Distribution of Legal Bristol Bay Red King Crab During the Fishing Season using Daily Fishing Logs
Leah Sloan, University of Alaska Fairbanks

BACKGROUND

Bristol Bay red king crabs are protected from bycatch in the trawl fisheries through closure (Figure 1) areas and bycatch limits. The Red King Crab Savings Area (RKCSA) was designed to protect adult red king crab (Kruse et al., 2010) and prohibits non-pelagic trawls year-round, except in the Red King Crab Savings Sub-Area (RKCSSA). Fishing may occur in the subarea as long as crab abundance was high enough to support a crab fishery the previous year. To protect juvenile red king crabs, all non-pelagic trawling is prohibited in the Near-Shore Bristol Bay Trawl Closure (except in Federal Reporting Area 516 from April 15th – June 15th) and Area 516 is closed to trawling from March 15th to June 15th to protect crabs during the molting and mating period. Red king crab are a prohibited species in non-pelagic trawl fisheries, thus when a prohibited species catch (PSC) is reached, all of Zone 1 is closed to non-pelagic trawling (Evans et al., 2012).

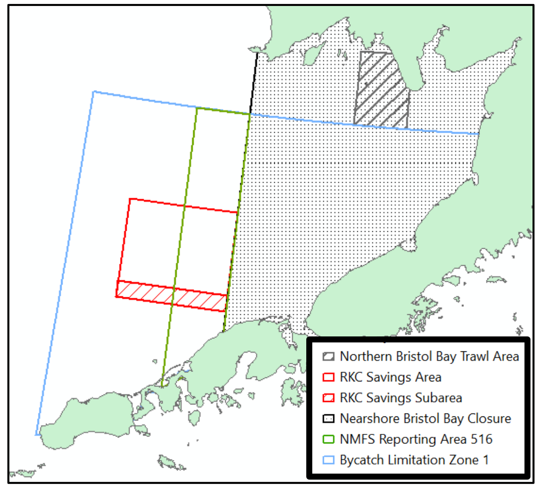

Figure 1: Areas in Bristol Bay that restrict non-pelagic trawl fisheries.

Stock assessments for Bristol Bay red king crabs are primarily based on the NMFS annual crab and groundfish trawl surveys (Bechtol et al., 2011). These surveys have been conducted each summer since 1968 in early June through late July/early August, providing an excellent time series with which to examine abundance trends, and a source of detailed information on summer crab distributions. However, there is no complimentary survey conducted during the fall or winter when the fishery occurs. Thus, our knowledge of fall/winter crab distributions is based solely on catch data from the fishing industry collected from fish tickets, by onboard observers, and by port samplers. These data are generally reported by large ADF&G statistical areas (0.5^{o} latitude x 1^{o} of longitude, except near shore) (Fitch et al., 2012) that do not allow for examination of fishing effort or crab distributions on a fine spatial scale.

Lack of detailed data on winter red king crab distributions is of concern because most king crab bycatch in non-pelagic groundfish trawls occurs in the winter (North Pacific Groundfish SAFE reports), especially in the rock sole fishery (Evans et al. 2012; Groundfish SAFE reports). Without detailed data on winter king crab distributions, the effectiveness of trawl closure areas is difficult to evaluate. King crab distributions vary over both seasonal and interannual time scales, potentially limiting the effectiveness of fixed closure areas. Crabs migrate to shallow waters in late winter for mating and molting, and release larvae in the spring (Bright, 1967). In the Bering Sea, female red king crabs typically remain in shallow waters, while males migrate to deeper waters in the late summer and fall (Loher, 2001). In recent cold years, summer distribution of king crabs shifted from central Bristol Bay to near-shore regions along the Alaska Peninsula (Chilton et al., 2011; Evans et al., 2012; Daly et al., 2013). Shifts in distribution—particularly if unaccounted for in management efforts—are cause for concern, because they may leave crabs more vulnerable to habitat disruption and bycatch (Evans et al., 2012).

Daily fishing logs (DFLs), kept by skippers in the red king crab fleet since rationalization in 2005, can help improve our understanding of legal male king crab distributions outside the summer survey period. DFLs contain information on the exact coordinates and depths of all strings set, as well as number of pots set per string and number of legal crabs retained. DFLs are hand-written by skippers, and carbon copies are submitted to NMFS and ADF&G each season. We digitized all DFLs from 2005 through 2015 to help elucidate the spatial distribution of legal Bristol Bay red king crab, including seasonal and interannual changes, and how these may be related to temperature.

In addition to DFLs, observer data could also provide information on king crab distributions during the fishing season. Independent observers have been required on all or a portion of the vessels in the Bristol Bay red king crab fishery since 1988. Bristol Bay king crab observers currently record detailed data on the catch in sampled pots, but they only sample 5% of the pots on 20% of the vessels (~1-2% of total pots) (Fitch et al., 2013). Rather than very specific information on a few pots, DFLs can provide an average catch per pot over an entire string (average 30 pots/ string). These two very different sources of data collected from the same fishery are compared to determine if they yield the same spatial relationships; although observer data are more precise for the pots sampled, there are far fewer observations and it may therefore not cover the same spatial area.

METHODS AND APPROACH

DFLs have been required in the Bristol Bay red king crab fishery since the 2005/06 fishing season. DFLs are recorded on carbon paper, with 5 copies of each entry; ADF&G and NMFS each get one of these copies, while the original stays with the vessel. We used ADF&G copies because archived logs were more accessible and ADF&G copies were expected to be more legible since they are the second carbon copy, whereas the NMFS versions are the fourth carbon copy. All ADF&G Bristol Bay red king crab DFLs from 2005/06 through the 2015/16 season were entered by hand into spreadsheets, encompassing a total of 29,222 records. Very few records were illegible or incomplete (<1%), but an unknown number of DFL pages were missing. To evaluate the completeness of these records we compared total catch for each year from DFL records to the fishery records of total catch recorded in the crab stock assessment and fishery evaluation (SAFE) reports. Figure 2 shows that these DFL records encompass a very large proportion of the total crabs fished each year, from 87.5% in 2005 to 96.6% in 2008.

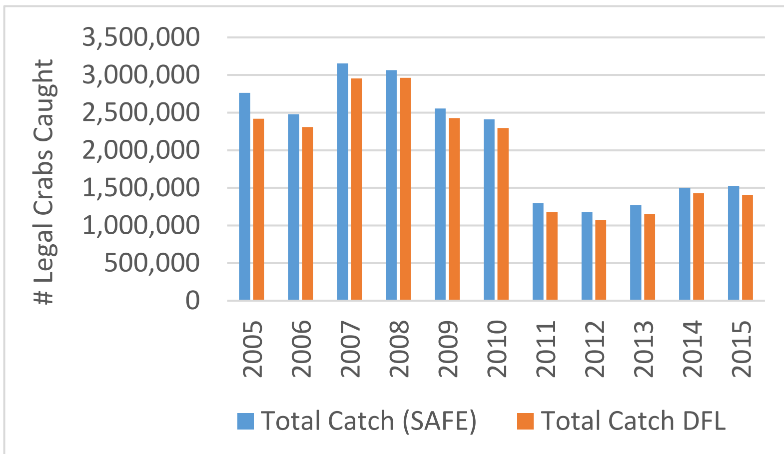

Figure 2: Total Bristol Bay red king crabs caught by year, as reported in the crab stock assessment and fishery evaluation report (SAFE) and from daily fishing logs (DFLs).

Catch per pot was calculated for each DFL entry (string of pots) as the number of crab caught divided by the number of pots hauled. Soak time (mean 63.8 hours) had very little effect on catch per pot ($R^2 = 0.053$), although there was a slightly positive relationship, primarily because long soak times are less likely to have zero catch (Figure 3). Because of the minimal effect of soak time, it was not taken into account in these analyses and catch per pot is used to represent catch per unit effort (CPUE).

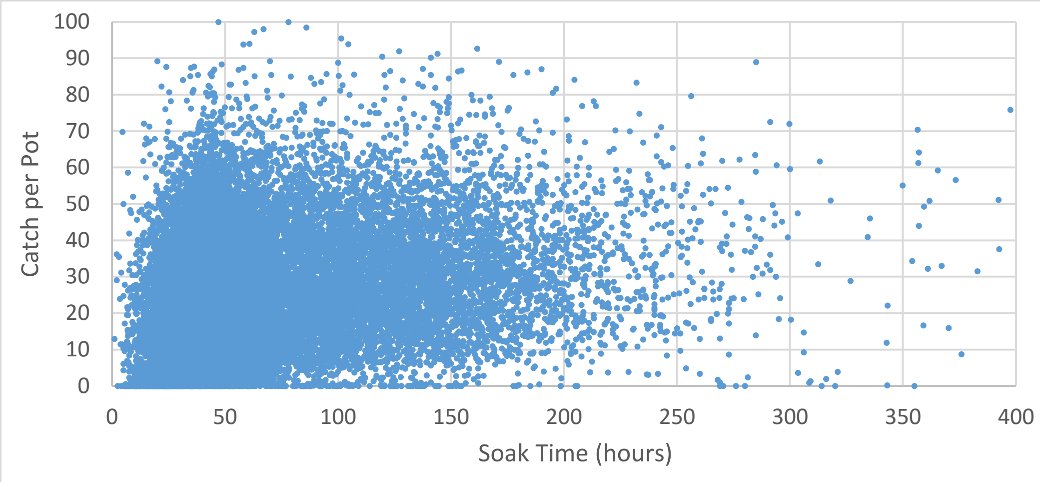

Figure 3: Catch per pot versus soak time for all years, 2005 - 2015

CPUE is used as a proxy for crab abundance throughout these analyses, although the limitations of this assumption are noted. All spatial analyses were conducted in ArcGIS 10.3, while other statistical analyses were conducted in R (version 3.2.5). Data were imported as line features because DFLs provide the coordinates of the first and last pot in each string and strings of pots are generally placed in straight lines. To eliminate biases from extreme values data were trimmed in two ways for spatial analyses. Firstly, only strings with more than 5 and no more than 100 pots were included. Extremely small strings have a small sample size and are likely to give highly variable values of CPUE and extremely large strings are unlikely to be set in straight lines and probably cover a much larger spatial area than can be understood by the two sets of coordinates given. In addition, strings with a linear length greater than 40 km were excluded because they did not provide good spatial resolution. The fishing location and catch information of crab vessels and processors is confidential. To maintain confidentiality, only results from an average of 3 or more vessels and processors are presented, and maps of point data were either interpolated using kriging or the points were aggregated into large polygons.

To elucidate patterns in crab distribution, we identified spatial clusters of high and low CPUE using the Getis-Ord Gi* statistic (Ord and Getis, 1995). This statistic measures localized spatial autocorrelation and can be used to identify statistically significant aggregations of high or low values, called “hot spots” and “cold spots”. We performed these analyses using the Hot Spot Analysis tool in ArcGIS. Hot spot analyses were run on string midpoints, because point data must be used for this analysis. The Gi* statistic identifies hot spots and cold spots by looking at the value of each feature and its neighbors and comparing those values to the global mean. For example, if a feature and its neighbors have high values than that feature is labeled as a hot spot. The size of the “neighborhood” must be specified, as it can drastically change the results. In general, a larger search radius around points (i.e., larger neighborhood) will help identify large-scale patterns and will produce larger hot spots, while a smaller search radius will identify local-scale patterns and will produce smaller hot spots. We used a search radius of 20 km in most analyses. This value was chosen for the following reasons: (1) as a fairly large value it could be used to identify large-scale patterns in crabs distributions that fishery management could respond to (i.e., changes in trawl closure areas), (2) the global spatial autocorrelation was maximized around 20 km for most years, which is considered ideal when running local statistics, and (3) as strings were up to 40 km long (mean 9.5 km), 40 km sets would fit within the 20 km search radius, because the midpoint of each set was used. To identify finer-scale patterns we also ran analyses using a 5 km and 10 km search radius for each year (not reported here).

Results

Before investigating spatial patterns, it was important to examine features of the data that could affect the interpretation of spatial results, especially as related to CPUE, catch, and effort and how they changed throughout the fishing season and among years. Firstly, the total allowable catch (TAC) has fluctuated between 20.4 (2007) to 7.8 (2011) million pounds of crab over the 11-year study period, which causes the differences seen in total catch (Figure 2). Changes in the TAC can affect the duration of the season and the average CPUE. Average CPUE varied between 18.5 (2010) and 34.1 (2015) (Figure 4). Since years with higher quotas could have the CPUE deflated throughout the longer fishing seasons as crabs are extracted, Figure 4 also shows the CPUE for the first 1 million crabs caught. Figures 5 shows how catch and effort accrue over the fishing season each year. Differences between the two can be explained by differences in CPUE; for example, the catch over time is almost identical for 2007 and 2008, but it takes far fewer pots in 2007 because the CPUE is higher.

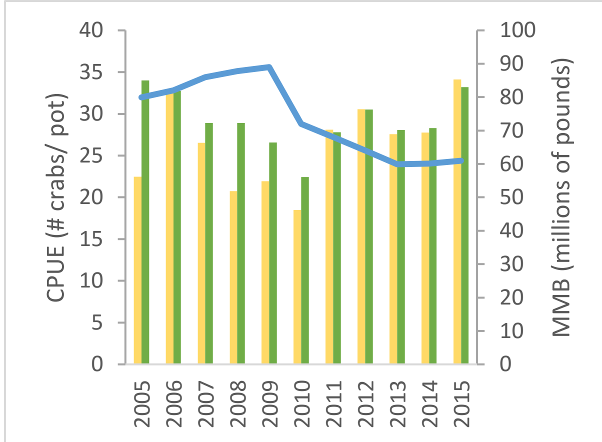

Figure 4: Bristol Bay red king crab average seasonal catch per unit effort (CPUE; yellow bars) and CPUE for the first 1 million crabs caught (green bars) from DFLS, also mature male biomass estimated in crab stock assessments (blue line)

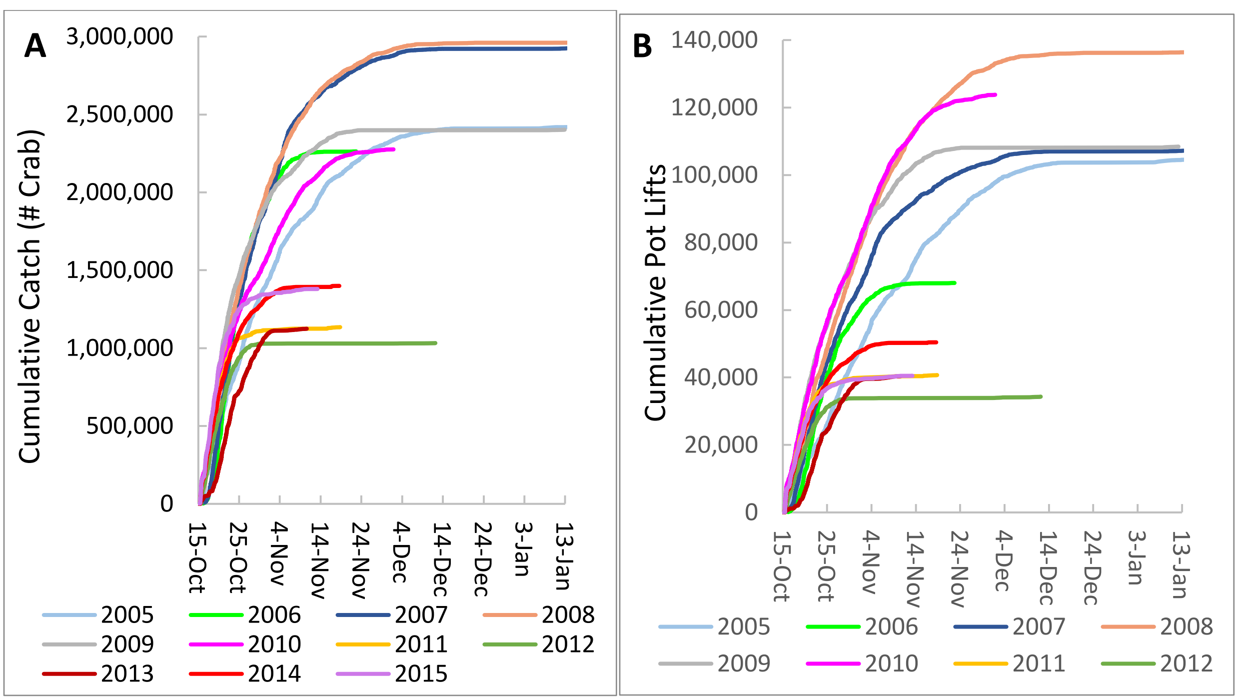

Figure 5: Trends in catch (A) and fishing effort (B) for the Bristol Bay red king crab fishery

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Spatial Analyses

Question 1: Across all 11 years where do aggregations of red king crab occur and how does this relate to current closure areas?

The hot spot analysis in Figure 6 shows statistically significant areas of high CPUE/crab abundance in red (hot spots) and statistically significant areas of low CPUE/crab abundance in blue (cold spots) on average over the 11 years. For this analysis I used a standardized CPUE; each CPUE was divided by the average CPUE for the corresponding year. I standardized the data because the average CPUE varied drastically between years, thus areas with relatively high CPUE in a low CPUE year would not necessarily be considered to have a high CPUE in other years and might not show up as hotspots. After standardization, all years should give equal weight in the analysis.

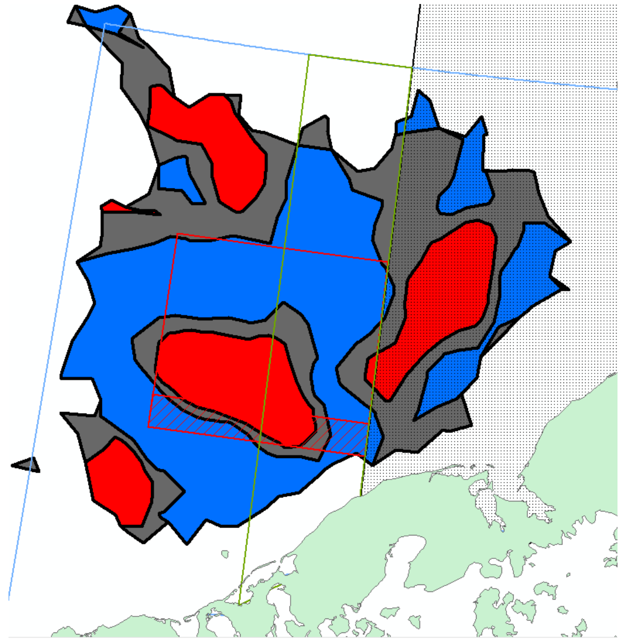

Figure 6: Getis-Ord hotspot analysis for Bristol Bay red king crab CPUE from 2005/06 through 2015/16 seasons; blue= statistically significant areas of low CPUE, red = statistically significant areas of high CPUE

These results indicate that over the past 11 years there are 4 large hotspots – one in the RKCSA, one in the nearshore closure area, and two in trawlable areas north and south of the RKCSA. The hot spot analyses by years (shown below) show that the northern hot spot is caused by only two years (2006 and 2007), as fishing does not generally occur this far north and west.

Question 2: What is the inter-annual variability in RKC fall/winter distributions?

Figure 7 shows hot spot analyses of CPUE by year for 2005 – 2015 using DFL data. We can see that 2005, 2014, and 2015 have similar patterns, with a single large hotspot in the RKCSA (especially in the southwest corner). In contrast, 2008 through 2013 have hot spots in a line along the Alaska Peninsula and further east in Bristol Bay; the exact locations and intensity change with the years, but in general there are hotspots as follows: (1) south of the western section of the RKCSA, (2) in the eastern side of the RKCSSA, and (3) east of the RKCSA. In 2006 there is a very different distribution, with a hotspot to northeast of the RKCSA. In 2007 there was a similar hot spot, although this year also has hotspots similar to 2008-2013. Figure 8 shows the hot spots for all years on one map, indicating the most important areas for red king crab.

NMFS summer bottom temperatures are shown in the corners of each map in Figure 7. Although these temperatures were not taken at the same season as our DFL data, there are some obvious general trends. The hot spots in 2005, 2014, and 2015 were very similar and these years were all “warm years”. The other years (except 2006), were also very similar and these years were "cold years" when the cold pool extends into Bristol Bay. The year 2006 was a transition year from a warm period (2001-2005) to a cold period (2007-2013).

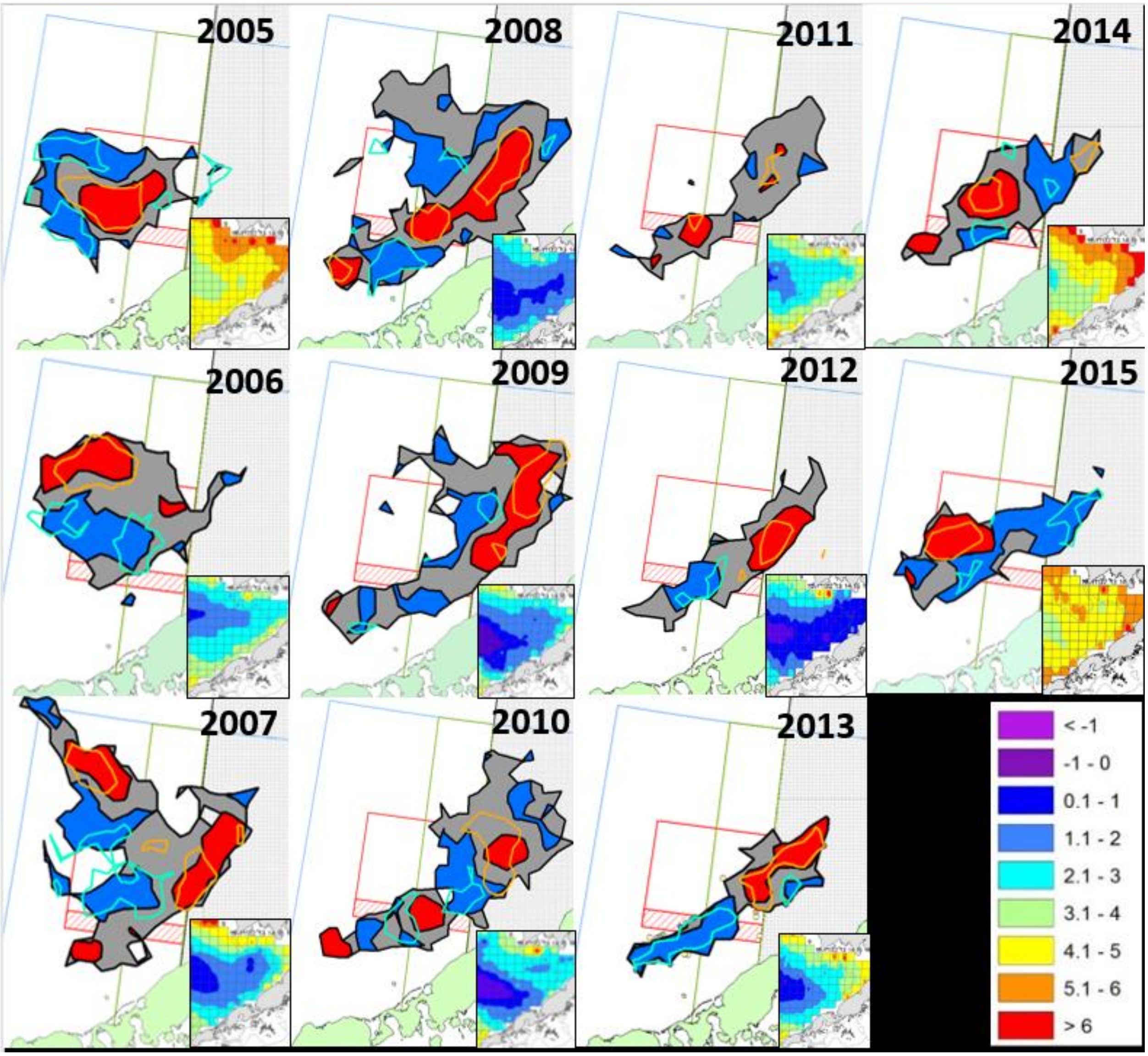

Figure 7: Hot spot analyses for 11 years, 2005 through 2015, using Daily fishing log (DFL) and observer data. DFL data is shown in solid polygons; blue= statistically significant areas of low CPUE, red = statistically significant areas of high CPUE, and gray = areas where fishing occurred but there was no significant difference in CPUE. Observer data is shown in hollow polygons; orange = statistically significant area of high CPUE, and turquoise = statistically significant area of low CPUE. Bottom temperature maps from the NMFS summer trawl survey (summer prior to fishery) are shown in the corner of each hot spot map.

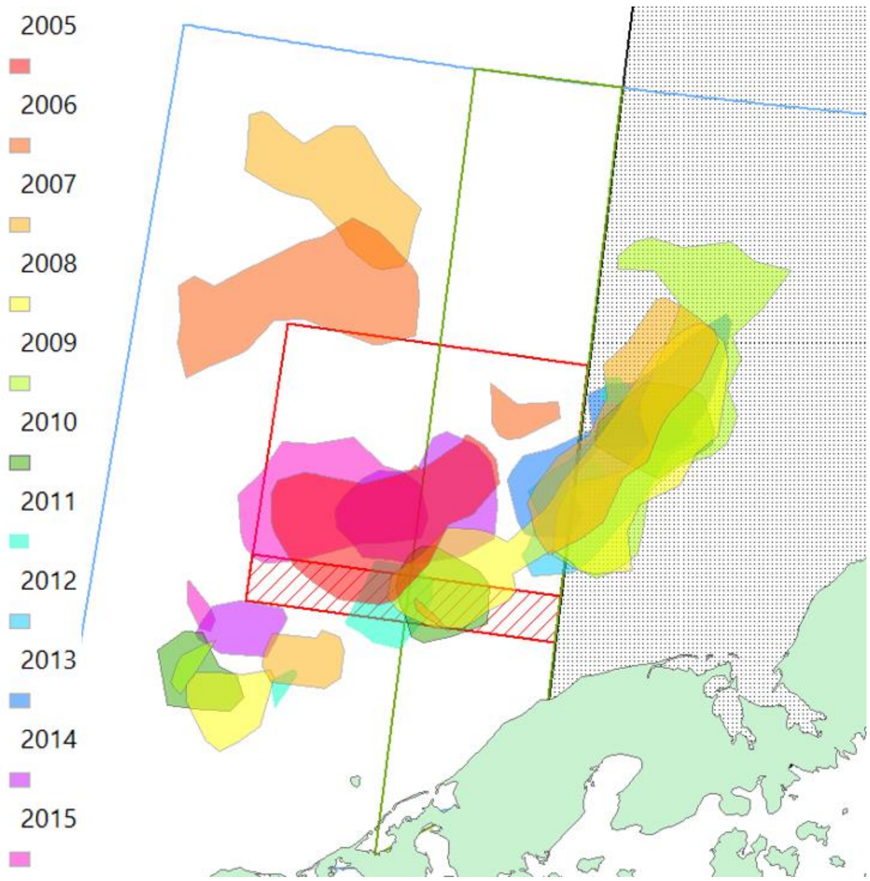

Figure 8: Hot spots from 2005 - 2015

Question 3: How does crab distribution shift between summer and winter?

Figure 9 shows summer distributions from NMFS surveys on top of hotspot analyses (interpolated), as well as the centers of distribution for both. DFL and NMFS data area at very different scales and the sampling locations differ dramatically; however, it is clear from these maps that there is a shift between summer and winter distributions. Summer survey data cannot be used to infer crab distributions during the fall/winter crab fishery.

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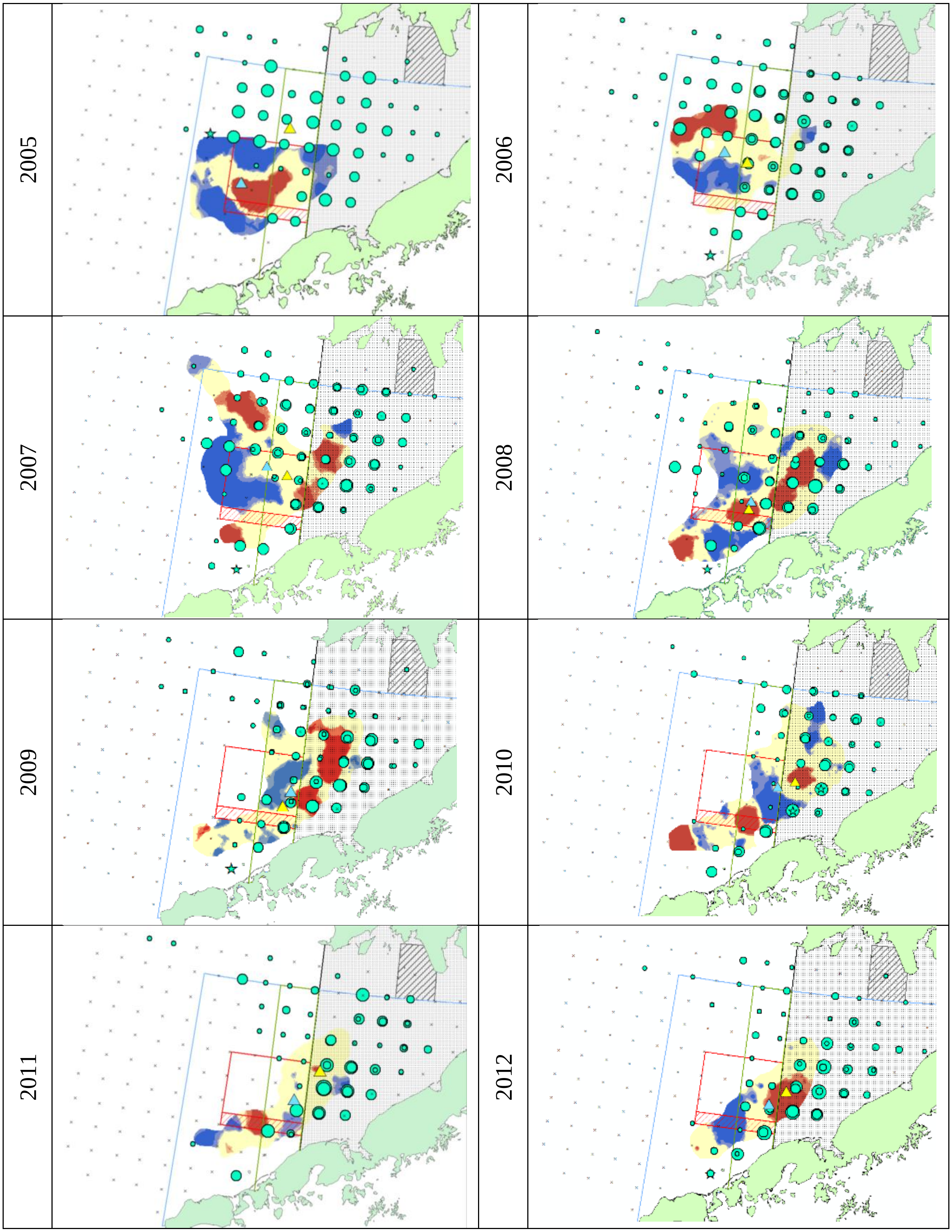

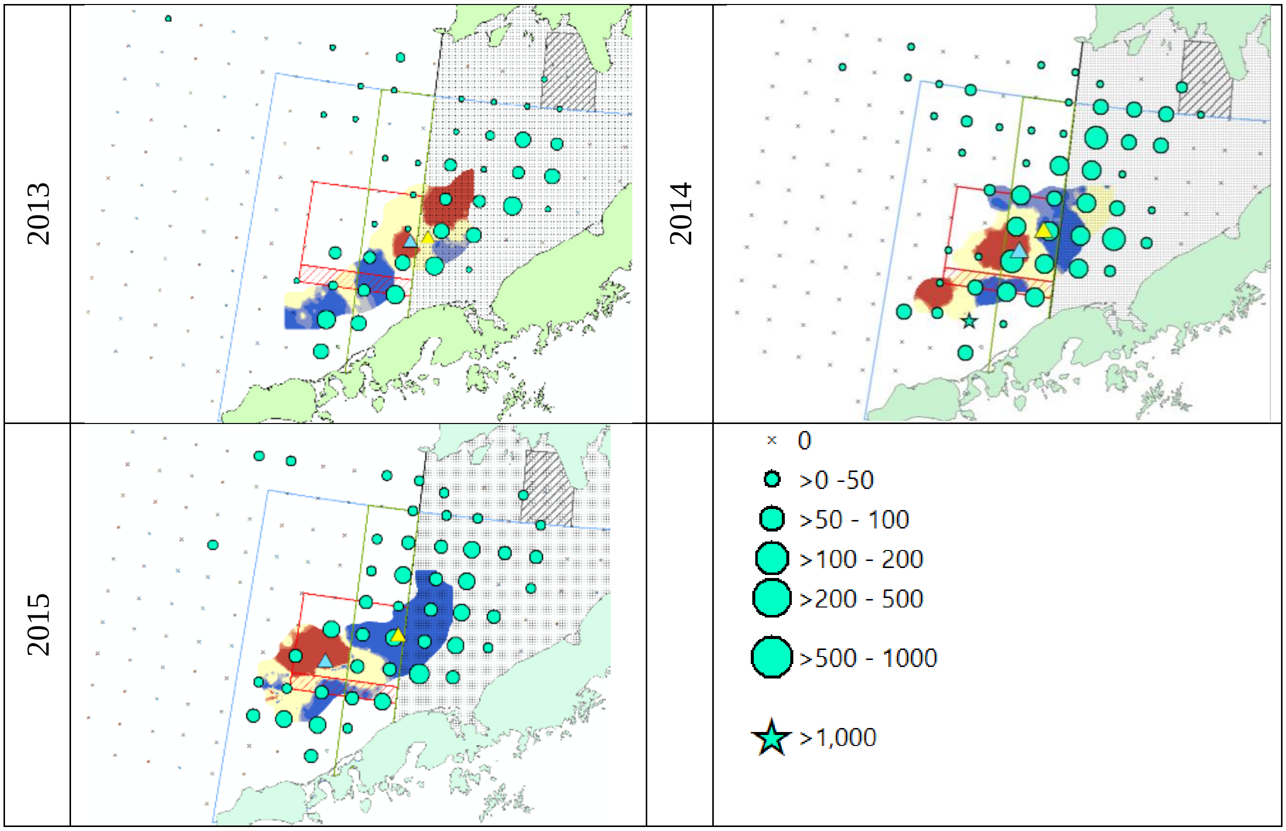

Figure 9: Hot spot analyses for 2005 – 2015 with summer NMFS survey data on legal male catch per kilometer (turquoise symbols) plotted on top; larger symbols represent higher catch. Light blue triangles are the centers of distribution for DFL data and yellow triangles are the centers of distribution for NMFS summer survey data.

DISCUSSION AND FUTURE WORK

Daily fishing logs provide a novel dataset that help elucidate the distribution of legal-sized male Bristol Bay red king crab during the fall fishery, when we lack detail distribution data from surveys. The DFL data include about 90% of the total catch annually, thus they can provide a clear picture of the spatial distribution of catch and effort each fishing season. DFL and observer data contain information from the same fishery, but these data are collected in a very different manner and the spatial accuracy of the sampling has not been evaluated for either. However, because hot spot analyses on observer and DFL data revealed very similar hot spots and cold spots, the accuracy of both data sets is verified.

Hot spot analyses of each year, from 2005 through 2015, indicate that areas of high crab abundance vary by year, particularly with warm and cold temperature regimes in the Bering Sea. In warm years there is generally one large hot spot within the RKCSA, while in cold years there are several hot spots along the Alaska Peninsula, within the RKCSA, south of the RKCSA, and within the near shore Bristol Bay closure area. Depending on the year, the subarea of the RKCSA may or may not have crab hot spots, thus trawl bycatch in the subarea may not be a reasonable proxy for bycatch within the core RKCSA. To further evaluate potential effects of trawling within the RKCSA, it would be helpful to examine bycatch rates in years when a crab hot spot occurred within the subarea of the RKCSA (e.g., 2008, 2010, and 2011).

If management goals are to maximize efficiency in the trawl fisheries, while minimizing the effects on king crab, then ideally trawl closure areas should be dynamic. Dynamic management of closure areas could rely on an environmental factor, like temperature, or the location of crabs earlier in the season (prior to the start of the trawl fishery). The hot spot analyses illustrate the importance of the RKCSA and other closure areas to crab during the crab fishing season (primarily Oct. and Nov.); however, most of the bycatch of Bristol Bay red king crab in trawl fisheries occurs in the rock sole fishery (Jan. to Apr.). Future work should determine if crab distributions are comparable between these time periods. If crab distributions are similar, then DFLs could be used to inform dynamic management of closure areas, either directly (closures based on crab distributions from DFLs) or indirectly (closures based on temperature regime, using patterns inferred from DFLs). A simple system for dynamic management would have only two closure options, one for “warm years” and one for “cold years”, which could be inferred from temperatures measured during the NMFS summer survey each year. A more complicated, yet detailed, form of dynamic management would use the crab distribution data from DFLs each crab fishery season to determine the specific placement of trawl closures each year. This latter approach would require that the crab fleet have electronic DFLs, which have not been implemented throughout the fleet.

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