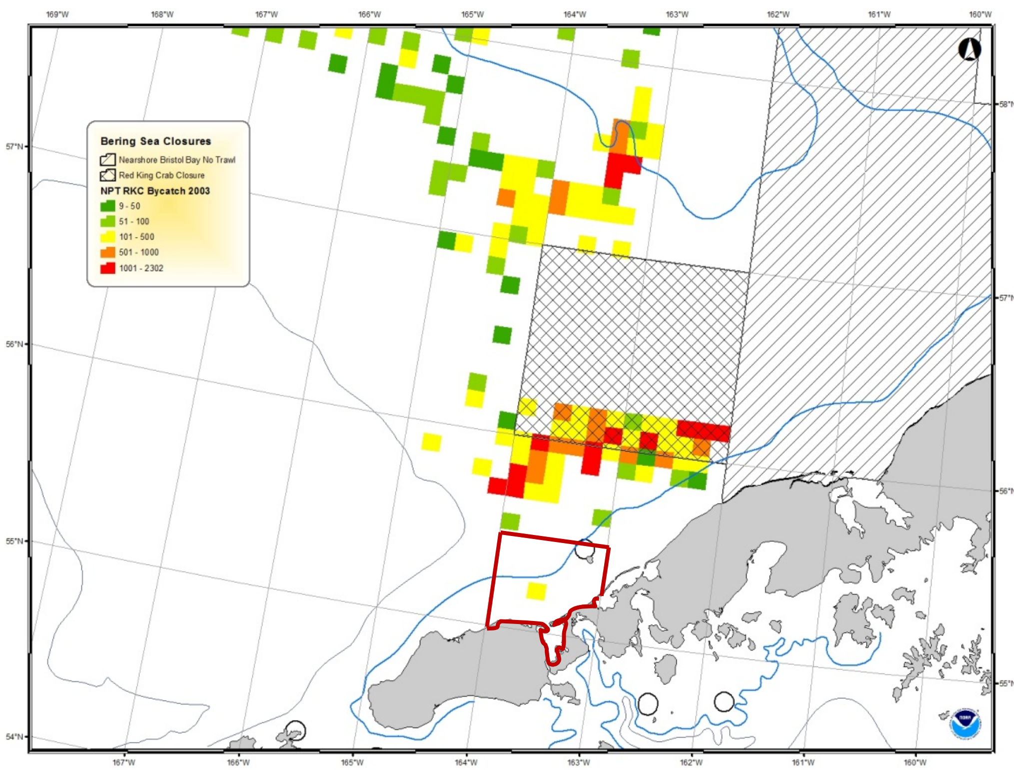


Figure 23 **Observed red king crab bycatch by nonpelagic trawl gear, 2004. The area outlined in red, southwest of Amak Island, represents ADFG statistical area 635504 and areas inshore.**

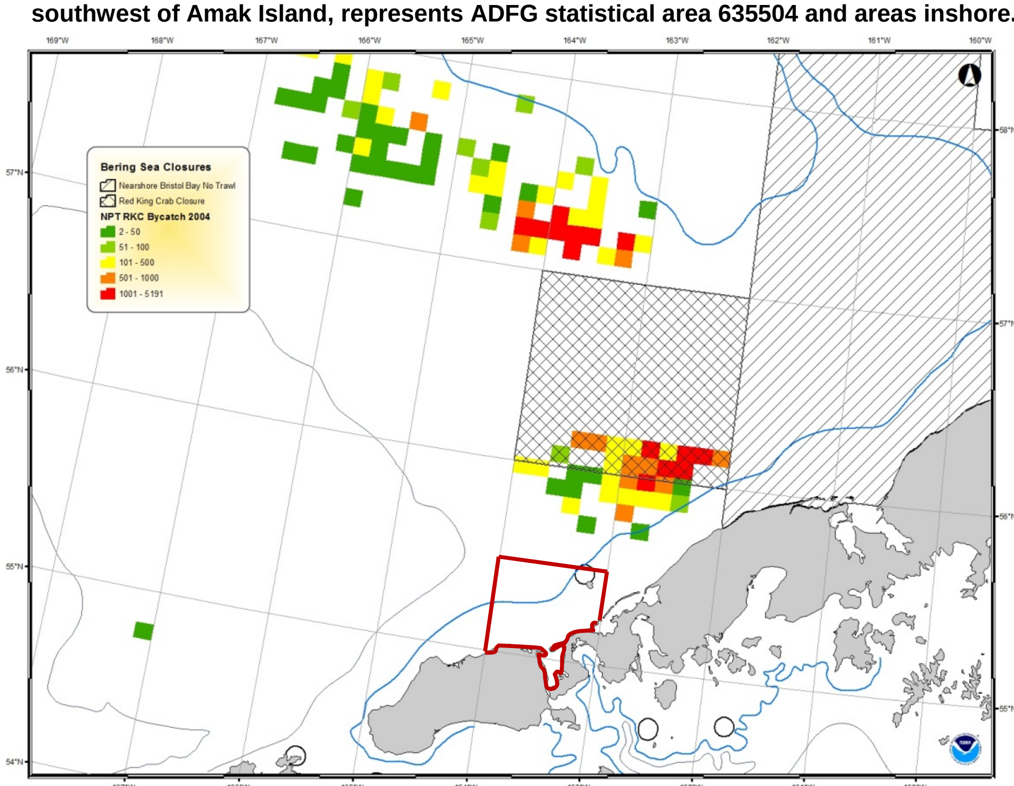


Figure 24 Observed red king crab bycatch by nonpelagic trawl gear, 2005. The area outlined in red, southwest of Amak Island, represents ADFG statistical area 635504 and areas inshore.

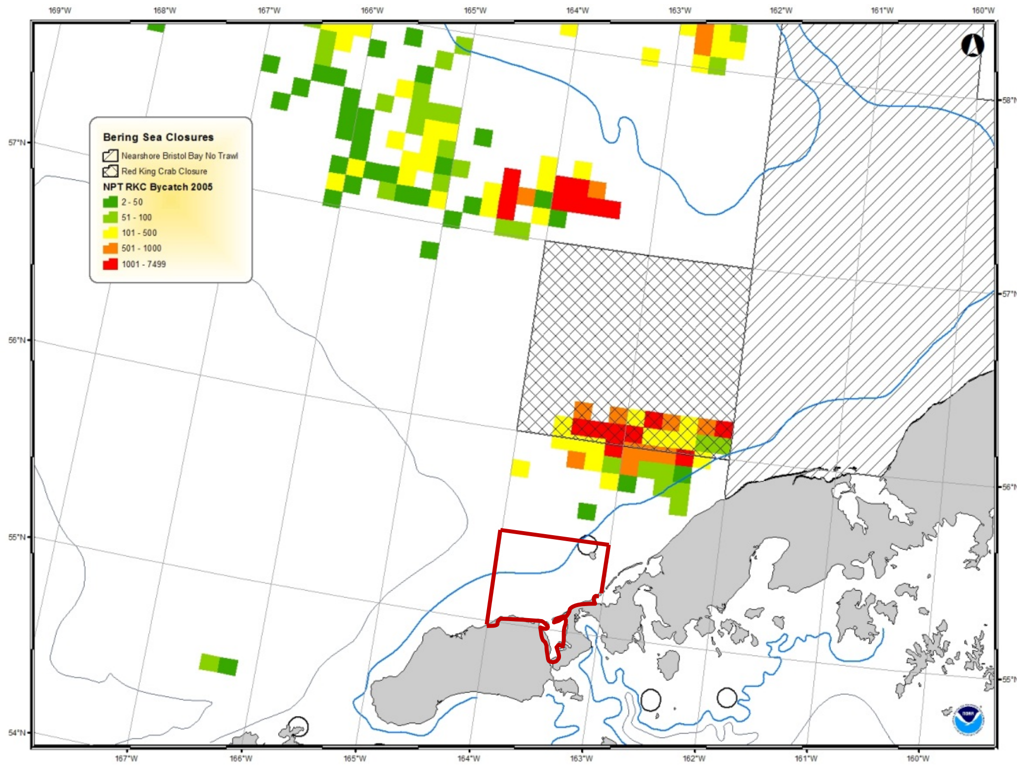


Figure 25 Observed red king crab bycatch by nonpelagic trawl gear, 2006. The area outlined in red, southwest of Amak Island, represents ADFG statistical area 635504 and areas inshore.

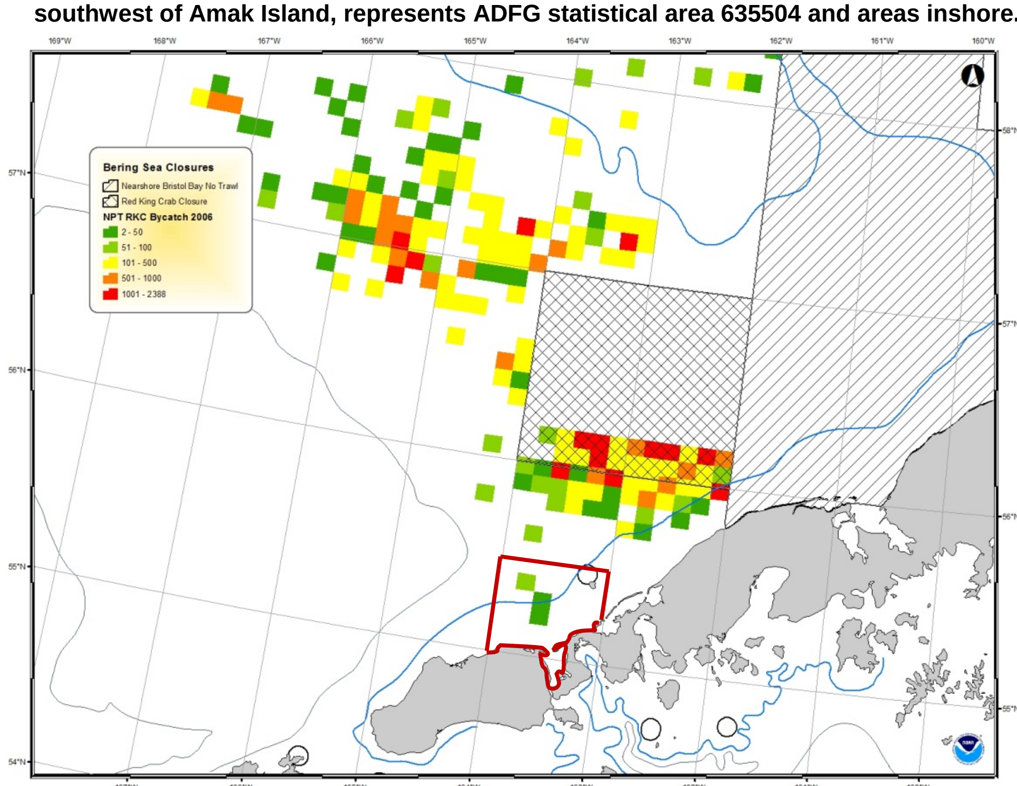


Figure 26 **Observed red king crab bycatch by nonpelagic trawl gear, 2007. The area outlined in red, southwest of Amak Island, represents ADFG statistical area 635504 and areas inshore.**

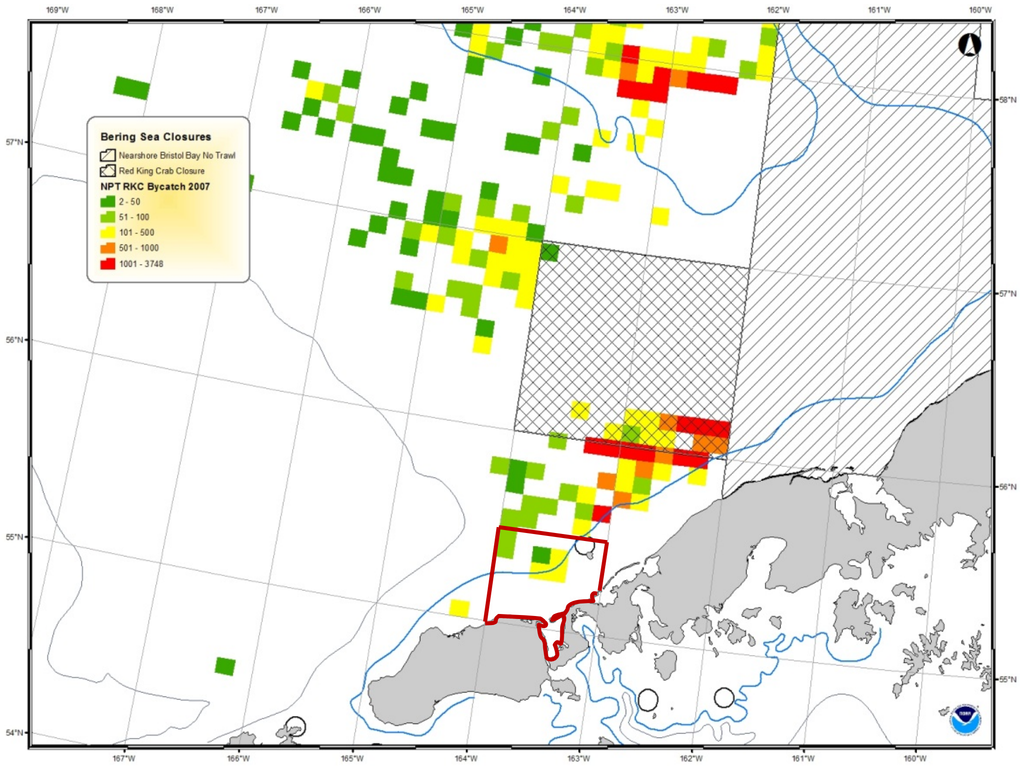


Figure 27 **Observed red king crab bycatch by nonpelagic trawl gear, 2008. The area outlined in red, southwest of Amak Island, represents ADFG statistical area 635504 and areas inshore.**

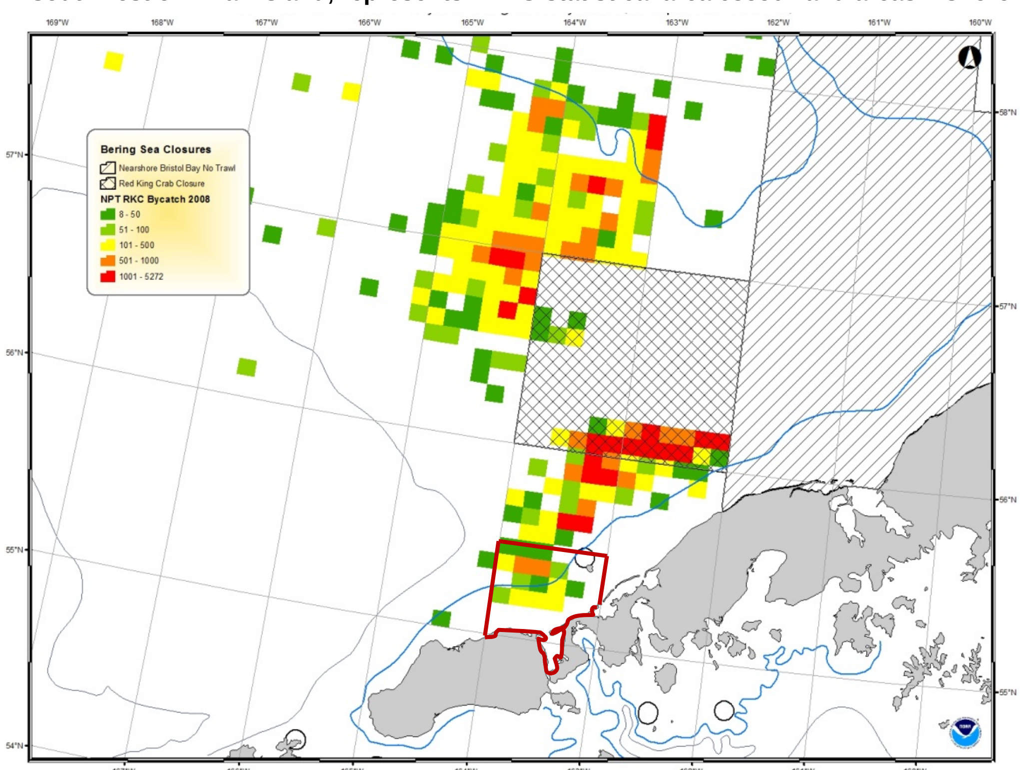


Figure 28 Observed red king crab bycatch by nonpelagic trawl gear, 2009. The area outlined in red, southwest of Amak Island, represents ADFG statistical area 635504 and areas inshore.

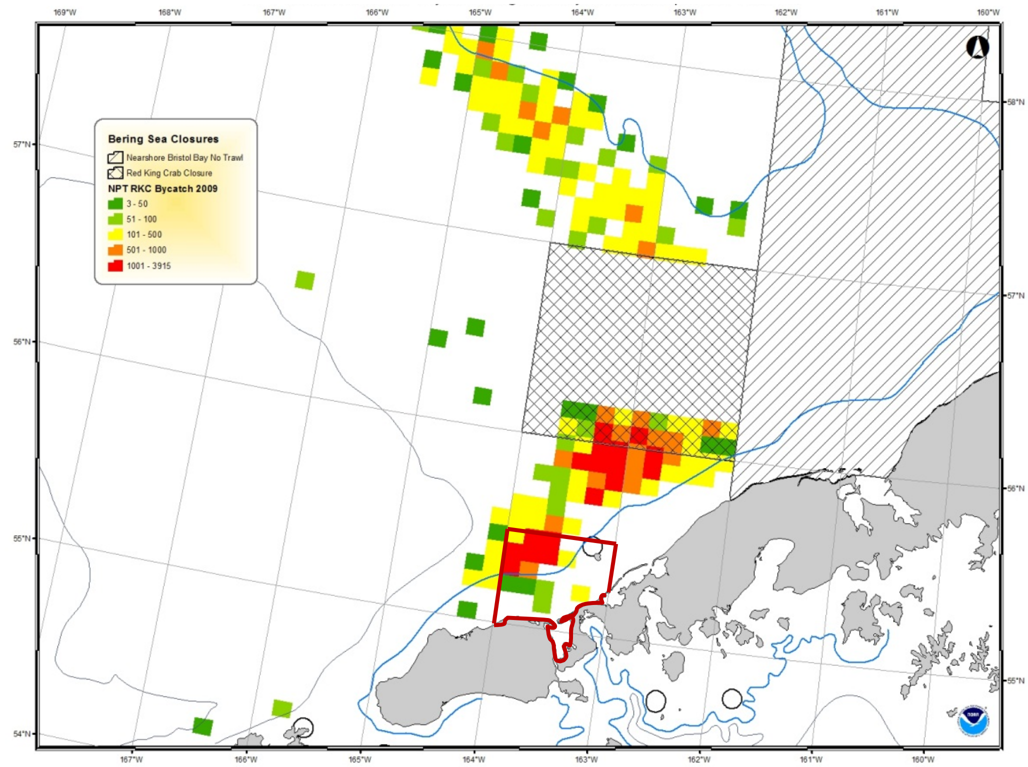


Figure 29 Observed red king crab bycatch by nonpelagic trawl gear, 2010. The area outlined in red, southwest of Amak Island, represents ADFG statistical area 635504 and areas inshore.

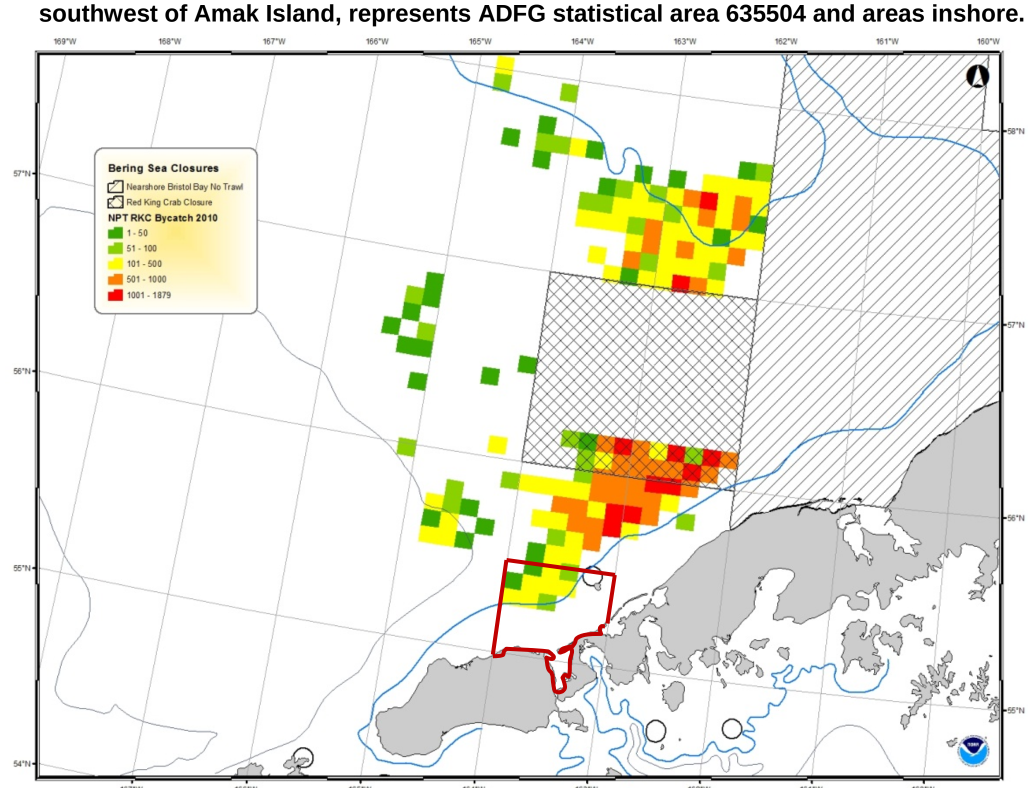
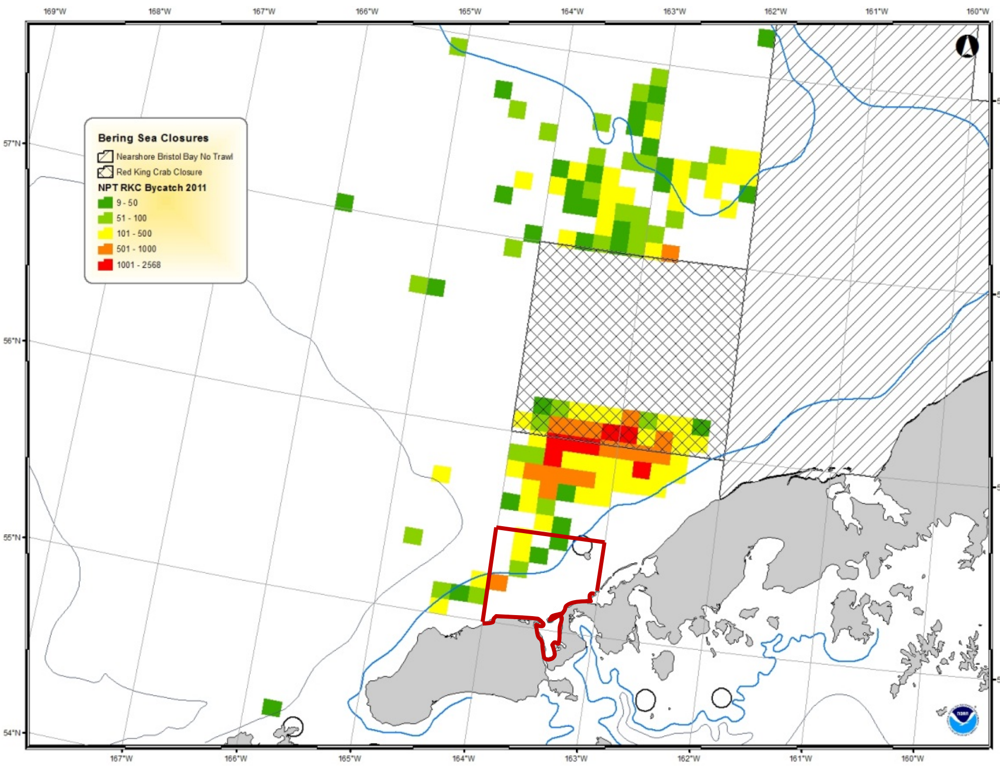


Figure 30 **Observed red king crab bycatch by nonpelagic trawl gear, 2011. The area outlined in red, southwest of Amak Island, represents ADFG statistical area 635504 and areas inshore.**



The issue of concern for this area is not necessarily the overall levels of bycatch of red king crab, but specifically, the bycatch ovigerous females in this area, as larvae hatched in this area are likely to have a higher chance of survival. A proportion, only, of observed catch is sampled for sex and length, and at this time, only sex data was available for this discussion paper. Table 3 provides an estimate of bycatch composition for the nonpelagic trawl fishery bycatch in the area southwest of Amak, from 2007 to 2011. In general, females represent a known proportion of between 32 and 57% of the sampled catch. 2009, which was the year of exceptionally high bycatch in this area, and for which the sample size is consequently much larger, shows a much lower proportion of females in the bycatch, however.

Table 3 **Estimate of observed red king crab bycatch composition in the area southwest of Amak Island (ADFG statistical area 635504 and inshore) intercepted with nonpelagic trawl gear, for 2007 to 2011**

Sex	2006	2007	2008	2009	2010	2011
Female	100%	32%	42%	2%	52%	57%
Male		68%	49%	78%	47%	14%
Unknown			8%	20%	1%	29%
Total number of samples	4	22	95	549	79	42

Source: NMFS Alaska Region comprehensive observer database, January 2012.

One way to assess whether this level of bycatch is a level of concern is to compare it to the total estimate of mature females in the red king crab population. The NMFS bottom trawl survey estimates the population of mature females annually (Table 4). Using the bycatch composition from sampled bycatch from Table 3, and assuming that all females and unknown samples were mature females, an estimate of the number of mature females that might have been taken in the bycatch is calculated for 2007 to 2011. In

2009, the year of highest bycatch in this area, the bycatch would have represented approximately 0.01% of the total mature female red king crab population.

Table 4 **Observed red king crab bycatch in the area southwest of Amak Island compared to biomass estimates for mature females from the NMFS bottom trawl survey, 2003 to 2011.**

Year	Observed bycatch in area southwest of Amak Island	Maximum estimate of females in bycatch, from Table 3 (females plus unknowns)	Biomass estimate for mature females	Bycatch as a percent of total mature female population
2007	891	285	32,305,653	0.0009%
2008	3,026	1,513	40,095,966	0.0038%
2009	14,530	3,197	30,148,323	0.0106%
2010	1,949	1,033	31,450,908	0.0033%
2011	1,478	1,271	28,474,399	0.0045%

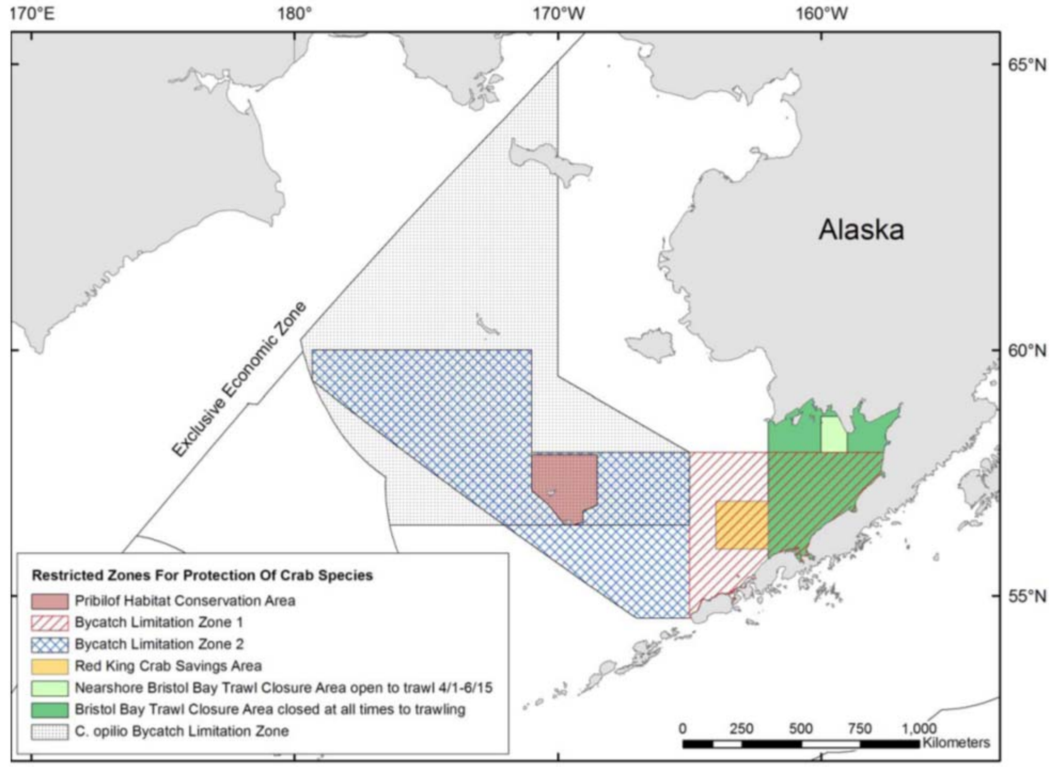
Assessing fishery interactions with the stock exclusively on the basis of bycatch, however, may also under-represent the issue of concern. Unobserved mortality of red king crab occurs in nonpelagic and pelagic trawl fisheries as well. Research undertaken by AFSC scientists estimated that averaging across size and sex, encounter with the trawl sweeps on nonpelagic gear results in a 9% mortality rate for red king crab. Encounters with the footrope result in a 15-30% mortality rate (Rose et al 2010). The Council implemented a required gear modification for the flatfish fisheries in 2011 to require elevated devices on the sweeps, partially in order to reduce unobserved mortality, however a footrope modification has not yet been successfully developed. Additionally, unobserved mortality may be occurring from pelagic pollock fisheries in the area, and effort from pelagic fisheries has been high in some years (Table 1).

5.5 Existing fishing closures for red king crab

Figure 31 illustrates the existing fishing closures for the protection of crab in the Bering Sea. All trawling is prohibited in the Nearshore Bristol Bay Trawl Closure[1]. Additionally, between March 15 and June 15, an area to the west south of 58 º N latitude, north of the Alaska Peninsula, and east of 162 ºW longitude closes also. The Red King Crab Savings Area is closed to nonpelagic trawling year round, with the exception of a subarea between 56 º N and 56 º10’ N latitude that may be opened in years when a guideline harvest level for the directed Bristol Bay red king crab fishery has been established. A PSC limit for red king crab is established for various trawl fishery targets in Zone 1. When the PSC limit is reached, the vessels to which the PSC limit applies are closed out of the area.

[1] With the exception of the Nearshore Bristol Bay Trawl Closure Area, which is open to trawling from April 1 to June 15.

Figure 31 Restricted Zones for protection of crab in the eastern Bering Sea.



An analysis of the efficacy of the closures for protecting the current distribution of the red king crab stock has not been attempted for this discussion paper. As discussed above, the distribution shifts depending on whether it is a warm year or a cold year in the Bering Sea, as the crab move away from the coldest water. Figure 33 through Figure 36 provide an illustration of the catch per unit effort (CPUE) of mature female red king crab at each NMFS bottom trawl survey station, for 2007 through 2011, relative to the existing crab closures. For a comprehensive analysis of the efficacy of existing closures, assistance from a crab stock assessment expert will be required, and such staff have not yet been available for this project. Should the Council wish to see a comprehensive analysis of the existing closures relative to the red king crab stock, the earliest this analysis could be brought back to the Council is December.

Figure 32 NMFS survey distribution of mature female red king crab for 2007.

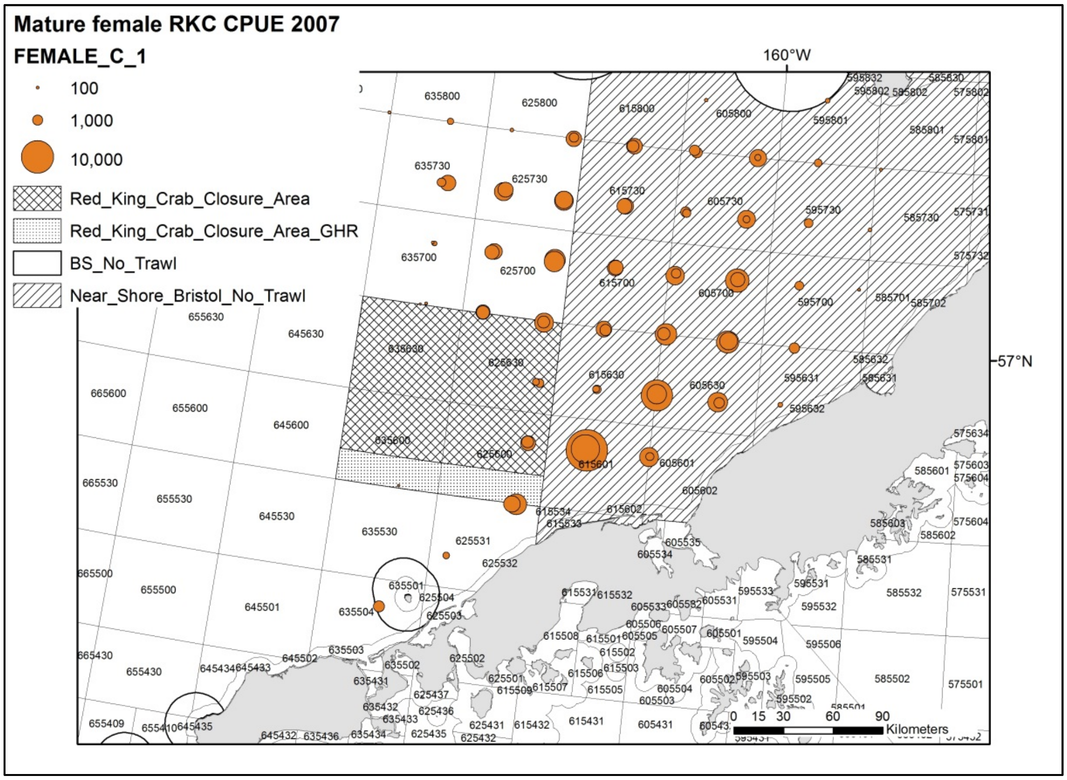


Figure 33 NMFS survey distribution of mature female red king crab for 2008.

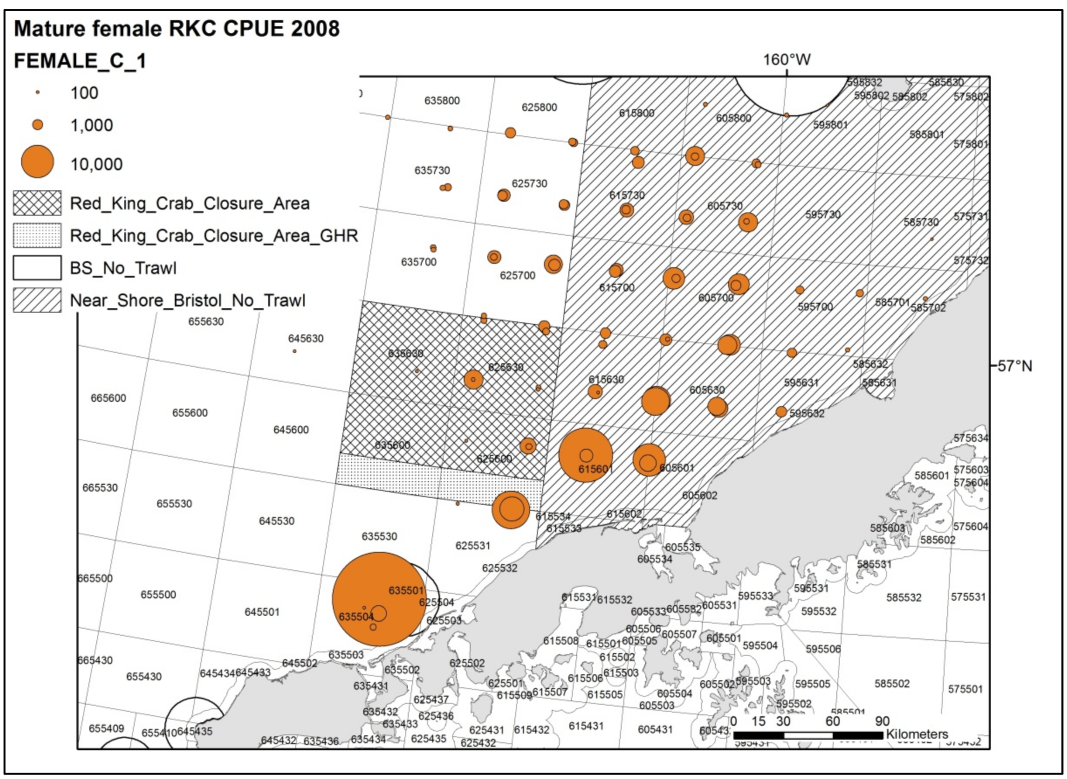


Figure 34 NMFS survey distribution of mature female red king crab for 2009.

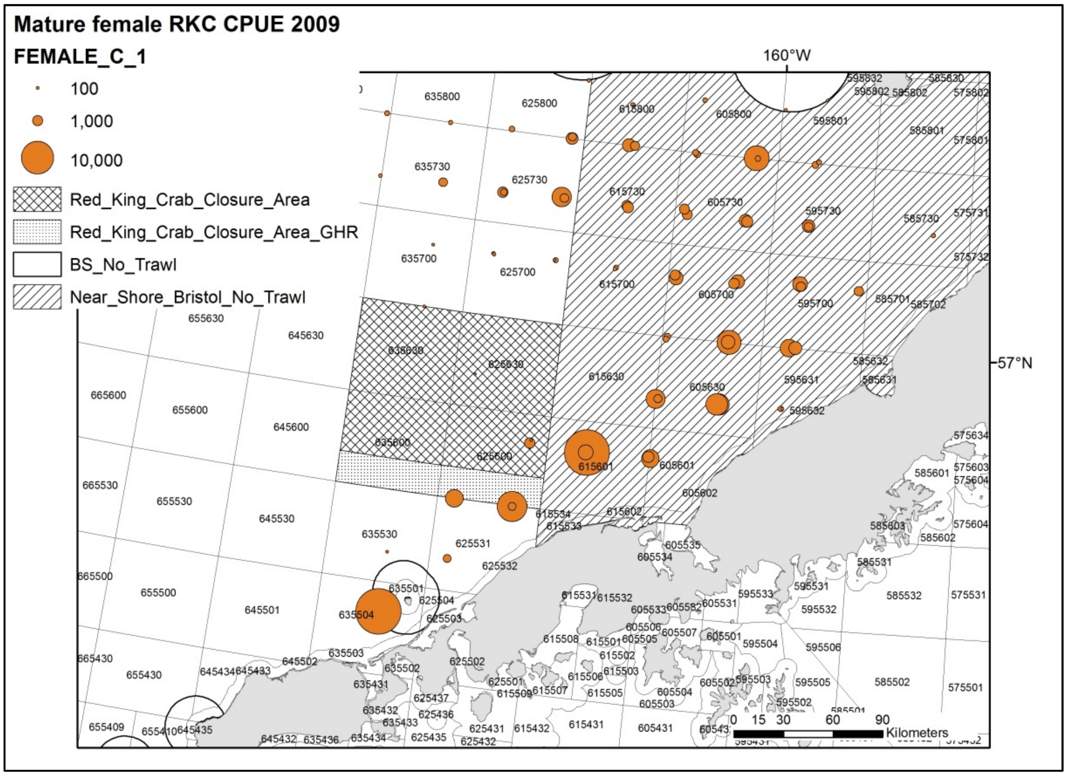


Figure 35 NMFS survey distribution of mature female red king crab for 2010.

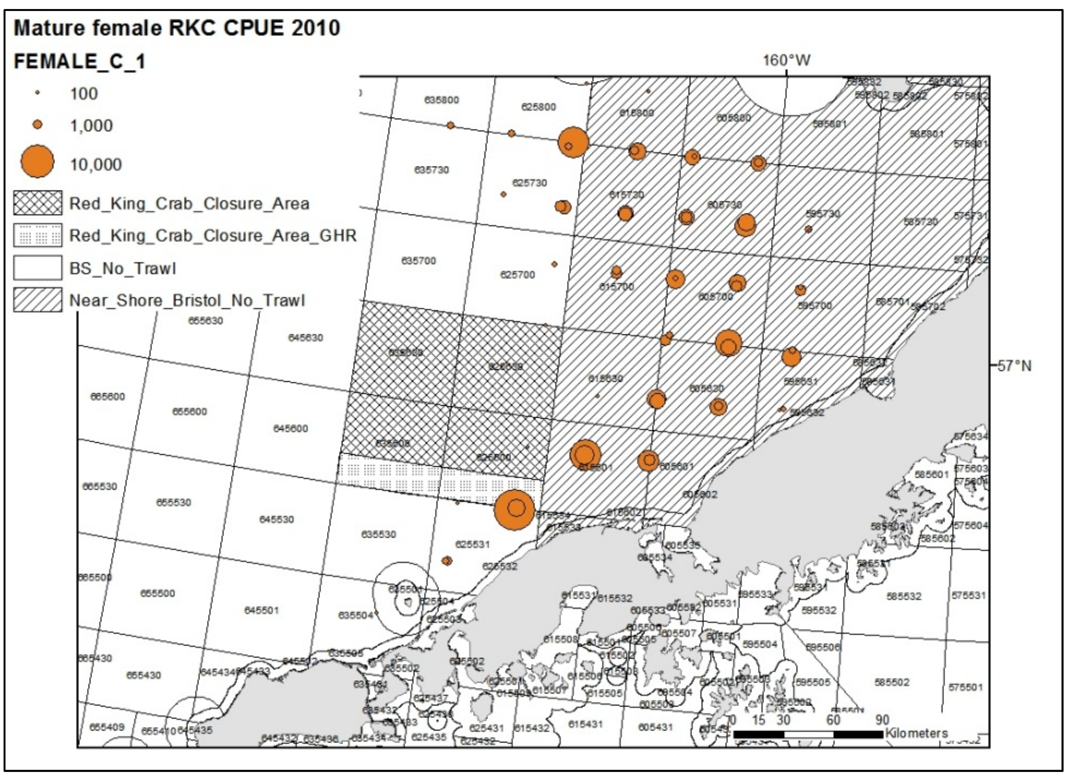
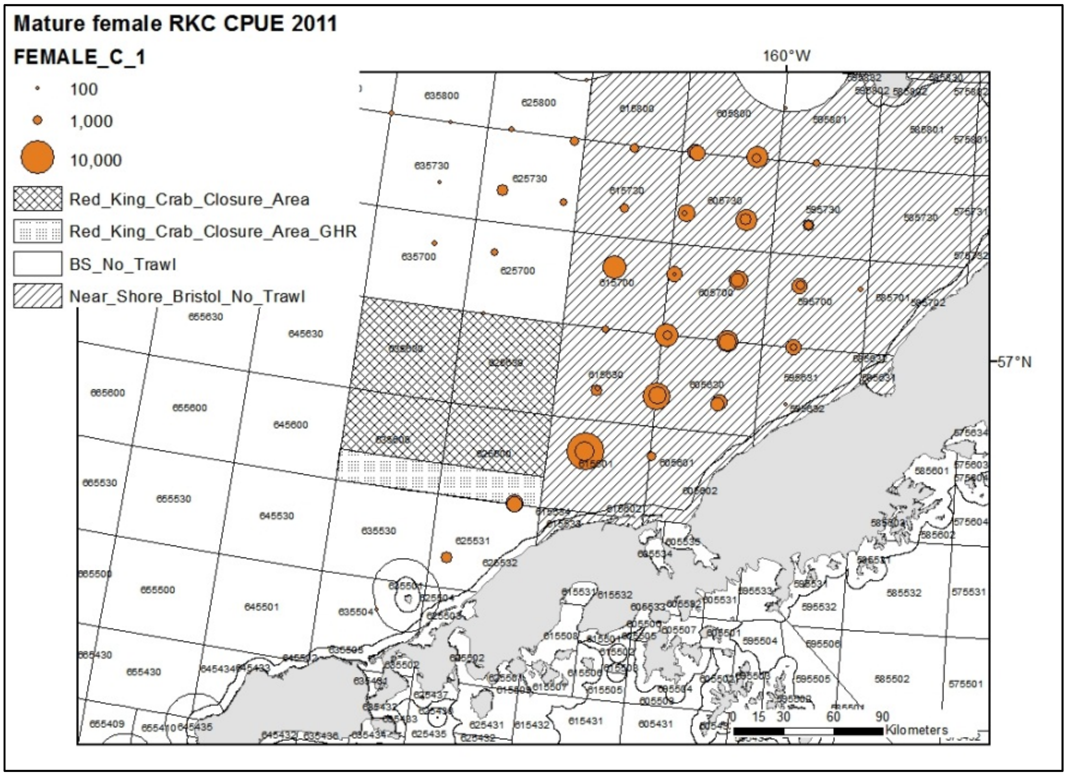


Figure 36 NMFS survey distribution of mature female red king crab for 2011.



6 Research questions

- **Adult distribution (tagging and observation):** As both red king crab and Tanner crab aggregate during larval release, molting, and mating, it is imperative to identify the habitats and areas in which these occur. By dual tagging ovigerous females during the EBS Trawl Survey with pop-up tags programmed to pop-up during the larval release season and acoustic tags, we should be able to locate the general area of hatching from the pop-up tag, and then locate the females or their exoskeletons (as they molt soon after hatching) at a much smaller scale using the acoustic tag. An alternative means of locating the aggregations would be to use a high-resolution side-scan sonar to locate the females. Then a remotely operated vehicle or video sled would be used to estimate habitat type and abundance of females in the area. This work would help to identify the specific areas of larval release.
- **Juvenile assessment:** Assess juvenile crab distribution in the nearshore region of Bristol Bay to predict likely larval release locations (based on temperature and current patterns) in cold and warm year. This study would include both Tanner and red king crab because both species demonstrate aggregative hatching behavior which makes them prime candidates for examining how larval release area affects recruitment and because they are likely to recruit into similar areas along the nearshore of Bristol Bay. To date, dive surveys have been the most reliable methods for juvenile crab habitat assessment due to the small and cryptic nature juveniles (Loher and Armstrong, 2000; Sundberg and Clausen, 1977). A collaborative effort is underway with the Bering Sea Research Foundation and the National Marine Fisheries Service in 2011 and 2012, to conduct nearshore surveys using a small mesh net to assess potential future recruits to the Bristol Bay red king crab stock.
- **Larval assessment:** Although larval assessment is time and cost intensive, the previous two projects could be combined with intensive sampling for larval crab. The movement of larvae

could be documented and used to parameterize a larval drift model by sampling multiple times over the summer. By combining this data with data on juvenile habitat from the previous project, the most important hatching areas could be identified.

- Conduct a time series analysis on female egg condition and distribution (e.g. Chilton et al. in press) with a focus on spatial distribution along the outer edges of the Bristol Bay stock.
- Conduct a time series analysis of environmental conditions and red king crab abundance related to recruit abundance to assess potential stock production processes related to temperature fluctuations in the eastern Bering Sea.

7 Options for Council action

This discussion paper provides an initial look at some of the concerns raised by the Crab Plan Team during the EFH 5-year review in 2010. There are two issues that were raised: the general conclusions about the effects of fishing on crab EFH that were reached during the 2005 EFH EIS, and specific concerns about a habitat area important for red king crab.

7.1 Conclusions on the impacts of fishing on crab EFH

The 2005 EFH EIS ties the evaluation of fishing impacts on habitat specifically to living and non-living structures on and in the ocean bottom. For certain life stages of crab species, however, oceanic parameters and pelagic habitat are critical for spawning success. Given the additional background provided in this discussion paper, the Council should decide whether further evaluation of this effects analysis is called for. In their initial review, the Crab Plan Team's primary concern was that the analysis concluded that some fishing effects on crab stocks were known, with which they disagreed. The Team's initial discussion was to recommend changing all "Minimal, temporary, or no effect" conclusions to "Unknown effect", however given the other concerns raised, the Team opted to defer this issue to the Council, to see whether a more comprehensive reconsideration of fishing effects on crab habitat should be initiated. The discussion paper has highlighted some avenues for revisiting the methodology for determining the effects of fishing on crab EFH. The Council should decide whether it is appropriate to initiate an evaluation of those effects as an outcome of the 2010 EFH 5-year review, or whether further research is needed, and this might be a subject that might be further developed in time for the 2015 EFH 5 year review. Of note, the Crab Plan Team has not had an opportunity to review this issue since May 2010.

7.2 Protection of key area in southwestern Bristol Bay

The Crab Plan Team highlighted fishing interactions with red king crab, and red king crab habitat, as an issue of concern during the EFH 5-year review in 2010. The red king crab population is currently at low biomass, and there is little recruitment predicted for the near future. As described in Section 5.3, it is hypothesized that larvae hatched from ovigerous females in the southwestern Bristol Bay have a better chance of juvenile survival than larvae hatched elsewhere in Bristol Bay. In addition, 2012 is predicted to be a cold year, when ovigerous females are more likely to be migrate inshore in the southwest.

Bycatch interactions of the groundfish fisheries with red king crab are described in Section 5.4. Nonpelagic trawl vessels are responsible for the majority of red king crab bycatch throughout the Bering Sea, and all observed bycatch within ADFG statistical area 635504, which has been equated with the area of concern, southwest of Amak Island. There is a notable difference in bycatch levels in the area depending on whether the Bering Sea is experiencing a warm year or a cold year. Based on observer samples, the bycatch composition varies annually, and females represented between 2 and 57% of the bycatch between 2007 and 2011. The red king crab stock may be impacted by factors other than bycatch, however, such as adverse impacts to crab habitat, or unobserved mortality of ovigerous females from nonpelagic and pelagic trawling. It is difficult to assess the degree to which these fishery interactions may be occurring southwest of Amak Island.

There are several avenues available to the Council with respect to this issue. Some suggestions for possible Council action are the following:

- No management action
- No management action until further research can be conducted, to verify the importance of this region to positive recruitment in the Bristol Bay stock:
    - Wait for the results from the planned 2012 collaborative survey with NMFS and BSFRF, to see whether cold year results support theory
    - Wait for results of comprehensive studies to better understand adult, juvenile and larval distribution and habitat usage (no funding currently allocated)
- Initiate analysis of EFH conservation measures to extend or establish annual or seasonal closures in southwestern Bristol Bay, based on the probability that oceanographic currents along the peninsula provide essential pelagic habitat for larval and early juvenile stages of red king crab, and therefore ovigerous females upstream need to be protected.
    - Extend the range of the red king crab savings area to protect more of the stock.
    - Apply a seasonal closure to protect the adult female red king crab from March to May during molting and mating
    - Close area southwest of Amak Island
- Designate a HAPC priority for areas important for ovigerous red king crab, and consider designating this area as a HAPC[2] (see reasoning above)
- Consider protection measures for this area on the basis of bycatch interactions of the groundfish fisheries with ovigerous female crab, and stock concerns. Initiate an analysis to:
    - establish or extend annual or seasonal closures in the southwestern Bristol Bay
    - broadly reconsider existing red king crab closures throughout the range of red king crab

8 Literature Cited

Armstrong, D.A., Armstrong, J.L., Jenson, G., Palacios, R., Williams, G., 1987. Distribution, abundance, and biology of blue king and Korean hair crabs around the Pribilof Islands, Outer Continental Shelf Environmental Assessment Program: Final Reports of Principal Investigators. U.S. Department of Commerce, NOAA, pp. 1-278.

Barange, M. and R. I. Perry. 2009. Physical and ecological impacts of climate change relevant to marine and inland capture fisheries and aquaculture. In K. Cochrane, C. De. Young, D. Soto, and T. Bahri (eds). Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. FOA Fisheries and Aquaculture technical paper. No. 530. Rome, FAO. pp 7-106.

Chilton, E.A., C.E. Armistead, and R.J. Foy. 2011. The 2011 eastern Bering Sea continental shelf bottom trawl survey: results for commercial crab species. NOAA Tech. Memo. NMFS AFSC 1989. 144 pp.

Dew, C.B., 1990. Behavioral ecology of podding red king crab, *Paralithodes camtschatica*. Canadian Journal of Fisheries and Aquatic Sciences 47, 1944-1958.

Dew, C.B., McConnaughey, R.A., 2005. Did trawling on the brood stock contribute to the collapse of Alaska's king crab? Ecological Applications 15, 919-941.

[2] Note, the Council is not scheduled to consider setting HAPC priorities again until 2015. However, the Council specifically noted during the 2010 HAPC consideration process, that should the outcome of this discussion paper be a recommended HAPC priority, it would be considered out of cycle.

Loher, T., and D.A. Armstrong. 2005. Historical changes in the abundance and distribution of ovigerous red king crabs (*Paralithodes camtschaticus*) in Bristol Bay (Alaska), and potential relationship with bottom temperature. Fish. Oceanogr. 14:292-306.

Loher, T., Armstrong, D.A., 2000. Effects of habitat complexity and relative larval supply on the establishment of early benthic phase red king crab (*Paralithodes camtschaticus* Tilesius, 1815) populations in Auke Bay, Alaska. Journal of Experimental Marine Biology and Ecology 245, 83-109.

Loher, T., Armstrong, D.A., 2000. Effects of habitat complexity and relative larval supply on the establishment of early benthic phase red king crab (*Paralithodes camtschaticus* Tilesius, 1815) populations in Auke Bay, Alaska. Journal of Experimental Marine Biology and Ecology 245, 83-109.

McMurray, G., Vogel, A.H., Fishman, P.A., 1984. Distruibution of larval and juvenile red king crab (*Paralithoides camtschatica*) in Bristol Bay, Outer Continental Shelf Environmental Assessment Program: Final Reports of Principal Investigators. U.S. Department of Commerce, NOAA, pp. 267-477.

NMFS. 2004. Final Environmental Impact Statement for Bering Sea and Aleutian Islands Crab Fisheries. National Marine Fisheries Service, Alaska Region

NPFMC and NMFS. 2010. Essential Fish Habitat 5-Year Review for 2010: Summary Report. http://www.fakr.noaa.gov/habitat/efh/review.htm. April 2010.

Orensanz, J., Ernst, B., Armstrong, D., Stabeno, P., Livingston, P., 2005. Contraction of the Geographic Range of Distribution of Snow Crab (Chionoecetes opilio) in the Eastern Bering Sea: An Environmental Ratchet? Reports of California Cooperative Oceanic Fisheries Investigations 45, 65-79.

Orensanz, J.M., Ernst, B., Armstrong, D., Stabeno, P., Livingston, P., 2004. Contraction of the geographic range of distribution of snow crab (*Chionoecetes opilio*) in the eastern Bering Sea: An environmental ratchet? CalCOFI Rep. 45, 65-79.

Rose, C., A. Stoner, J. Munk, J. Gauvin, C. Hammond. 2010. Quantification of unobserved mortality rates of snow, Tnner, and redking crabs (*Chinoecetes opilio, C. bairdi, and Paralithodes camtschaticus*) after encountres with trawls on the seafloor. NPRB Project 711 Final Report. May 2010. http://doc.nprb.org/web/07_prjs/711_final%20report.pdf

Rosenkranz, G., Tyler, A., Kruse, G., Niebauer, H., 1998. Relationship between wind and year class strength of Tanner crabs in the southeastern Bering Sea. Alaska Fishery Research Bulletin 5, 18-24.

Rosenkranz, G.E., Tyler, A.V., Kruse, G.H., 2001. Effects of water temperature and wind on year-class success of Tanner crabs in Bristol Bay, Alaska. Fisheries Oceanography 10, 1-12.

Shirley, T., Shirley, S., 1989. Temperature and salinity tolerances and preferences of red king crab larvae. Marine and Freshwater Behaviour and Physiology 16, 19-30.

Shirley, T., Zhou, S., 1997. Lecithotrophic development of the golden king crab Lithodes aequispinus (Anomura: Lithodidae). Journal of Crustacean Biology 17, 207-216.

Stabeno, P.J., N.A. Bond, N.B. Kachel, S.A. Salo, and J.D. Schumacher. 2001. On the temporal variability of the physical environment over the south-eastern Bering Sea. Fish. Oceanogr. 10:81-98.

Stone, R., O'Clair, C., Shirley, T., 1992. Seasonal migration and distribution of female red king crabs in a southeast Alaskan estuary. Journal of Crustacean Biology 12, 546-560.

Stone, R.P., Oclair, C.E., Shirley, T.C., 1993. Aggregating behavior of ovigerous female red king crab, *Paralithodes camtschaticus*, in Auke Bay, Alaska. Canadian Journal of Fisheries and Aquatic Sciences 50, 750-758.

Sundberg, K., Clausen, D., 1977. Post-larval king crab (*Paralithodes camtschatica*) distribution and abundance in Kachemak Bay Lower Cook Inlet, Alaska, 1976. In: Trasky, L., Flagg, L., Burbank, D. (Eds.), Environmental studies of Kachemk Bay and Lower Cook Inlet. Alaska Department of Fish and Game, Anchorage.

Tyler, A.V. and G.H. Kruse. 1996. Conceptual modeling of brood strength of red king crabs in the Bristol Bay region of the Bering Sea, p. 511-543. In High Latitude Crabs: Biology, Management, and Economics. Alaska Sea Grant College Program Report No. 96-02, University of Alaska, Fairbanks, AK.

Zheng, J., and G.H. Kruse. 2006. Recruitment variation of eastern Being Sea crabs: Climate-forcing or top-down effects? Prog. Oceanogr. 68:184-204.

Zheng, J., Kruse, G., 2000. Recruitment patterns of Alaskan crabs in relation to decadal shifts in climate and physical oceanography. ICES J. Mar. Sci. 57, 438.

Zheng, J., Kruse, G., 2000. Recruitment patterns of Alaskan crabs in relation to decadal shifts in climate and physical oceanography. ICES J. Mar. Sci. 57, 438.

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