History of Alaska Red King Crab, *Paralithodes camtschaticus*, Bottom Trawl Surveys, 1940–61

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Introduction

The U.S. government was integrally involved with the development of Alaska's red king crab, *Paralithodes camtschaticus*, fishing industry (Blackford, 1979). In 1940 Congress appropriated funds for surveys of Alaska's fishery resources (Schmitt, 1940; FWS, 1942). Based on the U.S. Fish and Wildlife Service's (FWS) exploratory work for red king crab during the 1940's, skeptical commercial trawlers expected the bulk of their profits to come from bottomfish. However, as commercial fishing ventures ramped up after World War II, it was soon apparent that red king crab dominated the epibenthic biomass of the southeastern Bering Sea and would be the major product (Blackford, 1979).

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As early as the 1930's, the Alaska red king crab resource was a heavily exploited species, with significant foreign commercial harvests occurring well before the first U.S. (1940–41) exploratory bottom trawl survey (Schmitt, 1940; FWS, 1942). During the 1930's, Japan and Russia together took 9–14 million kg of king crab per year from the southeast Bering Sea, within the vast area referred to as Bristol Bay.

In 1946, U.S. fishermen began commercial king crab fishing in these same waters, and by 1963 the United States dominated the fishery (Blackford, 1979). By 1960, after trawls and tangle nets were outlawed as capture methods for Alaska king crab, only pots could be fished and only male crabs could be retained, with all females and undersize males being released. Despite these substantial restrictions, during the 1970's, the male-only red king crab fishery was the most valuable single-species fishery in Alaska and, after decades of increasing catches, the all-time record U.S. harvest of 59 million kg of Bristol Bay legal crab (males with a carapace length ≥135 mm) was recorded in 1980. Then, in 1981, the Bristol Bay red king crab population abruptly collapsed in one of the more precipitous declines in the history of U.S. fisheries management. In the opinion of Alaska crab managers and modelers (Otto, 1986; Zheng and Kruse, 2002; NPFMC[1]), the crash of the Bristol Bay red king crab stock was a natural phenomenon unrelated to commercial fishing.

Considering the history of the Bristol Bay red king crab commercial fishery and the unresolved issues surrounding the 1981 collapse (Dew and McConnaughey, 2005), it is possible that data from the 1940–61 surveys might be of some help in answering the question of whether the stock was overfished. An important reference point used to assess the relative health of a stock is the virgin stock biomass (B_0). If the ratio between current and virgin biomass (B/B_0) is below some predetermined threshold, then the stock is diminished to the point where it may be characterized as being overfished. According to Pereyra et al.[2], the baseline year for the Bering Sea bottom trawl program is 1975. However, it is likely that earlier surveys, conducted during the 1940's and 1950's, can tell us more about the B_0 of Bristol Bay red

ABSTRACT—Thirteen bottom trawl surveys conducted in Alaska waters for red king crab, Paralithodes camtschaticus*, during 1940–61 are largely forgotten today even though they helped define our current knowledge of this resource. Government publications on six exploratory surveys (1940–49, 1957) included sample locations and some catch composition data, but these documents are rarely referenced. Only brief summaries of the other seven annual (1955–61) grid-patterned trawl surveys from the eastern Bering Sea were published. Although there have been interruptions in sampling and some changes in the trawl survey methods, a version of this grid-patterned survey continues through the present day, making it one of the oldest bottom-trawl surveys in U.S. waters. Unfortunately, many of the specific findings made during these early efforts have been lost to the research community. Here, we report on the methods, results, and significance of these early surveys, which were collated from published reports and the unpublished original data sheets so that researchers might begin incorporating this information into stock assessments, ecosystem trend analyses, and perhaps even revise the baseline population distribution and abundance estimates.*

[1]NPFMC. 2000. Stock assessment and fishery evaluation (SAFE) report for the king and Tanner crab fisheries of the Bering Sea and Aleutian Islands (BSAI) regions. Crab model structures and model fits. Appendix 1:330–348. Compiled by the plan team for king and Tanner crab fisheries of the BSAI. Unpubl. rep. available from the North Pacific Fishery Management Council, 605 West 4th Avenue, Suite 306, Anchorage, AK.

[2]Pereyra, W. T, J. E. Reeves, and R. G. Bakkala. 1976. Demersal fish and shellfish resources of the eastern Bering Sea in the baseline year 1975. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., NWAFSC Proc. Rep., 619 p.

king crab than a 1975–80 data series collected from a highly exploited stock on the brink of collapse. Also, according to an Environmental Impact Statement on Essential Fish Habitat, "the abundance of red king crabs in the late 1970's was anomalously high and should not be viewed as a realistic goal for restoring the population" (NMFS, 2005:L-19). However, the accuracy of this statement is difficult to verify without reference to data from surveys during the 1940's, 1950's, and 1960's.

From 1940 through 1961, a series of bottom-trawl surveys was conducted to determine the biology, distribution, and means of commercially exploiting the red king crab population in Alaska waters. The first surveys (1940–49, 1957) were wide-ranging explorations, as well as cooperative arrangements between government research agencies and the private fishing industry, with the intent of identifying crab concentrations and harvest methods needed to create a self-sustaining U.S. red king crab canning industry. The later surveys (1955–61) were conducted on a predetermined grid station pattern in the eastern Bering Sea and run by researchers at the Seattle Biological Laboratory, or "Montlake Lab," to monitor the effect of the red king crab fishery on crab populations. [The parent research agency was termed the Fish and Wildlife Service from 1940 to 1955 and then the USFWS Bureau of Commercial Fisheries (BCF) starting in 1956.] In the early1960's the red king crab program was transferred from Seattle, Wash., to Juneau, Alaska. The program was again moved to Kodiak, Alaska, in 1970 (Greenwood, 1982). The interruptions in the red king crab program might partly explain why these early surveys are never referenced in the reports on current annual crab (e.g. Rugolo et al.[3]) and groundfish bottom trawl surveys (e.g. Acuna and Lauth, 2008), which are conducted jointly by the Alaska Fisheries Science Center's (AFSC) Shellfish Assessment (Kodiak) and Groundfish Assessment (Seattle) Programs, and is a direct descendant of these original trawl surveys. Our objective is to describe the purpose, effort, and findings of the early red king crab bottom trawl surveys so that the information can be utilized today. Besides red king crab data, there is also catch information on other invertebrate and fish species, seafloor substrate types, foreign fishing vessel activity, surface and bottom water temperatures, and bird and marine mammal sightings.

Figure 1.—The halibut schooner *Dorothy*, which participated in the 1940–41 Alaska king crab exploration and in the 1948 *Pacific Explorer* fleet expedition. Its small engine could be supplemented with sail supported by two masts. Bottom trawl gear was set and retrieved over the side. The dories on the stern of the vessel were used by pairs of men for halibut hand-lining. Photo of the *Dorothy* at Mitrofania Island, Alaska, courtesy of the Lokken collection (#212012) at the Museum of History and Industry, Seattle, Wash. Photo credit: Puget Sound Maritime Historical Society.

Exploratory Bottom Trawl Surveys, 1940–49, 1957

Tondeleyo and *Dorothy* (1940) and *Dorothy, Champion*, and *Locks* (1941)

The primary motivation for launching the Alaska red king crab investigations was to determine the information needed (areas of abundance, crab capture methods, and canning techniques) to develop a domestic crab fishing industry, as it was noted that Americans were purchasing millions of pounds of canned Alaska crab meat taken by Japanese and Russian vessels operating in Alaska waters (FWS, 1942). The first red king crab exploration was undertaken in the fall of 1940 aboard the *Tondeleyo* and *Dorothy* (Fig. 1) (Schmitt, 1940), and it was completed aboard the *Dorothy*, *Champion,* and *Locks* in 1941 (FWS, 1942). These were private vessels chartered by the eight staff members of the Alaska Crab Investigation Staff of the Fishery Technical Laboratory in Seattle (Montlake) with money provided by Congress (FWS, 1942). This survey was the most extensive in terms of geographic area covered, seasons fished, gear experi-

[3]Rugolo, L. J., E. A. Chilton, C. E. Armistead, and J. A. Haaga. 2006. Report to industry on the 2006 eastern Bering Sea crab survey. AFSC Proc. Rep. 2006-17, 61 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., Kodiak Fish. Res. Cent., Kodiak

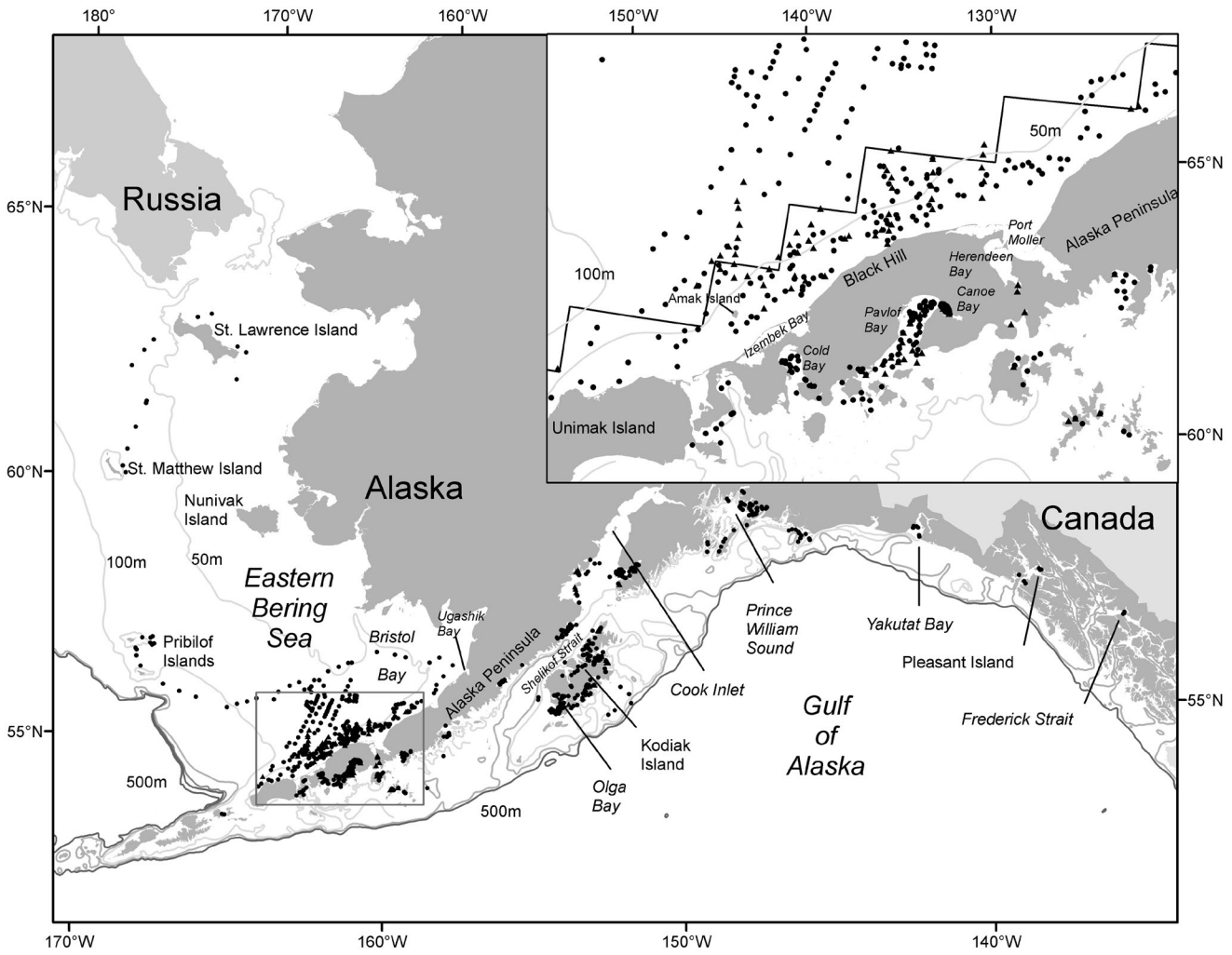

Figure 2.—Bottom trawl (●) and tangle net (▲) sampling locations during red king crab exploratory surveys conducted by the *Tondeleyo* and *Dorothy* in 1940, and by the *Dorothy*, *Champion*, and *Locks* in 1941. The stair-step line within the inset map shows the approximate southern extent of the present day survey (the center of the southernmost stations where most modern trawling occurs).

mentation, and overall impact on the other trawl surveys conducted during this era. Operations ranged from Frederick Sound in Southeast Alaska to Yakutat Bay, Prince William Sound, Cook Inlet, Kodiak Island, Shelikof Strait, the south side of the Alaska Peninsula, the southern Bering Sea, and north to St. Lawrence Island (Fig. 2). Inlets of all types were a major focus, with over 100 bays, coves, lagoons, ports, and harbors surveyed. Fishing ranged from late February through late November, so that seasonal changes in distribution and condition were observed. Over the years, the four vessels made 765 bottom trawl attempts and 151 tangle-net settings, caught over 39,000 red king crab, and reported various successes and failures due to conditions that would be encountered by future fishermen and researchers. Extensive results were published in a special May 1942 supplement to the FWS publication "Fishery Market News," and the hand-written data sheets are stored at the AFSC's Kodiak Laboratory; only a portion of those were accessed for this project. Thus, nearly all the results come from the publication.

Trawls vs. Tangle Nets

During this 1940–41 project, researchers compared the effectiveness and utility of catching crabs with bottom trawls and tangle nets in order to make recommendations to the U.S. fishing industry (FWS, 1942). The tangle nets had 45.7 cm (18 in) meshes, were 365.8 m (200 fathoms) long, 1.8 m (6 ft) high, and set vertically on the seafloor to entangle crab as they walked into the net (FWS, 1942: Fig. 26). Two general types of otter trawls were experimented with during the survey: the Atlantic

type had two seams and was low-opening (FWS, 1942: Fig. 28), whereas the Pacific type net had four seams and a higher opening (FWS, 1942: Fig. 29). Additionally, a modified Atlantic net with large meshes (20.3 cm or 8 in) and a larger Pacific trawl were tried. The trawls used wooden doors that were attached directly to the wing tips, so that door spread was essentially the same as net spread. Several conclusions and recommendations about the tested gears were made (FWS, 1942). Compared to tangle nets, the trawls were better at prospecting and exploring large areas, and large catches could be made in just a few minutes when crab concentrations were found. Also, trawls were nonselective, catching males, females, and juveniles equally, which was an advantage in assessment surveys. However, unlike tangle nets, trawls were destructive to the crab, catching and killing relatively immobile soft-shelled females on the spawning grounds. Also, trawl sampling was hit or miss in areas of high concentration, and trawls were often damaged in areas of rough seafloor, resulting in loss of catch.

Advantages of tangle nets were that they were effective and consistent in high abundance areas, and, in consideration for commercial fishing, they selected males over females, selected the more mobile hard-shelled crab over soft-shelled crab, and selected larger over smaller crab. The disadvantages were that tangle nets were poor for exploring, and the process of disentangling the captured crab was laborious and time-consuming. In 31 instances where both gears were fished in the same locations, with a 90 min soak for the tangle net and a 90 min set and retrieval period for the trawl, the tangle nets caught 50% more males (FWS, 1942). In overall catches, the tangle net males averaged 3 pounds heavier than those in the trawls (FWS, 1942).

Red and Blue King Crab Distributions

Red king crab were caught in a majority of the fishing attempts, and the crab ranged from Yakutat, through the Gulf of Alaska, and along the south and north sides of the Alaska Peninsula (FWS, 1942). In the southeast Bering Sea the largest catches were made along the Black Hill area, from Izembek Bay to Port Moller (Fig. 2). On the south side of the Alaska Peninsula, Pavlof and Canoe Bays had the highest catches and "were the most promising of all the Pacific [non Bering Sea] regions visited" (FWS, 1942:p. 57). Olga Bay had the highest catches in the Kodiak Island area. No great concentrations of blue king crab, *P. platypus*, were discovered, but they were abundant in the northern Bering Sea around the Pribilof, St. Matthew, and St. Lawrence Islands, where they replaced the red king crab. Isolated populations of blue king crab were found in Herendeen Bay on the north side of the Alaska Peninsula, Olga Bay on Kodiak Island, and a single blue king crab was found off Pleasant Island in Southeast Alaska.

While the 1940–41 survey was exploratory and conducted largely by personnel without experience for this type of research, the results clearly indicated the vast amount of red king crab biomass in the southeast Bering Sea. In Bristol Bay and adjacent waters (to long. 165.3°W), 19,162 red king crab were collected in 214 successful tows (about 80 crab per hour of effort) during April–September 1941. For reference, today's standard survey of the same general area collects an average of less than 2,000 red king crab, or about 8 crab per hour of effort. Some of this tenfold difference in crab density can be attributed to the fact that today's survey, although intended to cover the entire range of the Bristol Bay red king crab stock and to estimate its abundance, does not trawl within the high-density spawning grounds inshore of the "standard" survey boundary (Fig. 2).

Of the 214 tows conducted in red king crab habitat during 1941, only 9% caught no red king crab; by comparison, 50–60% of today's Bristol Bay survey tows are devoid of red king crab (Dew and Austring, 2007). From Unimak Island east along the Alaska Peninsula to Ugashik Bay, the 1941 Bristol Bay survey was divided into two areas—inshore and offshore. The offshore operations were conducted in waters 55–185 km from shore where males were more abundant (5,159 males caught vs. 1,513 females). The inshore operations, extending 55 km from shore, accounted for a greater proportion of the survey crab and the catches were generally dominated by females (7,539 females caught vs. 4,951 males).

The 1941 survey was the only one to describe the Bering Sea distribution of adult red king crab during the mating season on spawning grounds within 5–40 km from shore. The largest catches were made on these nearshore grounds along the western end of the Alaska Peninsula between Amak Island and Port Moller (FWS, 1942). The largest catch (3,188 crab, 57% females) was taken on 1 May in a 1.5 h tow in 38–44 m between Amak Island and Black Hill (Fig. 2). This catch was so heavy, estimated at 8,200 kg (9 tons), that it stopped the vessel, perhaps limiting the total catch.

Based on several tows in this area, investigators made the following observation: "Evidently huge beds of moulting females are mating with the males at this time of the year, and they are massed together in such a manner as to make them easy prey for a type of gear like the otter trawl, which scrapes along the bottom" (FWS, 1942: p. 72). While it is difficult to precisely define the areal extent of that aggregation, multiple tows indicated that the distribution of this molting-mating aggregation was continuous throughout at least a 140 km^2 area. This high-concentration spawning area, 37 km west of long. 162°W, is unprotected by any of the present-day trawl closures in the southeastern Bering Sea (Witherell and Woodby, 2005). Also, this spawning location (lat. 55.583°N, long. 162.583°W) is approximately 20 km inshore of today's stock-assessment survey boundary at lat. 55.7°N, long. 162.8°W, suggesting that large numbers of adult crab would be unavailable to a survey that was conducted during spawning but which did not extend inshore of the standard-survey boundary (Dew, 2008).

The second-largest catch in the 1941 survey (1,422 crab, 73% females) was

taken on 2 May in a 1 h tow in 44–46 m between Black Hill and Port Moller (Fig. 2). Again, the location (lat. 56.033°N, long. 161.567°W) of this large (>200 km^2) spawning aggregation was about 20 km inshore of today's survey boundary running between lat. 56.0°N, long. 162.2°W and lat. 56.3°N, long. 161.5°W off Black Hill–Port Moller. Similar to the dense aggregation of females off Amak–Black Hill, the females here, 93 km farther east along the Alaska Peninsula, were in a soft or molting condition in early May that resulted in most of them dying upon capture.

According to the 1942 report, trawl catches along the Alaska Peninsula diminished moving from Port Moller eastward "until a drag off Ugashik (lat. 57.667°N, long. 158.217°W) resulted in a 'skunk' haul" (FWS, 1942: p. 74). Today, this same area of Bristol Bay east of Port Moller, an area characterized by low crab abundance and little trawling activity (Dew and McConnaughey, 2005: Fig. 3), is protected from trawling as part of the Nearshore Bristol Bay Trawl Closure, which includes all waters east of long. 162°W.

Other Species

Vast quantities of flatfishes, *Pleuronectidae*, were taken as bycatch in the Bering Sea, though flatfish caught in Cook Inlet were of better quality (FWS, 1942). Catches of cod, *Gadus macrocepahlus*, were low, but it was hypothesized that this was due to using low-rise trawls and that the distribution of large cod extended farther north into the Bering Sea than had been believed previously. Aside from red king crab, Canoe Bay was noteworthy for large catches of flatfish and Tanner crab, *Chionoecetes* sp., which ranged up to 4,000 individuals in a 30 min tow.

Prince William Sound only yielded small quantities of fish. Although not mentioned in the publication, catches of "hake" or "silver hake," but without scientific names, were recorded on the individual data sheets from the shallows on the north side of the Alaska Peninsula, ranging up to 3,200 kg (7,000 lbs) in a 90 min bottom tow. It is unclear if the fish species referred to as "hake" was Pacific hake, *Merluccius productus* (Robins et al., 1991), which is not reported from Bering Sea surveys (Acuna and Lauth, 2008).

Figure 3.—The University of Washington's research vessel *Alaska* during the Alaska Fisheries Science Center's 1992 U.S. West Coast bottom trawl survey. Photo credit: Mark Zimmermann.

Another fish species listed on some of the same data sheets, but never within the same hauls, is referred to as "pollock," which was more common and presumably meant walleye pollock, *Theragra chalcogramma*, the most abundant species in the Bering Sea (Acuna and Lauth, 2008).

Interruption

Alaska red king crab exploratory cruises were discontinued during World War II, 1942–45, but at the end of the war the potential for harvesting underutilized marine resources reported from the 1940–41 explorations resulted in the government-financed conversion (via the Reconstruction Finance Corporation or RFC) of the *Pacific Explorer* into a factory processor and the construction of four smaller fishing vessels; the *Alaska*, *Washington*, *Oregon,* and *California* (Greenwood, 1982). Part of the vessel lease agreement from the RFC to the Pacific Exploration Corporation (PEC) included allowing government researchers to participate in the cruises (Greenwood, 1982). To complement this vessel construction effort, a North Pacific Exploratory Fishing and Gear Research (EF&GR) program was established at the FWS's Montlake Lab in Seattle in 1948 (Greenwood, 1982). During this era, EF&GR staff participated in three individual vessel cruises in 1947, 1948, and 1949; a ten-vessel fishing cruise with the *Pacific Explorer* factory processor in 1948; and a 1957 exploratory cruise aboard the *Tordenskjold*.

Alaska 1947

The 1947 cruise was a private venture to catch, process, and freeze Bering Sea red king crab, operated by the PEC using the RFC-purchased vessel *Alaska* (Fig. 3) (King, 1949). An observer from the International Fisheries Commission (IFC, now the International Pacific Halibut Commission or IPHC) tagged halibut while an observer from the FWS

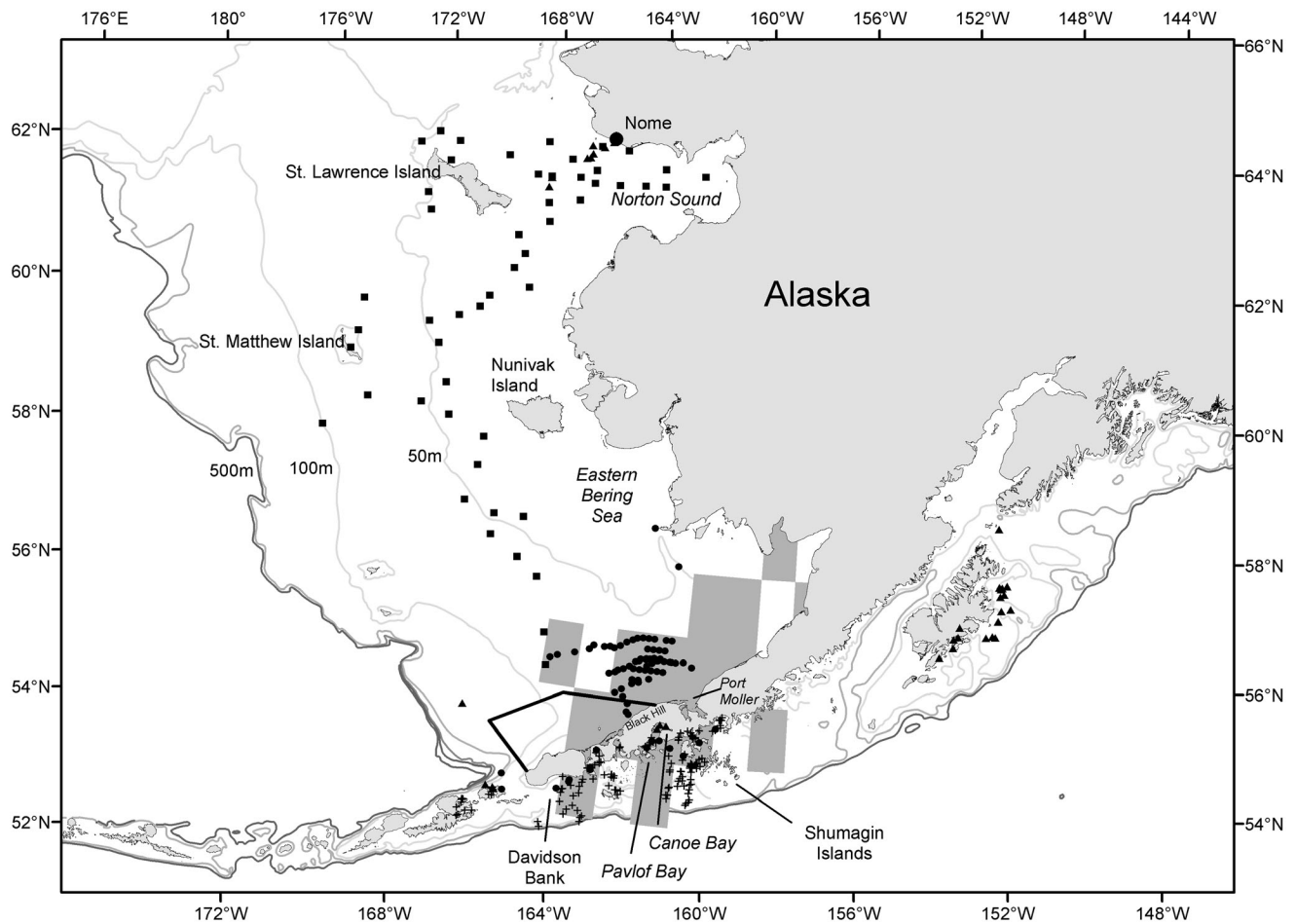

Figure 4.—Bottom trawl sampling locations during the *Alaska* 1947 (●), *Washington* 1948 (▲), and *Deep Sea* 1949 (■) red king crab exploratory cruises. Bottom trawl, shrimp trawl, and pot sampling locations (+) are shown for the 1957 *Tordenskjold* exploration in the Shumagin Islands area. *Pacific Explorer* fleet sampling effort of 1948 is only shown in one degree latitude/longitude blocks (■). The location of the Pot Sanctuary in the southern Bering Sea is shown with a solid black boundary (—).

collected information about crab and other groundfish. The original FWS data sheets are stored at the AFSC's Kodiak Laboratory and were not examined, but separate data sheets were also recorded by the IFC representative and these were accessed at the IPHC. While only data from the FWS publication (King, 1949) were utilized for this data rescue project, it is interesting to note that there are several discrepancies between the catch composition on the halibut data sheets and the FWS publication (King, 1949), suggesting separate data recording by the FWS and IPHC representatives during the cruise.

The 1947 cruise focused the most effort and caught the most marketable crab off the Black Hill area in the southeast Bering Sea, the region first prospected by the 1940–41 exploration (Fig. 4), thus confirming the high concentration of marketable male king crab and the ease of towing on the seafloor in this area (King, 1949). Over 14,000 red king crab were caught in only 148 trawl attempts. Large numbers of juvenile red king crab were caught in only two tows, one just offshore from the Black Hill area and the other about 65 km north from Port Moller.

The main impediments to trawling were large invertebrate catches which clogged and filled the net. While catches of halibut were low, the trawl caught tons of cod, pollock, and flatfish, which were discarded as waste, although King (1949) subsequently speculated that commercial fisheries might develop for these species. While, in general, only weights of major fish and invertebrate species were recorded, lengths of fish were measured from a few hauls and surface and bottom water temperatures were collected from 31 tows.

Pacific Explorer Fleet 1948

In early 1948, a fleet of 10 catcher vessels which included the *Bear*, *Borris*, *Dorothy* (Fig. 1), *Foremost* (Fig. 5), *Jeanette F.* (Fig. 6), *Kiska*, *Mars*, *Pearl Harbor*, *Sunbeam,* and *Tordenskjold* (Fig. 7), in support of the factory vessel *Pacific Explorer*, went to the Bering

Sea to catch, process, freeze, and can seafood (Wigutoff and Carlson, 1950). The PEC operated the factory ship and chartered the catcher vessels for a 90-day period of fishing. Fishing market specialist Norman Wigutoff (FWS, Ketchikan) and chief of exploratory fishing Carl Carlson (FWS, Honolulu) observed operations on the factory vessel and assisted with resolving problems with fishing methods, fishing gear, and canning operations (Greenwood, 1982). Logbooks were recorded by the catcher vessel skippers and provided to the FWS after the cruise. Summaries of catches from 1,099 trawl and 84 tangle-net sets were published in Wigutoff and Carlson (1950) but the actual locations are generalized, either by 10 minute or one degree latitude and longitude intervals (Fig. 4). Many fishing trials with insufficient catch and position information were not reported. The original data sheets are stored in the AFSC's Kodiak Laboratory archives but were not examined for this report.

The fleet started north from Seattle in the spring and met in early April in Pavlof Bay to await melt of the remaining Bering Sea ice and to experiment with crab fishing and processing methods in an area of known red king crab abundance (Wigutoff and Carlson, 1950). Within a 10-day period, a total of 31,657 male crab were taken from Pavlof and Canoe Bays—more than double what the *Alaska* had caught in the Bering Sea during a month of fishing in the previous year (King, 1949).

After the practice fishing in Pavlof and Canoe Bays, most of the fishing was done in the southeast Bering Sea, off the Black Hill area, slightly southeast of the fishing area of the 1947 *Alaska* cruise, and was of sufficient extent and duration to determine the general king crab reproductive migratory pattern. Trawls from 18 April to 5 July 1948 along the Alaska Peninsula from the western end of Unimak Island to Ugashik Bay collected more than 19,000 female red king crab and, similar to 1941, these crab were most abundant within the Unimak–Amak–Black Hill region.

The 12.7 cm mesh of the trawl's cod-end was sufficiently large to retain only the larger females, most of which would have been multiparous (carrying other than their first egg clutch and defined as ≥100 mm carapace length: Dew, 2008) crab forming the bulk of the broodstock (all gravid females). In the

Figure 5.—The schooner *Foremost* which was employed in the 1948 *Pacific Explorer* expedition for red king crab. Photo of the *Foremost* at Ketchikan, Alaska, courtesy of the Lokken collection (#223964) at the Museum of History and Industry, Seattle, Wash. Photo credit: Puget Sound Maritime Historical Society.

Figure 6.—The combination vessel *Jeanette F.* which was employed in the 1948 *Pacific Explorer* expedition for red king crab, docked opposite the *Deep Sea*, Lowell Wakefield's crab processing vessel. Photo of the *Jeanette F.* courtesy of the Joe Williamson collection (#5620) at the Museum of History and Industry, Seattle, Wash. Photo credit: Puget Sound Maritime Historical Society.

Figure 7.—The schooner *Tordenskjold* which was employed in red king crab explorations in 1948 and 1957 and in red king crab grid-patterned bottom trawl surveys in 1955–56 and 1958–59. Photo of the *Tordenskjold* courtesy of the Lokken collection (#209487) at the Museum of History and Industry, Seattle, Wash. Photo credit: Puget Sound Maritime Historical Society.

Unimak–Amak–Black Hill region, an area that was to become the original "Pot Sanctuary" (Beale, 1971) and referred to as Naab's "Special Sanctuary" in Dew and McConnaughey (2005), broodstock abundance (females per tow) in the 1948 survey was more than 20 times greater than that found in the Nearshore Bristol Bay Trawl Closure (all waters east of 162°W longitude), which is a protected area today. Large males had a similar distribution, with the highest densities in the Pot Sanctuary and the lowest densities east of Port Moller, within the region protected by today's trawl closure.

Again, tangle nets selectively caught male king crab and were better for conservation of the stock, but fishermen found disentangling the crab too difficult and resorted to tearing the PEC supplied nets to remove crab (Wigutoff and Carlson, 1950). Small flatfish, Pacific cod, walleye pollock (called whiting in the catch appendix of Wigutoff and Carlson, 1950), Tanner crab, and horsehair crab, *Erimacrus isenbeckii*, made up the bulk of the bycatch. Most of the small flatfish caught were considered too small for filleting and in too poor condition for marketing, so they were processed into fish meal, while most of the cod were large, in great condition, and processed at sea for commercial sales. One very interesting, accidental discovery was made during this cruise; an outbreak of respiratory illness among some of the workers on the *Pacific Explorer* resulted from an allergic reaction to breathing fumes from the crab cooking and canning process, crab asthma (Wigutoff and Carlson, 1950).

New bottom trawls were created for this catcher fleet based on experience from the 1940–41 survey—an Atlantic style trawl with a 29 m (95 ft) headrope and a 36 m (118 ft) footrope and a Pacific style trawl with a 25.3 m (83 ft) headrope and a 30.8 m (101 ft) footrope (Wigutoff and Carlson, 1950). Fishermen preferred the Atlantic over the Pacific trawl. The tangle nets were 1.8 m (6 ft) tall curtains of 40.6–45.7 cm (16–18 in) mesh 274.3 m (150 fathoms) long that rested on the seafloor.

Washington 1948

Ownership of the *Washington* was transferred from the PEC to the Montlake Lab in July 1948 (Greenwood, 1982) through special Congressional funding, which also supported vessel operations (Ellson et al., 1949). That fall the BCF used the vessel to explore the Norton Sound and St. Lawrence Island area (Fig. 4) of the northern Bering Sea, complementing previous research farther to the south. The first tow was not attempted until mid-September off of Nome and bad weather quickly forced the cruise south. On the way back to Seattle, three trawl hauls were conducted in Pavlof and Canoe Bays, resulting in the bulk of the red king crab catch of the entire cruise (194 of 212 crab). Unfortunately, the Canoe Bay crab were mostly brooding females and therefore, despite the large catch, further trawls were abandoned to avoid disturbing the nursery area. In the logbook for 3 October 1948, J. G. Ellson wrote "Canoe Bay population apparently all female and young crab this time of year also nursery area for flatfish as all taken were small. Believe Bay should be closed to fishing at least at this time of year, possibly permanently." Interviews with residents of coastal communities indicate that sea lions had recently increased rapidly in abundance and their predation had reduced cod and halibut abundance, but this is not supported with scientific observations.

The *Washington* traveled about 11,455 km (6,185 miles) during the 2-month cruise and completed only 32 bottom tows in a month of fishing (Ellson et al., 1949). After the return to Seattle, whole, frozen samples of rock sole, *Lepidopsetta* sp.; yellowfin sole, *Limanda aspera*; flathead sole, *Hippoglossoides* sp.; sand sole, *Psettichthys melanostictus*; and English sole, *Parophrys vetulus*, were partially thawed, filleted, refrozen, and compared with local flatfish. Laboratory analysis demonstrated that water loss upon thawing was comparable to local fish and the Alaska flounder fillets were rated higher for color, flavor, and texture at local fish markets. Thus, some of the bycatch or waste fish species from the 1940–41 exploration (FWS, 1942), the 1947 *Alaska* cruise (King, 1949), and the 1948 *Pacific Explorer* fleet cruise (Wigutoff and Carlson, 1950) were shown to be marketable, perhaps due to improved flesh quality and the late summer period. The authors of the 1949 Fishery Leaflet (J. G. Ellson, B. Knake, and J. Dassow) all participated in the

cruise, which later became known as Exploratory Cruise #1. The original log book is archived at the AFSC.

Deep Sea 1949

The 1949 cruise was conducted aboard the chartered vessel *Deep Sea* (Fig. 8), another RFC venture operated by Lowell Wakefield's Deep Sea Trawlers (later called Wakefield Seafoods) (Greenwood, 1982). The northern Bering Sea and Norton Sound area (Fig. 4) were finally explored on this cruise in the relatively good weather of summer, but found only 115 red and blue king crab in 51 tows (Ellson et al., 1950). No concentrations of any commercial species were found in the north and the seafloor north of St. Lawrence Island was too abrasive and rocky to trawl. Three catches exceeding 1,000 juvenile Tanner crab per 60 min tow were recorded from south of St. Lawrence Island, north of St. Matthew Island, and south of Nunivak Island. Some fish weights and lengths were collected and some stomach contents analysis was performed. Bottom samples were collected with a sounding lead, and catch data were related to water temperatures and depths. As in the 1948 *Washington* cruise, the small flatfish were reported to be in good condition. The bottom trawl was described as an Iceland trawl and dimensions were reported in a FWS Fishery Leaflet (Ellson et al., 1950). The *Deep Sea* 1949 cruise became known as Exploratory Cruise #2. The original data sheets, which list the FWS participants as J. G. Ellson, Donald Powell, Henry Hildebrand, and Ernest Dietrich, also provide net diagrams, some fish lengths, and stomach contents and are also archived at the AFSC.

Tordenskjold 1957

The *Tordenskjold* was chartered with Saltonstall–Kennedy Act funds in 1957 to explore for commercial quantities of red king crab in the region from Davidson Bank to the Shumagin Islands (Fig. 4) because of the large red king crab catches in Pavlof and Canoe Bays taken during the 1940–41 exploration (Johnson, 1959), during the spring of 1948 by the *Pacific Explorer* fleet (Wigutoff and Carlson, 1950), and during the fall of 1948 by the *Washington* (Ellson et al., 1949). Despite prospecting with a bottom trawl, a shrimp trawl, and king crab pots, no large quantities of red king crab were found. There were several catches of shrimp exceeding 450 kg (1,000 lbs), especially at the edge of Pavlof Bay, but the largest commercial trawl catch was 2,300 kg (5,000 lbs) of cod. Small catches of Pacific hake, ranging from 1 to 10 fish, were recorded in five otter trawl tows, including three which also had walleye pollock, again indicating the presence of a population of the fish in this area. Water temperatures were not recorded but 134 substrate observations were made.

Figure 8.—The side trawler and fish and crab factory processor *Deep Sea*, built by Lowell Wakefield's Deep Sea Trawlers company later renamed Wakefield Seafoods. Photo courtesy of the Joe Williamson collection (#3342-4) at the Museum of History and Industry, Seattle, Wash. Photo credit: Puget Sound Maritime Historical Society.

Monitoring/Gridded Surveys 1955–61

The era of long-term monitoring and grid-patterned red king crab bottom trawl surveys, designed for abundance estimates and stock monitoring, began with strong international cooperation. The International North Pacific Fisheries Commission (INPFC) was established in 1952 and initiated a cooperative U.S.–Japan red king crab monitoring program in 1954 (INPFC, 1954a) out of concern that the stock was already being fully exploited in the Bering Sea (INPFC, 1954b).

Prior to the official start of this cooperative program, in April 1953, BCF crab biologist Takashi Miyahara was transported to the Japanese king crab factory processor *Tokei Maru* near Amak Island by the *Deep Sea* (Fig. 8) so Japanese fishing operations could be observed. The *Deep Sea* also hosted a Japanese crab biologist to observe U.S. fishing operations (Miyahara, 1954). No U.S. research cruise was conducted in 1954, but biologists joined the *Deep Sea* during king crab commercial trawling operations in the Bering Sea and tagged 1,108 male king crab on the carapace or legs with Peterson disc tags affixed with nickel pins (INPFC, 1956). Since crab grow by shedding their integument, this tagging method was quickly abandoned and never repeated, but 28 of the 61 tags returned during 1955 had stayed on the crab for more than a year, leading to the serendipitous discovery that adult male crab do not molt every year. A study during trawling operations of the *Deep Sea* showed that soft-shelled (recently molted) males and females suffered high mortalities, ranging from 30% to 80%, as a result of being captured in trawls.

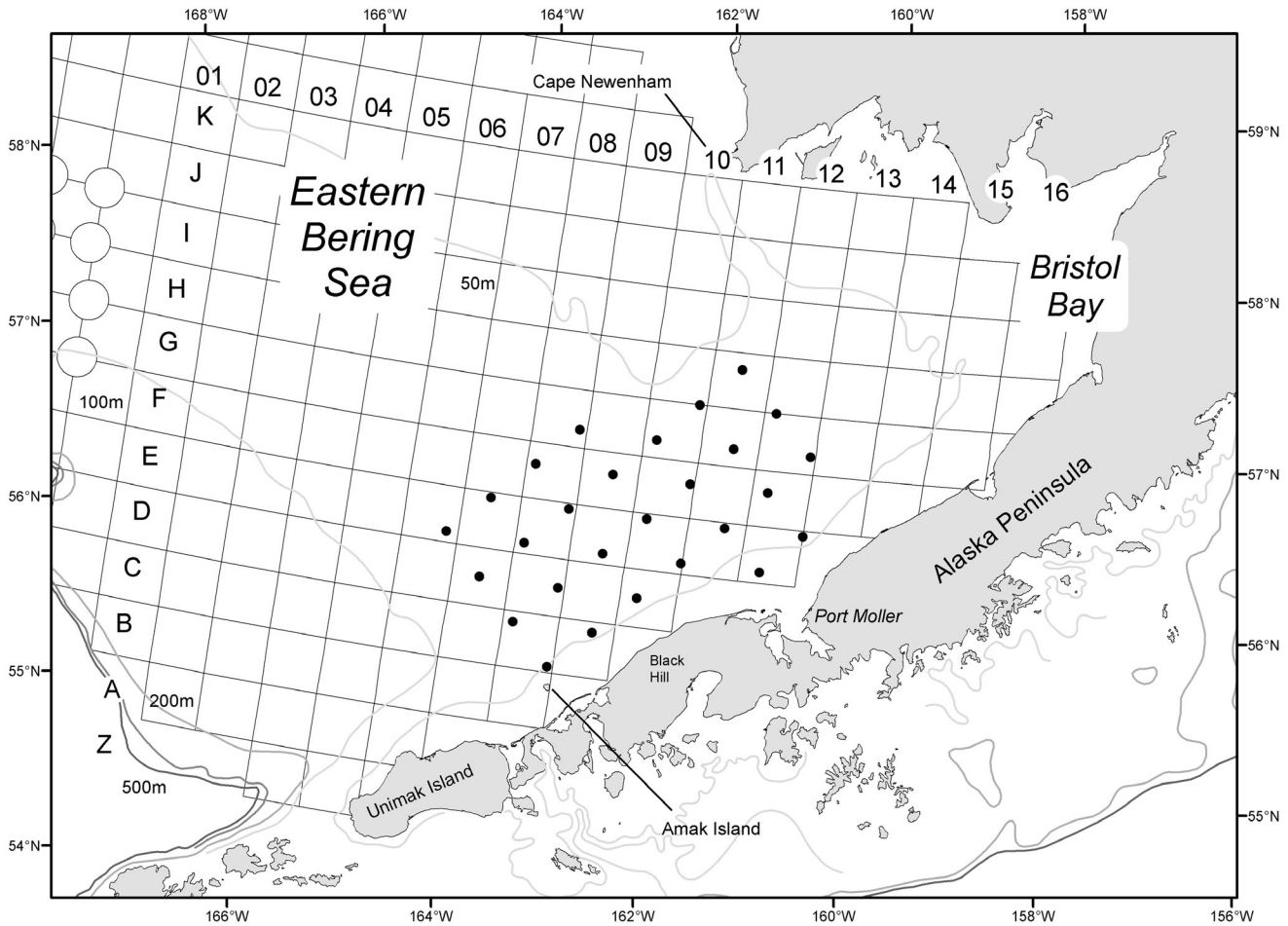

Figure 9.—Bottom-trawl stations from the first Bering Sea gridded bottom trawl surveys conducted by the *Tordenskjold* in 1955 and 1956 (actual trawling locations omitted for clarity). All stations were sampled in both cruises, except for the station near Amak Island, which was only sampled in 1956. Current Alaska Fisheries Science Center Bering Sea station sampling grid is shown for comparison of station locations.

Starting in 1955, most of the U.S research effort was allocated to preplanned, grid-patterned bottom trawl surveys conducted by chartered vessels with BCF biologists onboard. Summaries of findings from these cruises were published in INPFC annual reports, and findings from specific experiments conducted during these trawl surveys were published in journal articles, but the trawl survey results were never published. All information reported here is from the original logbooks kept aboard the vessels during the surveys and from handwritten data summary sheets found with the logbooks, which are archived at the AFSC's Kodiak Laboratory. Additionally, there was a cooperative arrangement made between BCF biologists and the University of Washington's Department of Oceanography to collect water temperatures, salinity, dissolved oxygen, water samples, and other data during government salmon explorations (Collins, 1956), and this practice was extended to the red king crab surveys, but not all of these data have been found.

Tordenskjold 1955

The first trawl survey with preplanned stations was conducted aboard the *Tordenskjold* (Fig. 7) in the summer of 1955 working on a 26-station (INPFC, 1956) diagonal grid (14′ latitude by 25′ longitude intervals) covering the southeast Bering Sea between Amak and Port Moller (Fig. 9). Initially the biologists tried to use traps to catch the crab, but after the traps were set, they were too difficult to relocate due to rough weather and high seas, which often dragged the traps far away (INPFC, 1956). (The problem of relocating the traps was solved by utilizing wire-mesh reflectors on buoys that could be seen on radar (Johnson, 1959; Blackford, 1979)). Additionally, it was felt that the traps tended to catch more males than females. Therefore, the trap effort was abandoned after a few days and four rounds of half-hour tows on the stations commenced between 10 June and 16 July, for a total of 104 hauls. Red

king crab were caught in every haul, ranging up to 99 males and 85 females within the same general area as the 1947 *Alaska* and the 1948 *Pacific Explorer* fleet surveys.

However, the survey did not sample the inshore area which had proven to be important in the 1940–41 survey, and no large crab concentrations were found, and plankton hauls failed to catch any crab larvae. "Hake" were recorded routinely during this cruise, and it is presumed that these were actually pollock, *T. chalcogramma*. Surface and bottom water temperatures were collected during each of the four rounds of trawling during this cruise and were available from the original data sheets, though they were not mentioned in the 1955 summary provided by Gast et al. (1956). The U.S.–Japan biologist exchange program continued, with Takashi Miyahara (FWS) working on the *Tokei Maru* and Seiwa Kawasaki (Japan Fishery Agency) working aboard the *Tordenskjold*.

Tordenskjold 1956

With the addition of a 27th station placed near Amak Island (Fig. 9), the same stations were trawled by the *Tordenskjold* in 1956 in two rounds, 9–20 July and 20 Aug.–1 Sept. (INPFC, 1957). Several tows were added for crab tagging, one of which, about 140 km northwest of Port Moller, caught an estimated 6,800 kg (15,000 lbs) of new-shell males (75–230 mm carapace width) in 60 min. The net was so heavy that it had to be cut open so that the catch could be spilled at sea and the net retrieved. A second 30 min tow in the same area caught 1,361 males and 2 females (roughly 4,500 kg). If accurate, the weight of both of these catches exceeds the largest catch of red king crab in the AFSC database, RACEBASE (3,300 kg). Several other tows covering an expanse greater than 200 km^2 helped define the minimal extent of this male aggregation, although the edges of the aggregation were not located.

In both 1955 and 1956, apparently only the start position and direction of each tow were recorded. Navigational methods used are not clear, but a note from the logbook on 18 July 1956, mentions latitude taken from "Sun line and Loran." Fishing effort was recorded as the approximate time the net was set down to the start of haulback. Fred Cleaver (BCF) participated in the 1956 survey and C. E. Atkinson is mentioned as a cruise coordinator. Temperature and salinity data from the 1956 survey were published in Love (1959).

Mitkof 1957

The *Mitkof* was chartered for the 1957 survey, which initiated a new, square-gridded station pattern (INPFC, 1958) with stations at intervals of 37 km (20 nmi) (Fig. 10). This station pattern, with rows designated by letters and columns designated by two-digit numbers, is still used today (Acuna and Lauth, 2008), but the reason this new station pattern supplanted the 1955–56 station pattern is not documented. This cruise sampled 77 stations in a single round of 30 min tows from 24 June through 25 July. This roughly tripled the spatial coverage from the first two gridded surveys, extending sampling north to Cape Newenham, east into Bristol Bay, and southwest to Unimak Island, but at the expense of conducting additional rounds of sampling.

Towing could not be completed near Unimak Island because of the rough seafloor and, as in the 1955 and 1956 surveys, the inshore spawning ground areas were not included in the survey design. Notes on the original data sheets indicate that radar was used to determine distance of tows and a roller ("lawnmower") with two recording devices was attached to the cod end of the net to record distance traveled along the seafloor (Carey and Heyamoto, 1972). The net spread was calculated by measuring the angle of the main wires to floats attached to the doors with a rangefinder (doors were directly attached to the net wings). Additionally a wire meter was used to try to measure the amount of main wire set for each tow, but it did not work well. No enormous red king crab catches were made as in the 1956 survey, but red king crab were caught at all but two stations, ranging up to 281 males at station E08 and 88 females at G12. A single male blue king crab was caught at I10, the only one identified during the 1955–1961 time series. A summary of the 1957 survey was published as a USFWS progress report (USFWS, 1957) which includes information on tag returns, growth rate estimates, and the first quantitative population estimates based on fishing effort, making it the first U.S. king crab stock assessment (USFWS, 1957; INPFC, 1958). Fred Cleaver participated in the 1957 survey.

Tordenskjold 1958

The *Tordenskjold* 1958 survey (Fig. 11) essentially replicated the 1957 survey, except that tows were increased to 60 min duration and there were two rounds of trawling, 29 April–3 June and 8 June–11 July (INPFC, 1959). This early round of trawling is temporally coincident with the early May catches of inshore mating aggregations sampled in 1941. For the first time, a more southern row of stations, Row Z, was added to the survey grid, although no reason for this addition was documented. A total of three inshore stations were added to the 1957 station pattern, Z05, A06, and D11, while station E13 was permanently deleted from the survey. Because the 1958 survey was conducted twice, once during spawning in April–June and again in June–July during the return of post-spawning red king crab, our analysis of the original data revealed the effects of emigration and immigration on survey estimates of abundance, distribution, and sex ratio.

Consistent with the influx of post-spawning crab from areas inshore of the survey area, the average density of male and female crab in the survey area increased between the two sampling phases, from 59.0 crab/tow during spawning in the 29 April–3 June phase, to 104.9 crab/tow in the 8 June–11 July phase. More specifically, the density of multiparous females (≥100 mm carapace length) in the survey area more than doubled between the two sampling phases, from 14.9 crab/tow during spawning, to 41.6 crab/tow in the June–July phase, as the newly mated crab returned to the survey area.

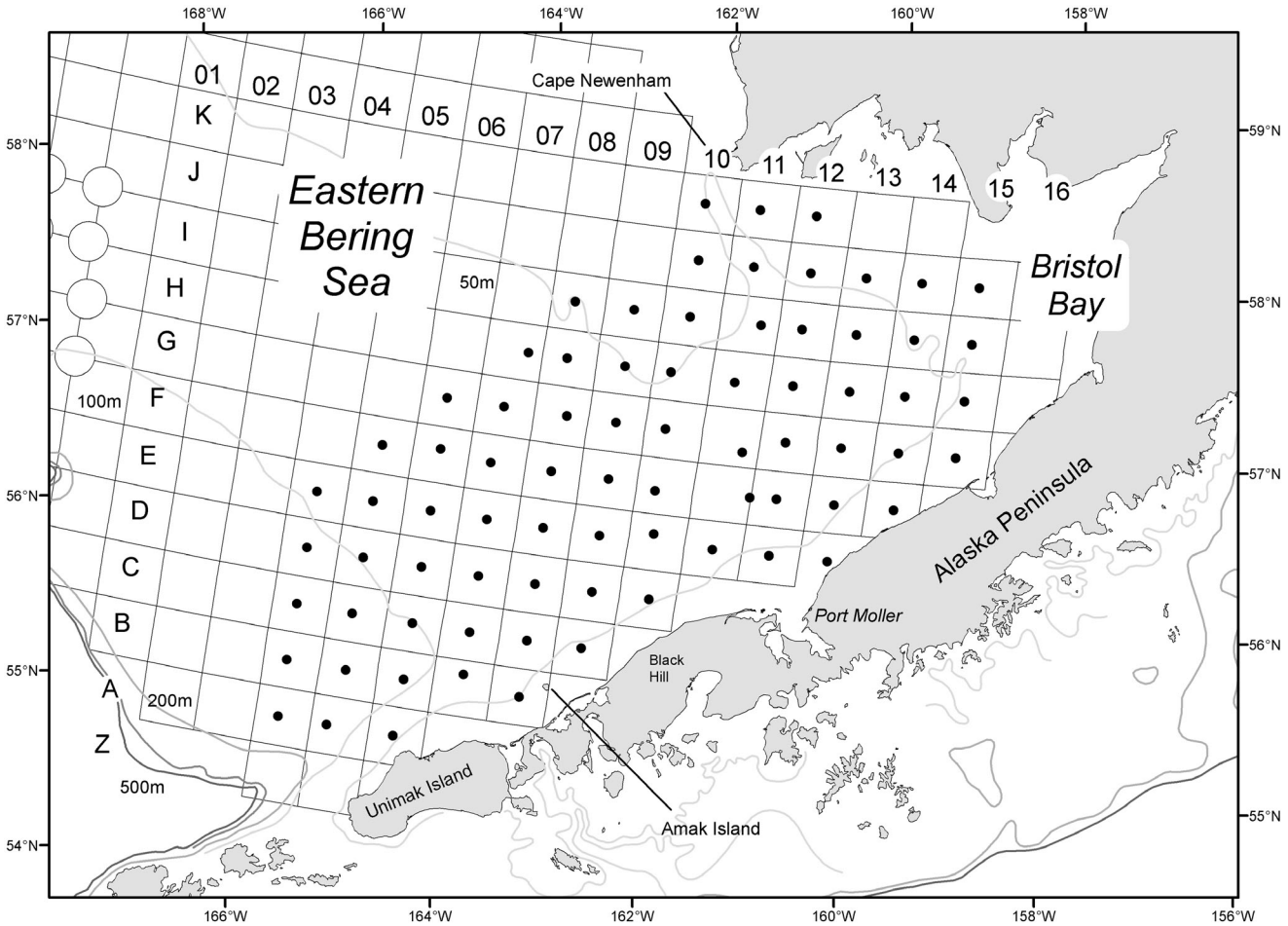

Figure 10.—Starting position of bottom trawl hauls during the *Mitkof* 1957 red king crab cruise. This is the first survey conducted on the current sampling grid.

Also, because the proportion of mature females participating in annual spawning is larger than that of the mature males (Dew, 2008), the sex ratio changed dramatically between sampling phases. During April–June 1958, while a relatively large proportion of the female population was outside the sampling area, mature males inside the sampling area were 0.60 of the mature population. In June–July, as predominantly female mature crab returned to the sampling area, the sex ratio changed to a male proportion of 0.39.

We believe the two-phase design of the 1958 survey was instrumental in demonstrating the importance of survey timing with regard to red king crab spawning movements. Because of substantial immigration by gravid females into the standard survey area after spawning, a Bristol Bay trawl survey conducted during red king crab spawning is unlikely to provide entirely reliable data with respect to stock abundance, sex ratio, or mating success (Dew, 2008). Nor is such a survey likely to provide information with which to evaluate habitat essential to a red king crab broodstock returning from inshore spawning grounds to settle into an 11-month period of egg incubation.

For example, our analysis of the April–June sampling in 1958 indicated that only 5% of Bristol Bay's multiparous broodstock was present at eight nearshore stations in the Unimak–Amak–Black Hill region (stations Z05, A05, A06, B05, B06, C06, C07, C08). However, by early July, after multiparous crab had returned from spawning, 34% of the total Bristol Bay multiparous broodstock was found at the same eight stations. Similarly, at two stations off the west end of Unimak Island (stations Z05 and A05), the broodstock density in 1958 increased from 1.5 crab/tow in April–June to 281.5 crab/tow in June–July. Based on such information the Unimak–Amak–Black Hill region was set aside during the 1960's as a special king crab refuge known as the "Pot Sanctuary," where trawling was prohibited (Simpson and Shippen, 1968; Naab, 1968a, b, 1971; Beale, 1971). Today the former Pot Sanctuary (Fig. 11) is a heavily trawled region known

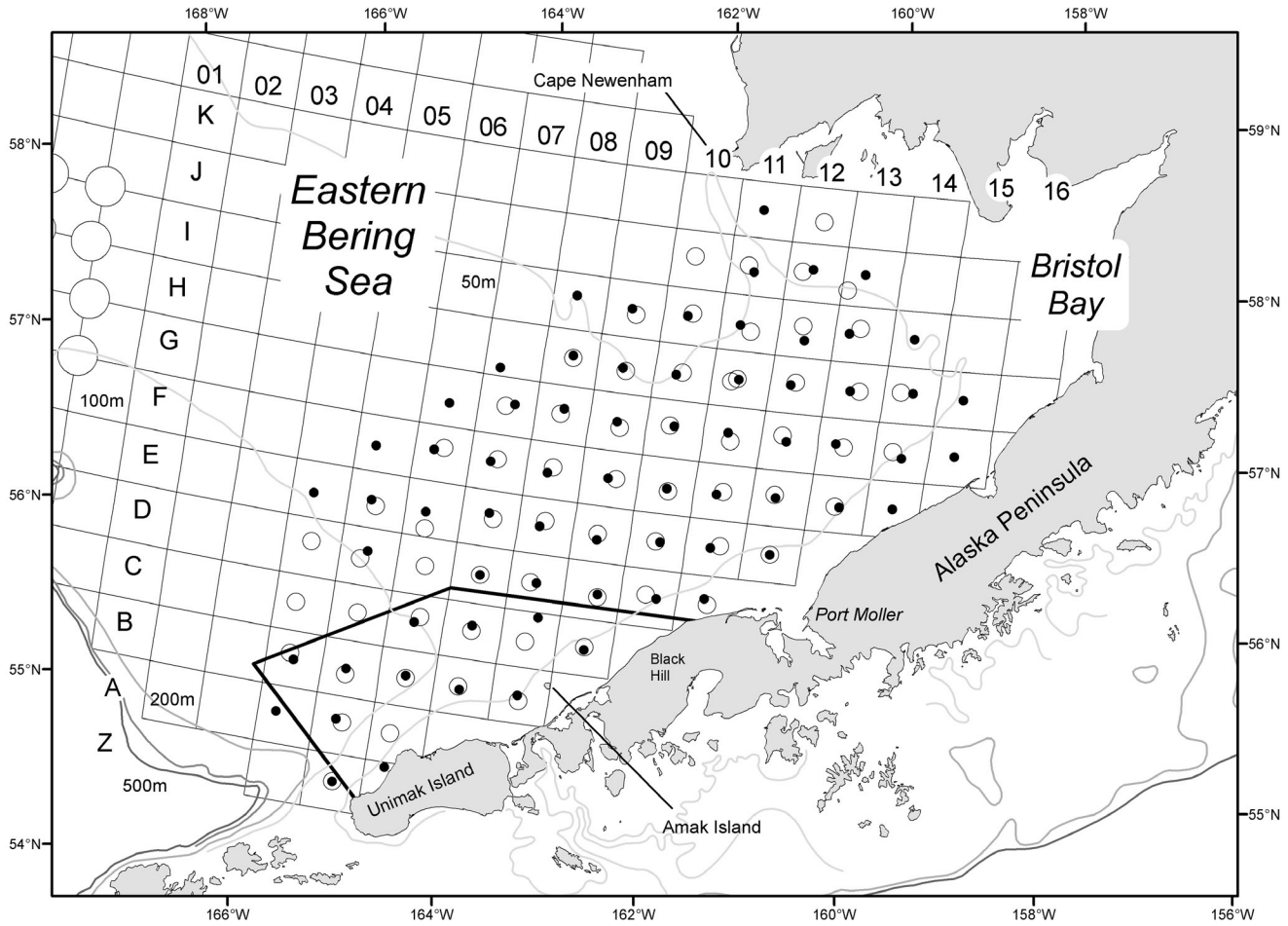

Figure 11.—Starting position of bottom trawl hauls during the first (●) 29 April–3 June and second (○) 8 June–11 July rounds aboard the *Tordenskjold* in 1958. The location of the Pot Sanctuary in the southern Bering Sea is shown with a solid black boundary (—).

as "Cod Alley," from which red king crab have largely disappeared (Dew and McConnaughey, 2005).

Biologists summarized the 1958 Bering Sea king crab trawl survey abundance data, tag releases and commercial fishery returns, growth estimates, meat content of new vs. old-shell crab, and gear selectivity (INPFC, 1959). An abundance estimate using tag returns was calculated, but these results unexpectedly differed from the trawl survey abundance estimate. Again, a gear comparison demonstrated how Japanese tangle nets selected for larger crab than the survey trawl net. This was the first survey for which a cruise plan was found. Fred Cleaver and Henry Sakuda (BCF) conducted the first round of sampling, Takashi Miyahara and Frank Hebard (BCF) conducted the second round, and both Cleaver and Miyahara are listed as cruise coordinators.

Tordenskjold 1959

In 1959, the *Tordenskjold* was chartered again for the red king crab survey (INPFC, 1960). Round 1 of trawling, 2–19 May, which occupied only the western two-thirds of stations due to rough weather (Fig. 12), consisted of 60-min tows. Round 2, 2–20 Aug., was a dedicated tagging cruise, in which repeated trawls for 30 or 60 min were made in a few locations, such as off Unimak Island, to meet a tagging quota (Fig. 12). Similar to the 1958 survey, broodstock density at stations Z05 and A05 off Unimak Island increased from 7.5 crab/tow in May to 98.3 crab/tow in August. Data from the early summer and late summer tows in the 1958 and 1959 surveys highlight the problem of relying on May–June surveys conducted during spawning to evaluate the importance of coastal waters off Unimak and Amak Islands as habitat for the Bristol Bay red king crab broodstock.

Without the knowledge of the results from the 1958 and 1959 surveys, the significant difference of having an early or late bottom trawl survey, especially in regard to the sampling of the inshore spawning areas, can result in misspecification of habitat that is essential to red king crab. For example, based on May–June data from red king crab surveys

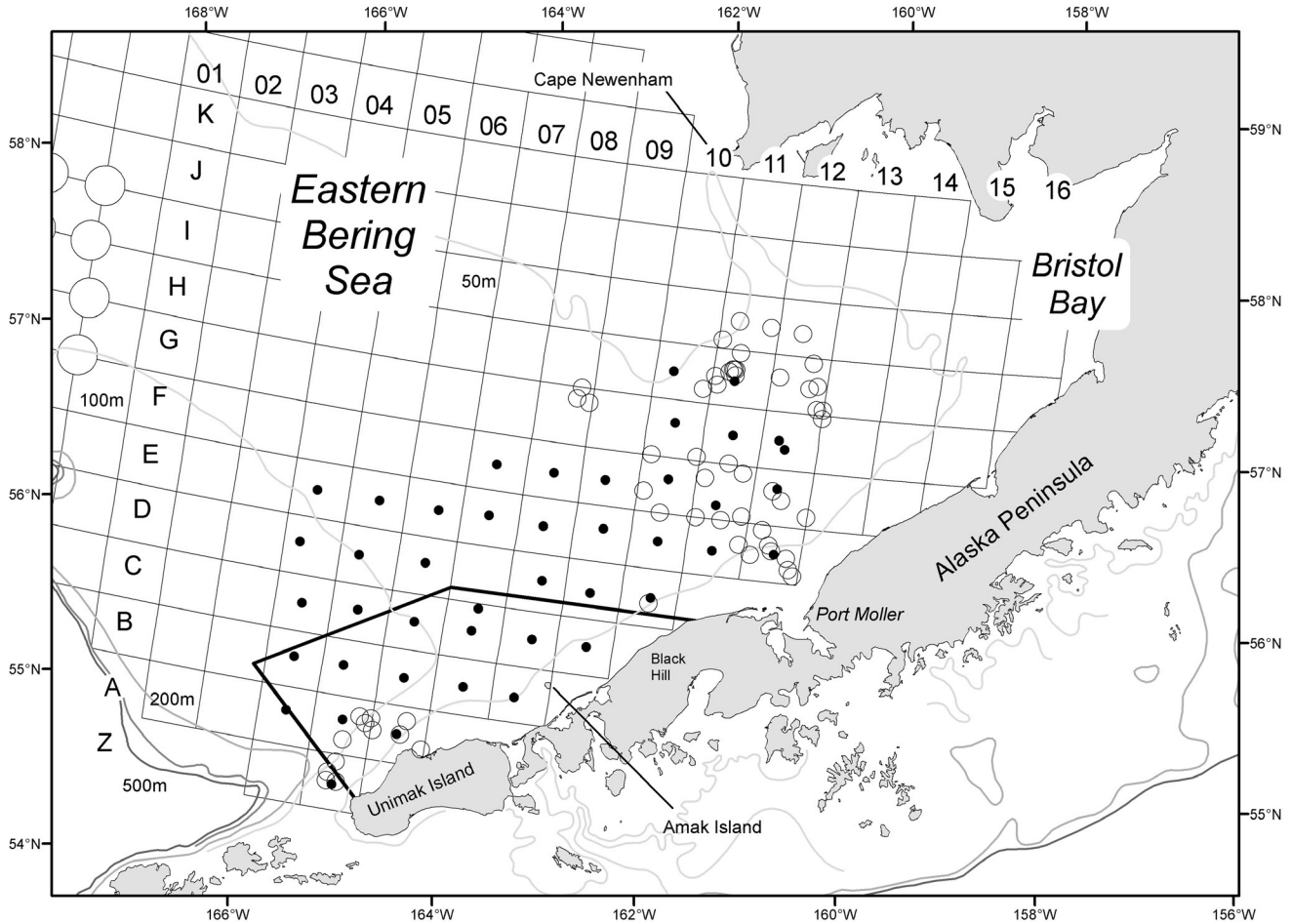

Figure 12.—Starting position of bottom trawl hauls during the *Tordenskjold* 1959 cruise (●) 2–19 May and red king crab tagging sites (○) 2–20 August. The location of the Pot Sanctuary in the southern Bering Sea is shown with a solid black boundary (—).

during 1987–2002, the environmental impact statement on essential fish habitat (NMFS, 2005) concluded that the area north of Unimak Island historically was unimportant as broodstock habitat (Dew, 2008). However, it is unlikely that the Pot Sanctuary (Fig. 12), America's first trawl-free refuge established specifically for red king crab (Naab, 1968a), would have been established if the Unimak–Amak–Black Hill region (now Cod Alley) was unimportant as habitat for Bristol Bay red king crab.

The 1959 cruise plan lists BCF scientists Sakuda and Hebard as participants in the station sampling round, Miyahara and Hebard as participants in the tagging round, and Miyahara as the cruise coordinator. Samples of invertebrates were retained from trawl hawls, and special dredge samples from the 1958 and 1959 surveys were taken for identification by Patsy McLaughlin (BCF) (McLaughlin, 1963). Temperature data collected in 1958 and 1959 are summarized in the figures and Appendix B of McLaughlin (1963).

Paragon 1960 and 1961

The *Paragon* (Fig. 13) was chartered for the 1960 (Miyahara, 1961) and 1961 (Shippen and Miyahara, 1962) surveys, each of which conducted 60-min tows in a single round. The surveys in both years were intended to cover a greater geographic extent so that the western, northern, and eastern red king crab distribution limits in the Bering Sea would be defined, but, in retrospect, this effort failed to completely encompass the bounds of the red king crab distribution. The 1960 survey was conducted late in the summer (2–30 Aug.) while the 1961 survey was earlier (7 July–4 Aug.).

The 1960 survey pattern (Fig. 14) was roughly equivalent to the greater spatial extent of the 1957 and 1958 surveys, while the 1961 survey concentrated on the southwest area, similar to the 1959 survey. Both surveys again had large catches of brooding females off of Unimak Island, in 1960 at stations C05, C06, and B06 and in 1961 at stations C06 and B06. Overall, crab catches were much lower in 1960 than in 1961, with the largest catches of males (n =

721) and females (n = 674) occurring at station E11 in 1961. The 1961 survey was the first to create new trawl stations on the corners of the grid pattern squares. These new stations proved to be, unfortunately, in a high abundance area of basketstars, *Gorgonocephalus eucnemis*, which coil their arms when disturbed and become entangled in the meshes of the trawl.

Cruise plans were found for both the 1960 and 1961 surveys. These documents describe the station pattern, sampling plans, trawl gear, and safety considerations for working on a vessel at sea. Surveys in both years used a 400 mesh Eastern type trawl, where the wing tips were connected directly to the doors. It is not clear if this same net was used for all the grid-pattern trawl surveys. The 1961 cruise plan has a short key for identifying fishes and the method for distinguishing hake and pollock is mentioned, along with a map showing that the distribution of hake, pollock, and cod is coincident in the area to the north of Unimak Island.

Hake were reported in catches in the vessel captain's logbook in 1960 but not in the scientist's data book on benthic species, where fish were rarely mentioned. In 1961, catches of between 100 and 300 lb of hake were recorded in four tows, all of which were in the southeastern Bering Sea, and pollock were caught in each of these tows, too. BCF scientists Doug Weber and Herb Shippen participated in the 1960 *Paragon* cruise but there were no IPHC staff (Herb Shippen[4]). Henry Sakuda, another BCF biologist (perhaps Alan Hazelwood), and Ray Hillson (IPHC) participated in the 1961 cruise (Shippen is listed as a participant in the cruise plan but he did not participate; Herb Shippen[4]).

Figure 13.—The vessel *Paragon* which conducted the 1960 and 1961 Bering Sea red king crab bottom trawl surveys. Photo (date 1937) courtesy of the Lokken collection (#224405) at the Museum of History and Industry, Seattle, Wash. Photo credit: Puget Sound Maritime Historical Society.

Epilogue

Organizations

Large-scale changes in the 1960's and 1970's in the fisheries research organizations involved in the Alaska red king crab program led to disruptions in the Bering Sea bottom trawl survey. The history can be traced to the Montlake Lab opening in Seattle in 1931, which provided office space for several different research groups, including the IFC, which was established in 1923. Due to the Montlake Lab program expansion and other factors, the IFC moved in 1936 (Atkinson, 1982) to the nearby University of Washington campus. Established in 1952, the INPFC, which provided a critical framework for international cooperation on the crab research and management in the Bering Sea, ended in 1992 and was replaced by the North Pacific Anadromous Fish Commission in 1993 (NPAFC, 1994).

Following Alaska statehood in 1959, an EF&GR base was established at Juneau, Alaska, in 1960 (Greenwood, 1982) and the responsibilities of the Seattle EF&GR base concerning Alaska commercial fisheries, including the Alaska Crab Investigation Program, were transferred to Juneau, although only two of the Seattle staff made the move north (Simpson, 1982). The 1961 red king crab survey was the last conducted by staff at Montlake, and the 1966 *Sonny Boy* king crab survey was the first by the staff at Auke Bay (Kirkwood and Hebard, 1967), but these data sheets have not yet been located.

During this interruption in the BCF Bering Sea trawl surveys in the early 1960's, the IPHC began their own time series by conducting bottom trawl surveys in the Bering Sea in 1963, 1965–66 (Best, 1970), 1967 (Best, 1969a), 1968–69 (Best, 1969b), 1970–72 (Best, 1974), and 1973–80 (Best and Hardman, 1982). These IPHC surveys were similar to the BCF surveys in that they occurred during the summer, utilized a 400 mesh eastern trawl (Best and Hardman, 1982) similar to the BCF trawl, and even used

[4]Shippen, H. Retired BCF and NMFS fisheries biologist, Personal commun. May 23, 2006.

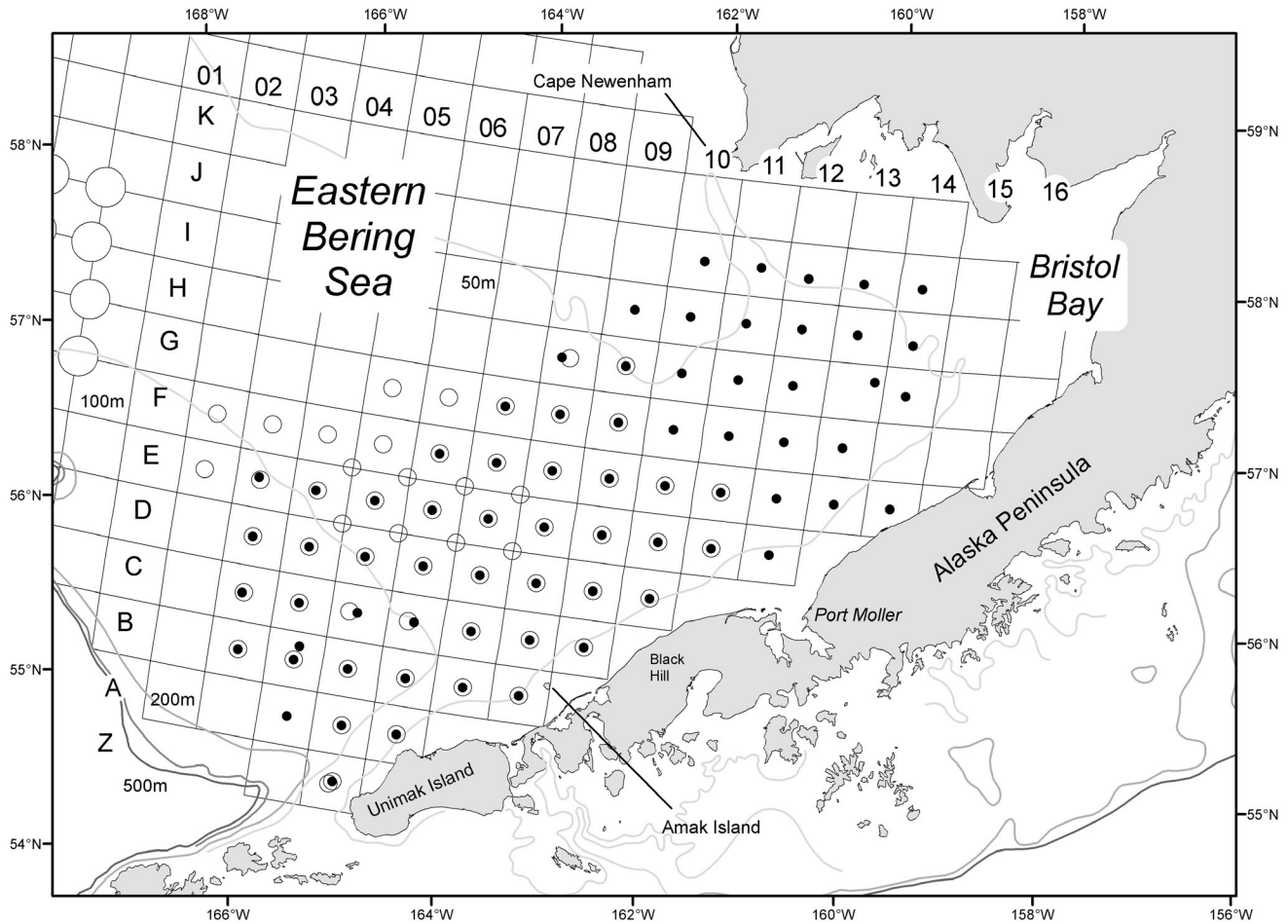

Figure 14.—Starting position of bottom trawl hauls during the *Paragon* 1960 cruise (●) (2–30 August) and during the *Paragon* 1961 cruise (○) (7 July – 4 August).

the charter vessel *Tordenskjold* in seven of the surveys (Best, 1970; Best and Hardman, 1982). These IPHC surveys were conducted on a 15' latitude and longitude diagonal grid more similar to the 1955–56 BCF surveys rather than the 1957–61 BCF surveys, but they still encompassed much of the same area. A letter from the IPHC director (F. Heward Bell) to the Juneau BCF director (Harry Rietze) mentions king crab data collected during the 1963 and 1965 IPHC surveys as well as the possibility of hosting a BCF biologist during the 1966 IPHC survey. A BCF red king crab biologist participated in the 1967 survey and collected crab data (Best, 1969a) but it is not known if similar crab data were collected on other IPHC surveys.

On 30 June 1964, the BCF red king crab research program was officially terminated in Seattle and the duties were transferred to Juneau (Shippen, 1965). Memos directing the transfer of all data sheets and records, from Seattle to the Juneau EF&GR base were written in 1966 and 1967, indicating that the program took several years to transfer. The Juneau EF&GR lab was moved again, to Kodiak in 1970 along with the *Oregon* (Greenwood, 1982). Annual Bering Sea bottom trawl surveys were conducted by Kodiak staff aboard the *Oregon* from 1971–80 (available in RACEBASE at the AFSC).

In 1970, Congress created the National Oceanic and Atmospheric Administration (NOAA), placing it in the U.S. Department of Commerce and incorporating the BCF and other marine components of the Bureau of Sport Fisheries and Wildlife to make National Marine Fisheries Service (NMFS) (Chandler, 1988). Several research programs at the Montlake Lab were united in 1971 to create the Northwest Fisheries Center (NWFC), one of four regional NMFS science centers in the United States, while the Auke Bay Laboratory was managed separately as one of four regional inshore and estuarine labs (Atkinson, 1982). In 1974, the Auke Bay Laboratory joined the NWFC (Atkinson, 1982), which was renamed the Northwest and Alaska Fisheries Center (NWAFC) in 1976. In 1989, the NWAFC was divided into the Northwest

Fisheries Science Center (NWFSC), which remained at the Montlake location in Seattle, and the Alaska Fisheries Science Center (AFSC), which had moved earlier to the new facility at Sand Point, also in Seattle.

In the early 1970's, the Montlake EF&GR base first became part of the NWAFC's Division of Marine Fish and Shellfish (MF&S); it later became part of the Resource Assessment and Conservation Engineering (RACE) Division which was primarily responsible for the newly created Marine Monitoring, Assessment and Prediction (MARMAP) Program (Greenwood, 1982). Additional staff, including the king crab researchers, were added to the MF&S Division for the MARMAP II program, splitting into the RACE and the Resource Ecology and Fisheries Management (REFM) Divisions in 1975 (Greenwood, 1982). Also in 1975, MARMAP, in coordination with the Bureau of Land Management's Outer Continental Shelf Environmental Assessment Program (OCSEAP), conducted the largest Bering Sea bottom trawl survey in terms of areal extent to date (Pereyra et al.[2]).

A follow-up survey in the spring of 1976 also covered a vast area (Smith and Bakkala, 1982). Together these surveys became recognized as the beginning of a new research program rather than the continuation and expansion of the earlier red king crab surveys, perhaps because the Kodiak Laboratory was still conducting Bering Sea red king crab bottom trawl surveys on the *Oregon*. Thus, the official start of the current Bering Sea trawl survey time series is 1975, and the title of that trawl survey report includes the phrase "In the baseline year of 1975," even though the gridded trawl surveys of 1955–61 are briefly mentioned in the text (Pereyra et al.[2]). Knowledge of the 1940–61 surveys and the findings of the biological sampling programs have been lost to the research community and largely forgotten.

Surveys

The Bering Sea bottom trawl grid survey is still conducted every summer, making it one of the oldest surveys of its kind in U.S. waters, although vessels, gear, and methods have changed over time, and there have been interruptions in the time series. The survey is typified by using bottom trawls for sampling the resource abundance, chartering private fishing vessels for research platforms, trawling only during daylight hours, and paying for the charters with external funding (as it has since the 1940–41 expedition). The scientific staff on each vessel typically includes a total of six biologists from the AFSC, two crab biologists from the Kodiak Laboratory, and four biologists generally focused on groundfish. The charter vessel crew conduct all the fishing with the trawl, both the vessel crew and scientific staff participate in sorting the catch, and the scientific staffers collect and record the catch data for their areas of expertise.

If the attempt at trap fishing at the beginning of the 1955 survey had been more successful, the whole time series for red king crab might have been based on baited pots rather than a bottom trawl. One substantial change in the use of bottom trawls in the trawl survey was that all of the older vessels lacked stern ramps, so catches had to be hoisted onto the deck by booms, which was a difficult and dangerous operation, especially in rough weather and on small vessels. Another substantial change in gear design is that the older survey trawls had the doors fixed to the trawl wing tips, defining a clear area swept, while the more recent trawls have the doors separated by dandylines, which act to herd mobile animals into the net (Somerton and Munro, 2001); the date and the reason for this change are unknown.

The survey's origin as a grid-patterned sampling program can be traced back either to the diagonal grid used in 1955–56 or the square grid first used in 1957, which is still utilized. The 1957 survey also marked the beginning of attempts to determine the length of seafloor contact to the net, to measure the distance across the opening of the net, to measure the amount of main wire used, and produced the first area-swept based biomass estimate, which was the first stock assessment (INPFC, 1958). King crab biomass estimates utilizing returns of tagged crab were attempted in 1958 and 1959. The extra, southern "Z" row of stations was first added to the survey in 1958, and the first corner stations were added in 1961, but any nearshore survey component directed towards the Unimak–Amak–Black Hill region spawning aggregations found in 1941 is no longer a standard part of the trawl survey.

Working closely with the fishing industry to conduct these surveys dates back to the first of all of these surveys in 1940–41, which was greatly facilitated by the cooperation of Lowell Wakefield and his king crab fishing company. It is hoped that these early surveys can be used to extend the current time series of catch data back at least 20 years prior to the official start in 1975. Additionally, the early surveys described in this manuscript include 510 surface water temperatures, 535 bottom water temperatures, 427 pairs of surface and bottom temperatures, and 1,262 substrate observations, which may prove useful for other projects.

Vessels

The fates of the red king crab survey vessels are as varied as the findings of the surveys for which the vessels were chartered. The *Mitkof*, built in 1940, continued fishing for many years after the 1957 charter, but it hit a rock and sank off Petersburg in southeast Alaska in 2004 (Loy, 2004). The *Tordenskjold*, built in 1911, is still berthed at Fishermen's Terminal, Seattle; it has conducted at least 14 other research cruises for the AFSC. The *Paragon* caught fire at sea and was lost a few years after its Bering Sea king crab trawl surveys in 1960–61; everyone was rescued when the ship burned (Shippen[4]). The University of Washington replaced its research vessel *Commando* with the *Alaska* in 1980 (Stickney, 1989) and operated it as a charter vessel for several years. The *Alaska* was chartered for at least 25 AFSC cruises which included the 1981 and 1983–1992 Bering Sea bottom trawl surveys. The *Alaska* completed its last AFSC survey in 1995 and was sold by the University in the late 1990's. The *Washington*, acquired by the Montlake Lab in July 1948, was sold in late 1948

and the money was applied toward the 1950 construction of the *John N. Cobb* (Greenwood, 1982), which was retired in 2008 (Orsi and Heard[5]). The *Oregon* was transferred to the NMFS Southeast Fisheries Science Center's EF&GR base in Pascagoula, Mississippi, but it was returned in 1969 for more Alaska cruises, becoming an official NOAA vessel in 1973 (Greenwood, 1982). It was decommissioned and transferred to the State of South Carolina in 1980 (Greenwood, 1982).

Industry

The cooperative efforts between the government and private king crab fishermen had a lasting impact on both entities, even though this mingling of efforts and the discoveries made have been largely forgotten. For example, the king crab asthma discovered during the 1948 *Pacific Explorer* expedition (Wigutoff and Carlson, 1950) was rediscovered and described as a new phenomenon over 30 years later at king crab processing plants in Dutch Harbor, Alaska (CDCP, 1982). As a result of the 1940–41 surveys, Captain Ellsworth F. Trafton of the *Dorothy*, Captain Harry Guffey of the *Locks*, and BCF Fishery Economist Leroy Christy (head of the 1941 cruise) became pioneers in the king crab industry (Blackford, 1979). A single, large BCF exploratory catch of crab in front of the Port Wakefield herring plant inspired Lowell Wakefield, son of the plant owner Lee Wakefield, to experiment with crab trawling and canning in the Raspberry Strait area and eventually to become the king crab industry leader (Blackford, 1979). The 1948 *Washington* cruise demonstrated that Bering Sea flatfish could be frozen and processed successfully for market in Seattle (Ellson et al., 1949).

Despite the poor crab catches by the *Deep Sea* during the 1949 charter, the money from the charter, along with successful king crab fishing trips before and after the charter, was a reversal of fortune that prevented the imminent bankruptcy of Lowell Wakefield's Deep Sea Trawlers (Blackford, 1979). While it might seem strange to describe a red king crab trawling operation for a species that is currently only associated with pot-fishing, pots were rarely used in that era. Trawling was a functional fishing method but the technology was rudimentary.

Wakefield solved navigational problems with the use of Loran, radar, and buoys for marking good fishing areas, and he solved technical trawling problems by hiring Boris Kanake (from the BCF) who replaced wooden rollers on the footrope with a ground-hugging, heavy steel footrope and designed a new, more efficient cod end. Additionally a deck winch enabled the crew to haul aboard large catches more easily and crab meat processing steps were streamlined. William Blackford was the primary captain of the *Deep Sea* for 7 years, but he retired from sea-duty in the mid-1950's, in part, in order to be closer to his family in Seattle (Blackford, 1979). Later, Captain Blackford helped his son Mansel G. Blackford to write an authoritative and highly readable account of Wakefield's company "Pioneering a modern business: Wakefield Seafoods and the Alaskan frontier" (Blackford, 1979). Mansel Blackford is currently a professor of history at Ohio State University.

Lowell Wakefield's red king crab company became successful and profitable despite other obstacles including rough weather, foreign and domestic fishing competition, the great 1964 Alaska earthquake, and the vast areas covered by his fishing, processing, and marketing operations (Blackford, 1979). When crab trawling was prohibited in Alaska state waters in 1960, it signaled the approaching end of the crab trawling era pioneered by Wakefield in the 1940's (Blackford, 1979). Such was the bond between industry and government that when the red king crab program was transferred from Seattle to Juneau, Takashi Miyahara quit the BCF and joined Wakefield's company as a manager in 1963 (Blackford, 1979).

Alaska king crab catches declined in the late 1960's, which led Wakefield's stockholders to accept a merger/buyout offer in late 1968 (Blackford, 1979). By 1971, most managers, including Miyahara, had left (Blackford, 1979). Lowell Wakefield is largely credited with being the father of the Alaska red king crab industry, and later in life he became an adjunct professor of fisheries at the University of Alaska. Since 1982, the Alaska Sea Grant College Program has coordinated an annual symposium series that bears his name.

Resources

Pacific Hake

There is great confusion among these cruises about the possible occurrence of Pacific hake, *Merluccius productus*, in some Bering Sea catches because of variations in the use of common names, the close physical similarity of Pacific hake and walleye pollock, and the widely held belief that Pacific hake do not occur in the Bering Sea. The common name for *Theragra chalcogramma* is given as either "Alaska pollock" or "silver hake" for collections made by the BCF during 1937–38 on its vessel *Brown Bear* mostly in the Aleutians, and *Merluccius productus* is not mentioned (Scheffer, 1959). This might explain some of the occurrences of "hake" on the original data sheets but not those where hake and pollock co-occurred in the same hauls, such as in the 1957 *Tordenskjold* exploration and the 1961 *Paragon* survey. The 1961 cruise plan even mentioned hake and pollock separately by scientific name.

Among contemporary (1955–61) BCF high seas salmon research cruises, Larkins (1964) mentions hake among numerous other bycatch species, including pollock, occasionally caught in surface gill-nets south of lat. 60° in the Bering Sea. An examination of several original records from these cruises, stored at the University of Washington, found bycatch mentioned as "whiting" and "silver hake" but without scientific names. There is no record of a catch of Pacific hake ever occurring in the Bering Sea among over 200 cruises within RACEBASE dating back to 1959 and nearly all records of hake are from

[5]Orsi, J., and B. Heard. 2008. "The *John N. Cobb* leaves a rich legacy." Alaska Fisheries Science Center Quarterly Report April–May–June 2008, p. 10–12.

hauls off British Columbia or the U.S. West Coast.

Aside from the records of hake from the 1957 *Tordenskjold* exploratory survey in the Shumagins, the next nearest record in RACEBASE is about 45 km south of the Shumagins, from the 2007 Gulf of Alaska bottom trawl survey. Additionally, two hake were caught and photographed (but not retained) near Kiska Island about 1,300 km west of the Shumagin Islands hake sites (Fig. 15) during the NMFS 2006 Aleutian Islands bottom trawl survey (Rooper, 2008).

Alaska fish guide books also have several contradictions about the occurrence of hake in the Bering Sea. The northern distribution of hake in Mecklenburg et al. (2002) is based primarily on Allen and Smith (1988), who based their northern distribution on the 1953–83 trawl surveys in AFSC's RACEBASE. Thus, both of these publications would have included the *Tordenskjold* 1957 Shumagin survey. The distribution maps of Allen and Smith (1988) and Mecklenburg et al. (2002) match well with that cruise but neither show any hake occurrence in the Bering Sea. Additionally, Mecklenburg et al. (2002) discounted the assertions of Fedorov (1973), who listed hake as a Bering Sea slope species, because there were no other Bering Sea references for hake, but Mecklenburg et al. (2002) did not mention the high-seas gillnet catches from the Bering Sea (Larkins, 1964). Mecklenburg et al. (2002) note that there was a single hake caught in Casco Cove at Attu Island in 1964 which is stored at the University of British Columbia fish collection (catalog number UBC 65-0005, collector is Peden), but which has no collection information.

Wilimovsky (1964) is probably the source of this hake, as he collected fish throughout the Aleutians by chemically treating tide pools, but does not mention hake among the most common specimens caught, nor does he specify the dates of his collections. However, he did sample at Attu and he thanks A. E. Peden as a field activity participant.

Older fish guide books, such as Kessler's (1985) guide to Alaska marine fish based on AFSC trawl surveys and

Figure 15.—Pacific hake, *Merluccius productus*, caught near Kiska Island by the *Sea Storm* in hauls 97 (A) and 186 (B) during the Alaska Fisheries Science Center's 2006 Aleutian Islands bottom trawl survey. Photos courtesy of Gulf of Alaska and Aleutian Islands bottom trawl survey staff.

Japanese guides based on their commercial fisheries in the Bering Sea (Okada and Kobayashi, 1968) and in the southwestern Bering Sea and Bristol Bay (Kobayashi and Ueno, 1956), do not mention hake. In his review on the world-wide distribution of *Merluccius* species, Hart (1947) shows hake extending into the Bristol Bay and Norton Sound portions of the Bering Sea, which was based on the northern limit of northwestern Alaska in Clemens and Wilby (1946). However, Clemens and Wilby retracted the northern boundary back to the Gulf of Alaska in a later edition (1961).

Thus, with all the contradictory evidence it seems difficult to state unequivocally whether or not hake were a part of the southern Bering Sea ecosystem in the 1950's and 1960's. I postulate (lead author M.Z.) that there was a small, self-sustaining stock in the southern Bering Sea and Shumagin area, perhaps migrating seasonally between these two areas, and that this stock was decimated by fishing or a regime shift, such that it is now fully or nearly extinct. Northern hake stragglers, such as those caught in NMFS bottom trawl survey tows in 2007 in the Gulf of Alaska and in 2006 in the Aleutian Islands, might be from remnants of this population or from more southern populations (Iwamoto et al., 2004).

Red King Crab

The abundance of red king crab in the Gulf of Alaska and the southeast Bering Sea has been greatly reduced since the 1940's. The Unimak broodstock of red king crab is now gone, replaced by a bottom trawl fishery for Pacific cod (Dew and McConnaughey, 2005). Pavlof Bay was made famous by Anderson and Piatt (1999) as an example of large-scale species shifts due to changing environmental conditions (regime shift), as recorded in a Gulf of Alaska small-mesh shrimp survey which started in 1972. Data from Anderson and Piatt (1999) show Gulf of Alaska red king crab peaking in abundance in the late 1970's and then crashing in the mid-1980's.

Today the former abundance of red king crab and the nursery status of Canoe Bay, which was discovered

during the 1940–41 expedition (FWS, 1942) and confirmed in 1948 by the *Pacific Explorer* fleet (Wigutoff and Carlson, 1950) and the *Washington* (Ellson et al., 1949), is forgotten. Indeed, neither Canoe Bay nor reports from these exploratory cruises are mentioned in Anderson and Piatt (1999). Perhaps the king crab stock in Canoe Bay has persisted even while the Pavlof Bay stock has disappeared.

Bans on the primarily foreign but conservative (FWS, 1942; Wigutoff and Carlson, 1950; INPFC, 1959) tangle nets (1954) and trawls (1960) to fish for red king crab in Alaska waters (Blackford, 1979) have not been adequate to preserve historical abundance levels. In Bristol Bay, the commercial pot harvest increased from 4 million kg in 1970 to an all-time record of 60 million kg in 1980, the same year that commercial fish trawling in the nearshore broodstock habitat began in earnest (Dew and McConnaughey, 2005). Thus, after an 11-year (1970–80) harvest increase of more than 1,000%, the population collapsed precipitously in 1981 and the Bristol Bay red king crab fishery was closed for the 1983 season and remains low to this day (NPFMC, 2007). Remnants of the historical red king crab aggregations, such as a 951 kg ($n = 332$) red king crab catch on the *Aldebaran* in 2003, the largest over an 8-year span (1995–2003), are still sometimes encountered in the Bering Sea bottom trawl survey (Fig. 16).

Figure 16.—The largest catch of red king crabs (951 kg, 332 crabs) from the Alaska Fisheries Science Center's Bering Sea bottom trawl survey in 2003, caught on the charter vessel *Aldebaran*. Pictured from left to right are Ivan Loyola (International Pacific Halibut Commission), John Brogan (Resource Ecology and Fisheries Management Division, AFSC), Brian Mason (Fisheries Monitoring and Analysis Division, AFSC), Gary Mundell (Resource Assessment and Conservation Engineering Division, AFSC), and Mike Burger (crew member of the *Aldebaran*). Other scientists participating in this cruise were Peter Cummiskey (Kodiak Laboratory, AFSC) and Terry Sample (Resource Assessment and Conservation Engineering Division, AFSC), who was probably the photographer.

Because the Bristol Bay (EBS) and Kodiak (GOA) red king crab fisheries were both closed in 1983, it is generally assumed that the timing of the population collapses was similar over a large geographical range encompassing the EBS and the GOA; however, exploitation histories and stock trajectories are quite different for the two areas (Zheng et al., 1996; Orensanz et al., 1998). The Kodiak-area red king crab fishery became firmly established in 1950 and the commercial catch peaked in 1965 at 40 million kg (Jackson and Manthey, 1969), some 14 years earlier than the 1980 Bristol Bay peak. The Kodiak-area catch then declined by about 78% over the next three seasons and stabilized at 8–10 million kg for the next 10–12 years, sustained only by a 4-fold increase in fishing effort during this time.

In the spring of 1967 the high proportion of unmated, new-shell females (58%) and the low proportion of males in the spawning population (<10%) signaled that the breeding-size males were being overharvested (McMullen, 1967; 1968). From 1971–73 to 1982 the rate of exploitation of Kodiak legal-male red king crab increased from about 20% to 70% (Orensanz et al., 1998), and there has been no Kodiak (GOA) commercial season since 1983.

The collapse of the Bristol Bay stock was more spectacular than the Kodiak decline, falling from a greater height (60 million kg vs. 40 million kg) in a shorter time (2–3 years vs. 17–18 years). However, similar to the demise of Kodiak's fishery, the collapse of the Bristol Bay stock was accompanied by historically high exploitation rates and depressed sex ratios (Dew and McConnaughey, 2005). Both the Kodiak and the Bristol Bay fisheries exhibited hallmark symptoms of overfishing not easily mistaken as natural mortality from environmental or ecological perturbations. Moreover, it is unlikely that a 1976–77 meteorological regime (Benson and Trites, 2002) shift could be a factor common to distinctly separate population collapses that occurred in 1965–68 (Kodiak) and 1980–83 (Bristol Bay). Regardless of the causes of these declines, the era of red king crab dominance, which inspired these 1940–60's surveys and commercial fisheries, is over for the foreseeable future.

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