2023 early-spring Cooperative Pot Sampling (CPS1) for Bristol Bay District red king crab (*Paralithodes camtschaticus*): design and preliminary results

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Abstract

Between 18 March and 4 April 2023, a total of 637 regularly-spaced stations placed along eleven transects in Bristol Bay (BB), Alaska, and covering an area spanning approximately 159° 39’ to 164° 16’ W lon, and from shallow waters north of the Alaska Peninsula BB to approximately 57° 50’ N lat, were fished using modified commercial crab pots (traps) in order to collect and sample red king crab (RKC) (*Paralithodes camtschaticus*) for a suite of biological attributes. A total of 10,191 RKC were captured at 450 (70.5%) of the survey stations: 76.8% (n = 7,824) of these crabs were male and 33.2% (n = 2,367) were female. The carapace length (CL) of all RKC was measured and shell conditions recorded. Females were examined to determine maturity status and the egg clutches carried by mature females were evaluated for volume and developmental stage. Pop-up Archival Transmitting (PAT) tags were deployed on 100 mature-size male RKC that had recently molted and were in a new hard-shell condition. Male RKC ranged from 17.6 – 190.2 mm (0.69 – 7.49”) CL: 36.1% (n = 2,824) were immature-size (<120 mm (4.7”) CL); 63.9% (n = 4,999) were mature-size (≥120 mm (4.7”) CL); 44.7% (n = 3,497) were legal-size (≥135 mm (5.3”) CL). Female RKC ranged from 57.0 – 174.6 mm (2.24 – 6.87”) CL: 81.7% (n = 1,934) of these individuals were determined to be morphometrically-mature. Immature females ranged in size from 57.0 – 99.9 mm (2.24 – 3.93”) CL and mature females from 82.1 – 174.6 (3.23 – 6.87”) mm CL (Fig. 12). No molting males and only five molting females were captured, the latter of which were all immature. No barren mature females were encountered. Overall, 43.5 % of mature females carried egg clutches that were approximately three-quarters full and 53.0% carried full clutches. Spatial distribution of mature-sized males and females did not appear to depart markedly from those which were observed during the subsequent (2023) National

Marine Fisheries Service trawl survey. However, for immature crabs of both sexes, the CPS1 distributions appear more similar to the 2023 trawl survey plots than to 2022. For crabs of mature and legal sizes, distributions observed during spring pot sampling appear somewhat less patchy than suggested by the summer trawl survey data. Across all demographics, the majority of crab were caught within the Nearshore Bristol Bay Trawl Closure Area (NBBTCA): 66% of all RKC were captured in the NBBTCA and percentages by demographic ranged from low of 61.7% for legal-sized males to a high of 75.8% for mature females. For males, just under 20% of individuals were encountered in the Red King Crab Savings Area (RKCSA). For females, the proportion of crab captured inside the RKCSA was 17.4% for mature individuals versus 7.6% for immature crabs. In addition to RKC, 570 Tanner crabs (*Chionoecetes bairdi*) were captured at 227 stations; 2,393 yellowfin sole (*Limanda aspera*) were captured at 420 stations; and 1,728 Pacific cod (*Gadus macrocephalus*) were captured at 510 stations. Smaller numbers of snow crab (*Chionoecetes opilio*), Tanner-snow crab hybrids, horsehair crab (*Erimacrus isenbeckii*), and Pacific lyre crab (*Hyas lyratus*) were encountered, in addition to great sculpin (*Myoxocephalus polyacanthocephalus*), walleye pollock (*Gadus chalcogrammus*), Pacific halibut (*Hippoglossus stenolepis*), northern rock sole (*Lepidopsetta polyxystra*), starry flounder (*Platichthys stellatus*), Alaska plaice (*Pleuronectes quadrituberculatus*), Alaska skate (*Bathraja parmifera*), unidentified skates (Rajidae), and sunflowers seastars (*Pycnopodia helianthoides*). Tags deployed on new hard-shell, mature-sized male RKC for 57 – 75 days had a 91% success rate in providing reliable locations with minimal error ellipses. There was a high degree of variability in direction of movement among individuals, but movement rates averaged 0.83 ± 0.50 km/day (0.45 ± 0.27 nmi/day), with a range of 0.08 to 2.53 km/day (0.04 to 1.37 nmi/day), and a prevailing overall trend of movement to the north and northeast.

Introduction

Red king crab (*Paralithodes camtschaticus*: hereafter "RKC") formerly represented one of the most lucrative fisheries in the Bering Sea and Gulf of Alaska. Following rapid capitalization, the Bristol Bay (BB) fishery exploded in the late 1970s with catches peaking at nearly 70,000 tons (63,500 mt), supported by a mature male biomass that is estimated to have been ~130,000 tons (118,000 mt) (Zacher et al. 2023). However, in the early 1980s, BBRKC productivity collapsed by an order of magnitude, culminating in closure of the directed fishery in 1983. Fishing resumed the following year, but exploited a population that was composed of a considerably lower biomass of both mature-size males (i.e., ≥120 mm (4.7”) carapace length (CL)) and reproductively-mature females (Fig. 1). Since the population collapse of the early 1980s, stock abundance has been relatively low and variable, with the abundance of legally-harvestable males (i.e., ≥135 mm (5.3”) CL or ≥165 mm (6.5”) carapace width (CW)) fluctuating between a low of approximately 5,400 tons (4,900 mt) in 1985 and a high of ~52,000 tons (47,000 mt) in 1991 (Zacher et al. 2023). The 1991 peak had appeared to represent a period of stock recovery, but the fishery was closed for a second time in 1994 due to declining female spawning biomass and remained closed in 1995. This second closure period led to the adoption of a rebuilding plan, supported by the development of a length-based stock assessment model (Zheng et al. 1995a, 1995b) and a formal management strategy evaluation (Zheng et al. 1997a, 1997b). A modest increase in RKC abundance followed and continued through the early 2000s. However, a declining trend in total biomass has been observed in recent years for both mature males and females, with the decline in the males beginning in approximately 2004 and since at least 2014 for females (Fig. 1). The 2021 female spawning stock biomass is estimated to have been at its lowest level since 1995 (Zacher et al. 2023) and the fishery was once again closed for the 2021 fishing season; it remained closed in 2022 in the face of an increase in estimated mature female biomass of less than 4% relative to 2021 (Zacher et al. 2023).

In response to the consecutive closures of the BBRKC fishery in 2021 and 2022, in September 2022 the Alaska Bering Sea Crabbers (ABSC), a trade organization representing Bering Sea crab harvesters, submitted a petition to the North Pacific Fishery Management Council (NPFMC; the “Council”) requesting short-term emergency action to protect RKC and crab habitat from fisheries-induced disturbances. Management of commercial fisheries in the BB District has a long history of restrictive measures that have resulted in the establishment of a series of closure areas in which the activities of various harvest sectors are limited. Four closure areas (Fig. 2) are of particular relevance to the management of BBRKC:

1) Bycatch Limitation Zone 1 (BLZ1), encompassing BB waters north of the Alaska Peninsula, south of 58° 00’ N lat, and east of 165° 00’ W lon; this is further divided into Reporting Area 516 spanning 162° 00’ to 163° 00’ W lon and Reporting Area 509 spanning 163° 00’ to 165° 00’ W lon;

2) the Red King Crab Savings Area (RKCSA), spanning 56° 00’ to 57° 00’ N lat and 162° 00’ to 164° 00’ W lon;

3) the Red King Crab Savings Subarea (RKCSS), defined as waters within the RKCSA between 56° 00’ and 56° 10’ N lat, and;

4) the Nearshore Bristol Bay Trawl Closure Area (NBBTCA), defined as all BB waters east of 162° W lon, within which lies the Northern Bristol Bay Trawl Area (NBBTA), located to the south and west of the Nushagak Peninsula, spanning 58° 00’ to 58° 43’ N lat and 159° 00’ to 16° 00’ W lon.

BLZ1 was the first of these management areas to be established, via Amendment 10 to the Bering Sea and Aleutian Islands (BSAI) Groundfish Fishery Management Plan (FMP). Amendment 10 was first enacted via emergency rule on June 3, 1986 (US Department of Commerce 1986) and permanently adopted in March of 1987 (US Department of Commerce 1987). The Amendment addressed concerns that bycatch of RKC and Tanner crabs (*Chionoecetes bairdi*) by domestic and joint-venture groundfish trawl fisheries was contributing to low crab abundance. Amendment 10 closed a section of BLZ1 (waters between 160° 00’ W and 162° 00’ W lon, from the Alaska Peninsula in the south to 58° 00’ N lat.) to trawling year-round. Areas immediately to the east and west within Bristol Bay, the former extending to the Alaska Peninsula and the latter to 162° 00’ W lon remained open to trawl fisheries but with bycatch limits for RKC and Tanner crabs established for both domestic and foreign fleets targeting yellowfin sole (*Limanda aspera*) and other flatfish. Amendment 12A, enacted in 1989 (US Department of Commerce 1989), established Statistical Area 516 spanning 162° 00’ to 163° 00’ W lon and closed that area to all trawl gear between March 15 and June 15 each year, with an exception for directed fishing for Pacific cod (*Gadus macrocephalus*) along the Alaska Peninsula, south of a line running from northeast to southwest and approximating waters shallower than 25 fathoms, subject to a bycatch cap of 12,000 red king crabs. Between 160° 00’ and 162° 00’ W lon, the Amendment allowed the Secretary of Commerce to authorize trawl fishing for Pacific cod “*provided that such fishing is in compliance with a scientific data collection* *and monitoring program, established by the Regional Director after consultation with the Council*". Currently, Area 516 of BLZ1 is closed to all trawling from March 15 through June 15 (US National Archives and Records Administration 2023).

The RKCSA was first established by emergency interim rule in January 1995, in response to the RKC fishery closures of 1994-95. It closed the area to all trawl gear from January 20 through April 25, 1995, "*to conserve the female red king crab stocks in the Bristol Bay area*" (50 CFR Parts 675 and 677; US Department of Commerce 1995a). That December, the closure was formalized as an inseason adjustment spanning January 20 through March 31, 1996, with the stated objective of preventing "*an excessive share of red king crab from being taken by the groundfish trawl fisheries early in the fishing season*" (50 CFR Part 675; US Department of Commerce 1995b). The December action redefined the closure as applying only to "*directed fishing for groundfish by vessels using other than pelagic trawl gear*". Further modifications occurred in January 1996 (50 CFR Part 679; US Department of Commerce 1996) and included the establishment of the RKCSS. In consideration of the area's importance to rock sole (*Lepidopsetta polyxystra*) fisheries, the RKCSS was to "*remain open to nonpelagic trawling for groundfish during the years in which a guideline harvest level for Bristol Bay red king crab is established*." Within this area, a separate prohibited species catch (PSC) limit was established that was constrained to no more than 35% of the total PSC apportioned to the rock sole fishery in any given year. The same ruling also established the Nearshore Bristol Bay Trawl Closure Area (NBBTCA,) in which all trawling was prohibited except with within the Northern Bristol Bay Trawl Area (NBBTA): in the NBBTA, trawling was allowed from 1200 hr on April 1 through 1200 hr on June 15 of each year (US Department of Commerce 1996). Although not explicitly stated as justification within the ruling, the decision to allow trawling within the NBBTA appears to have been in response to written public commentary that suggested that "*Support exists for … leaving open the subarea between 58° and 58°43' N. lat, which is a productive yellowfin sole fishing ground*", and to which NMFS indicated agreement.

ABSC's 2022 petition requested that that the RKCSA and RKCSS be closed to all fishing gears from January 1 to June 30, 2023, by emergency rule. The NPFMC declined to enact the proposed rule. However, it passed a motion (i.e., D2 Council Motion BBRKC; available at: https://meetings.npfmc.org/CommentReview/DownloadFile?p=1f631d76-5e1f-4d3b-b36cfa0509c60972.pdf&fileName=D2%20

Council%20Motion% 20BBRKC.pdf) at its October 2022 meeting that encouraged the development of "*methods to gather data on interannual and seasonal distribution of crab, such as additional surveys and tagging studies*". A prior discussion paper, prepared for the Council's April 2022 meeting (Cunningham and Cates 2022), had sought to provide "*information on Bristol Bay red king crab molting/mating annual cycle and how seasonality of this overlap with fisheries*" and to provide guidance regarding "*responsive spatial management measures … and how they might be applied to protect BBRKC.*" A subsequent analysis responding directly to the ABSC's emergency rule request (Cates et al. 2022) identified a lack of objective, quantitative information on RKC distributions that could be used to guide bycatch avoidance throughout the year. In particular, the most unbiased information on RKC distributions is obtained from the NMFS trawl survey; but, such data represent only snapshots of summer distribution. Data obtained from the directed fishery provide insight into the seasonal redistribution of legal-size males (Zacher et al. 2018); but, these data fail to represent other demographics (i.e., sex, size, or maturity categories) of interest, such as female spawning stock and sublegal-size individuals of both sexes. Additional information regarding seasonal redistribution and migration patterns is needed.

Seasonal migration is a common feature of commercially-exploited marine species that reside in the Bering Sea and Aleutian Islands region, including walleye pollock (*Gadus chalcogrammus*; Kotwicki et al. 2005), Pacific cod (Bryan et al. 2021), Pacific halibut (*Hippoglossus stenolepis*; Loher 2022), and snow crab (*Chioneocetes oilio*; Nichol and Somerton 2015). For RKC, seasonal migration of reproductive females has been documented in southeast Alaska using acoustic tags (Stone et al. 1992). Analyses of fishery logbook and catch data (Zacher et al. 2018) have suggested that legal-size male crabs in Bristol Bay are found farther to the south and west in autumn than during the summer, and/or farther from the Alaska Peninsula. These data also demonstrate that the relative proportion of legal-size males taken from trawl-exclusion areas varies interannually, likely as a function of temperature. Sex-specific differences in migratory behavior may arise from differences in life history between the sexes. For example, egg-bearing females may be more limited in their abilities to move because they need to remain at temperatures that allow for successful embryo development. In contrast, males may be able to redistribute throughout the year in order to find habitat that represents a metabolic thermal optimum for feeding and growth (*sensu* Hernández-Sandoval et al. 2018). Regardless of the drivers that are involved, RKC distribution within

Bristol Bay is not likely to be static throughout the year and summer survey data may be insufficient to provide year-round guidance for avoidance of RKC bycatch at optimal spatial and temporal resolutions.

In addition to obtaining survey data outside of the summer season, Pop-up archival transmitting (PAT) tags can be a powerful tool for studying the movement and environmental conditions experienced by animals in cases in which data that span specific periods of time are desired. PAT tags are electronic tags that contain a sensor package, an automated release mechanism, and satellite-broadcast capabilities, allowing for environmental data to be collected while attached to the host animal and recovered via satellite telemetry. Broadcast dates (and, hence, period at liberty) may be pre-specified, and the tag's final position is determined by the receiving satellite's use of the Doppler shift in the received signal (Keating 1995). This has the advantage of allowing for determination of final location even if individuals move to areas absent of fishery effort or where reporting of physical recoveries is reduced (e.g., in Russian waters for animals tagged in Alaska). Additionally, locations during time at liberty can, under ideal conditions, be inferred from archived light data (*sensu* Block et al. 1998; Loher 2022) and may allow for state-space modelling of movement (Pederson et al. 2018; Nielsen et al. 2019) that cannot be achieved using conventional mark-recapture data. Satellite-tagging studies of BBRKC were first initiated in July 2020 to study intra-annual movement patterns and the seasonal use of trawl closure areas. Initial work focused on summer to fall movement of mature-size males to compare data derived from the fall directed fishery to tagging. More recently, efforts have focused on elucidating movement into winter and spring, which are particularly important seasons for red king crab, encompassing molting, larval release, and mating, as well as being a period of higher bycatch in trawl fisheries. From 2020 through 2022, 470 satellite tags have been deployed on eastern Bering Sea red king crab (225 females, 245 males) through collaborate research between NMFS, the Alaska Department of Fish and Game (ADF&G), and the Bering Sea Fisheries Research Foundation (BSFRF). However, our understanding of the seasonal distribution of BBRKC males and females in the winter/spring is still incomplete. Using satellite tags on males and primiparous (i.e., first-spawning) females is challenging because tag attachment does not allow tags to be retained through the molt and these crab molt in late winter (~February). Multiparous females (i.e., individuals that have spawned previously) molt later in the spring and, thus, tags can be left on these animals for longer periods; but, scaling individual movement vectors to population level distribution patterns is challenging.

In the current study, a sampling project employing modified commercial king crab pots (traps) was executed during early spring, 2023, within a portion of the Bristol Bay RKC management district to: a) evaluate crab distribution in comparison to those observed during summer trawl surveys; b) investigate maturity, molting, and reproductive status, and; c) tag mature-size male red king crabs with satellite-transmitting archival tags programmed to detach and report during the summer of 2023, coincident with the prosecution of the summer trawl survey.

Methods

Survey design and pots

The complete survey design was composed of a total of 694 stations arranged in eleven transects, each running approximately north-to-south, with transects separated by 15.0 nmi (27.7 km) and spanning approximately 159° 39' to 164° 16' W lon from east to west (Fig. 3). Individual stations were positioned 2 nmi (3.7 km) apart along each transect and the transects extended from shallow waters (i.e., minimum depths of 14 fm (26 m)) in southern BB to approximately 57° 50' N lat. This design resulted in a grid that covered approximately 35% of the spatial extent of the BBRKC management District and falling within an area that during the NMFS EBS Continental Shelf summer trawl survey (Zacher et al. 2023) is represented by 47 trawl stations. Over the last 10 years, this area has contained, on average, 91 ± 1 % of all mature female and 83 ± 2 % of all mature-sized male RKC that have been captured during NMFS EBS summer trawl surveys.

Fishing was conducted by two vessels (Fig. 4):

1) the FV *Silver Spray*, a 130-ton (118 mt), house-forward crab vessel measuring 116' (35.4 m) in length overall (LOA) and 30' (9.1 m) beam; homeport Kodiak, AK, and;

2) the FV *Summer Bay*, a 196-ton (178 mt), house-aft crab vessel measuring 107' (32.6 m) LOA and 26' (7.9 m) beam; homeport Dutch Harbor, AK.

At each station that was fished during the pot survey, latitude and longitude of pot-setting was recorded to the nearest 0.01' as determined by the GPS unit on the vessel's bridge and recorded at the vessel's position when the pot first landed in the water. Water depth at the same position, according to the depth sounder on the bridge, was recorded to the nearest 0.1 fathoms (~0.2 m) and time set and hauled were recorded, to the nearest minute, as the time that the pot left the pot launcher until hauling began, defined as the time when line retrieval via the pot hauler was initiated.

Fishing was conducted using modified, square commercial king crab pots. The pots used on both vessels were constructed of a double frame: an outer frame composed of 1.5” (38 mm) round steel rod; and an inner frame, which supported the pot’s webbing, composed of 0.75” (19 mm) round steel rod (Fig. 5). On the *Silver Spray*, the outer frame measured 80.5” (2.05 m) square by 33” (0.84 m) tall and the inner frame was 77.25” (1.96 m) square by 31” (0.79 m) tall; on the Summer Bay, the outer frame measured 84” (2.1 m) square by 34” (0.86 m) tall and the inner frame was 78” (2.0 m) square by 32” (0.81 m) tall. The double-frame design of these pots allows for the outer frame to take the landing force and abrasion of the seabed while protecting the pot’s webbing from damage. All pots contained two rectangular funnels on opposing sides of the pot. The funnels spanned the entire width and height of the pot wall at their outer opening and tapered to a rectangular opening inside of the pot. Each funnel was upward-sloping (i.e., the floor of the funnel was longer than its roof) and the opening was mounted in the funnel’s roof such that the funnel’s opening pointed largely upwards (Fig. 5, *upper*). On the *Summer Bay*, the funnel openings measured 38” (96.5 cm) by 11” (28.0 mm) and extended a maximum distance of ~28” (70 cm) into the pot at the lower lip of the opening, which was positioned approximately 22” (56 cm) above the floor of the pot (i.e., this is the distance that a crab would “drop” upon entering an empty pot) (Fig. 5). The funnels of the pots used by the *Silver Spray* were of slightly-variable specifications: funnel width was 34.5” (87.6 cm) with heights ranging from 7.5” to 9” (19.0 to 22.0 mm); the funnels extended a maximum distance of 23.25” (59.0 cm) into the pot at the lower lip of the funnel’s opening and were positioned between 16” and 20” (40.6 to 50.8 cm) above the floor of the pot. Funnels on the pots used by the *Summer Bay* were not fitted with triggers or funnels. Some pots used by the *Silver Spray* were fitted with plastic funnel hoods; however, these hoods were propped open (Fig. 5) in order to disable them and not impede the entry of crabs into the pot (Fig. 5). On pots used aboard the *Silver Spray*, the body was lined with 5.25” (13.3 cm) stretched-mesh webbing and the funnels lined with 3.75” (9.5 cm) stretched-mesh webbing. The *Summer Bay*’s pots used 4” (10.2 cm) stretched-mesh webbing on the body and 3.5” (9.0 cm) by 2.5” (5.1 cm) stretched-mesh webbing to line the funnels. These webbing sizes are smaller than used on red king crab pots during commercial fishing, which are required to contain at least one panel composed of a minimum of 9” (22.9 cm) stretched-mesh. Smaller meshes were employed herein to enhance the retention of sublegal-size and juvenile crabs. Where pots had been constructed with escape rings, these were covered by webbing and therefore not functional; again, this was to prevent small crabs from escaping the pots. All pots were equipped with a section of webbing that was secured with biodegradable cotton twine, which would degrade and allow crabs and other bycatch to escape from the pots if they were lost on the grounds. Pots weighed between 760-810 pounds (345-367 kg), unbaited.

Each pot was baited using approximately eight pounds (3.6 kg) of fresh-frozen (i.e., unsalted), chopped Pacific herring (*Clupea pallasii*) that was contained a single 14” x 18” (36 cm x 46 cm) bait bag hung from the center of the pot’s roof (Fig. 5, *upper*) and introduced into the pot through a side-panel that also served as the door for emptying the pot of its catch (Fig. 5, *lower*). Each pot contained a bridle that was attached to two “shots” (i.e., 33 fm (60 m)) of buoy line: one shot of sinking (nylon) line was attached to the pot bridle and one shot of floating (polypropylene) line led from the sinking line to the first pot buoy. Two buoys were employed: an A3 “diver” buoy (i.e., measuring approximately 17” (43 cm) in diameter and 23” (58 cm) long, including the eye, and containing ~14.5 gal (55 l) of air); followed by a shorter length (~10 fm; 18 m) of floating line that led to an LD2 (11” (28 cm) by 24” (61 cm)) trailer buoy. In addition, the *Silver Spray* employed a standard 12” (15 cm) by 6” (30 cm) cork as a third and final buoy. When fishing particularly shallow stations, the *Silver Spray* removed one shot of buoy line.

Oceanographic sampling

Oceanographic conditions and depths fished were monitored using dataloggers affixed to the pots. A combination of three models of datalogger manufactured by RBR Ltd. (Ottawa, Ontario, Canada; https://rbr-global.com/about-rbr/contact-rbr/) were employed: 1) XR-420-CTD (n = 11); 2) RBR*duet* TD (n = 6), and; 3) TDR-2050 (n = 4). The XR-420-CTD is a cylindrical unit that measures 310 mm (12.2”) in length and 64 mm (2.5”) in diameter and records temperatures between -5° and 35° C (23° and 95° F) at a resolution of <0.00005° C (<0.00009° F) and nominal accuracy of ±0.002° C (0.0036° F); and conductivities (i.e., salinities) from 0 to 85 mS/cm at 0.01 resolution and nominal accuracy of ±0.003

mS/cm at 35 psu and 15° C (59° F). The RBR*duet* TD is a cylindrical unit that measures 200 mm (7.9”) in length and 25.4 mm (1.0”) in diameter and records temperature at the same resolution as the XR-420-CTD. TDR-2050s were the manufacturer’s precursor to the RBR*duet*, measured 235 mm (9.3”) by 38 mm (15.2”) and recorded temperature at resolutions equivalent to the RBR*duet*. The majority of loggers (n = 19) were equipped with pressure transducers rated to 2,000 decibar (where 1 dbar of pressure is nearly equivalent to 1 m (3.28’) of seawater); each vessel carried a single logger with a 1,000-dbar transducer. These transducers were capable of determining water depth to a resolution of <2 m (<6.56’) at a nominal accuracy of 1 m (3.28’); and a resolution of <1 m (<3.28’) at a nominal accuracy of 0.5 m (1.64’), respectively. All loggers were owned and administered by ADF&G who routinely return the units to RBR for calibration every three years, on a rotating basis. For deployment, loggers were placed inside the crab pots, attached to their roof (Fig. 6), and programmed to record each measured parameter at 10-minute intervals throughout the pot soak.

RKC sampling

All RKC that were captured were processed and biological data collected from each crab. Subsampling protocols were developed in case larger numbers of crabs than could reasonably be processed were captured at any individual station; however, these protocols did not need to be employed. The carapace length (CL) of each RKC was measured to the nearest 0.1 mm as the distance across the crab’s dorsal surface from the center of the posterior margin of the carapace to the base of one of the eye orbits at the base of the rostrum (Fig. 7, *upper*). Measurements were taken using a variety of mechanical and digital calipers (Fig. 7, *lower*): 1) Mitutoyo Research and Development (Kirkland, Washington, USA) mechanical Vernier calipers; 2) Sylvac (Fowler High Precision, Canton, Massachusetts, USA) S_Cal Pro digital calipers, and; 3) iGaging (San Clemente, California, USA) Absolute Origin IP54 0-12” bluetooth-enabled digital electronic calipers.

RKC were identified by sex and additional data were collected depending upon the sex of the individual. Shell condition in female RKC may be an indicator of imminent breeding potential, as female RKC do not store sperm (i.e., unlike Tanner and snow crabs (*Chionoecetes opilio*); Adams and Paul 1983, Saint-Marie and Lovrich 1994) and must therefore mate during each year’s molting cycle. Shell hardness may affect a crab’s vulnerability to fishing gear and subsequent probability of survival following return to the sea (*sensu*

Stoner et al. 2008, Yochum et al. 2017), and shell condition in both sexes is used as an input in stock assessment models as it may be a predictor of parameters such as molting probability, growth increment, and mortality rates (Zheng et al. 2021). For all crabs, shell condition was assigned to one of the following categories, consistent with the descriptions found in Donaldson & Beyersdorfer (2003): 0 = premolt or molting; 1 = recently-molted, soft and pliable; 2 = new hard-shell, both firm and clean; 3 = old-shell, slightly worn; 4 = old-shell, worn; 5 = very old-shell. Note that shell hardening in RKC is a progressive process in which the shell can require in excess of two months postmolt to achieve full harness (Stevens 2009). Evaluation of whether any given shell was "pliable" during the current survey was determined subjectively; i.e., no quantitative measures of shell "hardness" (e.g., via durometer readings: Stevens 2009) were used to determine the division between Shell Conditions 1 and 2.

For mature female RKC, a given individual's reproductive status and position in the molt-mate cycle can be inferred from an examination of the eggs that she bears. Completion of the molt-mate cycle is indicated by uneyed (i.e., recently-extruded) eggs. Conversely, the presence of eyed eggs (i.e., containing visible embryos), hatching eggs, or empty egg cases indicate the progression of egg incubation toward and through larval release; and absence of eggs in morphologically-mature females (a.k.a. "barren") may be an indicator of reproductive failure (e.g., environmentally- or physiologically-induced (Ganji 2011) skipped spawning (*sensu* Jørgensen et al. 2006), or a relative lack of suitable mates (*sensu* Baker et al. 2022)). For female RKC, egg clutch assessments were conducted as per NMFS EBS trawl survey protocols (Zacher et al. 2023). The presence or absence of eggs was noted and the development stage (i.e., egg "condition") and the size of each egg clutch was recorded. Egg condition categories were defined as follows: 0 = no eggs; 1 = uneyed; 2 = eyed; 3 = dead; 4 = empty egg cases; 5 = hatching. Determination of the presence/absence of "eyes" (i.e., developing embryos) within the eggs was conducted with the naked eye and did not employ magnifying devices. Clutch size categories were defined relative to the expected size of a full clutch, where a full clutch is expected to fully cover the abdomen and causes considerable distension of the abdominal flap due to its mass (Donaldson and Beyersdorfer 2003). Clutch fullness was assigned to the following categories: 0 = no eggs, crab is immature; 1 = mature crab with no eggs; 2 = trace to 1/8 clutch; 3 = 1/4 clutch; 4 = 1/2 clutch; = 3/4 clutch; 6 = full. Assignment to a clutch fullness category was subjective (i.e., no empirical volumetric measurements were taken) and each crab was assigned to the fullness category that came closest to its estimated clutch size (e.g., a female whose clutch appeared to be 60% full would be assigned category “4” because it is closer to 50% than to 75%). For female RKC that were not egg-bearing, maturity was determined on the basis of ventral anatomy, according to Donaldson and Beyersdorfer (2014). In mature females, the abdominal flap entirely covers the first coxa (i.e., basal section) of each of the walking legs, whereas in immature individuals the abdominal flap is relatively small and the coxae of the walking legs are exposed.

For male lithodid crabs, morphometric maturity may be inferred from changes in chela (claw) height relative to carapace length and width (*sensu* Olsen 2016) and physiological maturity is indicated by the development and presence of spermatophores (Filina 2011). However, for regulatory purposes, ADF&G simply defines “mature” as meaning “*male red king crab that are 4.7 inches (120 mm) or more in carapace length*” (ADF&G 2023). For male RKC, we will follow that convention to facilitate comparisons between results of the current survey and both ADF&G and NMFS documents describing similar aspects of the stock. By extension, we will refer to all male RKC that are <120 mm (<4.7”) CL as “immature-size”, regardless of their functional abilities to reproduce. Finally, males ≥135 mm (5.3”) CL will be referred to as “legal-size” males, as this currently represents the minimum size for retention in the directed fishery.

All RKC were visually inspected for signs of disease and, if noted, the apparent nature of the disease was recorded. Specifically, crab were scanned for the following pathologies: 1) bacterial shell disease (Meyers and Burton 2009); 2) rhizocephalan barnacles (esp. *Briarosaccus* spp.; Sheilds 2012, Sloan and Hardy 2017); 3) cottage cheese disease (i.e., microsporidian infection; Stentiford et al. 2014); 4) leatherback (i.e., incomplete calcification of the exoskeleton; Morado et al. 2014), and; 5) snailfish (Liparidae) eggs (Gardner et al. 2016).

Bycatch sampling

At each station, all crabs were sorted by species. Hybrid crabs representing a cross between Tanner and snow crab were identified by a combination of characteristics including curve of the epistome margin, eye color, carapace shape, and space between or shape of the rostrum horns (Karinen and Hoopes 1971, Urban et al. 2002). Tanner crabs, snow crabs, and Tanner-snow hybrids were enumerated by sex. Fish were enumerated by species and non-crab invertebrates were identified to lowest known taxa.

Tagging

Wildlife Computers (Redmond, Washington, USA) Pop-up Archival Transmitting (PAT) tags were deployed on 100 mature-size male RKC that had recently molted and were in a new hard-shell condition. Two models of tag were used: 20 miniPATs; and 80 mrPAT "mark-report" tags. The miniPAT measures 118 mm (4.64") in length by 38 mm (1.50") in maximum diameter, with a plastic-coated braided-cable antenna protruding from the distal end. The miniPAT is capable of recording temperature, depth, and ambient light levels for periods of up to two years at recording intervals of one minute; or recording at longer or shorter logging intervals depending upon intended deployment duration. The mrPAT is somewhat smaller, measuring 118 mm (4.64") by 28 mm (1.10") and records temperature and tag-tilt. Only crab with no, or very minimal injuries (e.g., spine breaks), were selected for tagging. Crabs that met the tagging criteria were placed in a tank with flowing seawater as soon as possible upon capture and there awaited tagging. The minimal tagging criteria required five new hard-shell mature males to be caught within a 5-pot string of gear. To distribute tags across the entire survey grid, one tag was deployed every other 5-pot string when the minimal criteria were met. In addition, more tags were placed at sites that met the hotspot criteria. If a 5-pot string captured >100 new hard-shell mature males, five crab were tagged from that string. A total of four "hotspots" of crab catch were identified. Following completion of all of the standard survey stations, undeployed tags remained; thus, to increase tagging density at hotspot sites, pots were reset in hotspot areas, tagging a total of 13 to 15 crab within each hotspot. Tags were attached to crabs by means of a polyolefin tubbing harness that wrapped around the crabs' carapace, going around the second walking legs (Fig. 8). The positively-buoyant tag floats approximately 7 cm (2.75") above the crab.

Graphical and statistical analyses

For NMFS summer trawl survey data, total crab abundance is estimated annually from the raw survey data using area-swept methods (Zacher et al. 2023) and subsequent quantitative stock assessment modeling (Palof and Siddeek 2022). Area-swept methods cannot be applied to pot survey data, and drawing similar inferences based on pot data would require, among other factors, a refined understanding of the attractive radius and distance-dependent fishing power of the traps (*sensu* Aedo and Arancibia 2003) under a variety of underlying environmental conditions. Quantitative abundance estimation methods based on pot/trap data do exist for a limited number of crab stocks: management of Florida stone crab (*Menippe* spp.) has relied on surplus production modeling based on commercial catch data from the trap fishery (Muller et al. 2006) and assessment models based on pot surveys have been employed for southeast Alaska RKC (*see* Quinn II et al. 2006). However, no such models exist for BBRKC and developing abundance estimation techniques for this stock based on pot survey data would require surveys that more-fully encompass the geographic range of the stock as well as multiple years of survey data. Herein, we will make no attempt to estimate the absolute or relative abundance of any demographic of RKC sampled and will instead simply report results as total numbers of crabs captured within each sex, size, and maturity category of interest and the ratios of total catch among those demographics.

Raw temperature data were interpolated for the survey area via ordinary kriging using R statistical software (R v.4.2.2; R Core Team 2023).

Where means (averages) are reported, errors will represent on standard deviation about the mean, unless otherwise noted.

Public data repository

Data generated during the course of this survey have been made publicly available and may be accessed from the NMFS Alaska Fisheries Science Center Shellfish Assessment Program's GitHub site (https://github.com/AFSC-Shellfish-Assessment-Program/CPS1).

Results

Survey completion

A total of 637 standard survey stations were fished between 18 March and 4 April 2023; 59 planned stations were not fished due to logistical considerations (e.g., location too shallow) and time constraints (Fig. 3). One additional station was dropped from the final dataset because the pot had been left unbaited. Among fished stations, 299 were fished by the FV *Summer Bay* and 338 by the FV *Silver Spray* (Fig. 3). Realized station coordinates resulted in a total of 99 stations within the RKCSA (i.e., 15.7% of stations fished), 24 stations (3.7%) within the RKCSS, and 271 stations (42.5%) within the NBBTCA; all stations were within

BLZ1. Station depths ranged from 14.0 – 50.6 fm (25.6 – 92.5 m). Ideally, soak time at each station would have been approximately 30 hours; however, logistics associated with weather, processing of catch, and running time between stations imparted variance around the ideal. Realized soak times ranged between 27.5 and 79.1 hours with the majority of soak times (92%; n = 586) falling within a positively-skewed distribution (Fig.9) that spanned 27.5 – 48.8 h. Falling to the right of (i.e., longer than) the primary distribution of soak times were two additional groupings: one composed of 20 stations with soak times ranging from 52.8 – 53.1 h; and a second group composed of 29 stations with soak times of 69.9 – 79.1 h (Fig. 9).

In addition to the standard survey stations, 47 experimental potlifts were conducted, as follows: 1) 30 potlifts were conducted from 3-6 April on survey Transects C, E, and I to collect additional crabs for tagging; 2) five potlifts were conducted between 21 March and 3 April to compare catch rates using varying volumes (i.e., two and four bait bags) and types of bait (i.e., herring and cod) and to observe catches using underwater cameras, and; 3) 12 potlifts conducted on 5 April for tagging. The results and graphics that follow will not include the additional stations; they will be limited to the 637 potlifts conducted at standard survey stations.

Oceanographic conditions

Temperature loggers were deployed at 38.6% (n = 246) of standard stations fished, distributed fairly evenly across the survey area (Fig. 10, *lower*). Mean water temperatures (i.e., averaged over the course of each pot soak when the pots were determined to be on-bottom) at individual stations ranged from -1.22 – 4.38° C (29.84 – 39.88° F) and averaged 2.02 ± 1.08° C (35.06 ± 1.94° F). The warmest temperatures were observed in the southwest of the survey area, closest to deepwater habitat north of Unimak Pass, and coldest temperatures were encountered in the northwest, in relatively shallow habitat southwest of Cape Newenham (Fig. 10, *lower*). Overall, bottom temperatures in the surveyed region were cooler than observed during the NMFS EBS summer trawl surveys that were conducted before and after the pot survey (i.e., during the summers of 2022 and 2023; Fig. 10, *upper*). Although sea ice was not encountered at any of the pot survey stations, relatively dense ice coverage was reported just north of the survey grid during the survey's first week and the ice retreated to waters offshore and west of Cape Newnham, and along the Alaska Peninsula in the Kvichak Bay region, by the time the survey was completed (Fig. 11). During sampling, the footprint of the associated cold pool extended into the survey grid in its northwest corner (Fig. 10, *lower*).

RKC catch composition

A total of 10,191 RKC were captured (Table 1) at 450 (70.5%) of the standard survey stations: 76.8% (n = 7,824) of these crabs were male and 33.2% (n = 2,367) were female. Considering only mature-sized individuals, the observed sex ratio was 72.1% male. This departs substantially from recent EBS trawl survey results, in which catch throughout the Bristol Bay District was roughly 52% male in 2022 and 37% male in 2023 (Zacher et al. 2023).

Male RKC that were captured at standard survey stations ranged from 17.6 – 190.2 mm (0.69 – 7.49") CL; the size of one individual was not obtained. Among the measured individuals, 36.1% (n = 2,824) were immature-size (<120 mm (4.7") CL); 63.9% (n = 4,999) were mature-size (≥120 mm (4.7") CL); 44.7% (n = 3,497) were legal-size (≥135 mm (5.3") CL). No molting males were observed. Immature males were predominantly (98.8%) new hardshell with a small proportion (1.1%) of old shell and three individuals with very old shell (Fig. 12). The occurrence of old shell condition increased with size for males larger than ~125 mm (4.92") CL, such that in mature-size males the proportion of new hard decreased to 57.6%, old shell increased to 38.1%, and 4.2% of individuals were very old shell. Among legal-size males, the proportion of new hard and old shell were similar (48.5% vs 45.8%, respectively) and old shell was 5.7%; these were similar to the relative proportions reported by Zacher et. al (2023) for the 2023 trawl survey. Across all sizes, a much smoother progression in the advancement of shell conditions with size can be seen in the CPS1 data than has been visible in recent trawl survey data (Fig. 12).

Female RKC ranged from 57.0 – 174.6 mm (2.24 – 6.87") CL: 81.7% (n = 1,934) of these individuals were determined to be morphometrically-mature. Immature females ranged in size from 57.0 – 99.9 mm (2.24 – 3.93") CL and mature females from 82.1 – 174.6 (3.23 – 6.87") mm CL (Fig. 13). Only five molting individuals were captured, all of which were immature. The remainder of immature females (98.9%) were new hardshell. Among morphometrically-mature females, 47.6% were new hard-shell and 52.2% were old shell. Overall, a substantially larger proportion of females were old shell than observed during recent summer surveys (Fig. 14), especially at sizes greater than ~100 mm (3.84") CL.

No barren mature females were encountered: all morphometrically-mature females bore egg clutches. No clutches contained dead eggs, hatching embryos, or empty egg cases. All clutches were composed of purple eggs; 44.3% of clutches contained uneyed eggs and 55.7% eyed eggs. The proportion of females carrying eyed versus uneyed eggs increased progressively with size, with eyed eggs rarely seen in females <93 mm (3.66") CL while representing the large majority of individuals >115 mm (4.53") CL (Fig. 15). Similarly, clutch fullness followed a clear progression of increasing volume with crab length (Fig. 16), in which half-clutches were represented by a small proportion of individuals (3.4%) primarily ranging from 84 – 104 (3.31 – 4.09") mm CL; females carrying three-quarter clutches produced a strongly regular distribution across individuals of 82 – 119 mm (3.23 – 4.69") CL; and full clutches were carried by the majority of individuals ≥110 mm (4.33") CL. Overall, 43.5 % of individuals carried three-quarter egg clutches and 53.0% carried full clutches.

RKC spatial distribution

Overall, RKC were distributed throughout the survey area except in its southwestern corner (Fig. 17, *lower*): RKC were largely absent south and west of a line running from roughly 56° 50' N lat x 164° 15' W lon southeastward to 52° 50' N lat x 162° 27' W lon. Zero-catch stations were also common on the southern ends of the transects from the Black Hills eastward, with the exception of the easternmost transect (Transect K; Fig. 17, *lower*) that terminated slightly farther offshore than on Transects E-J. The observation of relatively low overall abundance in the southwest was similar to that which was observed during the 2022 and 2023 NMFS EBS summer trawl surveys (17, *upper*).

The distributions of legal-size (Fig. 18, *lower*) and mature-size (Fig. 19, *lower*) males were similar to one another, as well as to the distribution of all RKC. Immature-size males displayed a somewhat patchier distribution than the larger males, especially within the survey's western transects (Fig. 20, *lower*). However, they still possessed an overall footprint that was similar to that of the larger males. For females, there was a greater disparity between the distribution of mature and immature individuals. Mature females (Fig. 21, *lower*) displayed a broad distribution that was similar to that of males. Immature females were largely absent from the four western-most transects as well as the survey's northeastern extent (Fig. 22, *lower*). Immature females were largely concentrated to the northeast of the RKCSA, with one "hotspot" located inside the NBBTCA and a second just north of the RKCSA boundary.

Across all demographics, the majority of crab were caught within the NBBTCA (Table 1): 66% of all RKC were captured in the NBBTCA and percentages ranged from 61.7% (legal-sized males) to 75.8% (mature females) among individual crab demographics. For males, just under 20% of each demographic was encountered in the RKCSA, as well as in the BLZ1 outside of the RKCSA and NBBTCA. For females, the proportion of crab captured inside the RKCSA was quite different for mature (17.4%) versus immature (7.6%) crabs. A considerably higher proportion of immature females (21.5%) was found outside of the RKCSA and to the west of the NBBTCA boundary than mature females (6.8%). This difference in proportional catch appears to have been due more to an absence of immature females in the RKCSA than due to an abundance of immature females in BLZ1 outside of the RKCSA.

For no plotted demographic did the overall spring distribution derived from CPS1 data appear markedly different than the distribution found during the 2023 NMFS summer trawl survey. However, for immature crabs of both sexes, the CPS1 distributions appear more similar to the 2023 trawl survey plots than to 2022. For crabs of mature and legal sizes, pot survey distributions appear somewhat less patchy than suggested by the trawl survey data. Further quantification of relative patchiness in each survey dataset and significant differences between and among geographic distributions via spatial statistics is warranted, to confirm or deny these visual impressions.

Other crab species

In addition to RKC, four distinct species of crabs were captured: Tanner crab, snow crab, Horsehair crab (*Erimacrus isenbeckii*), and Pacific lyre crab (*Hyas lyratus*). Additionally, a small number (n = 4) of Tanner-snow crab hybrids were captured. Tanner crabs were the most abundant (Table 2), represented by 570 individuals captured at a total of 227 stations; most (98.1%) of these crabs were male. All snow crab and Tanner-snow hybrids were male, and occurred at considerably lower abundance and at fewer stations than Tanner crabs (Table 2).

Tanner crabs were distributed throughout the survey region, with the greatest concentration in the western half of the grid in a triangle comprising the deepest water and extending northwestward, roughly parallel to the 100-m isobath (Fig. 23). Snow crabs (Fig. 24) were found only in the western half of the survey grid, in a distribution that largely overlapped that of Tanner crab, but with a smaller total footprint.

Fish and macroinvertebrates

The most commonly-encountered fish species (Table 2) were Pacific cod (n = 1,728 individuals captured at 510 stations) and yellowfin sole (n = 2,393 individuals from 420 stations). Great sculpin (*Myoxocephalus polyacanthocephalus*; n = 78) were captured at 69 stations. Additionally, small numbers of walleye pollock (*Gadus chalcogrammus*), Pacific halibut (*Hippoglossus stenolepis*), northern rock sole (*Lepidopsetta polyxystra*), starry flounder (*Platichthys stellatus*), Alaska plaice (*Pleuronectes quadrituberculatus*), Alaska skate (*Bathraja parmifera*), unidentified skates (Rajidae), and sunflowers seastars (*Pycnopodia helianthoides*) were encountered (Table 2).

Pacific cod were broadly distributed throughout the survey grid (Fig. 25), but displayed somewhat lower abundance along an east-west axis through the central RKCSA and westward into BLZ1 than elsewhere. Pacific cod were absent from stations on the northern end of Transects A-D, where the coldest temperatures were recorded. Yellowfin sole were also broadly distributed and found at highest abundance in nearshore waters along the Alaska Peninsula and along, and just outside of, the 50-m isobath in northern BB (Fig. 26).

RKC Tagging

Tags deployed during CPS1 had a 91% success rate in providing reliable locations with minimal error ellipses (Fig. 27). New hard-shell mature male RKC had an average movement rate of 0.83 ± 0.50 km/day (0.45 ± 0.27 nmi/day), with a range of 0.08 to 2.53 km/day (0.04 to 1.37 nmi/day), over 57–75 days at liberty. There was a high degree of variability in direction of movement (Fig. 27), but with a prevailing trend of movement to the north and northeast (Fig. 28). Tags released from crabs and reported their locations, providing information that is coincident with the NMFS eastern Bering Sea trawl survey in Bristol Bay. Survey results and tagging show the same general area occupied in Bristol Bay (Fig. 29). Additional analyses of finer scale patterns in distribution are underway.

Discussion

The current study was largely successful in demonstrating the feasibility of conducting pot sampling for BBRKC in early spring, thereby generating data on demographic composition, relative abundance, and stock distribution at a time of year when data for the population have generally been unavailable. Additionally, the sampling was explicitly designed and executed to target and sample RKC, without the need to simultaneously survey a wide range of groundfish species. As a result, considerably more crabs were encountered and sampled during CPS1 than during the subsequent EBS trawl survey, including nearly three times as many mature females within the CPS1 grid than were captured during the trawl survey within the BB District. As such, many important aspects of RKC biology may be better-described by the current data than most years' trawl surveys have been able to generate. In general, changes in shell condition, maturity, and egg production according to crab size occurred in considerably clearer progression within the CPS1 length-frequency plots. Such data can allow for more thorough analyses and novel insight into aspects of RKC ecology that are difficult or impossible to obtain from summer trawl survey data. For example, the length or age at which 50% of individuals within a population become mature (i.e., L50) and the range of sizes over which individuals in a population reach maturity can are important life history parameters used to manage populations and evaluate their responses to both fishing pressure (Sharp and Hendry 2009) and environmental change (e.g., McLeay et al. 2019). Ideally, the data describing the maturation process will follow a smooth sigmoidal (S-shaped) progression over the maturing sizes, thereby allowing confident estimation of the maturation curve's inflection point (= L50); such a form can be seen in the CPS1 data for female RKC (Fig. 12). Ultimately, multiple years of trawl survey data might be combined to generate a reasonable fit to a sigmoidal maturation curve. However, it can be unsatisfying and imprecise to pool data over multiple years and derive a longer-term mean when populations are subjected to environmental change, such that maturation dynamics may change within the period described by the data pooling.

In most years, the summer trawl survey occurs when molting and mating have been largely completed, providing an understanding of the results of the most-recent breeding season but less insight into active spawning and reproductive dynamics within the breeding season. Inspection of the CPS1 data suggest that it fell largely in the midst of spawning, when primiparous females had molted and mated and multiparous females were largely preparing to spawn. The length-frequency distributions depicting shell (Fig. 14) and egg (Fig. 15) condition contain a clear mode of small crab that had molted and were in new hard-shell condition bearing clutches of recently-extruded uneyed eggs, while most of the larger females had old shells, eyed eggs, and none had empty egg cases, indicating that they would likely molt soon. The ability to put survey platforms on the water early in the year can allow for the collection of data that may improve our understanding of reproductive dynamics, as well as providing data on changes in distribution on seasonal scales. At the same time, it is important to recognize that the structure of catches may vary seasonally and across gear types as a function of changes in selectivity, especially as influenced by the behavior of the crabs. This can be particularly true for baited gear, as changes in feeding motivation and individuals' willingness to interact with sampling gear can be influenced by a variety of factors including age, sex, physiological condition, and breeding status. In the current survey, of particular note was a substantially different sex ratio in pot catches relative to that which is commonly observed during summer trawl surveys. The pot survey results were biased in favor of males to a much greater degree than trawl survey data and produced a clear lack of molting and recently-molted individuals despite evidence (i.e., the progression of shell and egg condition classes) that egg hatch and molting was likely ongoing.

For commercially-exploited crustaceans, apparent changes in catchability according to size, sex, and season have been observed elsewhere when sampled using traps. For example, using both trammel nets (i.e., a form of benthic gillnet) and traps to survey Mediterranean spiny lobsters (*Palinurus elephas*), Goñi et al (2003) observed clear differences in male and female catch rates based on season. Female catch was quite similar between sampling gears and remained relatively constant throughout the year. However, male size structure was represented differently between traps and nets and the relative proportion of males captured followed a seasonal progression in which males were highly under-represented during the molting period and displayed greatest catchability when spawning. In Mediterranean spiny lobster, spawning takes place while both the males and females are hard-shelled, during the intermolt period a few weeks after female molting (Yeap et al. 2022). Trap-shyness during molting in this species appears to be sex-specific and displayed primarily by males. For females, the authors (Goñi et al 2003) hypothesized that shelter-seeking behavior and their tendency to be more gregarious might enhance their catchability year-round. The result of the divergent sex-specific behaviors will therefore be changes in the inferred sex ratio of the population as derived from pot sampling, especially among reproductive size classes, even though little change is likely to be occurring in the underlying population. In contrast to spiny lobsters, Brunson et al. (2023) found that pots consistently produced a higher male sex ratio than trawl sampling for blue crab (*Callinectes sapidus*) in Chesapeake Bay estuaries. The male bias was further accentuated in summer and winter relative to spring and autumn. While the authors were unable to explain the apparently greater affinity of males for pots overall, they hypothesized that the seasonal variance in sex ratios was related to changes in female catchability due to breeding behavior: in particular, increased catch rates of females when they are preparing to molt and breed. Sublegal-size females in a pre-molt status (i.e., “peeler” crabs) are attracted to mature males. Peeler crabs represent an important target demographic for the commercial fishery because they are held after capture and allowed to molt into marketable soft-shells (Huang et al. 2015) and the peeler-crab fishery often “baits” its pots with large mature males in order to increase female peeler catches (Bishop et al. 1983). In cases in which mature males enter the traps of their own accord during the spawning season, the result may be a marked increase in female catchability within those pots and the false perception that the underlying sex ratio has changed.

In the current survey, the general lack of molting individuals in concert with a much lower proportion of females than is estimated from trawl-survey data is consistent with female pot shyness. However, closer inspection suggests the results may reflect pot shyness in both sexes combined with earlier molting in males. The only molting individuals that were captured were females, despite having caught more than three times as many males. There is no evidence in the CPS1 data that molting males were inclined to enter the pots. Rather, if females molt later than males, which is consistent with RKC mate-guarding behavior (Powell et al. 2002) in which males must be hard-shell either in advance of the females or well afterwards in order to ensure their ability to clasp and guard their molting mate, then it is likely that the population was composed of a much higher proportion of molting females than molting males and the females were therefore underrepresented in the catch. Regardless of the ultimate mechanism (i.e., whether pot shyness is sex-specific or the catches were a result of differential molt timing), a survey that is biased against females could have consequences in terms of the management actions that might be suggested using the data derived from it. Although the current survey was not intended to estimate total abundance of any demographic of the population, one of its objectives was to investigate the spatial distribution of each demographic outside of the summer season and produce information that might be adapted for use by trawl fleets to avoid RKC bycatch during winter-spring fisheries. At its June 2023 meeting, the NPFMC moved to "*explore further action that could be implemented through framework agreements for the pot CV sector and trawl sectors … to reduce BBRKC mortality … responsive to seasonal spatial distribution of BBRKC and focus avoidance on more discrete areas of relatively higher female BBRKC abundance*" (NPFMC 2023). In order for such guidance to be effective, the data describing female distribution must be accurate to the greatest degree possible. If pots under-sample females in late winter and early spring, potentially due to pot shyness associated with molting and mating, complications and inaccuracies could arise, with the nature of those inaccuracies being dependent upon the effect of pot-shyness on inferred distribution patterns. For example, if pot-shy, molting females are distributed evenly throughout the underlying population, then the effect of undersampling those individuals may simply be a down-scaling of apparent total abundance, but the data would still provide an accurate representation of relative distribution and the location of "hotspots" that bycatch fisheries might avoid. However, if the distribution of pot-shy females is patchy, then the relative distribution inferred from pot sampling may be different than the true underlying distribution. In particular, failure to locate and characterize aggregations of molting females that are likely to be the more vulnerable to handling mortality than hard-shell individuals (Stevens 1990) could create the possibility of guiding bycatch fisheries into the areas where those crabs exist, instead of avoiding them, simply due to a lack of informative data regarding their locations. At present, there is no way to infer from the existing data whether female catches in the current survey were proportional to their underlying distribution or departed from it; or, if catches were not fully representative of underlying spatial distribution, to what degree they may have failed to represent specific size class(es), shell, and clutch conditions. Future sampling should seek to address this issue by including additional, paired sampling using techniques free from this specific bias (*sensu* Hanamseth et al. 2022), thereby allowing for a comparison of the structure and distribution of catches between or among sampling techniques.

In addition to addressing apparent pot shyness, future sampling should seek to standardize pot gear among vessels, to the greatest degree practicable, in order to avoid any potential spatial biases within the survey region. For example, the current survey employed pots that had been manufactured using slightly different webbing sizes on the pots' main body and funnels. In all cases, the webbing sizes were considerably smaller than employed during commercial fishing operations and so their ability to retain large males and mature females is unlikely to have differed. However, if one were interested in indexing small, pre-recruit individuals then it is possible that even small differences in webbing sizes could result in slightly different selectivities, which could translate into perceived spatial variance in the apparent abundance of the smallest crabs even if no such variance existed. This could be accentuated if pots of different configuration are used within discrete spatial "blocks" within a survey, such that the selectivity differences have discrete spatial footprints. For example, in the current survey, a north-south difference in the perceived abundance or distribution of small crabs could arise due to one vessel having fished the northern half of the grid with pots of that were of slightly different configuration than the pots used in the southern half of the grid. Ideally, all pots used for future work should be standardized to ensure equivalent selectivity and fishing power across all demographics of potential interest, including standardization of pot size, funnel design, webbing sizes; and bait type, source, quality, and quantity. In cases in which complete standardization is impractical, differences in selectivity among pot configurations could be examined (e.g., Zhou and Kruse 1999, Herrmann 2021) and accounted for by conducting paired sampling at individual stations to quantify any differences and applying selectivity coefficients to survey data *post hoc* to standardize the resulting catches (*sensu* Gibson-Reinemer et al. 2017). However, this can be a large undertaking necessitating dedicated studies and often cannot be directly introduced into the design of surveys, themselves. Alternatively, if all pots cannot be standardized to a single strict configuration, then one might elect to evenly distribute pot configurations among all vessels and deploy them in either a randomized or orthogonal design that eliminates the potential for systematic spatial bias in catches.

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		NBBTCA		RKCSA		RKCSS		BLZ1-W	
Demographic	**Total**	#	%	#	%	#	%	#	%
Legal-size (≥135 mm) males	3,498	2,160	61.7	689	19.7	66	1.9	649	18.6
Sublegal-size (<135 mm) males	4,326	2,796	64.6	804	18.6	308	7.1	726	16.8
Mature-size (≥120 mm) males	5,000	3,098	62.0	979	19.6	122	2.4	923	18.5
Immature-size (<120 mm) males	2,824	1,858	65.8	514	18.2	252	8.9	452	16.0
Mature females	1,934	1,466	75.8	336	17.4	74	3.8	132	6.8
Immature females	433	307	70.9	33	7.6	9	2.1	93	21.5
Total catch	10,191	6,729	66.0	1,862	18.3	457	4.5	1,600	15.7

Table 1: Number of red king crab (*Paralithodes camtschaticus*) captured at standard survey stations during the 2023 Bristol Bay Cooperative Pot Sampling (CPS1) survey, and the proportion of each demographic (i.e., sex, size, or maturity category) that was captured, within each of four trawl management areas in Bristol Bay, Alaska. For males, mature-sized versus immature-sized simply represents a size distinction (i.e., based on carapace length) that follows regulatory convention, irrespective of any individual crab's actual reproductive status. In inches, the cutoff for legal-size is 5.3" and for mature-size is 4.7". For females, maturity indicates morphometric maturity (i.e., ability to spawn). Trawl management areas are abbreviated as follows: NBBTCA = Nearshore Bristol Bay Trawl Closure Area; RKCSA = Red King Crab Savings Area; RKCSS = Red King Crab Savings Subarea; BLZ1-W = waters of Bycatch Limitation Zone 1 west of 164° 00' W longitude and not included within the RKCSA. See Figure 2 for the boundaries of each area. Note that the RKCSS is subdivision within the RKCSA; therefore, the **Total** listed for each demographic is smaller than the sum of catches across all areas: i.e., the **Total** will exclude the catch listed for the RKCSS.

Species,	**Common name**	**# captured**	**# stations**
Chionoecetes bairdi			
male	Tanner crab	559	223
female	Tanner crab	11	10
Chionoecetes opilio			
male	Snow crab	64	45
female	Snow crab	0	0
C. bairdi x opilio			
male	Hybrid Tanner-snow crab	4	4
female	Hybrid Tanner-snow crab	0	0
Erimacrus isenbeckii	Horsehair crab	3	3
Hyas lyratus	Pacific lyre crab	8	8
Gadus chalcogrammus	Walleye pollock	2	2
Gadus macrocephalus	Pacific cod	1,728	510
Hippoglossus stenolepis	Pacific halibut	11	10
Lepidopsetta polyxystra	Northern rock sole	1	1
Limanda aspera	Yellowfin sole	2,393	420
Platichthys stellatus	Starry flounder	1	1
Myoxocephalus polyacanthocephalus	Great sculpin	78	69
Pleuronectes quadrituberculatus	Alaska plaice	1	1
Bathraja parmifera	Alaska skate	6	4
Rajidae spp.	Unidentified skates	11	9
Pycnopodia helianthoides	Sunflower seastar	12	6

Table 1: Summary of bycatch species (i.e., excluding red king crab, *Paralithodes camtschaticus*) encountered at standard survey stations during the 2023 Bristol Bay Cooperative Pot Sampling (CPS1) survey in Bristol Bay, Alaska, including the total number of individuals of each species/sex that were captured and the number of standard stations at which they were encountered.

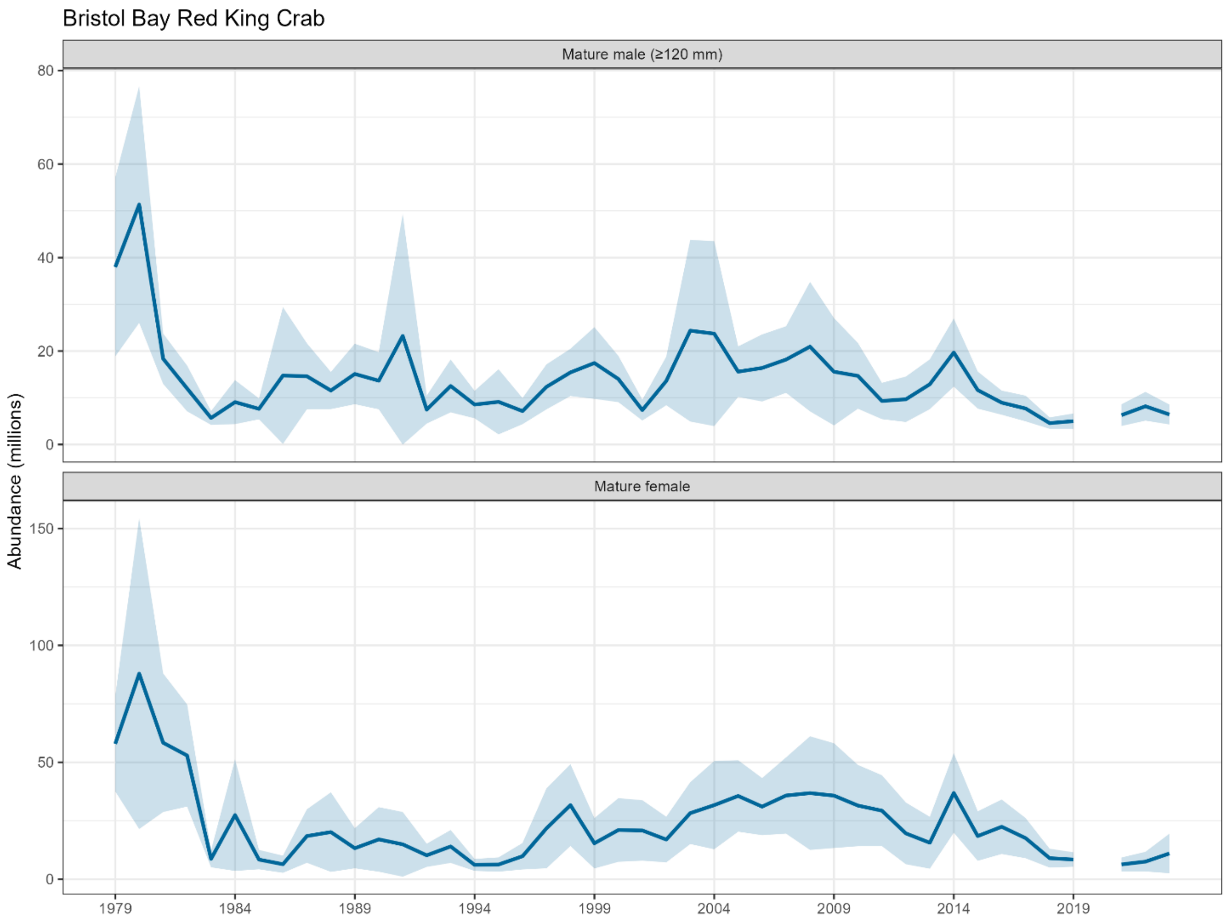


Figure 1. Estimated abundance of mature-sized (≥120 mm (4.7”) carapace length) and morphometrically-mature female red king crab (*Paralithodes camtschaticus*) in Bristol Bay, Alaska, from 1979 through 2023, derived from National Marine Fisheries Service Eastern Bering Sea summer trawl survey data.

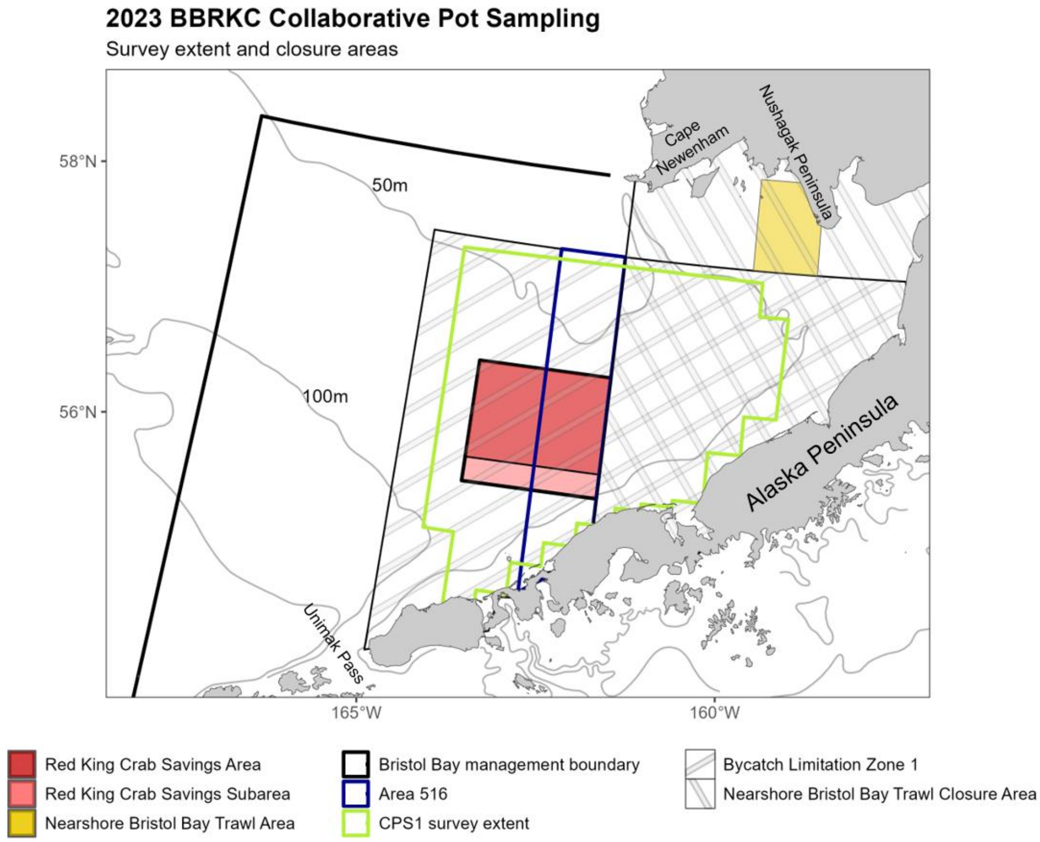


Figure 2. Trawl closure and management areas in Bristol Bay, Alaska. The large area outlined in black is the extent of the Bristol Bay red king crab (*Paralithodes camtschaticus*) management unit; the area outlined in green indicates the intended coverage of the Bristol Bay Cooperative Pot Sampling (CPS1) survey, conducted in March-April 2023.

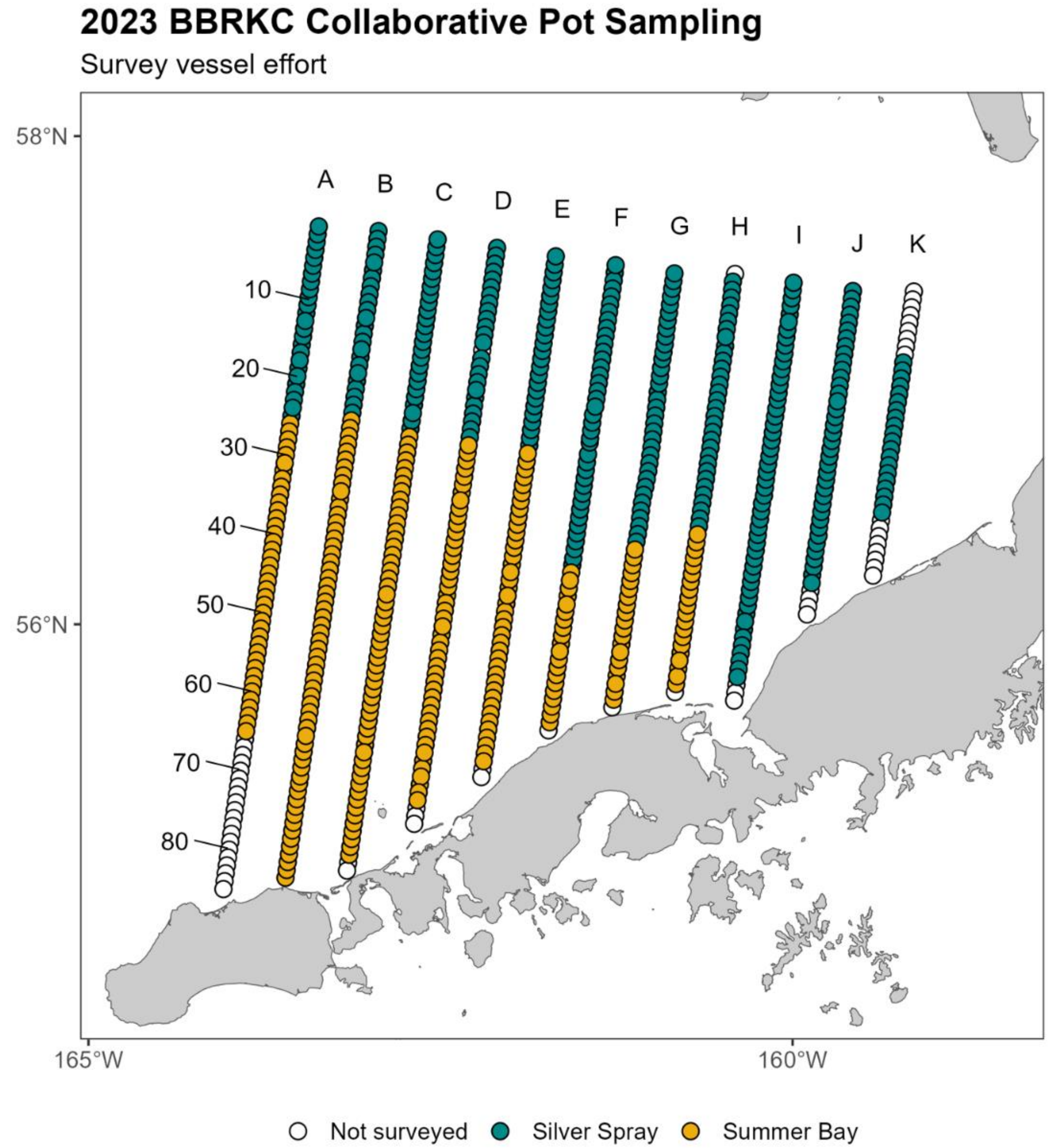


Figure 3. Design and execution of stations included in the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey. The complete standard design included all 694 stations depicted. Stations denoted in white were not fished due to logistical and time constraints, and one station was omitted because the pot had not been baited, resulting in a total of 637 stations fished. Stations fished by each vessel are indicated in blue (fished by the F/V *Silver Spray*) and yellow (F/V *Summer Bay*).

Figure 4. Vessels that conducted pot fishing for red king crab (*Paralithodes camtschaticus*) during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey. *Upper panel*: FV *Silver Spray*. *Lower panel*: F/V *Summer Bay* (*photo credit*: Cory Lescher).

Figure 5. Pots used aboard the FV *Silver Bay* for capturing red king crab (*Paralithodes camtschaticus*) during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey. Pots were modified commercial traps fitted with smaller mesh and meshed-over escape rings to enhance retention of juvenile and sublegal crab. *Upper panel*: Side view of a pot (*photo credit*: Vicki Vanek). Note the upward-sloping funnels and centrally-hung bait bag. *Lower panel*: A pot being emptied of its catch (*photo credit*: Cory Lescher). Note the double-frame construction of the pots. The black plastic hoods attached to the funnel-ends have been propped open to become disabled; the rectangles inward of the open hoods are the openings of the funnels into the pot. An open hood can also be seen on the left-hand funnel in the *upper* image.

Figure 6. An RBR Ltd. XR-420 CTD datalogger affixed to the roof of a crab-survey pot used to capture red king crab (*Paralithodes camtschaticus*) during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey (*photo credit*: Vicki Vanek). CTD = Conductivity (i.e., an indicator of salinity), Temperature, and Depth meter.

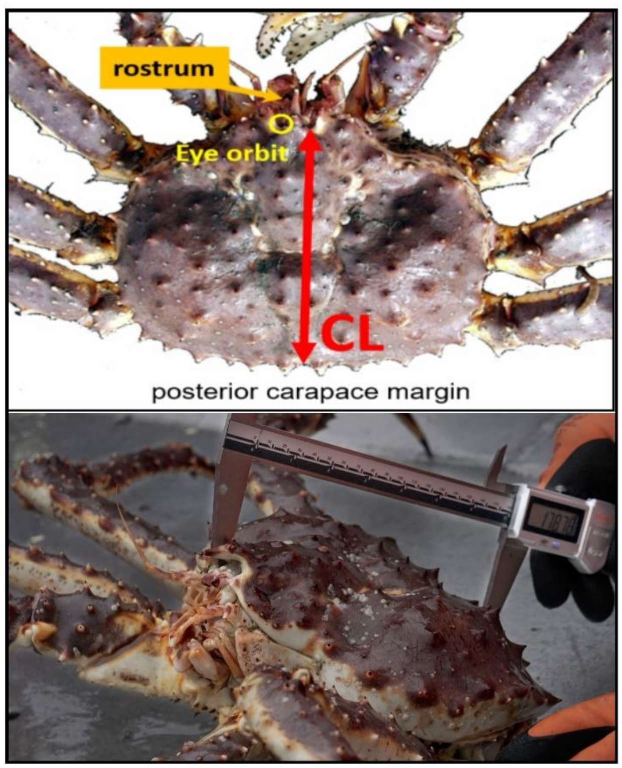


Figure 7. Measurement of carapace length (CL) in red king crab (*Paralithodes camtschaticus*). *Upper*: CL is the distance from the center of the posterior margin of the crab's carapace, measured from between the marginal spines, to the deepest point of one of the crab's eye orbits, at the base of the rostrum. *Lower*: a crab being measured using digital calipers (*photo credit*: Cory Lescher). Note the placement of the calipers in the crab's right eye orbit (the left orbit is visible on the near side of the rostrum).

Figure 8. A Bristol Bay red king crab (*Paralithodes camtchaticus*) tagged with a Wildlife Computers (Redmond, Washington, USA) Pop-up Archival Transmitting (PAT) during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey (*photo credit*: Cory Lescher). The tag is attached to a polyolefin tubing harness that wraps around the crab's carapace.

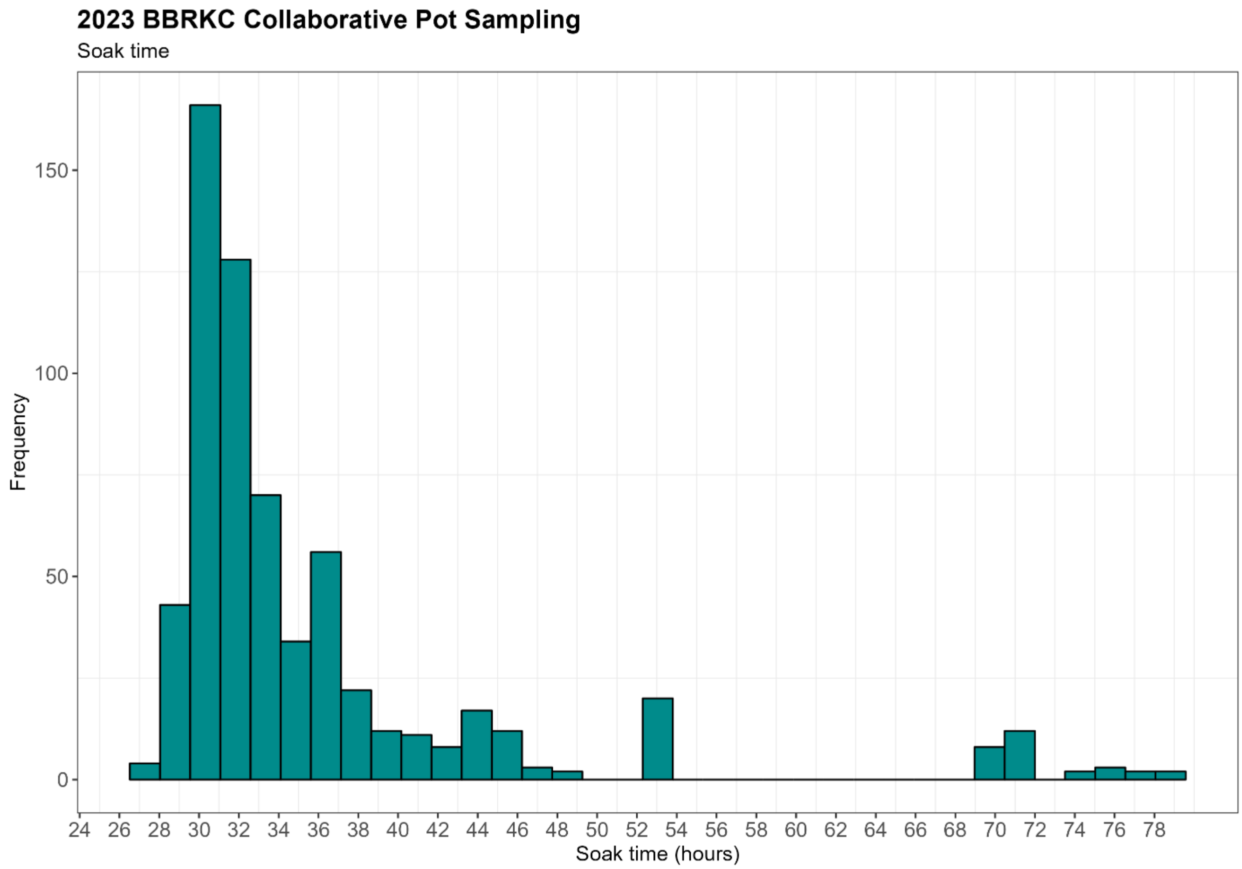


Figure 9. Distribution of soak times employed during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey, targeting red king crab (*Paralithodes camtschaticus*).

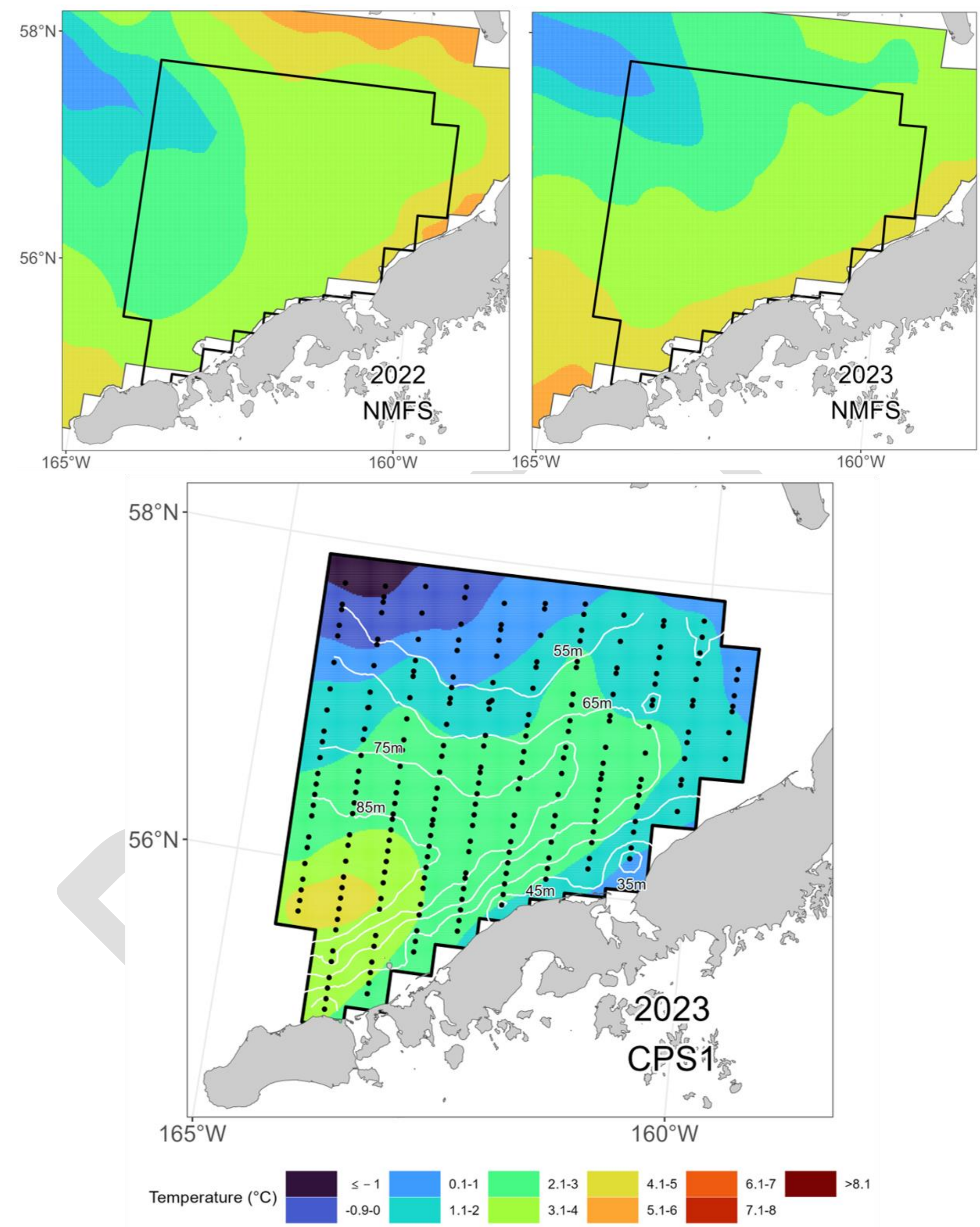
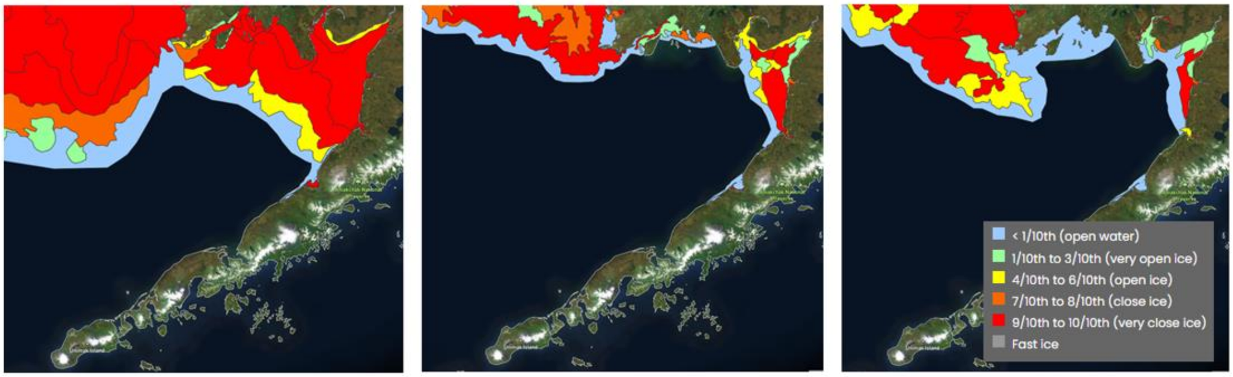


Figure 10. Bottom temperature in the CPS1 area. *Top panels:* Summer temperatures from the NMFS survey. *Bottom panel:* March/April temperature from CPS1, with logger locations.



March 19, 2023 March 29, 2023 April 6, 2023

Figure 11. Sea ice conditions in Bristol Bay (Alaska) during the course of the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey. Ice cover ranges in density from red (nearly complete coverage) to light blue (open water with <10% ice). Sea ice was not encountered at any of the survey stations but occurred just north of the survey grid at the initiation of sampling.

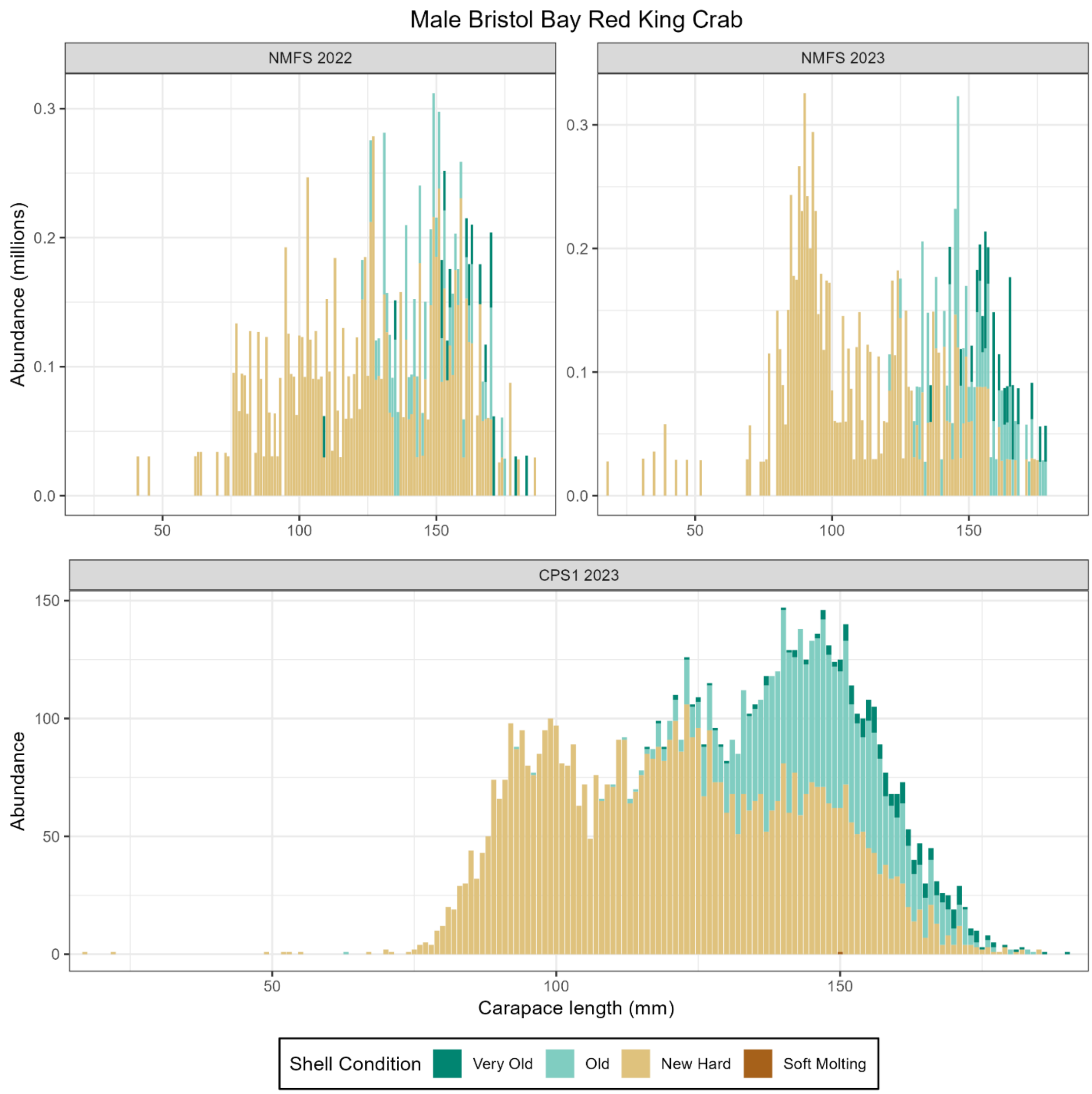


Figure 12. *Lower panel:* size frequency (by carapace length) distribution of all male red king crab (*Paralithodes camtschaticus*) captured during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey, depicting the abundance of individuals within 1 mm size bins possessing various shell conditions. *Upper panels*: male shell conditions, by length, as observed during US National Marine Fisheries Service trawl survey data within the Bristol Bay District during the summers of 2022 and 2023.

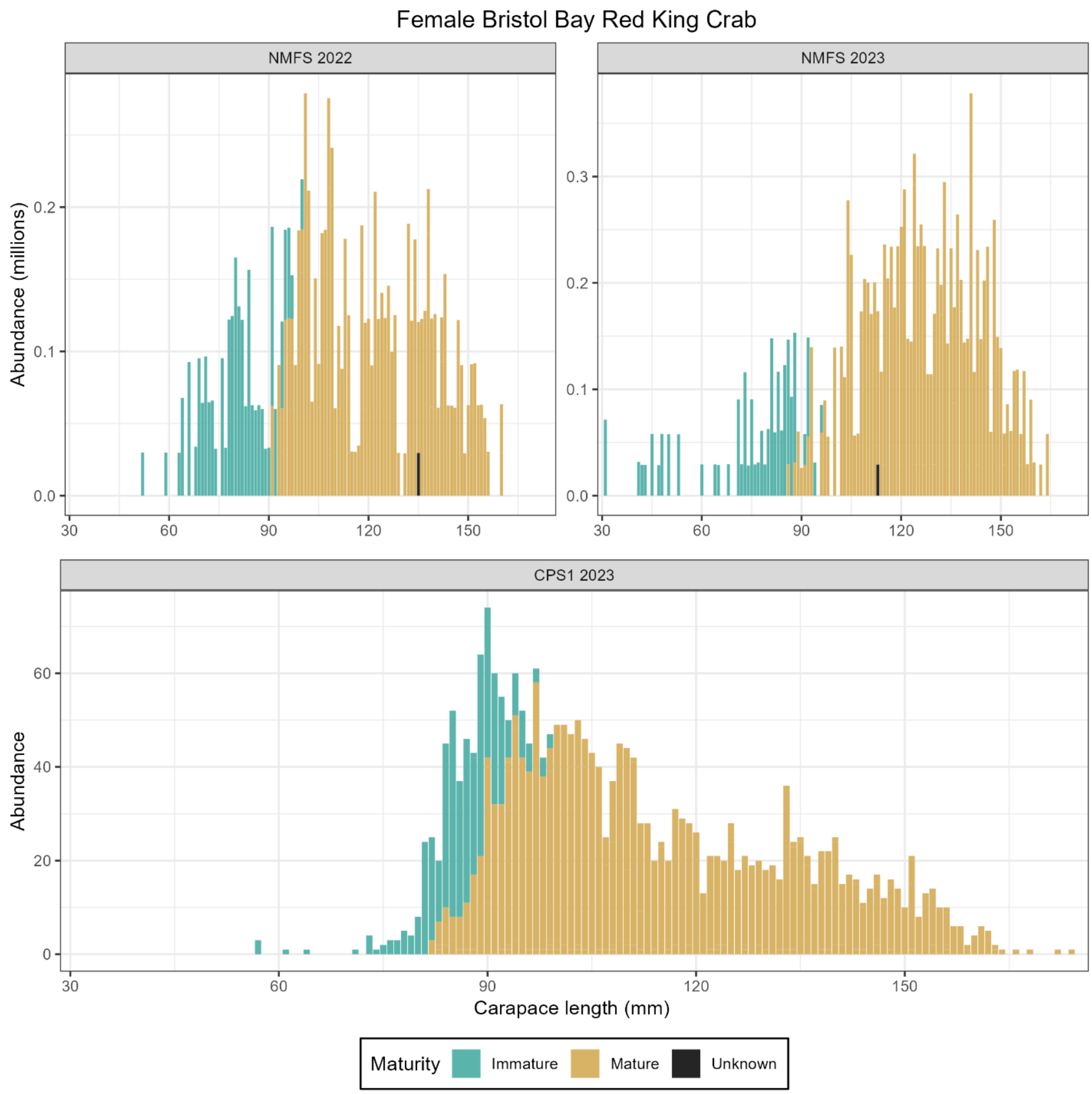


Figure 13. *Lower panel:* size frequency (by carapace length) distribution of all female red king crab (*Paralithodes camtschaticus*) captured during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey, depicting the abundance within 1 mm size bins of morphometrically-mature and immature individuals. *Upper panels*: female maturity, by length, as observed during US National Marine Fisheries Service trawl survey data within the Bristol Bay District during the summers of 2022 and 2023.

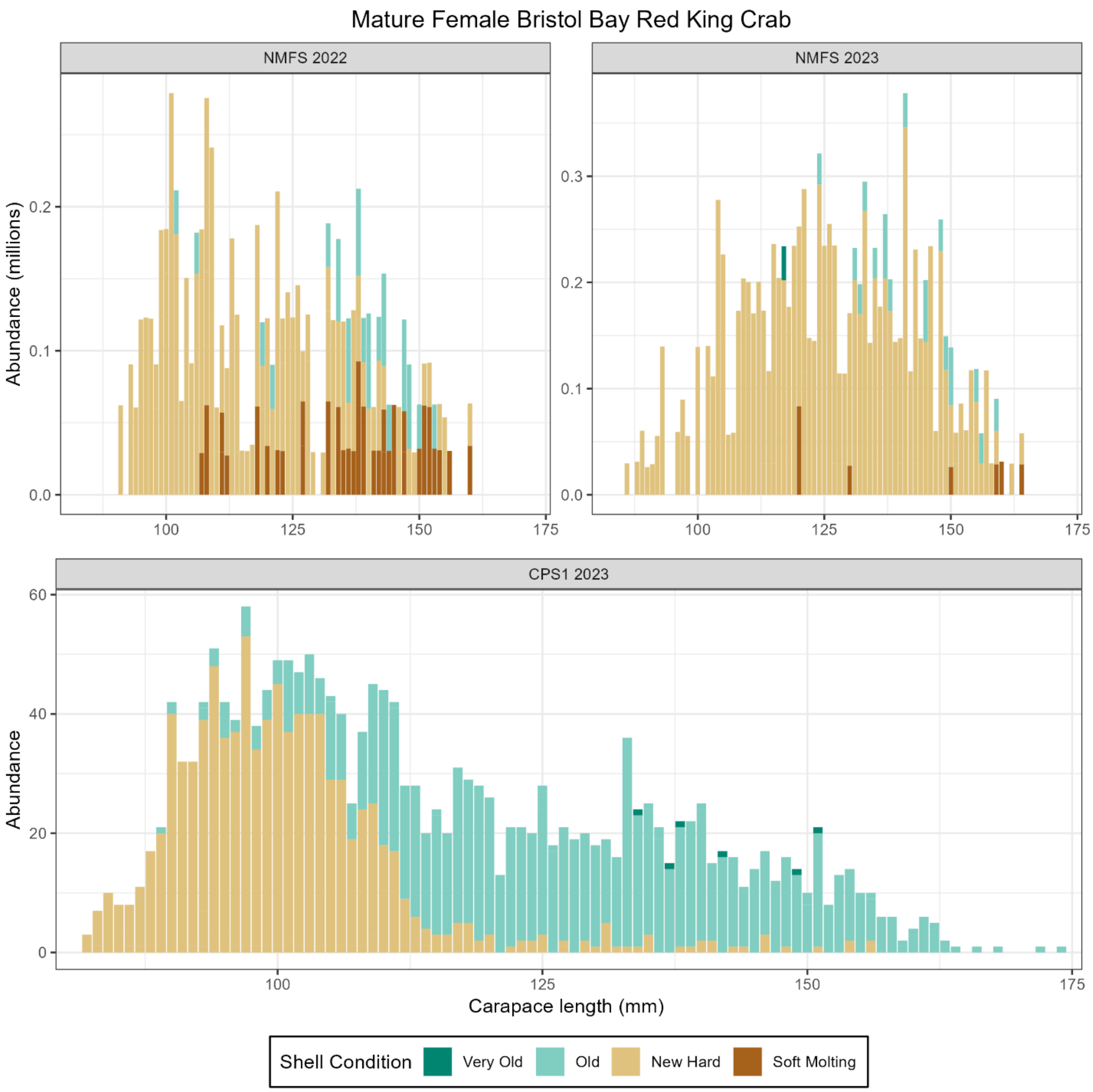


Figure 14. *Lower panel:* size frequency (by carapace length) distribution of morphometrically-mature female red king crab (*Paralithodes camtschaticus*) captured during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey, depicting the abundance of individuals within 1 mm size bins possessing various shell conditions. *Upper panels*: mature female shell conditions, by length, as observed during US National Marine Fisheries Service trawl survey data within the Bristol Bay District during the summers of 2022 and 2023.

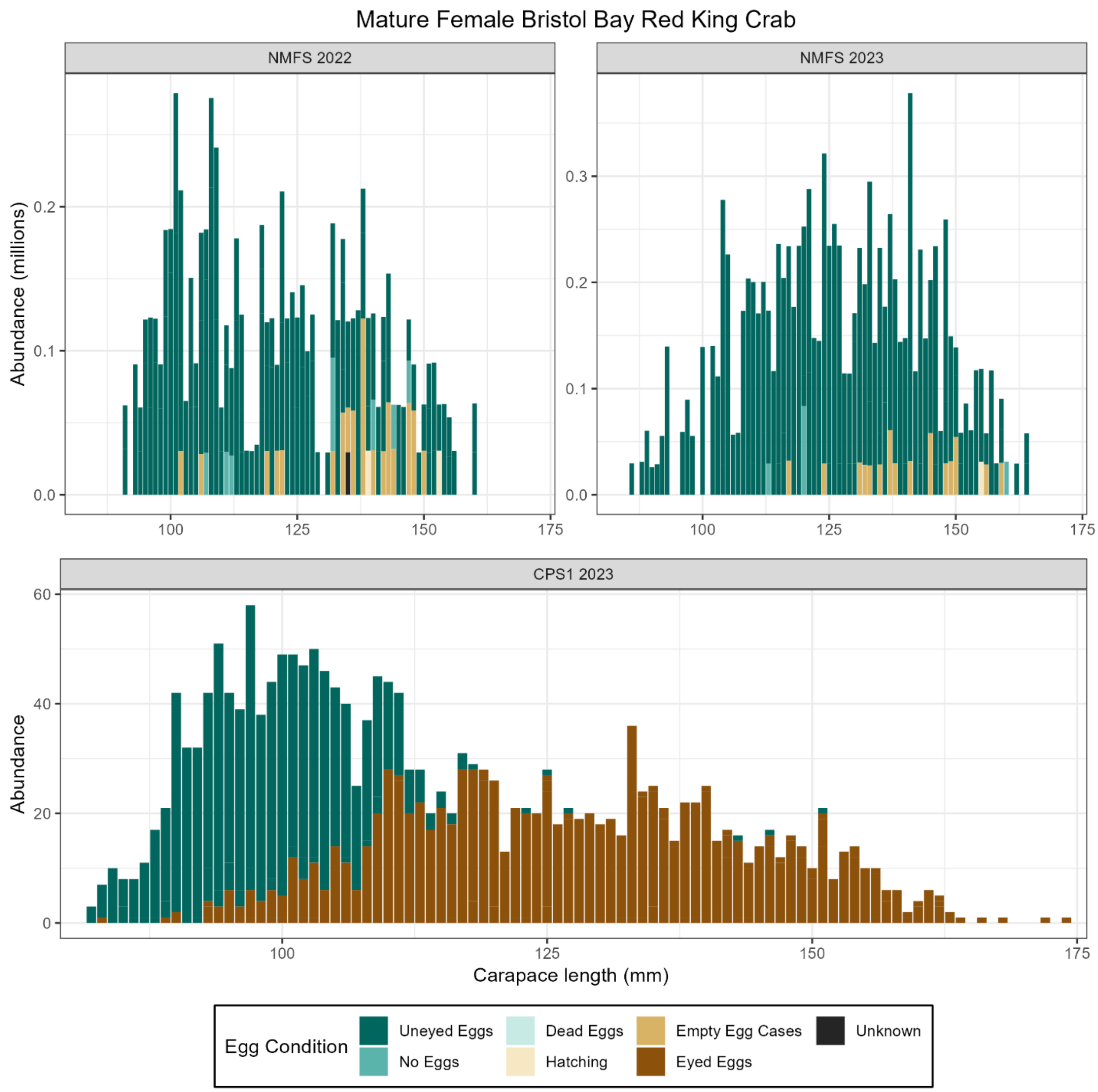


Figure 15. *Lower panel:* size frequency (by carapace length) distribution of morphometrically-mature female red king crab (*Paralithodes camtschaticus*) captured bins during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey, depicting the abundance of individuals within 1 mm size bins exhibiting each measure of egg condition. *Upper panels*: mature female egg conditions, by length, as observed during US National Marine Fisheries Service trawl survey data within the Bristol Bay District during the summers of 2022 and 2023.

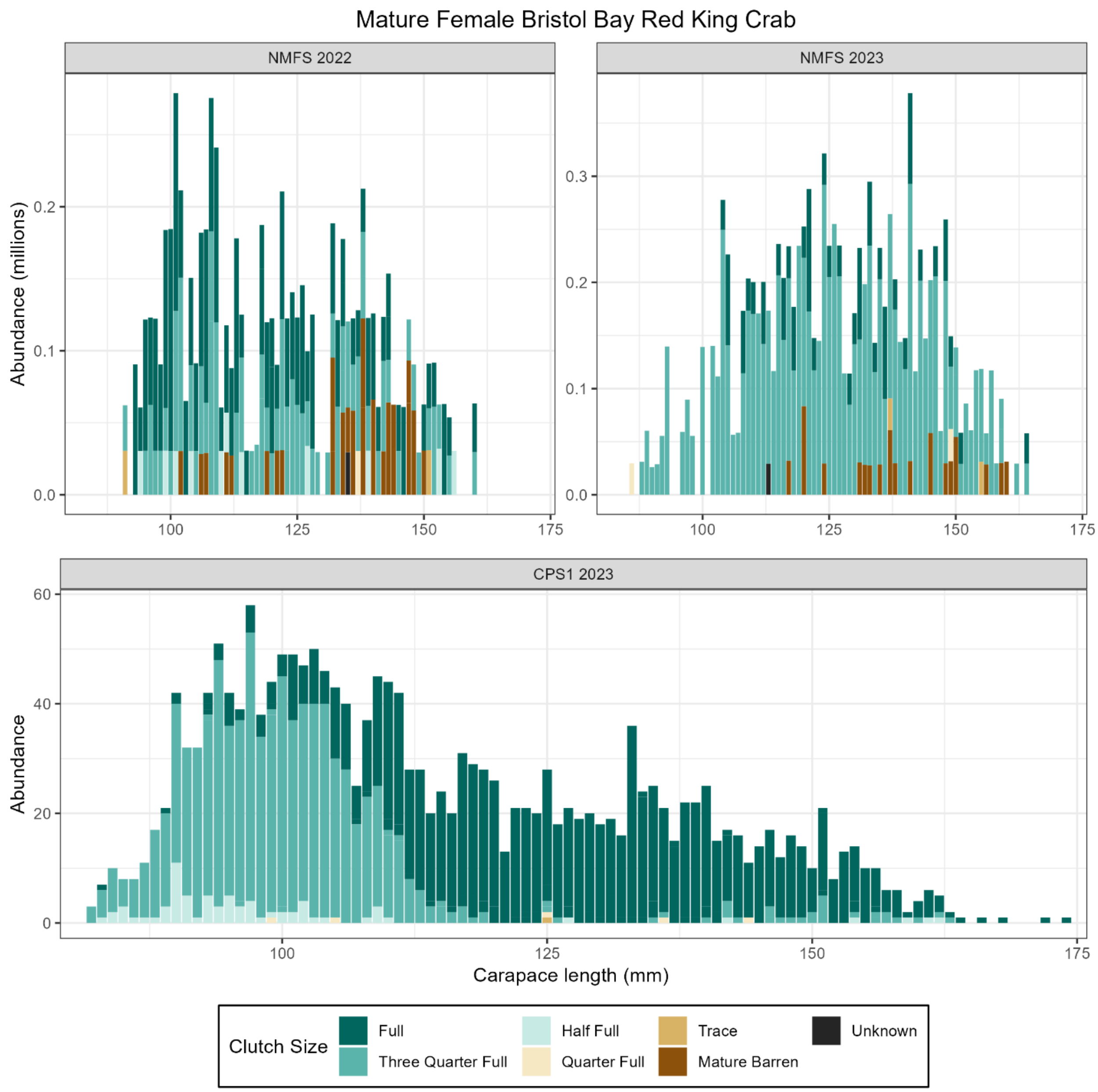
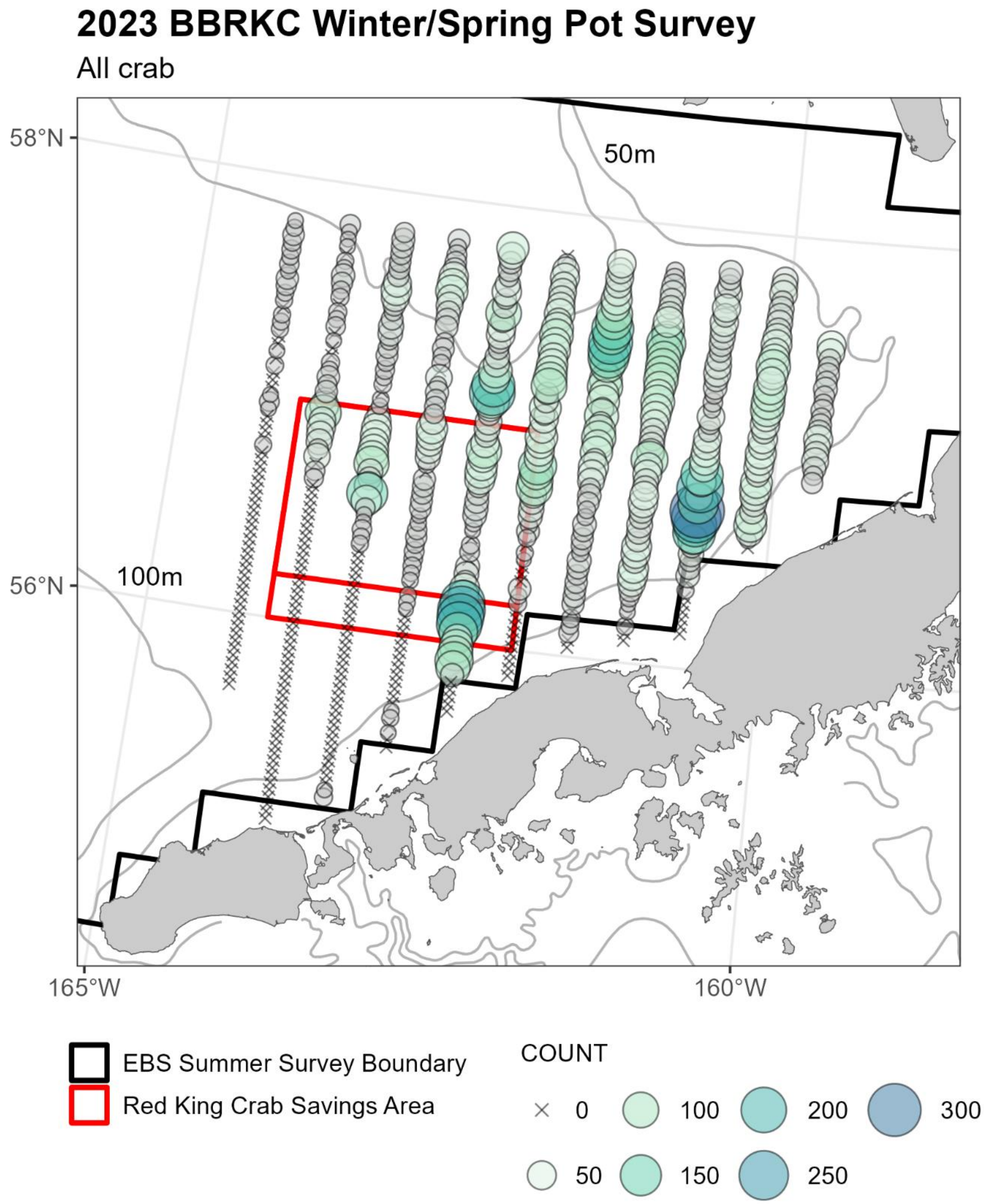


Figure 16. *Lower panel:* size frequency (by carapace length) distribution of morphometrically-mature female red king crab (*Paralithodes camtschaticus*) captured during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey, depicting the abundance of individuals within 1 mm size bins displaying each measure of clutch fullness condition. *Upper panels*: mature female egg conditions, by length, as observed during US National Marine Fisheries Service trawl survey data within the Bristol Bay District during the summers of 2022 and 2023.



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1024 **Figure 17.** Spatial distribution and relative abundance of all red king crab (*Paralithodes camtschaticus*)
1025 captured during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey. Spot size is
1026 proportional to the number of crabs captured at each location, as indicated in the legend.

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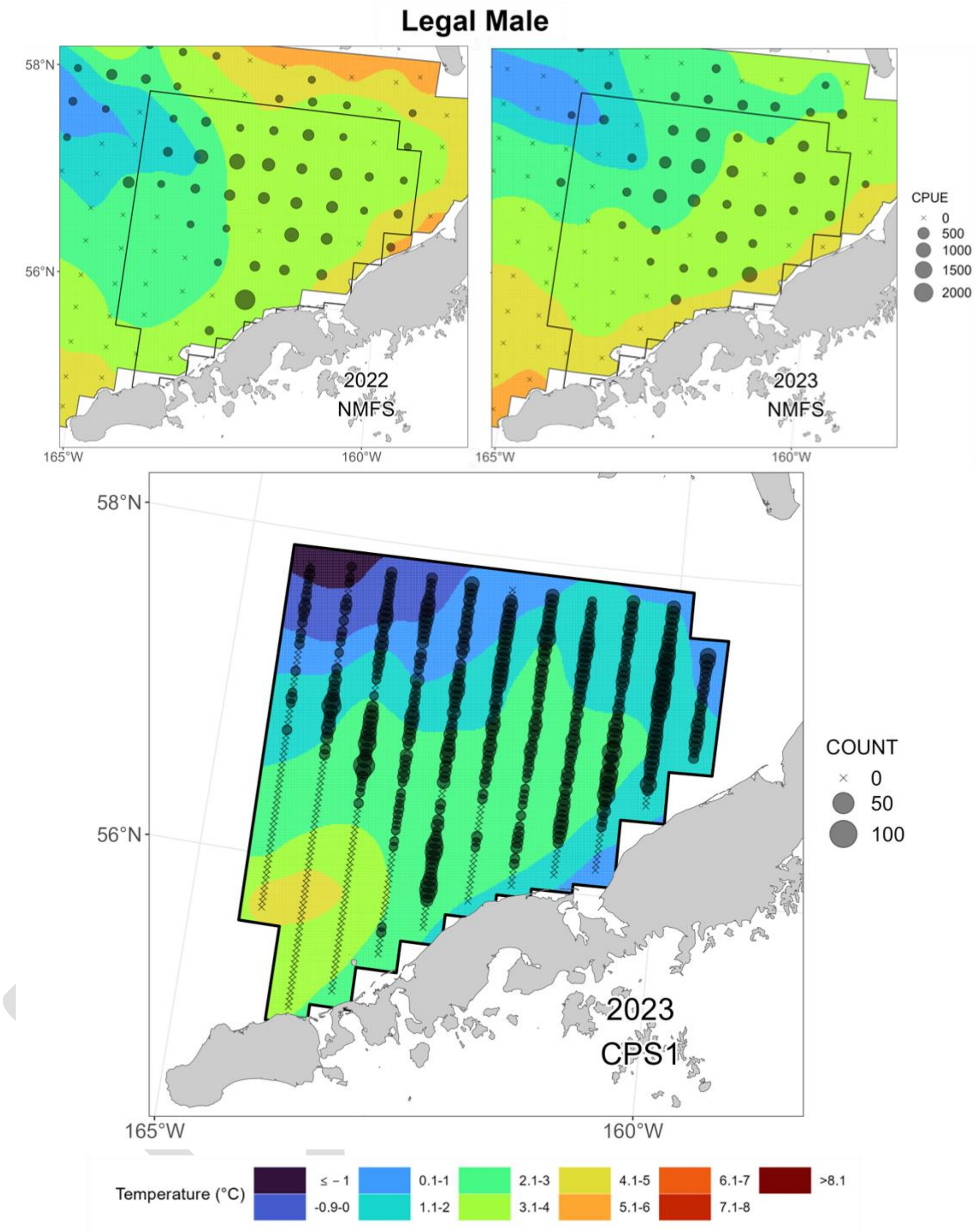

Figure 18. *Lower panel:* Spatial distribution and relative abundance of male red king crab (*Paralithodes camtschaticus*) ≥135 mm (5.3”) carapace length (i.e., legal-size) captured during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey. Spot size is proportional to the number of crabs captured at each location, as indicated in the legend. Abundance data are overlain on smoothed bottom temperatures obtained from temperature loggers placed inside the pots. *Upper panels*: legal-size male red king crab abundance and bottom temperatures observed during US National Marine Fisheries Service trawl survey data within the Bristol Bay District during the summers of 2022 and 2023.

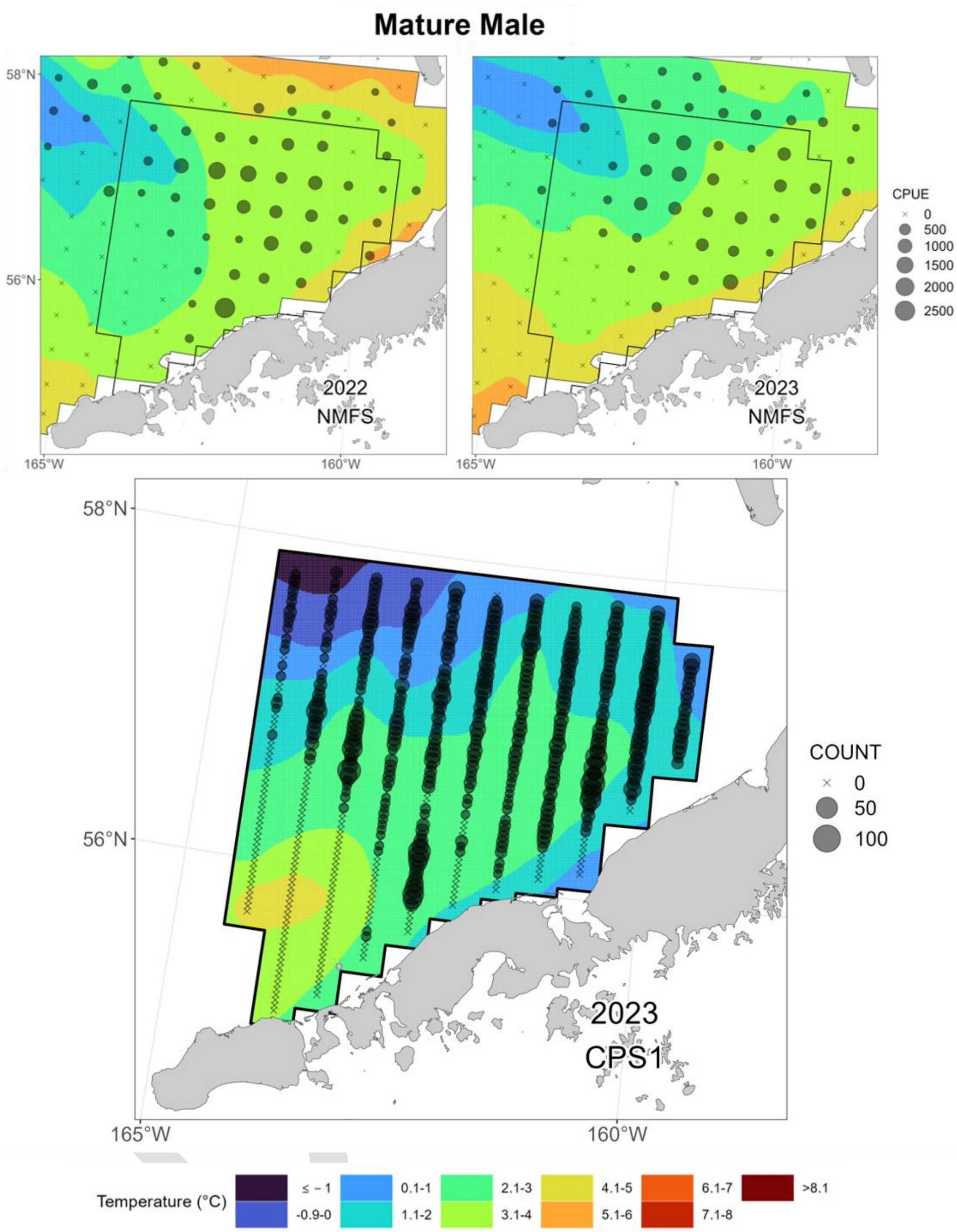

Figure 19. *Lower panel:* Spatial distribution and relative abundance of male red king crab (*Paralithodes camtschaticus*) ≥120 mm (4.7”) carapace length (i.e., mature-size) captured during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey. Spot size is proportional to the number of crabs captured at each location, as indicated in the legend. Abundance data are overlain on smoothed bottom temperatures obtained from temperature loggers placed inside the pots. *Upper panels*: mature-size male red king crab abundance and bottom temperatures observed during US National Marine Fisheries Service trawl survey data within the Bristol Bay District during the summers of 2022 and 2023.

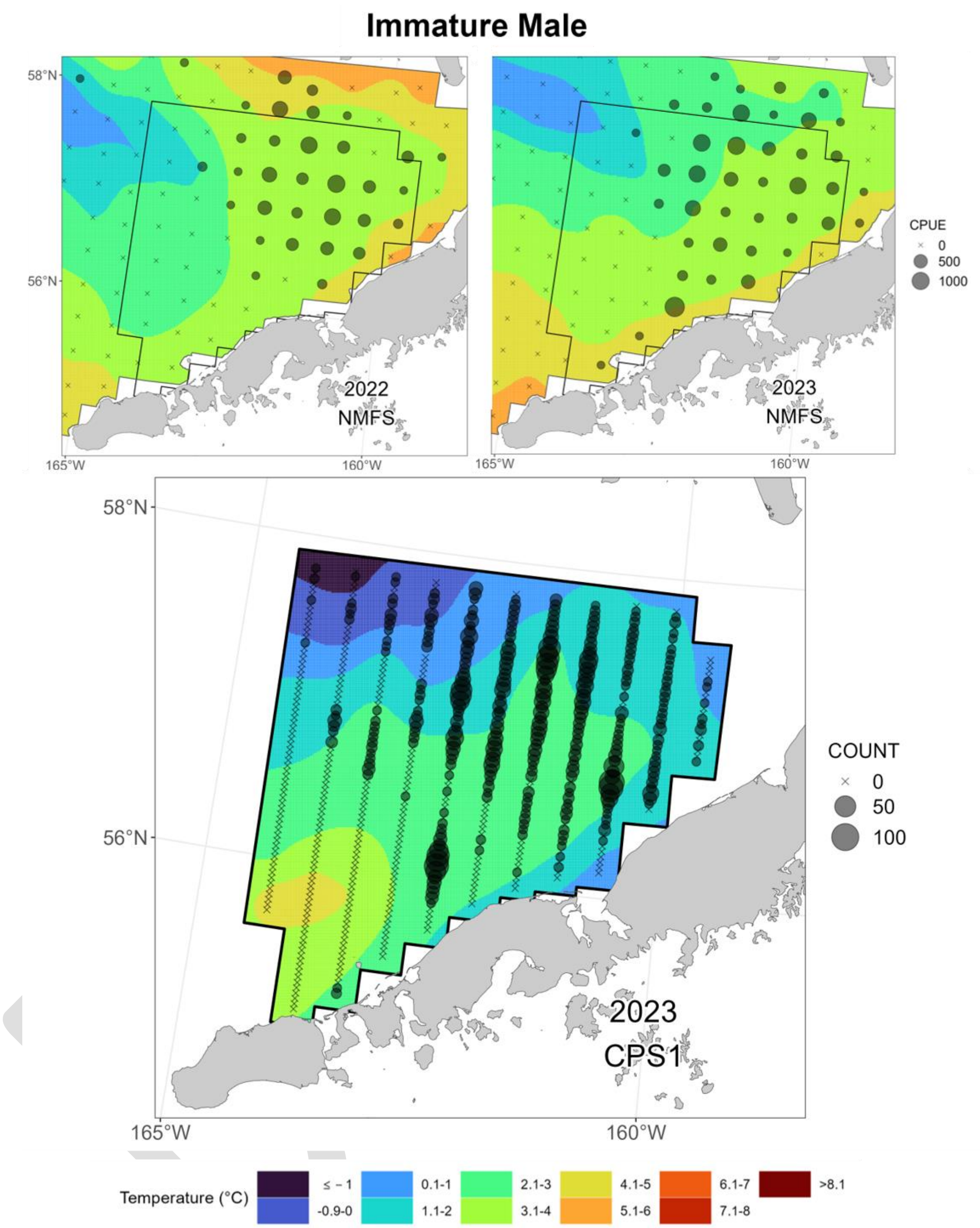

Figure 20. *Lower panel:* Spatial distribution and relative abundance of male red king crab (*Paralithodes camtschaticus*) <120 mm (4.7") carapace length (i.e., inmature-size) captured during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey. Spot size is proportional to the number of crabs captured at each location, as indicated in the legend. Abundance data are overlain on smoothed bottom temperatures obtained from temperature loggers placed inside the pots. *Upper panels*: immature-size male red king crab abundance and bottom temperatures observed during US National Marine Fisheries Service trawl survey data within the Bristol Bay District during the summers of 2022 and 2023.

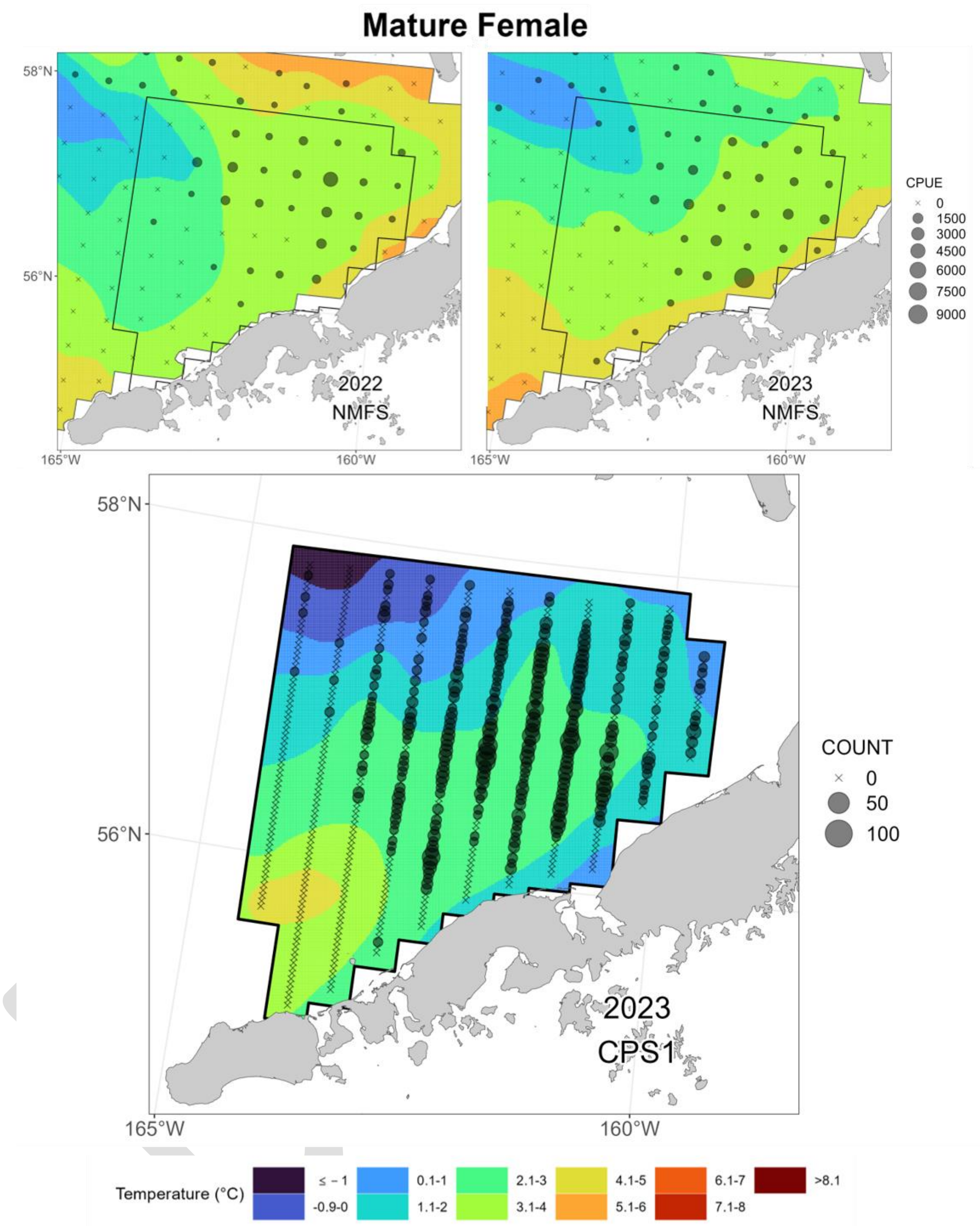

Figure 21. *Lower panel:* Spatial distribution and relative abundance of morphometrically-mature red king crab (*Paralithodes camtschaticus*) captured during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey. Spot size is proportional to the number of crabs captured at each location, as indicated in the legend. Abundance data are overlain on smoothed bottom temperatures obtained from temperature loggers placed inside the pots. *Upper panels*: mature female red king crab abundance and bottom temperatures observed during US National Marine Fisheries Service trawl survey data within the Bristol Bay District during the summers of 2022 and 2023.

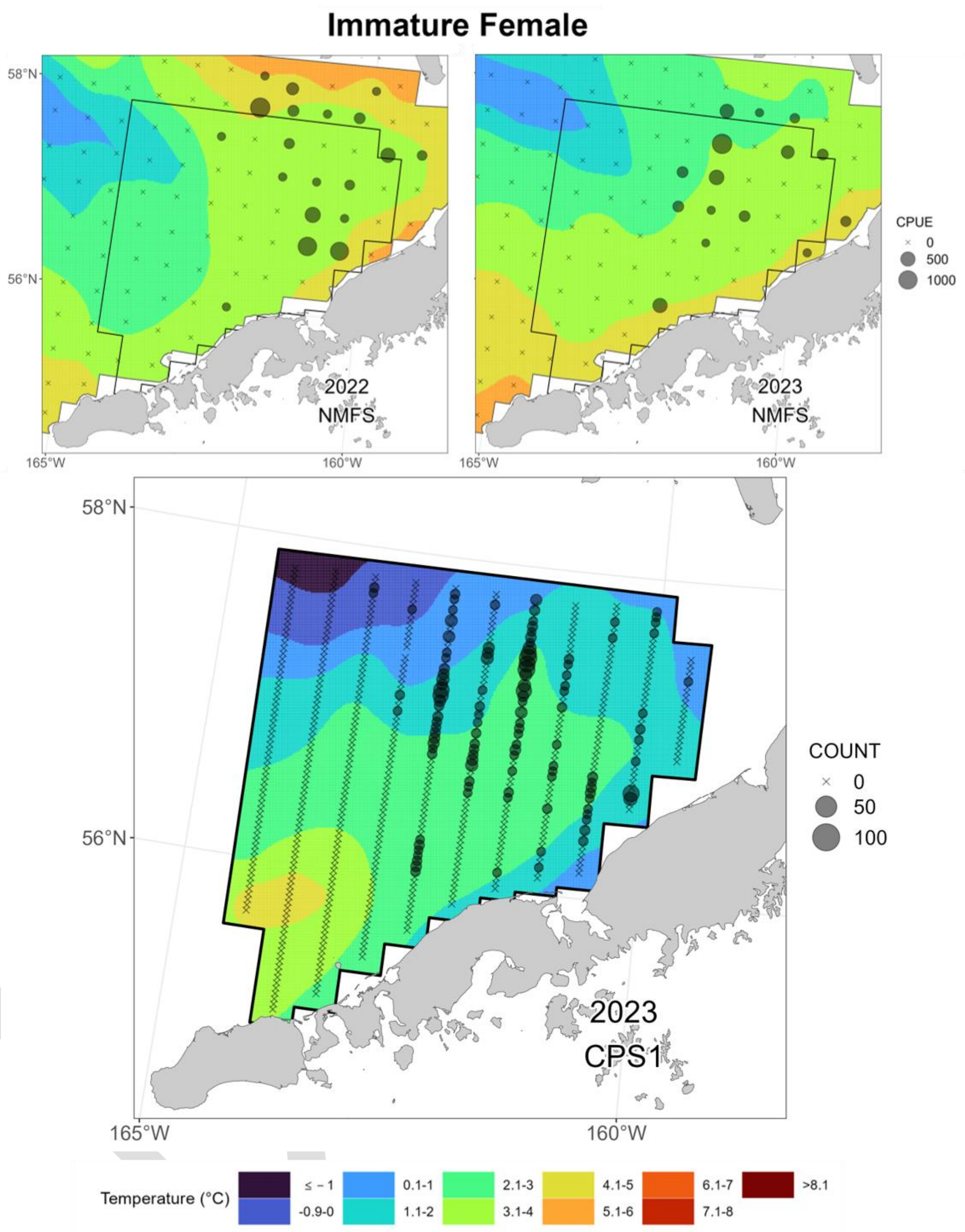

Figure 22. *Lower panel:* Spatial distribution and relative abundance of morphometrically-immature red king crab (*Paralithodes camtschaticus*) captured during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey. Spot size is proportional to the number of crabs captured at each location, as indicated in the legend. Abundance data are overlain on smoothed bottom temperatures obtained from temperature loggers placed inside the pots. *Upper panels*: immature female red king crab abundance and bottom temperatures observed during US National Marine Fisheries Service trawl survey data within the Bristol Bay District during the summers of 2022 and 2023.

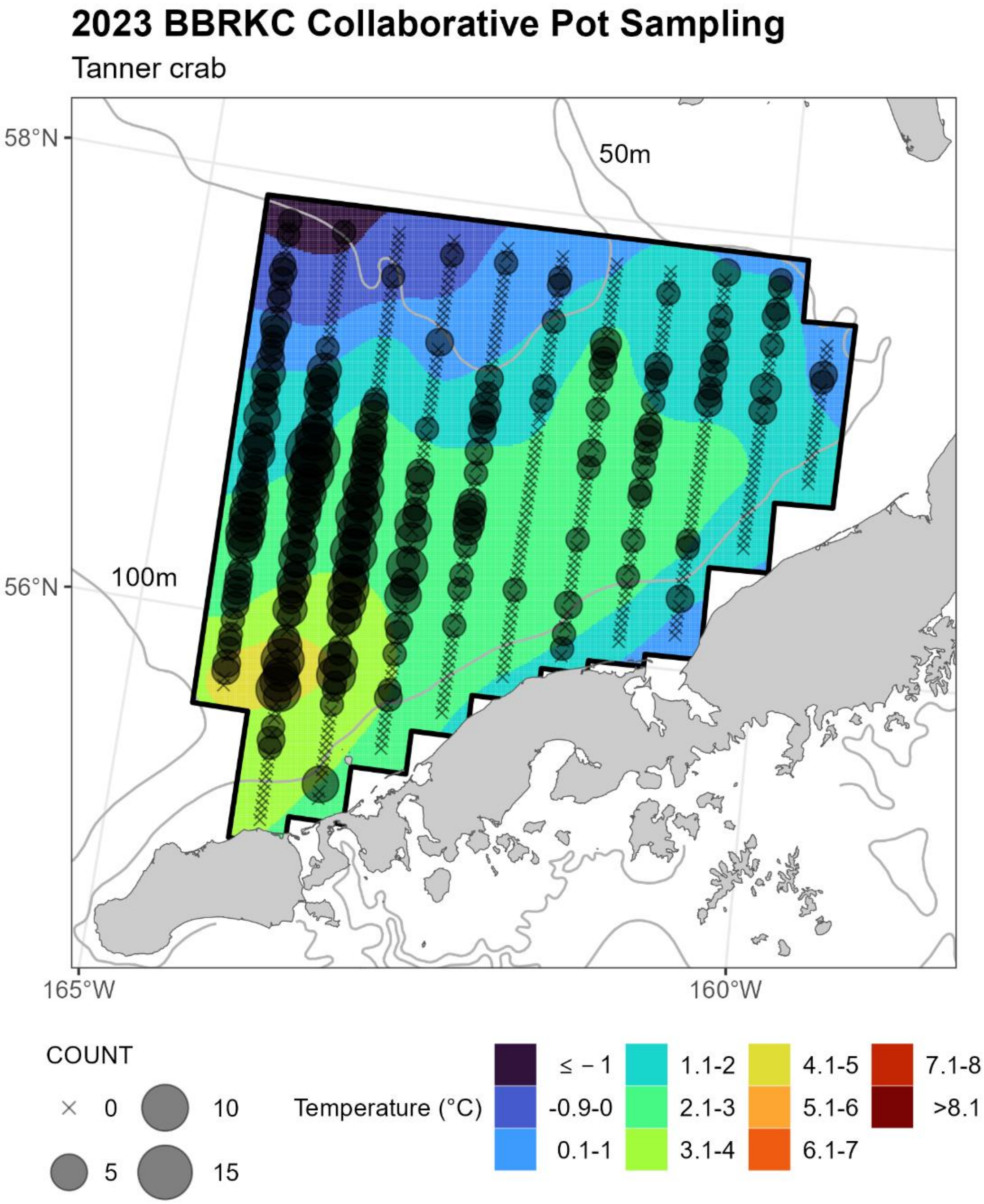

Figure 23. Spatial distribution and relative abundance of all Tanner crab (*Chionoecetes bairdi*) captured during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey. Spot size is proportional to the number of crabs captured at each location, as indicated in the legend. Abundance data are overlain on smoothed bottom temperatures obtained from temperature loggers placed inside the pots.

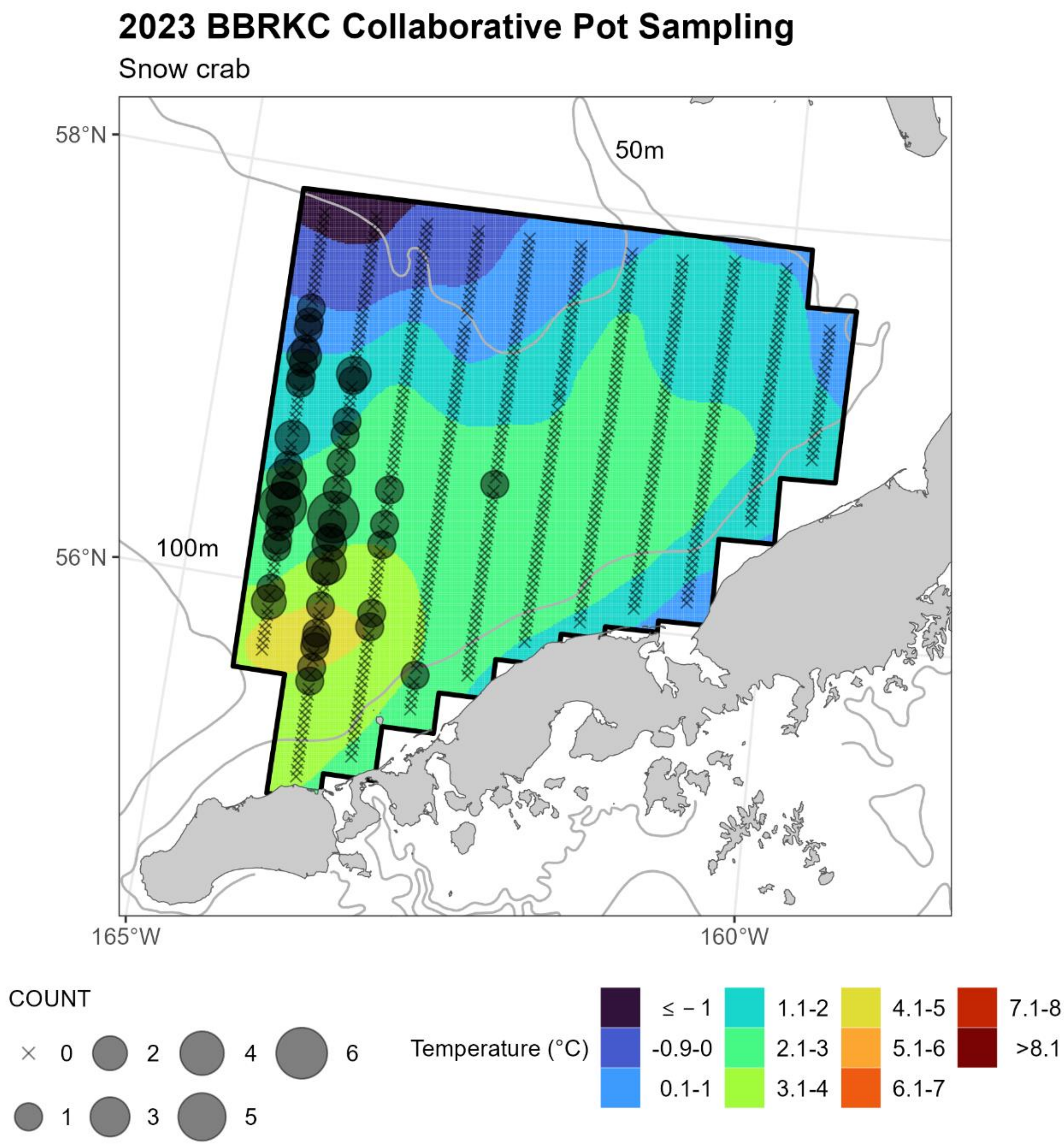

Figure 24. Spatial distribution and relative abundance of all snow crab (*Chionoecetes opilio*) captured during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey. Spot size is proportional to the number of crabs captured at each location, as indicated in the legend. Abundance data are overlain on smoothed bottom temperatures obtained from temperature loggers placed inside the pots.

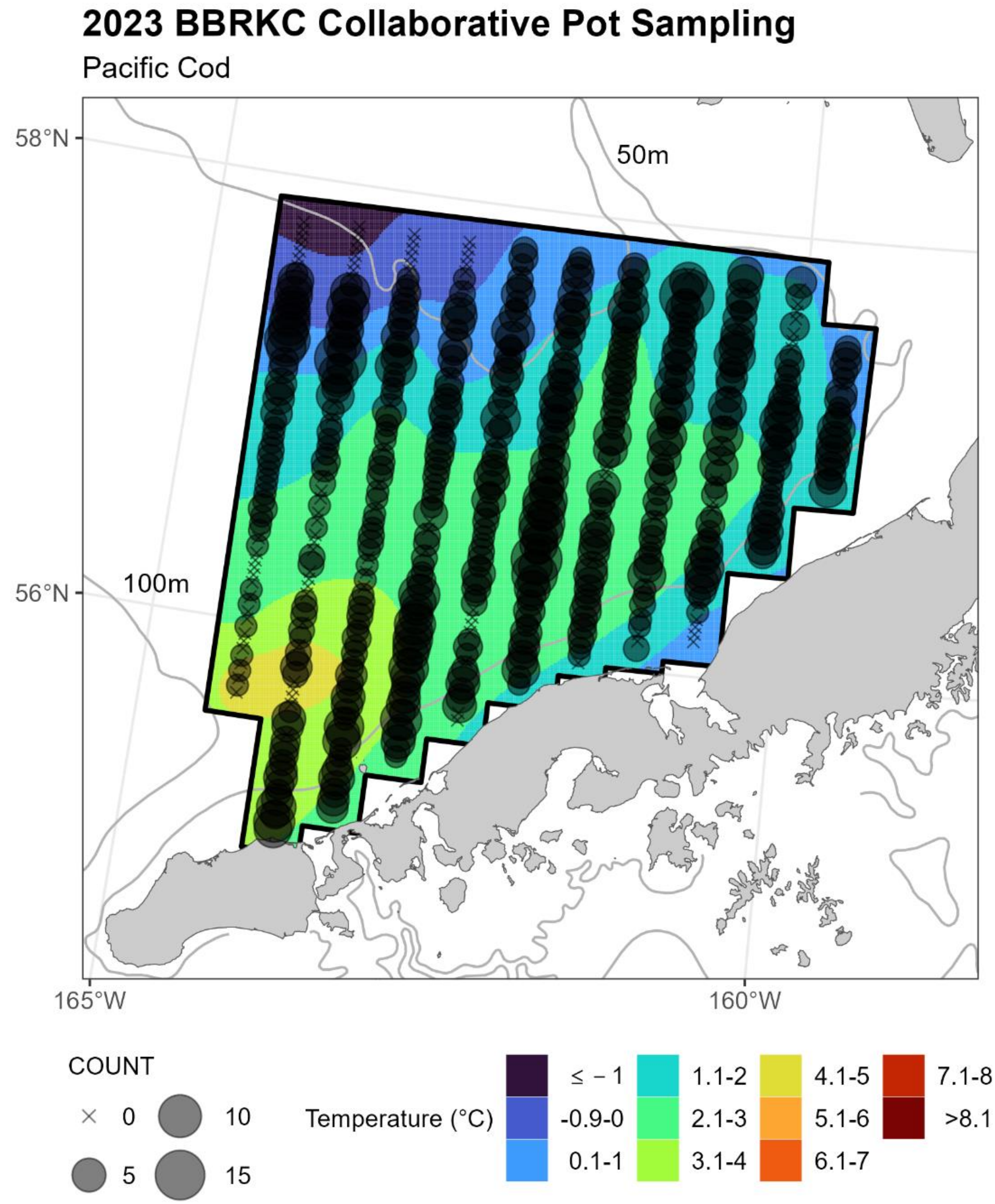

Figure 25. Spatial distribution and relative abundance of all Pacific cod (*Gadus macrocephalus*) captured during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey. Spot size is proportional to the number of fish captured at each location, as indicated in the legend. Abundance data are overlain on smoothed bottom temperatures obtained from temperature loggers placed inside the pots.

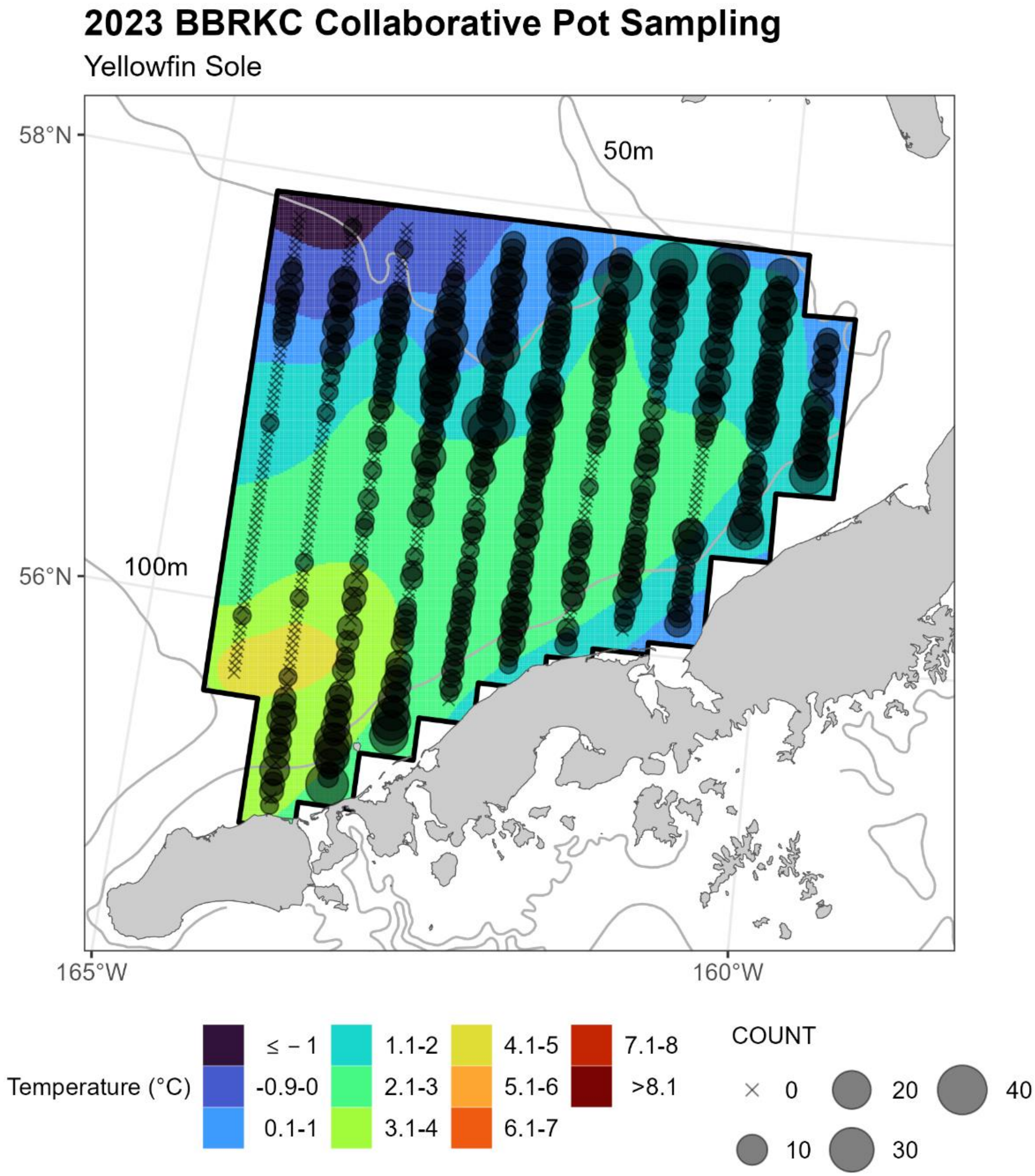

Figure 26. Spatial distribution and relative abundance of all yellowfin sole (*Limanda aspera*) captured during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey. Spot size is proportional to the number of fish captured at each location, as indicated in the legend. Abundance data are overlain on smoothed bottom temperatures obtained from temperature loggers placed inside the pots.

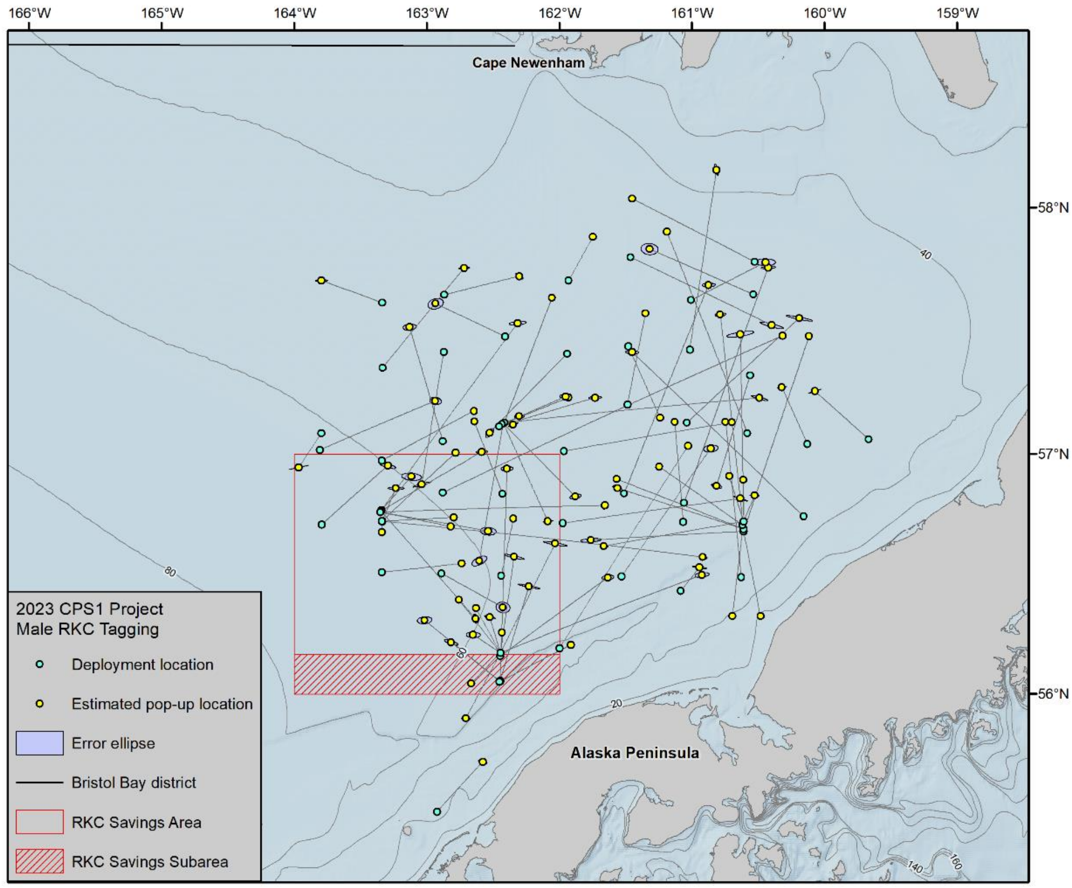

Figure 27. Movement vectors for new hard-shell, mature-size male Bristol Bay red king crab (*Paralithodes camtchaticus*) that were tagged with Pop-up Archival Transmitting (PAT) tags in late March to early April, 2023, during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey, and released from crab and reported locations via satellite from 1-3 June 2023.

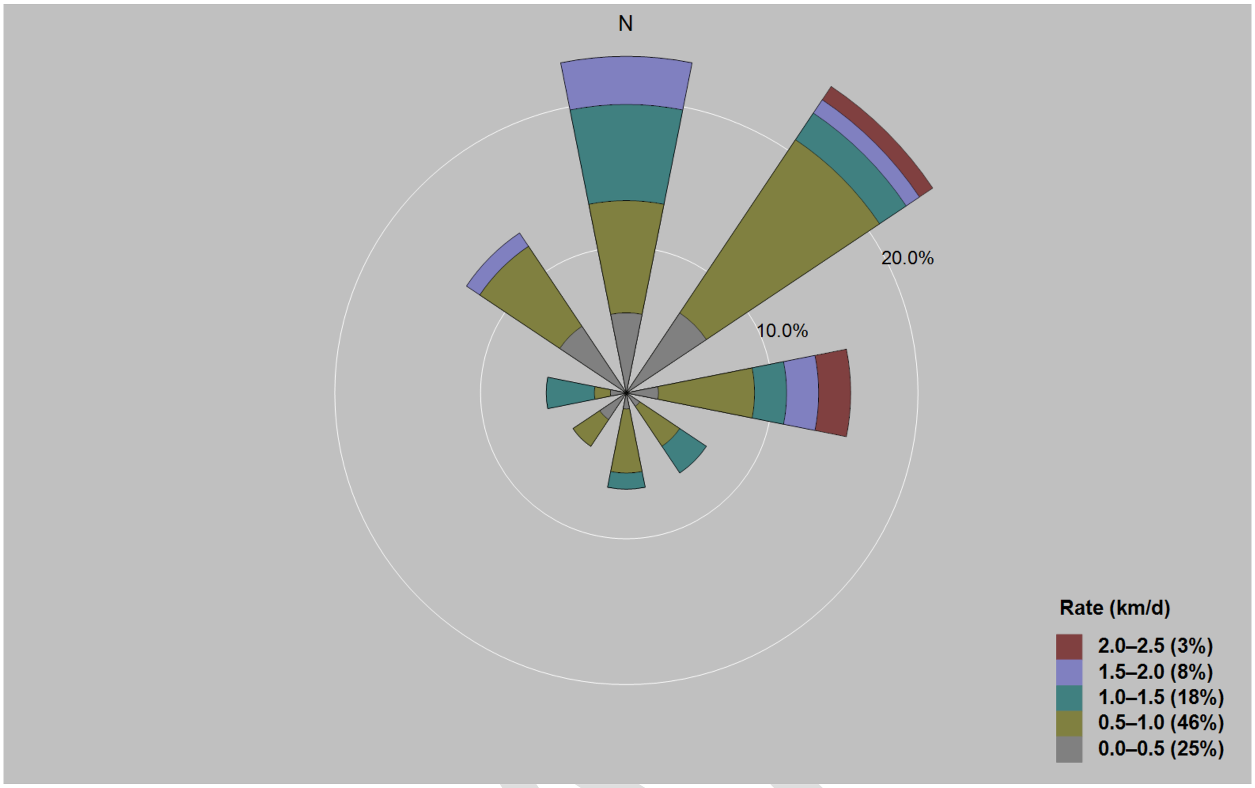

Figure 28. Rose plot showing movement rate and direction of movement between tagging and tag reporting for new hard-shell, mature-size male Bristol Bay red king crab (*Paralithodes camtchaticus*) that were tagged with Pop-up Archival Transmitting (PAT) tags in late March to early April, 2023, during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey, and whose tags released and reported final locations via satellite from 1-3 June 2023.

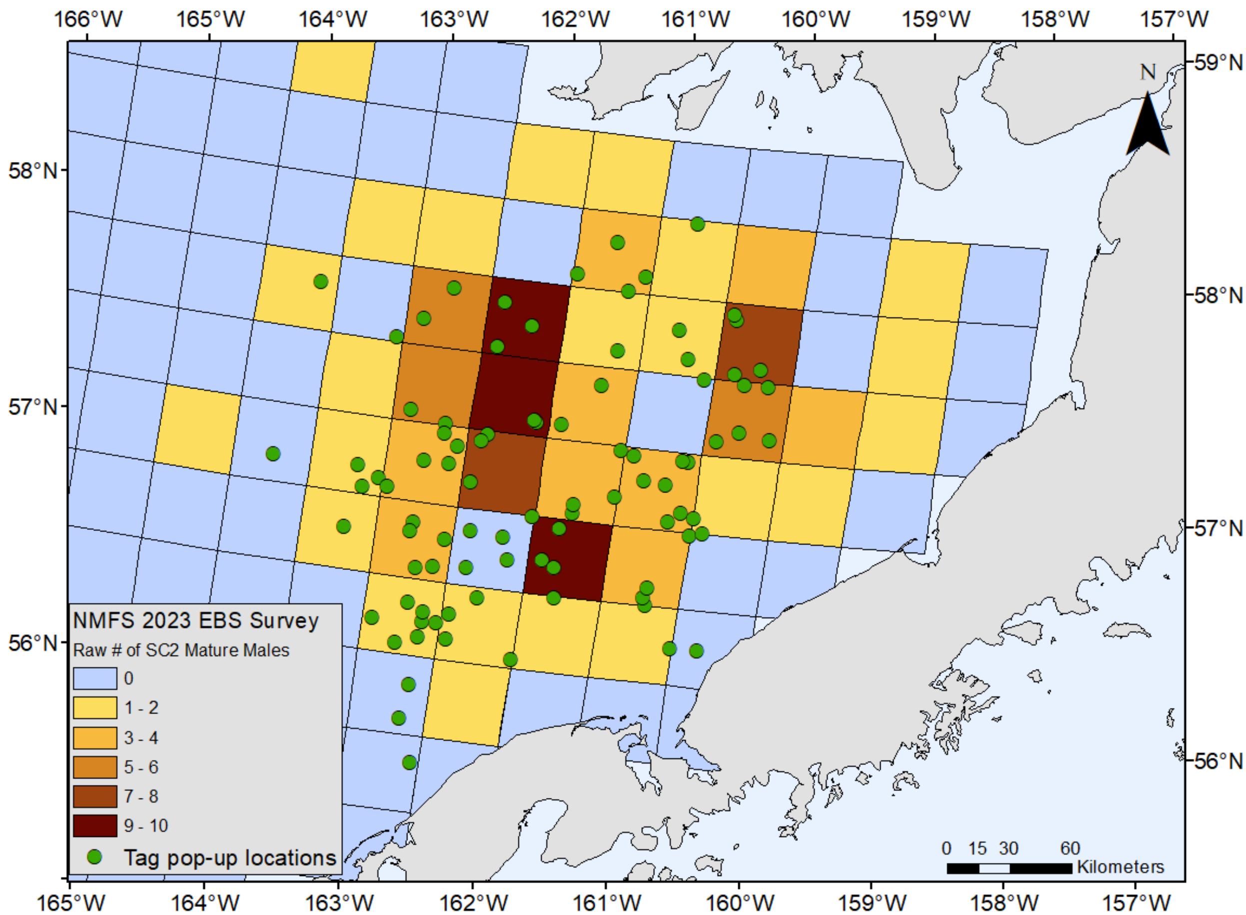

Figure 29. Pop-up locations for pop-up archival transmitting (PAT) tags that were placed on new hard-shell mature Bristol Bay red king crab (*Paralithodes camtchaticus*) during the 2023 Bristol Bay (Alaska) Cooperative Pot Sampling (CPS1) survey. Tags surfaced while the NMFS eastern Bering Sea trawl survey was surveying Bristol Bay. Pop-up locations are overlaid on trawl survey results for new hard-shell mature-size males.