9. Pribilof Islands Golden King Crab

May 2020 Crab SAFE Draft Report

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Executive Summary

1. Stock:

Pribilof Islands (Pribilof District) golden king crab *Lithodes aequispinus*

2. Catches:

Commercial fishing for golden king crab in the Pribilof District has been concentrated in the Pribilof Canyon. The domestic fishery developed in 1982/83, although some limited fishing occurred at least as early as 1981/82. Peak retained catch occurred in 1983/84 at 388 t (856,475 lb). The fishing season for this stock has been defined as a calendar year (as opposed to 1-July-to-30-June crab fishing year) after 1983/84. Since then, participation in the fishery has been sporadic and annually retained catch has been variable: from 0 t (0 lb) in the ten years that no vessels participated (1984, 1986, 1990–1992, 2006–2009, 2015, and 2016) to 155 t (341,908 lb) in 1995, when seven vessels made landings. The fishery is not rationalized. There is no state harvest strategy in regulation. A guideline harvest level (GHL) was first established for the fishery in 1999 at 91 t (200,000 lb). The GHL was reduced to 68 t (150,000 lb) for 2000–2014 and reduced to 59 t (130,000 lb) in 2015. No vessels participated in the directed fishery and no landings were made during 2006–2009. Catch data from 2003–2005 and 2010–2014 cannot be reported here under the confidentiality requirements of State of Alaska (SOA) statute Sec. 16.05.815. The 2003 and 2004 fisheries were closed by emergency order to manage the retained catch towards the GHL; the 2005 and 2010–2014 fisheries were not closed by emergency order. No vessels participated in the directed fishery during 2015 or 2016, but 2 vessels fished in 2017 and 2019 and one vessel fished in 2018. Discarded (non-retained) catch has occurred in the directed golden king crab fishery, the eastern Bering Sea snow crab fishery, the Bering Sea grooved Tanner crab fishery, and in Bering Sea groundfish fisheries. Estimates of annual total fishery mortality during 2001–2019 due to crab fisheries range from 0 t to 73 t, with an average of 31 t. Estimates of annual fishery mortality during 1991/92–2019 due to groundfish fisheries range from <1 t to 9 t, with an average of 2 t (estimates of annually discarded catch during Bering Sea groundfish fisheries are reported for crab fishing years from 1991 to 2008, and by calendar years from 2009 to 2019). Total fishery mortality in groundfish fisheries during the 2019 crab fishing year was 3.91 t.

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3. **Stock biomass:**

Stock biomass (all sizes, both sexes) of golden king crab have been estimated for the Pribilof Canyon area using the area-swept technique applied to data obtained from the biennial eastern Bering Sea upper continental slope trawl survey performed by NMFS-AFSC in 2002, 2004, 2008, 2010, 2012, and 2016 (Hoff and Britt 2003, 2005, 2009, 2011; Hoff 2013, 2016). See Appendix A1 for summaries of the slope survey as they pertain to data on and estimates of Pribilof Island golden king crab stock biomass. Complete data on size-sex composition of survey catch are available only from the 2008–2016 biennial surveys (J. Hoff, NMFS-AFSC, Kodiak). Biomass estimates by sex and size class from the 2008, 2010, 2012, and 2016 surveys were presented in May 2017 (Pengilly and Daly 2017).

4. **Recruitment:**

Estimated from size-sex composition data from the eastern Bering Sea upper continental slope trawl survey, mature male biomass in the entire survey area increased slightly from 812 t (1,790,154 lb) in 2012 to 869 t (1,916,329 lb) in 2016, and from 256 t (564,383 lb) in 2012 to 463 t (1,021,602lb) in 2016 in the Pribilof canyon.

5. **Management performance:**

No overfished determination (i.e., MSST) has been made for this stock, although approaches to using data from the biennial NMFS-AFSC eastern Bering Sea upper continental slope surveys have been presented to, and considered by, the Crab Plan Team (Gaeuman 2013a, 2013b; Pengilly 2015, Pengilly and Daly 2017; Appendix B). Two vessels participated in the 2019 directed fishery and 3.91 t of fishery mortality occurred during groundfish fisheries in 2019 (mostly in Greenland Turbot and Rockfish fisheries). Overfishing did not occur in 2017, 2018, or 2019. The GHL for the 2017-2019 seasons was 59 t. The 2021, 2022, and 2023 OFL and ABC in the table below are the author's recommendations, which follow previous determinations.

Management Performance Table (values in t)

Calendar Year	MSST	Biomass (MMB)	GHL[a]	Retained Catch	Total Catch[b]	OFL	ABC
2016	N/A	N/A	59	0	0.24	91	68
2017	N/A	N/A	59	Conf. [c]	Conf. [c]	93	70
2018	N/A	N/A	59	Conf. [c]	Conf. [c]	93	70
2019	N/A	N/A	59	Conf. [c]	Conf. [c]	93	70
2020	N/A	N/A	59			93	70
2021	N/A	N/A				93	70
2022	N/A	N/A				93	70
2023	N/A	N/A				93	70

a. Guideline harvest level, established in lb and converted to t.

b. Total retained catch plus estimated bycatch mortality of discarded catch during crab fisheries and bycatch mortality due to groundfish fisheries are included here, but not for 2017-2019 because the directed fishery is confidential.

c. Confidential under Sec. 16.05.815 (SOA statute).

Management Performance Table (values in millions of lb)

Calendar Year	MSST	Biomass (MMB)	GHL[a]	Retained Catch	Total Catch[b]	OFL	ABC
2016	N/A	N/A	130,000	0	<0.001	0.20	0.15
2017	N/A	N/A	130,000	Conf. [c]	Conf. [c]	0.20	0.15
2018	N/A	N/A	130,000	Conf. [c]	Conf. [c]	0.20	0.15
2019	N/A	N/A	130,000	Conf. [c]	Conf. [c]	0.20	0.15
2020	N/A	N/A	130,000			0.20	0.15
2021	N/A	N/A				0.20	0.15
2022	N/A	N/A				0.20	0.15
2023	N/A	N/A				0.20	0.15

a. Guideline harvest level.
b. Total retained catch plus estimated bycatch mortality of discarded catch during crab fisheries and bycatch mortality due to groundfish fisheries are included here, but not for 2017-2019 because the directed fishery is confidential
c. Confidential under Sec. 16.05.815 (SOA statute).

6. Basis for the OFL and ABC:

The values for 2021-2023 are the author's recommendation.

Calendar Year	**Tier**	**Years to define Average catch (OFL)**	**Natural Mortality[b]**	**Buffer**
2016	5	1993–1998[a]	0.18 yr^{-1}	25%
2017	5	1993–1998[a]	0.18 yr^{-1}	25%
2018	5	1993–1998[a]	0.18 yr^{-1}	25%
2019	5	1993–1998[a]	0.18 yr^{-1}	25%
2020	5	1993–1998[a]	0.18 yr^{-1}	25%
2021	5	1993–1998[a]	0.18 yr^{-1}	25%
2022	5	1993–1998[a]	0.18 yr^{-1}	25%
2023	5	1993–1998[a]	0.18 yr^{-1}	25%

a. OFL was for total catch and was determined by the average of the annual retained catch for these years multiplied by a factor of 1.052 to account for the estimated bycatch mortality occurring in the directed fishery plus an estimate of the average annual bycatch mortality due to non-directed crab fisheries and groundfish fisheries for the period.
b. Assumed value for FMP king crab in NPFMC (2007); does not enter into OFL estimation for Tier 5 stocks.

7. PDF of the OFL:

Sampling distribution of the recommended Tier 5 OFL was estimated by bootstrapping. The standard deviation of the estimated sampling distribution of the recommended OFL (Alternative 1) is 23 t (CV = 0.25; section G.1).

8. Basis for the ABC recommendation:

A 25% buffer on the OFL, the default; i.e., ABC = (1-0.25)·OFL. This is a data-poor stock.

9. A summary of the results of any rebuilding analyses:

Not applicable; stock is not under a rebuilding plan.

A. Summary of Major Changes

1. **<u>Changes to the management of the fishery</u>:** Fishery continues to be managed under authority of an ADF&G commissioner's permit; guideline harvest level (GHL) was reduced from 68 t (150,000 lb) to 59 t (130,000 lb) in 2015 to account for bycatch mortality in the directed fishery, non-directed crab fisheries, and groundfish fisheries, and to avoid exceeding the ABC. The GHL remained at 59 t (130,000 lb) from 2016 to 2020.

2. **<u>Changes to the input data</u>:**
   - Retained catch and discarded catch data have been updated with the results for the 2019 directed fishery, during which two vessels participated, but bycatch in other crab fisheries in 2019 was zero.
   - Discarded catch estimates from groundfish fisheries have been listed by calendar year from 2009 to 2019, including 3.91 t of bycatch mortality for 2019.

3. **<u>Changes to the assessment methodology</u>:** This assessment follows the methodology recommended by the CPT since May 2012 and the SSC since June 2012.

4. **<u>Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL</u>:** The computation of OFL in this assessment follows the methodology recommended by the CPT in May 2012 and the SSC in June 2012 applied to the same data and estimates with the same assumptions that were used for estimating the 2013–2020 Tier 5 OFLs; computations applied directly to data and estimates expressed in metric units resulted in minor changes in results used in previous assessments due to rounding.

B. Responses to SSC and CPT Comments

<u>Responses to the most recent two sets of SSC and CPT comments specific to the assessment</u>:

- SSC, October 2019: "*The SSC encourages further efforts to move this analysis to Tier 4 and encourages the CPT to also consider VAST models in addition to RE modelling….. **The SSC strongly supports continued efforts to provide a fishery independent index of abundance for crab and groundfish species on the Bering Sea continental slope.** The SSC supports the development of a collaborative industry-based survey to provide data in the absence of the NMFS slope survey.*"
  - **<u>Response:</u>** We further explored RE modelling. An industry-cooperative survey is in development.
- CPT, September 2019:
  - *Continue the work using the random effects model by incorporating 2004 NMFS slope survey data point and possibly the 2002 data point in model runs. If needed, consider setting a lower bound on process error, although it was noted that this approach did not work for Pribilof Islands red king crab.*
    - **<u>Response:</u>** Included 2002 and 2004 estimates in Tier 4 scenario 2. Did not change process error lower bound, as model appeared to converge.
  - *Explore the feasibility of a simplified Gmacs model to assess the stock.*
- ***<u>Response:</u>*** *Work started; data is being compiled.*
  - *Consider initiating an industry cooperative survey to assess abundance trends.*

- **<u>Response:</u>** In the works.

- SSC, June 2017:
  - *Following up on a SSC request, requests for waivers from harvesters were obtained. However, discussions are still in progress regarding processor waivers. The SSC hopes that these discussions will be fruitful.*
    - **<u>Response:</u>** Inquired. No progress in obtaining confidentiality waivers from processors.
  - *The SSC would appreciate additional insights from the assessment author into the performance of the random effects model.*
    - **<u>Response:</u>** We further explored the random effects model performance and provide details in Appendix A.
- CPT, May 2017:
  - *Investigate whether size frequency data is available for the 2002 and 2004 surveys, so that biomass estimates for mature and legal males could be estimated and included in the model simulations.*
    - **<u>Response:</u>** Crab specimen data collection not part of 2002 survey protocol. Crab specimen data does exist for 2004 survey (in its original form) but we have not been able to acquire it. As a work around, we calculated the ratio of MMB:Total biomass for 2008-2016 surveys, and applied the average to total biomass to obtain MMB for 2002 and 2004.
  - *Investigate the sex ratios in 2008, 2012, 2012, and 2016 data. If the sex ratios are reasonably stable in each of those years, then mature and legal biomass estimates could be made in 2002 and 2004 using the sex ratios from the known survey years (i.e., use 2002 and 2004 raw survey data to get size compositions to extend time series backwards via scaling).*
    - **Response:** See previous comment.
  - *Put bounds on the process error and rerun the model.*
    - **<u>Response:</u>** After investigating the model performance in the .par file, it appears the model did converge (maximum gradient component is <0.0001).

C. Introduction

1. **<u>Scientific name</u>:** *Lithodes aequispinus* J. E. Benedict, 1895

2. **<u>Description of general distribution</u>:**

General distribution of golden king crab:

> Golden king crab, also called brown king crab, range from Japan to British Columbia. In the BSAI, golden king crab are found at depths from 200 m to 1,000 m, generally in high-relief habitat such as inter-island passes (NMFS 2004).
>
> Golden, or brown, king crab occur from the Japan Sea to the northern Bering Sea (ca. 61° N latitude), around the Aleutian Islands, on various sea mounts, and as far south as northern British Columbia (Alice Arm) (Jewett et al. 1985). They are typically found

on the continental slope at depths of 300–1,000 m on extremely rough bottom, and are frequently found on coral (NMFS 2004, pages 3–43).

The Pribilof District is part of king crab Registration Area Q (Figure 1). Leon et al. (2017) define those boundaries:

> The Bering Sea king crab Registration Area Q southern boundary is a line from 54°36′N lat, 168°W long, to 54°36′N lat, 171°W long, to 55°30′N lat, 171°W long, to 55°30′N lat, 173°30′E long. The northern boundary is the latitude of Point Hope (68°21′N lat). The eastern boundary is a line from 54°36′N lat, 168°W long, to 58°39′N lat, 168°W long, to Cape Newenham (58°39′N lat). The western boundary is the United States-Russia Maritime Boundary Line of 1990 (Figure 2-4). Area Q is divided into 2 districts: the Pribilof District, which includes waters south of Cape Newenham; and the Northern District, which includes all waters north of Cape Newenham.

The NMFS-AFSC conducted an eastern Bering Sea continental slope trawl survey on a biennial schedule during 2002–2016 (the 2014 survey was cancelled). Results of this survey from 2002–2016 show that the biomass, number, and density (in number per area and in weight per area) of golden king crab on the eastern Bering Sea continental slope are higher in the southern areas than in the northern areas (Gaeuman 2013a, 2013b; Haaga et al. 2009; Hoff 2013, 2016; Hoff and Britt 2003, 2005, 2009, 2011; Pengilly 2015; Pengilly and Daly 2017). Of the six survey subareas (see Figure 1 in Hoff 2016), biomass and abundance of golden king crab were estimated through 2016 to be highest in the Pribilof Canyon area (survey subarea 2), and most of the commercial fishery catches for golden king crab have occurred there (Neufeld and Barnard 2003; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006; Leon et al. 2017).

Results of the 2002–2016 biennial NMFS-AFSC eastern Bering Sea continental slope trawl surveys showed that a majority of golden king crab on the eastern Bering Sea continental slope occurred in the 200–400 m and 400–600 m depth ranges (Hoff and Britt 2003, 2005, 2009, 2011; Haaga et al. 2009; Hoff 2013, 2016). Commercial fishing for golden king crab in the Bering Sea typically occurs at depths of 100–300 fathoms (183–549 m; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006; Gaeuman 2011, 2013c, 2014; Neufeld and Barnard 2003); average depth of pots fished in the 2002 Pribilof District golden king crab fishery (the most recently prosecuted fishery for which fishery observer data are not confidential) was 214 fathoms (391 m).

3. **<u>Evidence of stock structure</u>:**
Although highest densities of golden king crab are found in the deep canyons of the eastern Bering Sea continental slope, golden king crab occur sporadically on the surveyed slope at locations between those canyons in the eastern Bering Sea (Hoff and Britt 2003, 2005, 2009, 2011; Gaeuman 2013b, 2014; Hoff 2013, 2016). Stock structure within the Pribilof District has not been evaluated. Fishery and slope survey data suggest that areas at the northern and southern border of the Pribilof District are largely devoid of golden king crab (Pengilly 2015, Pengilly and Daly 2017; Appendix A1), but the stock relationship between golden king crab within and outside of the Pribilof District has not been evaluated.

4. **Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology):**

The following review of molt timing and reproductive cycle of golden king crab is adapted from Watson et al. (2002):

> Unlike red king crab, golden king crab may have an asynchronous molting cycle (McBride et al. 1982; Otto and Cummiskey 1985; Sloan 1985; Blau and Pengilly 1994). In a sample of male golden king crab 95–155-mm CL and female golden king crab 104–157-mm CL collected from Prince William Sound and held in seawater tanks, Paul and Paul (2000) observed molting in every month of the year, although the highest frequency of molting occurred during May–October. Watson et al. (2002) estimated that only 50% of 139-mm CL male golden king crab in the eastern Aleutian Islands molt annually and that the intermolt period for males ≥150-mm CL averages >1 year.
>
> Female lithodids molt before copulation and egg extrusion (Nyblade 1987). From observations on embryo development in golden king crab, Otto and Cummiskey (1985) suggested that time between successive ovipositions was roughly twice that of embryo development and that spawning and molting of mature females occurs approximately every two years. Sloan (1985) also suggested a reproductive cycle >1 year with a protracted barren phase for female golden king crab. Data from tagging studies on female golden king crab in the Aleutian Islands are generally consistent with a molt period for mature females of two years or less and that females carry embryos for less than two years with a prolonged period in which they remain in barren condition (Watson et al. 2002). From laboratory studies of golden king crab collected from Prince William Sound, Paul and Paul (2001b) estimated a 20-month reproductive cycle with a 12-month clutch brooding period.
>
> Numerous observations on clutch and embryo condition of mature female golden king crab captured during surveys have been consistent with asynchronous, aseasonal reproduction (Otto and Cummiskey 1985; Hiramoto 1985; Sloan 1985; Somerton and Otto 1986; Blau and Pengilly 1994; Blau et al. 1998; Watson et al. 2002). Based on data from Japan (Hiramoto and Sato 1970), McBride et al. (1982) suggested that spawning of golden king crab in the Bering Sea and Aleutian Islands occurs predominately during the summer and fall.

The success of asynchronous and aseasonal spawning of golden king crab may be facilitated by fully lecithoatrophic larval development (i.e., the larvae can develop successfully to juvenile crab without eating; Shirley and Zhou 1997).

Current knowledge of reproductive biology and maturity of male and female golden king crab was reviewed by Webb (2014).

Note that asynchronous, aseasonal molting and the prolonged intermolt period (>1 year) of mature female and the larger mature male golden king crab likely makes scoring shell conditions very difficult and especially difficult to relate to “time post-molt,” posing problems for inclusion of shell condition data into assessment models.

5. Brief summary of management history:

A complete summary of the management history through 2015 is provided in Leon et al. (2017).

The first domestic harvest of golden king crab in the Pribilof District was in 1981/82 when two vessels fished. Peak retained catch and participation occurred in 1983/84 at a retained catch of 388 t (856,475 lb) landed by 50 vessels (Tables 1a and 1b). Since 1984; the fishery has been managed with a calendar-year fishing season under authority of a commissioner’s permit and landings and participation have been low and sporadic. Retained catch since 1984 has ranged from 0 t (0 lb) to 155 t (341,908 lb), and the number of vessels participating annually has ranged from 0 to 8. No vessels fished in 2006–2009, 2015, and 2016, one vessel fished in each of 2010, 2012–2014, and 2018 and two vessels fished in 2011, 2017, and 2019.

The fishery is not rationalized and has been managed inseason to a guideline harvest level (GHL) since 1999. The GHL for 1999 was 91 t (200,000 lb), whereas the GHL for 2000–2014 was 68 t (150,000 lb). Following the reduction of ABC from 82 t for 2014 to 68 t for 2015, the GHL was reduced in 2015 to 59 t (130,000 lb).

Catch statistics for 2003–2005, 2010–2014, and 2017-2019 are confidential under Sec. 16.05.815 of SOA statutes. It can be noted, however, that the 2003 and 2004 fisheries were closed by emergency order to manage the fishery retained catch towards the GHL, whereas the 2005 and 2010–2014 fisheries were not closed by emergency order. With regard to 2004, “Catch rates during the 2004 fishery were among the highest on record, and the fishery was the shortest ever at approximately three weeks in duration” (Bowers et al. 2005).

A summary of relevant fishery regulations and management actions pertaining to the Pribilof District golden king crab fishery is provided below.

Only males of a minimum legal size may be retained. By State of Alaska regulation (**5 AAC 34.920 (a)**), the minimum legal size limit for Pribilof District golden king crab is 5.5-inches (140 mm) carapace width (CW), including spines. A carapace length (CL) ≥124 mm is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007). Golden king crab may be commercially fished only with king crab pots (as defined in 5 AAC 34.050); pots used to take golden king crab in Registration Area Q (Bering Sea) may be longlined (5 AAC 34.925(f)). Pots used to fish for golden king crab in the Pribilof District must have at least four escape rings of no less than five and one-half inches inside diameter installed on the vertical plane or at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized golden king crab (5 AAC 34.925 (c)). The sidewall “…must contain an opening equal to or exceeding 18 inches in length... The opening must be laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 30 thread.” (5 AAC 39.145(1)). There is a pot limit of 40 pots for vessels ≤125-feet LOA and of 50 pots for vessels >125-feet LOA (5 AAC 34.925 (e)(1)(B)). Golden king crab can be harvested from 1 January through 31 December only under conditions of a permit issued by the commissioner of ADF&G (**5 AAC 34.910 (b)(3)**). Since 2001, those conditions have included the carrying of a fisheries observer.

D. Data

1. **Summary of new information:**
    1. Retained catch and estimated discarded catch during the 2019 directed, estimated discarded catch during other crab fisheries in 2019 (no catch), and the estimated discarded catch in groundfish fisheries during 2019 have been added.

2. **Data presented as time series:**

a. ***Total catch** and b. **Information on bycatch and discards**:*

- The 1981/82–1983/84, 1984–2019 time series of retained catch (number and weight of crab, including deadloss), effort (vessels and pot lifts), average weight of landed crab, average carapace length of landed crab, and CPUE (number of landed crab captured per pot lift) are presented in Tables 1a and 1b.
- The 1993–2019 time series of weight of retained catch and estimated weight of discarded catch and estimated weight of fishery mortality of Pribilof golden king crab during the directed fishery and all other crab fisheries are given in Table 2. Discarded catch of Pribilof golden king crab occurs mainly in the directed golden king crab fishery, when prosecuted, and to a lesser extent in the Bering Sea snow crab fishery and the Bering Sea grooved Tanner crab fishery when prosecuted. Because the Bering Sea snow crab fishery is largely prosecuted between January and May and the Bering Sea grooved Tanner crab fishery is prosecuted within a calendar-year season, discarded catch in the crab fisheries can be estimated on a calendar year basis to align with the calendar-year season for Pribilof District golden king crab. Observer data on size distributions and estimated catch numbers of discarded catch were used to estimate the weight of discarded catch of golden king crab by applying a weight-at-length estimator (see below). Observers were first deployed to collect discarded catch data during the Pribilof District golden king crab fishery in 2001 and during the Bering Sea grooved Tanner crab fishery in 1994. Retained catch or observer data are confidential for at least one of the crab fisheries in 1999–2001, 2003–2005, 2010−2014, and 2017-2019. Following Siddeek et al. (2014), the bycatch mortality rate of golden king crab captured and discarded during Aleutian Islands golden king crab fishery was assumed to be 0.2. Following Foy (2013), bycatch mortality rate of king crab during the snow crab fishery was assumed to be 0.5. The bycatch mortality rate during the grooved Tanner crab fishery was also assumed to be 0.5.
- The groundfish fishery discarded catch data are grouped into crab fishery years from 1991/92–2008/09, and by calendar years from 2009–2019. The 1991/92–2019 time series of estimated annual weight of discarded catch and total fishery mortality of golden king crab during federal groundfish fisheries by gear type (combining pot and hook-and-line gear as a single "fixed gear" category and combining non-pelagic and pelagic trawl gear as a single "trawl" category) is provided in Table 3. Following Foy (2013), the bycatch mortality of king crab captured by fixed gear during groundfish fisheries was assumed to be 0.5 and of king crab captured by trawls during groundfish fisheries was assumed to be 0.8. Data from 1991/92–2008/09 are from federal reporting areas 513, 517, and 521, whereas the data from 2009–2019 are from the State statistical areas falling within the Pribilof District.

- Table 4 summarizes the available data on retained catch weight and the available estimates of discarded catch weight.

c. ***Catch-at-length:*** Not used in a Tier 5 assessment; none are presented.

d. Survey biomass estimates: Survey biomass estimates are not used in a Tier 5 assessment. However, see Appendix A for biomass estimates of mature male golden king crab using data from the 2002–2016 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey.

e. ***Survey catch at length:*** Survey catch at length data are not used in a Tier 5 assessment. However, see Appendix A for size data composition by sex of golden king crab during the 2002–2016 Bering Sea upper continental slope trawl surveys.

f. ***Other data time series:*** None.

3. Data which may be aggregated over time:

a. Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):

The author is not aware of data on growth per molt collected from golden king crab in the Pribilof District. Growth per molt of juvenile golden king crab, 2–35 mm CL, collected from Prince William Sound have been observed in a laboratory setting and equations describing the increase in CL and intermolt period were estimated from those observations (Paul and Paul 2001a); those results are not provided here. Growth per molt has also been estimated from golden king crab with CL ≥90 mm that were tagged in the Aleutian Islands and recovered during subsequent commercial fisheries (Watson et al. 2002); those results are not presented here because growth-per-molt information does not enter into a Tier 5 assessment.

See section **C.4** for discussion of evidence that mature female and the larger male golden king crab exhibit asynchronous, aseasonal molting and a prolonged intermolt period (>1 year).

b. Weight-at length or weight-at-age (by sex):

Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female golden king crab according to the equation, Weight = $A*CL^B$ (from Table 3-5, NPFMC 2007) are: A = 0.0002988 and B = 3.135 for males and A = 0.0014240 and B = 2.781 for females.

c. Natural mortality rate:

The default natural mortality rate assumed for king crab species by NPFMC (2007) is M=0.18. Note, however, natural mortality was not used for OFL estimation because this stock is classified as Tier 5.

4. Information on any data sources that were available, but were excluded from the assessment:

- Standardized bottom trawl surveys to assess the groundfish and invertebrate resources of the eastern Bering Sea upper continental slope were performed in 2002, 2004, 2008, 2010, 2012, and 2016 (Hoff and Britt 2003, 2005, 2009, 2011; Haaga et al. 2009, Gaeuman 2013a, 2013b; Hoff 2016). Data and analysed results pertaining to golden king crab from the 2002–2016 EBS upper continental slope surveys are provided in Appendices A and B but are not used in this Tier 5 assessment.

- Data on the size and sex composition of retained catch and discarded catch of Pribilof District golden king crab during the directed fishery and other crab fisheries are available but are not presented in this Tier 5 assessment.

E. Analytic Approach

1. History of modeling approaches for this stock:

Gaeuman (2013a, 2013b), Pengilly (2015), and Pengilly and Daly (2017) presented assessment-modelling approaches for this stock to the Crab Plan Team using data from the biennial NMFS EBS continental slope survey. However, this stock continued to be managed as a Tier 5 stock for 2018-2020, as had been recommended by NPFMC (2007) and by the CPT and SSC in 2008−2017.

2. Model Description: Subsections a–i are not applicable to a Tier 5 sock.

Only an OFL and ABC is estimated for Tier 5 stocks, where "the OFL represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock" (NPFMC 2007). Although NPFMC (2007) defined the OFL in terms of the retained catch, total-catch OFLs may be considered for Tier 5 stocks for which non-target fishery removal data are available (Federal Register/Vol. 73, No. 116, 33926). The CPT (in May 2010) and the SSC (in June 2010) endorsed the use of a total-catch OFL to establish the OFL for this stock. This assessment recommends – and only considers – use of a total-catch OFL for 2021-2023.

Additionally, NPFMC (2007) states that for estimating the OFL of Tier 5 stocks, "The time period selected for computing the average catch, hence the OFL, should be based on the best scientific information available and provide the required risk aversion for stock conservation and utilization goals." Given that a total-catch OFL is to be used, alternative configurations for the Tier 5 model are limited to: 1) alternative time periods for computing the average total-catch mortality; and 2) alternative approaches for estimating the discarded catch component of the total catch mortality during that period.

With regard to choosing from alternative time periods for computing average annual catch to compute the OFL, NPFMC (2007) suggested using the average retained catch over the years 1993 to 1999 as the estimated OFL for Pribilof District golden king crab. Years post-1984 were chosen based on an assumed 8-year lag between hatching and growth to legal size after the 1976/77 "regime shift". With regard to excluding data from years 1985 to 1992 and years after 1999, NPFMC (2007) states, "The excluded years are from 1985 to 1992 and from 2000 to 2005 for Pribilof Islands golden king crab when the fishing effort was less than 10% of the average or the GHL was set below the previous average catch." In 2008 the CPT and SSC endorsed the approach of estimating OFL as the average retained catch during 1993–1999 for setting a retained-catch OFL for 2009. However, in May 2009 the CPT set a retained-catch OFL for 2010, but using the average retained catch during 1993–1998; 1999 was excluded because it was the first year that a preseason GHL was established for the fishery. In May 2010, the CPT established a total-catch OFL computed as a function of the average retained catch during 1993–1998, a ratio-based estimate of the bycatch mortality during the directed fishery of that period, and an estimate of the "background" bycatch mortality due to other fisheries. Other time periods, extending into years post-1999, had been considered for computing the average retained catch in the establishment of the 2009, 2010, and 2011 OFLs, but those time periods were rejected by the CPT and the SSC. Hence the period for calculating the retained-catch portion of the Tier 5 total-catch OFL for this stock has been firmly established by the CPT and SSC at 1993–1998 (the CPT said "this freezes the time frame..."). For the 2012 and the 2013 OFLs, the CPT and SSC recommended the period 2001–2010 for calculating the ratio-based estimate of the bycatch mortality during the 1993–1998 directed fishery, the period 1994–1998 for calculating the estimated bycatch mortality due to non-directed crab fisheries during 1993–1998, and the period 1992/93–1998/99 for calculating the estimated bycatch mortality due to groundfish fisheries during 1993–1998.

Two alternative approaches for determination of the 2013 OFL were presented to the CPT and SSC in May–June 2013. Alternative 1 was the status quo approach (i.e., the approach used to establish the 2012 total-catch OFL). Alternative 2 was the same as Alternative 1 except that it used updated discarded catch data from crab fisheries in 2011. Alternative 2 was presented specifically to allow the CPT and the SSC to clarify whether the 2013 and subsequent OFLs should be computed using data collected after 2010, or if the time periods for data used to calculate the 2013 and subsequent OFLs should be "frozen" at the years used to calculate the 2012 OFL. The CPT and the SSC both recommended Alternative 1, clarifying that Tier 5 OFLs for future years should be computed using only data collected through 2010. Following that recommendation from CPT and the SSC, only one alternative was presented for computing the 2014–2017 Tier 5 OFLs (i.e., the Alternative 1 that was presented in 2013). The 2021-2023 Tier 5 OFL recommended here uses the same approach as used for the 2013–2020 Tier 5 OFLs.

3. Model Selection and Evaluation:

a. ***Description of alternative model configurations***

The recommended OFL is set as a total-catch OFL using 1993–1998 to compute average annual retained catch, an estimate of the ratio of bycatch mortality to retained catch during the directed fishery, an estimate of the average annual bycatch mortality due to the non-directed crab fisheries during 1994–1998, and an estimate of average annual bycatch mortality due to the groundfish fisheries during 1992/93–1998/99; i.e.,

$$OFL_{2021\text{-}2023} = (1+R_{2001–2010})*RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,92/93–98/99},$$

where,

- $R_{2001–2010}$ is the average of the estimated annual ratio of bycatch mortality to retained catch in the directed fishery during 2001–2010
- $RET_{1993\text{-}1998}$ is the average annual retained catch in the directed crab fishery during 1993–1998
- $BM_{NC,1994\text{-}1998}$ is the estimated average annual bycatch mortality in non-directed crab fisheries during 1994–1998
- $BM_{GF,92/93–98/99}$ is the estimated average annual bycatch mortality in groundfish fisheries during 1992/93–1998/99.

The average of the estimated annual ratio of bycatch mortality to retained catch in the directed fishery during 2001–2010 is used as a factor to estimate bycatch mortality in the directed fishery during 1993–1998 because, whereas there are no data on discarded catch for the directed fishery during 1993–1998, there are such data from the directed fishery during 2001–2010 (excluding 2006–2009, when there was no fishery effort).

There are no discarded catch data available for the non-directed fisheries during 1993, thus 1994–1998 is used to estimate average annual bycatch mortality in non-directed fisheries.

The estimated average annual bycatch mortality in groundfish fisheries during 1992/93–1998/99 is used to estimate the average annual bycatch mortality in groundfish fisheries during 1993–1998 because 1992/93–1998/99 is the shortest time period of crab fishery years that encompasses calendar years 1993–1998.

Statistics on the data and estimates used to calculate $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,93/94\text{-}98/99}$ are provided in Table 5; the column means in Table 5 are the calculated values of $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,93/94\text{-}98/99}$. Using the calculated values of $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,93/94\text{-}98/99}$, the calculated value of OFL_{2018} is,

$$OFL_{2021\text{-}2023} = (1+0.052)*78.80 \text{ t} + 6.09 \text{ t} + 3.79 \text{ t} = 93 \text{ t (204,527 lbs)}.$$

b. ***Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed:*** See the table, below.

Model	Retained- vs. Total-catch	Time Period	Resulting OFL (t)
Recommended/status quo	Total-catch	1993–1998	93

This is recommended as being the best approach with the limited data available and follows the advice of the CPT and SSC to “freeze” the period for calculation of the OFL at the time period that was established for the 2012 OFL and uses the computations recommended by the CPT and SSC in 2013.

c. ***Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models:*** See Section E, above.

d. ***Convergence status and convergence criteria for the base-case model (or proposed base-case model):*** Not applicable.

e. ***Table (or plot) of the sample sizes assumed for the compositional data:*** Not applicable.

f. ***Do parameter estimates for all models make sense, are they credible?:***
The time period used for determining the OFL was established by the SSC in June 2012. Retained catch data come from fish tickets and annual retained catch is considered a known (not estimated) value. Estimates of discarded catch from crab fisheries data are generally

considered credible (e.g., Byrne and Pengilly 1998; Gaeuman 2011, 2013c, 2014), but may have greater uncertainty in a small, low effort fishery such as the Pribilof golden king crab fishery. Estimates of bycatch mortality are estimates of discarded catch times an assumed bycatch mortality rate. The assumed bycatch mortality rates (i.e., 0.2 for crab fisheries, 0.5 for fixed-gear groundfish fisheries, and 0.8 for trawl groundfish fisheries) have not been estimated from data.

g. ***Description of criteria used to evaluate the model or to choose among alternative models, including the role (if any) of uncertainty:*** See section E.3.c, above.

h. ***Residual analysis (e.g. residual plots, time series plots of observed and predicted values or other approach):*** Not applicable.

i. ***Evaluation of the model, if only one model is presented; or evaluation of alternative models and selection of final model, if more than one model is presented:*** See section E.3.c, above.

4. Results (best model(s)):

a. List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties: Not applicable.

b. Tables of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible; include estimates from previous SAFEs for retrospective comparisons): See Tables 2–5.

c. Graphs of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible): Information requested for this subsection is not applicable to a Tier 5 stock.

d. Evaluation of the fit to the data: Not applicable for Tier 5 stock.

e. Retrospective and historic analyses (retrospective analyses involve taking the "best" model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments): Not applicable for Tier 5 stock.

f. Uncertainty and sensitivity analyses (this section should highlight unresolved problems and major uncertainties, along with any special issues that complicate scientific assessment, including questions about the best model, etc.): For this assessment, the major uncertainties are:

- Whether the time period is "representative of the production potential of the stock" and if it serves to "provide the required risk aversion for stock conservation and utilization goals", or whether any such time period exists.
    - Only a period of 6 years is used to compute the OFL, 1993–1998. The SSC has noted its uneasiness with that situation ("6 years of data are very few years upon which to base these catch specifications." June 2011 SSC minutes).

- No data on discarded catch due to the directed fishery are available from the period used to compute the OFL.
    - Estimation of the OFL rests on the assumption that data on the ratio of discarded catch to retained catch from post-2000 can be used to accurately estimate that ratio in 1993–1998.
- The bycatch mortality rates used in estimation of total catch.
    - Bycatch mortality is unknown and no data that could be used to estimate the bycatch mortality of this stock are known to the author. Hence, only the values that are assumed for other BSAI king crab stock assessments are considered in this assessment. The estimated OFL increases (or decreases) relative to the bycatch mortality rates assumed: doubling the assumed bycatch mortality rates increases the OFL estimate by a factor of 1.15; halving the assumed bycatch mortality rates decreases the OFL estimate by a factor of 0.92.

F. Calculation of the OFL

1. **Specification of the Tier level and stock status level for computing the OFL:**
    - Recommended as Tier 5, total-catch OFL estimated by estimated average total catch over a specified period.
    - Recommended time period for computing retained-catch OFL: 1993–1998.
        - This is the same time period that was used to establish OFL for 2010–2020. The time period 1993–1998 provides the longest continuous time period through 2019 during which vessels participated in the fishery, retained-catch data can be retrieved that are not confidential, and the retained catch was not constrained by a GHL. Data on discarded catch contemporaneous with 1993-1998 to the extent possible are used to calculate the total-catch OFL.

2. **List of parameter and stock size estimates (or best available proxies thereof) required by limit and target control rules specified in the fishery management plan:** Not applicable for Tier 5 stock.

3. **Specification of the total-catch OFL:**

a. Provide the equations (from Amendment 24) on which the OFL is to be based:

From **Federal Register** / Vol. 73, No. 116, page 33926, “For stocks in Tier 5, the overfishing level is specified in terms of an average catch value over an historical time period, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information.” Additionally, “For stocks where nontarget fishery removal data are available, catch includes all fishery removals, including retained catch and discard losses. Discard losses will be determined by multiplying the appropriate handling mortality rate by observer estimates of bycatch discards. For stocks where only retained catch information is available, the overfishing level is set for and compared to the retained catch” (FR/Vol. 73, No. 116, 33926). That compares with the specification of NPFMC (2007) that the OFL “represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock.”

b. Basis for projecting MMB to the time of mating: Not applicable for Tier 5 stock.

c. ***Specification of F_{OFL}, OFL, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring:*** See table below. Because less than three vessels participated in the 2017, 2018, and 2019 directed fisheries, catch numbers are not reported here under the confidentiality requirements of State of Alaska (SOA) statute Sec. 16.05.815. Although fishery mortality occurred during groundfish fisheries in 2017, 2018, and 2019, this and the fishery mortality in the directed fisheries did not exceed the corresponding OFL. As such, overfishing did not occur in 2017, 2018, and 2019. Values for the 2021-2023 OFL and ABC are the author's recommendations.

Management Performance Table (values in t)

Calendar Year	MSST	Biomass (MMB)	GHL[a]	Retained Catch	Total Catch[b]	OFL	ABC
2016	N/A	N/A	59	0	0.24	91	68
2017	N/A	N/A	59	Conf.	Conf.	93	70
2018	N/A	N/A	59	Conf. [c]	Conf. [c]	93	70
2019	N/A	N/A	59	Conf.	Conf.	93	70
2020	N/A	N/A	59			93	70
2021	N/A	N/A				93	70
2022	N/A	N/A				93	70
2023	N/A	N/A				93	70

a. Guideline harvest level, established in lb and converted to t.
b. Total retained catch plus estimated bycatch mortality of discarded catch during crab and groundfish fisheries. Total reratined catch is not listed for 2017–2019 because the directed fishery is confidential under Sec. 16.05.815(SOA statute).
c. Confidential under Sec. 16.05.815 (SOA statute). GHL not attained.

Management Performance Table (values in millions of lb)

Calendar Year	MSST	Biomass (MMB)	GHL[a]	Retained Catch	Total Catch[b]	OFL	ABC
2016	N/A	N/A	130,000	0	<0.001	0.20	0.15
2017	N/A	N/A	130,000	Conf.	Conf.	0.20	0.15
2018	N/A	N/A	130,000	Conf.[c]	Conf.[c]	0.20	0.15
2019	N/A	N/A	130,000	Conf.	Conf.	0.20	0.15
2020	N/A	N/A	130,000				
2021	N/A	N/A					
2022	N/A	N/A					
2023	N/A	N/A					

a. Guideline harvest level, established in lb and converted to t.
b. Total retained catch plus estimated bycatch mortality of discarded catch during crab and groundfish fisheries. Total reratined catch is not listed for 2017–2019 because the directed fishery is confidential under Sec. 16.05.815(SOA statute).
c. Confidential under Sec. 16.05.815 (SOA statute). GHL not attained.

4. Specification of the retained-catch portion of the total-catch OFL:

a. **Equation for recommended retained-portion of total-catch OFL.**

Retained-catch portion = average retained catch during 1993–1998 (Table 5).
= 79 t.

Note that a retained catch of 79 t would exceed the author's recommended ABC for 2021, 2022, 2023 (70 t); see G.4, below.

5. **Recommended F_{OFL}, OFL total catch and the retained portion for the coming year:** See sections ***F.3*** and ***F.4***, above; no F_{OFL} is recommended for a Tier 5 stock.

G. Calculation of ABC

1. PDF of OFL. A bootstrap estimate of the sampling distribution (assuming no error in estimation of discarded catch) of the status quo Alternative 1 OFL is shown in Figure 2 (1,000 samples drawn with replacement independently from each of the four columns of values in Table 5 to calculate $R_{2001\text{-}2010}$, $RET_{1993\text{-}1998}$, $BM_{NC,1994\text{-}1998}$, $BM_{GF,92/93\text{-}98/99}$, and OFL_{2016}). The mean and CV computed from the 1,000 replicates are 92 t and 0.25, respectively. Note that generated sampling distribution and computed standard deviation are meaningful as measures in the uncertainty of the OFL only if assumptions on the choice of years used to compute the Tier 5 OFL are true (see Sections E.2 and E.4.f).

2. List of variables related to scientific uncertainty.

- Bycatch mortality rate in each fishery that discarded catch occurs. Note that for Tier 5 stocks, an increase in an assumed bycatch mortality rate will increase the OFL (and hence the ABC) but has no effect on the retained-catch portion of the OFL or the retained-catch portion of the ABC.
- Estimated discarded catch and bycatch mortality for each fishery that discarded catch occurred in during 1993–1998.
- The time period to compute the average catch under the assumption of representing "a time period determined to be representative of the production potential of the stock."
- Stock size in 2020 is unknown.

3. List of additional uncertainties for alternative sigma-b. Not applicable to this Tier 5 assessment.

2. **Author recommended ABC.** 25% buffer on OFL; i.e., ABC = (1-0.25)·(93 t) = 70 t (153,395 lb).

H. Rebuilding Analyses

Not applicable; this stock has not been declared overfished.

I. Data Gaps and Research Priorities

Data from the 2008–2016 biennial NMFS-AFSC eastern Bering Sea upper continental slope trawl surveys have been examined for their utility in determining overfishing levels and stock status by Gaeuman (2103a, 2013b), Pengilly and Daly (2017), and Appendix A of this assessment. Cancellation of the survey that was scheduled for 2018 and 2020 raised uncertainties on the prospects for obtaining fishery-independent survey data on this stock in the future. However, ADF&G is currently exploring the feasibility of initiating in industry-cooperative survey as a means to acquire biological data for future assessments.

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Tables

Table 1a. Commercial fishery history for the Pribilof District golden king crab fishery, 1981/82 through 2019: number of vessels, guideline harvest level (GHL; established in lb, **converted to t**), weight of retained catch (Harvest; **t**), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (**kg**) of landed crab.

Fishing/Calendar Year	Vessels	GHL	Harvest[a]	Crab[a]	Pot lifts	CPUE	Average weight
1981/82	2	–	CF	CF	CF	CF	CF
1982/83	10	–	32	15,330	5,252	3	2.1
1983/84	50	–	388	253,162	26,035	10	1.5
1984	0	–	0	0	0	–	–
1985	1	–	CF	CF	CF	CF	CF
1986	0	–	0	0	0	–	–
1987	1	–	CF	CF	CF	CF	CF
1988 - 1989	2	–	CF	CF	CF	CF	CF
1990 - 1992	0	–	0	0	0	–	–
1993	5	–	31	17,643	15,395	1	1.7
1994	3	–	40	21,477	1,845	12	1.9
1995	7	–	155	82,489	9,551	9	1.9
1996	6	–	149	91,947	9,952	9	1.6
1997	7	–	81	43,305	4,673	9	1.9
1998	3	–	16	9,205	1,530	6	1.8
1999	3	91	80	44,098	2,995	15	1.8
2000	7	68	58	29,145	5,450	5	2.0
2001	6	68	66	33,723	4,262	8	2.0
2002	8	68	68	34,860	5,279	6	2.0
2003	3	68	**CF**	**CF**	**CF**	**CF**	**CF**
2004	5	68	**CF**	**CF**	**CF**	**CF**	**CF**
2005	4	68	CF	CF	CF	CF	CF
2006 - 2009	0	68	0	0	0	–	–
2010	1	68	CF	CF	CF	CF	CF
2011	2	68	CF	CF	CF	CF	CF
2012	1	68	CF	CF	CF	CF	CF
2013	1	68	CF	CF	CF	CF	CF
2014	1	68	CF	CF	CF	CF	CF
2015	0	59	0	0	0	–	–
2016	0	59	0	0	0	–	–
2017	2	59	CF	CF	CF	CF	CF
2018	1	59	CF	CF	CF	CF	CF
2019	2	59	CF	CF	CF	CF	CF

Note: CF: confidential information due to less than three vessels or processors having participated in fishery;
CF: confidential information and fishery was closed by emergency order to manage the harvest to the preseason GHL.

[a] Deadloss included.

Table 1b. Commercial fishery history for the Pribilof District golden king crab fishery, 1981/82 through 2019: number of vessels, guideline harvest level (GHL; **lb**), weight of retained catch (Harvest; **lb**), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (**lb**) of landed crab.

Fishing/Calendar Year	Vessels	GHL	Harvest[a]	Crab[a]	Pot lifts	CPUE	Average weight
1981/82	2	–	CF	CF	CF	CF	CF
1982/83	10	–	69,970	15,330	5,252	3	4.6
1983/84	50	–	856,475	253,162	26,035	10	3.4
1984	0	–	0	0	0	–	–
1985	1	–	CF	CF	CF	CF	CF
1986	0	–	0	0	0	–	–
1987	1	–	CF	CF	CF	CF	CF
1988 - 1989	2	–	CF	CF	CF	CF	CF
1990 - 1992	0	–	0	0	0	–	–
1993	5	–	67,458	17,643	15,395	1	3.8
1994	3	–	88,985	21,477	1,845	12	4.1
1995	7	–	341,908	82,489	9,551	9	4.1
1996	6	–	329,009	91,947	9,952	9	3.6
1997	7	–	179,249	43,305	4,673	9	4.1
1998	3	–	35,722	9,205	1,530	6	3.9
1999	3	200,000	177,108	44,098	2,995	15	4.0
2000	7	150,000	127,217	29,145	5,450	5	4.4
2001	6	150,000	145,876	33,723	4,262	8	4.3
2002	8	150,000	150,434	34,860	5,279	6	4.3
2003	3	150,000	**CF**	**CF**	**CF**	**CF**	**CF**
2004	5	150,000	**CF**	**CF**	**CF**	**CF**	**CF**
2005	4	150,000	CF	CF	CF	CF	CF
2006 - 2009	0	150,000	0	0	0	–	–
2010	1	150,000	CF	CF	CF	CF	CF
2011	2	150,000	CF	CF	CF	CF	CF
2012	1	150,000	CF	CF	CF	CF	CF
2013	1	150,000	CF	CF	CF	CF	CF
2014	1	150,000	CF	CF	CF	CF	CF
2015	0	130,000	0	0	0	–	–
2016	0	130,000	0	0	0	–	–
2017	2	130,000	CF	CF	CF	CF	CF
2018	1	130,000	CF	CF	CF	CF	CF
2019	2	130,000	CF	CF	CF	CF	CF

Note: CF: confidential information due to less than three vessels or processors having participated in fishery.

CF: confidential information and fishery was closed by emergency order to manage the harvest to the preseason GHL.

[a] Deadloss included.

Table 2. Weight (**t**) of retained catch and estimated discarded catch of Pribilof golden king crab during crab fisheries, 1993–2019, with total fishery mortality (**t**) estimated by applying a bycatch mortality rate of 0.2 to the discarded catch in the directed fishery and a bycatch mortality rate of 0.5 to the discarded catch in the non-directed fisheries.

		Discarded (no mortality rate applied)			
Calendar Year	Retained	Pribilof Islands golden king crab	Bering Sea snow crab	Bering Sea grooved Tanner crab	Total Mortality
1993	30.60	no data	0.00	no data	—
1994	40.36	no data	3.80	1.15	—
1995	155.09	no data	0.63	15.65	—
1996	149.24	no data	0.24	2.34	—
1997	81.31	no data	4.05	no fishing	—
1998	16.20	no data	33.00	no fishing	—
1999	80.33	no data	0.00	confidential	—
2000	57.70	no data	0.00	confidential	—
2001	66.17	17.82	0.00	confidential	confidential
2002	68.24	19.00	1.06	no fishing	72.57
2003	confidential	confidential	0.15	confidential	72.20
2004	confidential	confidential	0.00	confidential	66.93
2005	confidential	confidential	0.00	confidential	29.85
2006	no fishing	no fishing	0.00	0.00	0.00
2007	no fishing	no fishing	0.00	0.00	0.00
2008	no fishing	no fishing	0.00	no fishing	0.00
2009	no fishing	no fishing	0.96	no fishing	0.48
2010	confidential	confidential	0.00	no fishing	confidential
2011	confidential	confidential	0.27	no fishing	confidential
2012	confidential	confidential	0.27	no fishing	confidential
2013	confidential	confidential	0.58	no fishing	confidential
2014	confidential	confidential	0.12	no fishing	confidential
2015	no fishing	no fishing	0.00	no fishing	0.00
2016	no fishing	no fishing	0.00	no fishing	0.00
2017	confidential	confidential	0.00	confidential	confidential
2018	confidential	confidential	0.00	no fishing	confidential
2019	confidential	confidential	0.00	no fishing	confidential

Table 3. Estimated annual weight (**t**) of discarded catch of Pribilof golden king crab (all sizes, males and females) during federal groundfish fisheries by gear type (fixed or trawl) with total bycatch mortality (**t**) estimated by assuming bycatch mortality rate = 0.5 for fixed-gear fisheries and bycatch mortality rate = 0.8 for trawl fisheries. 1991/92–2008/09 is listed by crab fishery year, while 2009-2019 are listed by calendar year.

Crab fishing year (1991/92–2008/09) or Calendar year (2009-2019)	Bycatch in groundfish fisheries (no mortality rate applied)			Total
	Fixed	Trawl	Total	Mortality
1991/92	0.05	6.11	6.16	4.91
1992/93	3.49	8.87	12.35	8.84
1993/94	0.51	9.64	10.14	7.96
1994/95	0.25	3.22	3.47	2.70
1995/96	0.41	1.90	2.31	1.72
1996/97	0.02	0.87	0.89	0.71
1997/98	1.34	0.49	1.83	1.06
1998/99	6.77	0.18	6.95	3.53
1999/00	4.79	0.65	5.43	2.91
2000/01	1.63	1.88	3.50	2.31
2001/02	1.50	0.36	1.85	1.03
2002/03	0.55	0.21	0.77	0.45
2003/04	0.23	0.18	0.41	0.26
2004/05	0.16	0.39	0.55	0.39
2005/06	0.09	0.06	0.15	0.09
2006/07	1.32	0.12	1.44	0.75
2007/08	8.47	0.16	8.63	4.36
2008/09	3.99	1.56	5.55	3.24
2009	2.67	2.55	5.22	3.38
2010	2.13	1.01	3.14	1.87
2011	0.85	1.33	2.18	1.49
2012	0.73	0.82	1.55	1.02
2013	0.50	2.49	2.99	2.24
2014	0.61	0.53	1.14	0.73
2015	0.81	1.89	2.70	1.92
2016	0.23	0.16	0.39	0.24
2017	0.15	1.34	1.49	1.15
2018	0.10	1.59	1.69	1.32
2019	0.05	4.86	4.91	3.91
Average	1.53	1.91	3.44	2.29

Table 4. Retained-catch weights (**t**) and estimates of discarded catch weights (**t**) of Pribilof Islands golden king crab available for a Tier 5 assessment; shaded, bold values are used in computation of the recommended (status quo Alternative 1) Tier 5 OFL.

		Retained catch weight	Discarded catch weight (estimated)			
		Fish tickets	Observer data: lengths, catch per sampled pot		Blend method; Catch Accounting System	
Calendar Year[a]	Crab Fishing Year[b]	Directed fishery	Directed fishery	Non-directed crab fisheries	Fixed gear, groundfish	Trawl gear, groundfish
	1981/82	Confidential				
	1982/83	31.74				
	1983/84	388.49				
1984	1984/85	0.00				
1985	1985/86	Confidential				
1986	1986/87	0.00				
1987	1987/88	Confidential				
1988	1988/89	Confidential				
1989	1989/90	Confidential				
1990	1990/91	0.00				
1991	1991/92	0.00			0.05	6.11
1992	1992/93	0.00			**3.49**	**8.87**
1993	1993/94	**30.60**			**0.51**	**9.64**
1994	1994/95	**40.36**		**4.95**	**0.25**	**3.22**
1995	1995/96	**155.09**		**16.28**	**0.41**	**1.90**
1996	1996/97	**149.24**		**2.58**	**0.02**	**0.87**
1997	1997/98	**81.31**		**4.05**	**1.34**	**0.49**
1998	1998/99	**16.20**		**33.00**	**6.77**	**0.18**
1999	1999/00	80.33		Confidential	4.79	0.65
2000	2000/01	57.70		Confidential	1.63	1.88
2001	2001/02	66.17	**17.20**	Confidential	1.50	0.36
2002	2002/03	68.24	**19.00**	1.06	0.55	0.21
2003	2003/04	Confidential	**Confidential**	Confidential	0.23	0.18
2004	2004/05	Confidential	**Confidential**	Confidential	0.16	0.39
2005	2005/06	Confidential	**Confidential**	Confidential	0.09	0.06
2006	2006/07	0.00	0.00	0.00	1.32	0.12
2007	2007/08	0.00	0.00	0.00	8.47	0.16
2008	2008/09	0.00	0.00	0.00	3.99	1.56
2009	2009/10	0.00	0.96	0.96	2.67	2.55
2010	2010/11	Confidential	**Confidential**	0.00	2.13	1.01
2011	2011/12	Confidential	Confidential	0.27	0.85	1.33
2012	2012/13	Confidential	Confidential	0.27	0.73	0.82
2013	2013/14	Confidential	Confidential	0.58	0.50	2.49
2014	2014/15	Confidential	Confidential	0.12	0.61	0.53
2015	2015/16	0.00	0.00	0.00	0.814	1.890
2016	2016/17	0.00	0.00	0.00	0.232	0.158
2017	2017/18	Confidential	Confidential	0.81	0.146	1.345
2018	2018/19	Confidential	Confidential	0.00	0.103	1.589
2019	2019/20	Confidential	Confidential	0.00	0.049	4.861

a. Year convention for retained weights in directed fishery, 1984-2019, estimates of discarded bycatch weights in directed, non-directed crab fisheries, and grounfish (2009-2019).

b. Year convention for retained weights in directed fishery, 1981/82-1983/84, and estimates of discarded bycatch rates in groundfish fisheries (1991/92-2008/09).

Table 5. Data for calculation of $RET_{1993-1998}$ (**t**) and estimates used in calculation of $R_{2001-2010}$ (ratio, t:t), $BM_{NC,1994-1998}$ (**t**), and $BM_{GF,92/93-98/99}$ (**t**) for calculation of the recommended (status quo Alternative 1) Pribilof Islands golden king crab Tier 5 2021-2023 OFL (**t**); values under $RET_{1993-1998}$ are from Table 1, values under $R_{2001-2010}$ were computed from the retained catch data and the directed fishery discarded catch estimates in Table 2 (assumed bycatch mortality rate = 0.2), values under $BM_{NC,1994-1998}$ were computed from the non-directed crab fishery discarded catch estimates in Table 2 (assumed bycatch mortality rate = 0.5) and values under $BM_{GF,92/93-98/99}$ are from Table 3.

Calendar Year[a]	Crab Fishing Year[b]	$RET_{1993-1998}$	$R_{2001-2010}$	$BM_{NC,1994-1998}$	$BM_{GF,92/93-98/99}$
1993	1992/93	30.60			8.84
1994	1993/94	40.36		2.48	7.96
1995	1994/95	155.09		8.14	2.70
1996	1995/96	149.24		1.29	1.72
1997	1996/97	81.31		2.03	0.71
1998	1997/98	16.20		16.50	1.06
1999	1998/99				3.53
2000	1999/00				
2001	2000/01		0.054		
2002	2001/02		0.056		
2003	2002/03		conf.		
2004	2003/04		conf.		
2005	2004/05		conf.		
2006	2005/06				
2007	2006/07				
2008	2007/08				
2009	2008/09				
2010	2009/10		conf.		
	N	6	6	5	7
	Mean	78.80	0.052	6.09	3.79
	S.E.M	24.84	0.004	2.87	1.25
	CV	0.32	0.07	0.47	0.33

a. Year convention corresponding with values under $RET_{1993-1998}$, $R_{2001-2010}$, and $BM_{NC,1994-1998}$.
b. Year convention corresponding with values under $BM_{GF,92/93-98/99}$.

Figures

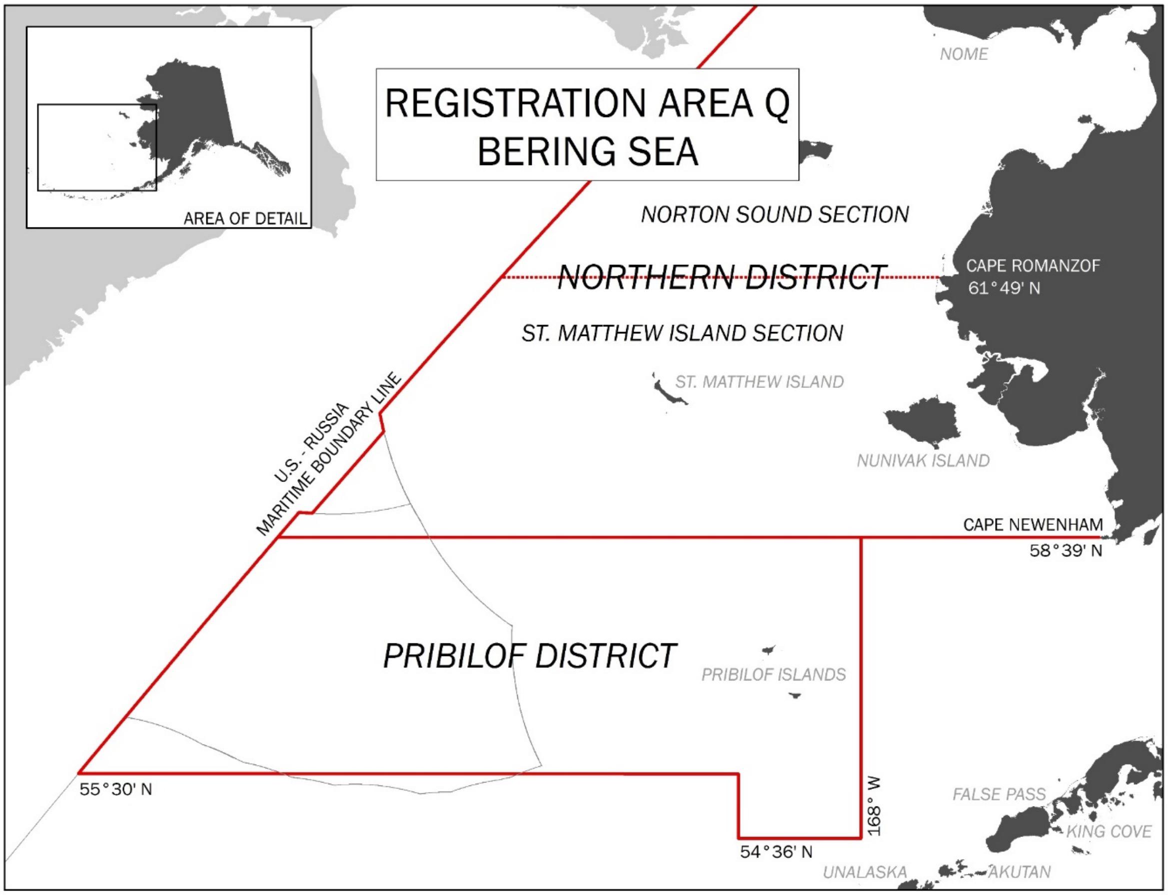

Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District.

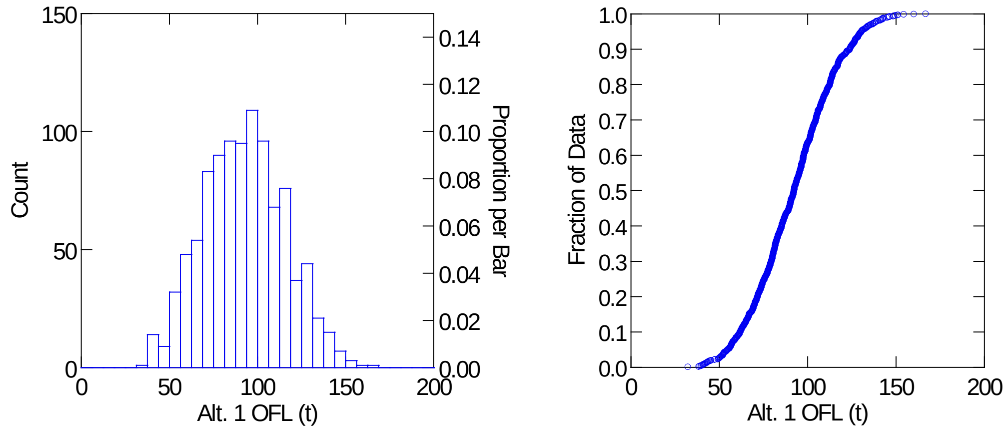

Figure 2. Bootstrapped estimates of the sampling distribution of the 2021-2023 Alternative 1 Tier 5 OFL (total catch, t) for the Pribilof Islands golden king crab stock; histogram on left, quantile plot on right.

Appendix A

Pribilof Islands Golden King Crab Tier 4 Calculations

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The PIGKC stock is currently managed as Tier 5, but we present Tier 4 calculations here. While fishery catch data are available, the OFL calculation presented here uses only NMFS-AFSC eastern Bering Sea continental slope bottom trawl survey data.

Data

Survey biomass estimates and length composition

The NMFS-AFSC conducted an eastern Bering Sea continental slope bottom trawl survey on a biennial schedule during 2002–2016 (2006, 2014, 2018, and 2020 surveys cancelled), and are the sole data source for estimating mature male biomass (MMB) for Pribilof Islands golden king crab (PIGKC, *Lithodes aequispinus*). Results of the 2002–2016 surveys showed that a majority of golden king crab on the eastern Bering Sea continental slope occurred in the 200–400 m and 400–600 m depth ranges (Hoff and Britt 2003, 2005, 2009, 2011; Hoff 2013, 2016). Biomass, number, and density (in number per area and in weight per area) of golden king crab on the eastern Bering Sea continental slope are higher in the southern areas than in the northern areas, with highest abundance in survey subarea 2 (Pengilly and Daly 2017). For the purpose of this document, we focus on survey subareas 2, 3, and 4 as they generally conform to the ADF&G Pribilof District Management Area (PDMA, Figs. 1-3, ADF&G 2017). Length composition data are available for 2008-2016 surveys but not the 2002 and 2004 surveys (Fig. 4). For the 2008-2016 surveys, we applied length-weight regression to size composition data to estimate the weight of each crab measured. MMB was calculated using a maturity size cut-off of 107 mm CL (Somerton and Otto 1986). An area-swept estimate of biomass and of the variance of the biomass estimate was computed for each stratum within a survey subarea and summed over strata within the subarea to obtain area-swept estimates of biomass within a subarea and of the variance of that biomass estimate; estimates of the biomass and associated variances within subareas were summed over subareas to obtain biomass estimates in aggregates of subareas and of the variances of those estimates.

Total catch, bycatch, discards, and retained catch size composition data

- The 1981/82–1983/84, 1984–2019 time series of retained catch (number and weight of crab, including deadloss), effort (vessels and pot lifts), average weight of landed crab, average carapace length of landed crab, and CPUE (number of landed crab captured per pot lift) are available, <u>but not used in the OFL calculation presented here</u>.

- The 1993–2019 time series of weight of retained catch and estimated weight of discarded catch and estimated weight of fishery mortality of Pribilof golden king crab during the directed fishery and all other crab fisheries are available, but not used in the OFL calculation presented here.
- The groundfish fishery discarded catch data (grouped into crab fishery years from 1991/92–2008/09, and by calendar years from 2009–2019) are available, but not used in the OFL calculation presented here.
- Retained catch size composition data is available for 2001-2019, but not used in the OFL calculation presented here.

Growth per molt

The authors are not aware of data on growth per molt collected from golden king crab in the Pribilof District. Growth per molt of juvenile golden king crab, 2–35 mm CL, collected from Prince William Sound have been observed in a laboratory setting and equations describing the increase in CL and intermolt period were estimated from those observations (Paul and Paul 2001a); those results are not provided here. Growth per molt has also been estimated from golden king crab with CL ≥90 mm that were tagged in the Aleutian Islands and recovered during subsequent commercial fisheries (Watson et al. 2002); those results are not presented here because growth-per-molt information does not enter into the OFL calculation presented here.

Weight-at length (by sex)

Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female golden king crab according to the equation, Weight = $A*CL^B$ (from Table 3-5, NPFMC 2007) are: A = 0.0002988 and B = 3.135 for males and A = 0.0014240 and B = 2.781 for females.

Natural mortality rate

The default natural mortality rate assumed for king crab species by NPFMC (2007) is M=0.18.

Analytic Approach

History of Modeling Approaches

The PIGKC stock assessment has followed the Tier 5 methodology since 2012, but interest in a Tier 4 method using a random effect model and NMFS-AFSC EBS slope survey data has received growing interest. In 2017, total biomass and mature male biomass were estimated by a random effects method with the inclusion of the 2016 survey data. At that time, the CPT recommended to use the Tier 5 assessment until the model was further explored and/or additional survey data was available. Here, we further explore the utility of the random effects model, though there has been no additional fishery-independent data since the 2017 assessment.

Random effects model

The program "Survey Average Random Effects" was used to estimate biomass from the area-swept MMB (males ≥107 mm) estimates in surveyed years and to project biomass estimates for unsurveyed years into 2022 via a state-space random walk plus noise model. The state-space random walk plus noise is formulated as a random effect model, where process errors are considered "random effects" drawn from an underlying normal distribution with μ=0 and estimated σ^2 (σ_λ^2), and integrated out of the likelihood. The method was developed by the NPFMC groundfish plan team's survey averaging working group as a smoothing technique similar to the Kalman Filter, but which provides more flexibility with non-linear processes and non-normal error structures (Spencer et al. 2015).

Model scenarios

We applied the random effects model to six iterations of the EBS slope survey MMB timeseries, which varied by 1) the number of MMB input years, 2) the spatial area extent, and 3) level of stratification (Table 1). Size composition data is only available for 2008, 2010, 2012, and 2016 survey, thus MMB area-swept estimates are only available for those years. However, we calculated the ratio of MMB to total biomass for the 2008, 2010, 2012, 2016 surveys (Table 2) and applied the average ratio to the 2002 and 2004 survey total biomass and variance to approximate MMB for 2002 and 2004 surveys. The Pribilof District Management Area (PDMA) boundaries do not align with those of the EBS slope survey subareas. All of survey subareas 2 and 3, nearly all of subarea 4, and portions of subareas 1 and 5 are encompassed by the PDMA. While most of the survey biomass occurs in subareas 2-4, some GKC occur in subareas 1 and 5. For some iterations, we included portions of these subareas when calculating MMB estimates. Finally, since survey stations towed in a given season are selected from a pool of available stations via a sampling design stratified by subarea and depth range, we included MMB timeseries where MMB was calculated using average survey MMB densities within strata within subareas, and strata within the survey area (i.e., similar depth strata were combined among subareas, and subareas were neglected) (Table 3). Model scenarios were as follows:

1. **2020a**: MMB and variance in MMB 2008-2016 computed among strata within subareas 2-4, summed within subareas, and then across subareas
2. **2020b:** MMB and variance in MMB 2008-2016 computed among strata within the survey area bounded by the Pribilof Islands district and summed across strata
3. **2020c:** MMB density and variance in MMB 2008-2016 density computed among strata within subareas 2-4 and summed across strata
4. **2020d**: The same as 2020a, but included MMB estimates for 2002 and 2004 (computed using the mean ratio of MMB:total biomass from 2008-2016)
5. **2020e**: The same as 2020b, but included MMB estimates for 2002 and 2004 (computed using the mean ratio of MMB:total biomass from 2008-2016)
6. **2020f:** The same as 2020c, but included MMB estimates for 2002 and 2004 (computed using the mean ratio of MMB:total biomass from 2008-2016)

Table 1. Model scenarios, where calculation of MMB inputs varied with changes to survey input years, the spatial extent of the stock, and levels of stratification (i.e., depth stratum, subareas). PDMA refers to the Pribilof District Management Area.

Model	Survey Years	Survey Area	Stratification Levels

2020a	2008 - 2016	Subareas 2 - 4	2
2020b	2008 - 2016	PDMA	1
2020c	2008 - 2016	Subareas 2 - 4	1
2020d	2002 - 2016	Subareas 2 - 4	2
2020e	2002 - 2016	PDMA	1
2020f	2002 - 2016	Subareas 2 - 4	1

Table 2. MMB:total biomass ratios used to estimate 2002 and 2004 MMB by model scenario. Ratios are different among scenarios, depending on the biomass calculation used (i.e., spatial area extent and stratification levels).

Survey year	**2020d**	**2020e**	**2020f**
2008	0.56	0.57	0.57
2010	0.33	0.39	0.40
2012	0.30	0.30	0.30
2016	0.50	0.49	0.49
Mean	0.42	0.44	0.44
SD	0.13	0.12	0.12

Table 3. Area of each stratum within subareas. For stratification, stratum area is computed as the sum of stratum areas among similar depths within the appropriate survey area.

Subarea	Stratum	Depth (m)	Stratum area (km^2)	Stratum area in PDMA (km^2)
1	1	200 - 400	4,012	88
	2	400 - 600	4,063	102
	3	600 - 800	1,742	105
	4	800 - 1,000	1,355	119
	5	1,000 - 1,200	1,107	128
2	1	200 - 400	1,158	1,158
	2	400 - 600	705	705
	3	600 - 800	591	591
	4	800 - 1,000	553	553
	5	1,000 - 1,200	536	536
3	1	200 - 400	904	904
	2	400 - 600	886	886
	3	600 - 800	910	910
	4	800 - 1,000	732	732
	5	1,000 - 1,200	676	676
4	1	200 - 400	1,236	1,094
	2	400 - 600	730	730
	3	600 - 800	694	694
	4	800 - 1,000	708	708
	5	1,000 - 1,200	662	662
5	1	200 - 400	424	167
	2	400 - 600	426	142
	3	600 - 800	432	145
	4	800 - 1,000	552	282
	5	1,000 - 1,200	570	317
6	1	200 - 400	2,596	0
	2	400 - 600	1,706	0
	3	600 - 800	917	0
	4	800 - 1,000	645	0
	5	1,000 - 1,200	496	0

Evaluation of the fit to the data

The random effects model appeared to converge for all MMB input scenarios (maximum gradient component < 0.0001) and fitted MMB and parameter estimation was primarily only sensitive to differing survey year inputs. Large CVs (> 20%) in all model iterations that used only data from 2008 – 2016 contributed to an estimated process error variance that was very small (σ_λ ~ 0.001) (Table 4), resulting in a 'flat' trend in fitted MMB (Fig. 5). When including the 2002 and 2004 MMB approximations, the model responded by capturing the relatively low survey biomass estimates in those years following a slight increasing trend (Fig. 5).

Table 4. Model parameter outputs.

Model	Joint Neg. Log Likelihood	σ_λ
2020a	0.40	0.001
2020b	1.21	0.001
2020c	1.09	0.001
2020d	2.00	0.117
2020e	2.54	0.106
2020f	2.59	0.110

Calculation of reference points

The Tier 4 OFL is calculated using the F_{OFL} control rule:

$$F_{OFL} = \begin{cases} 0 & if\ \frac{MMB}{B_{MSY}} \le 0.25 \\ \frac{M\left(\frac{MMB}{B_{MSY}} - \alpha\right)}{1 - \alpha} & if\ 0.25 < \frac{MMB}{B_{MSY}} < 1 \\ M & if\ MMB > B_{MSY} \end{cases}$$

where MMB is quantified at the mean time of mating date (15 February), B_{MSY} is defined as the average MMB for a specified period (either 2002-2016 or 2008-2016, defined in Table 1), M = 0.18 yr^{-1}, and α = 0.1. The Tier 4 OFL (Table 5) was calculated by applying a fishing mortality determined by the harvest control rule (above) to the mature male biomass at the time of fishing, which remained constant starting in 2016 (i.e., the last data input year).

Table 5. Comparisons of management quantities for the six model scenarios.

Model	B_{MSY} (t)	MMB (t)	$MMB_{projected}$	MMB / B_{MSY}	F_{OFL}	OFL (t)	OFL (lbs)
2020a	589.1	589.1	526.4	0.894	0.159	77.256	170,321
2020b	574.6	574.7	513.5	0.894	0.159	75.365	166,152
2020c	639.8	639.8	571.7	0.894	0.159	83.907	184,984
2020d	514.6	614.2	548.8	1.066	0.180	90.404	199,307
2020e	503.7	584.5	522.3	1.037	0.180	86.046	189,699
2020f	557.3	657.6	587.7	1.055	0.180	96.807	213,424

Authors recommendation

Our preferred model scenario is 2020e. While there is uncertainty in the using MMB approximations for 2002 and 2004 survey data inputs, we feel the confident the approximations capture the population trends indicated by total biomass survey estimates for these years. As such, the benefits of incorporating the additional data input years likely outweigh this added uncertainty. Further, we feel that refining the survey data inputs by the PDMA boundaries is more appropriate than using survey subareas 2-4 only, as doing so captures the full extent of this stock within the PDMA. Computing MMB and variance in MMB among stratum, within subareas for the portions of subarea 5 and 1 that are included in the PDMA is not possible due to a small number of stations within individual strata. Since subarea boundaries are likely not meaningful for PIGKC stock delineation, computing MMB estimates with stratification by depth only within the PDMA seems appropriate.

While model estimation of MMB is a step forward in capturing population dynamics of the stock, uncertainty about future bottom trawl surveys and associated data availability is a concern. We recommend PIGKC continue to be managed as a Tier 5 stock until future surveys are solidified. The authors highlight the importance of the NMFS EBS slope bottom trawl survey, and hope that the survey is not discontinued. ADF&G is currently exploring feasibility and design of an industry-cooperative pot survey to meet data needs for PIGKC. This pot survey will be critical if the NMFS EBS slope bottom trawl survey is discontinued, but several years of data collection will be needed before data can be incorporated in model simulations.

Data gaps and research priorities

PIGKC is a data poor stock, with little information for capturing essential population dynamics including abundance and biomass. Fishery independent data are needed for estimating population abundance and biomass, spatial distribution, size at maturity, and length-weight relationships. Increased uncertainty with the future of the NMFS-AFCS biennial bottom trawl survey has elevated the need to establish an industry-cooperative survey to fill these data gaps.

Acknowledgements

We thank the Jerry Hoff for providing survey data, and the Crab Plan Team, Jim Ianelli, Martin Dorn, Katie Palof, and Jack Turnock for guidance on the use of the random effects model.

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Figures

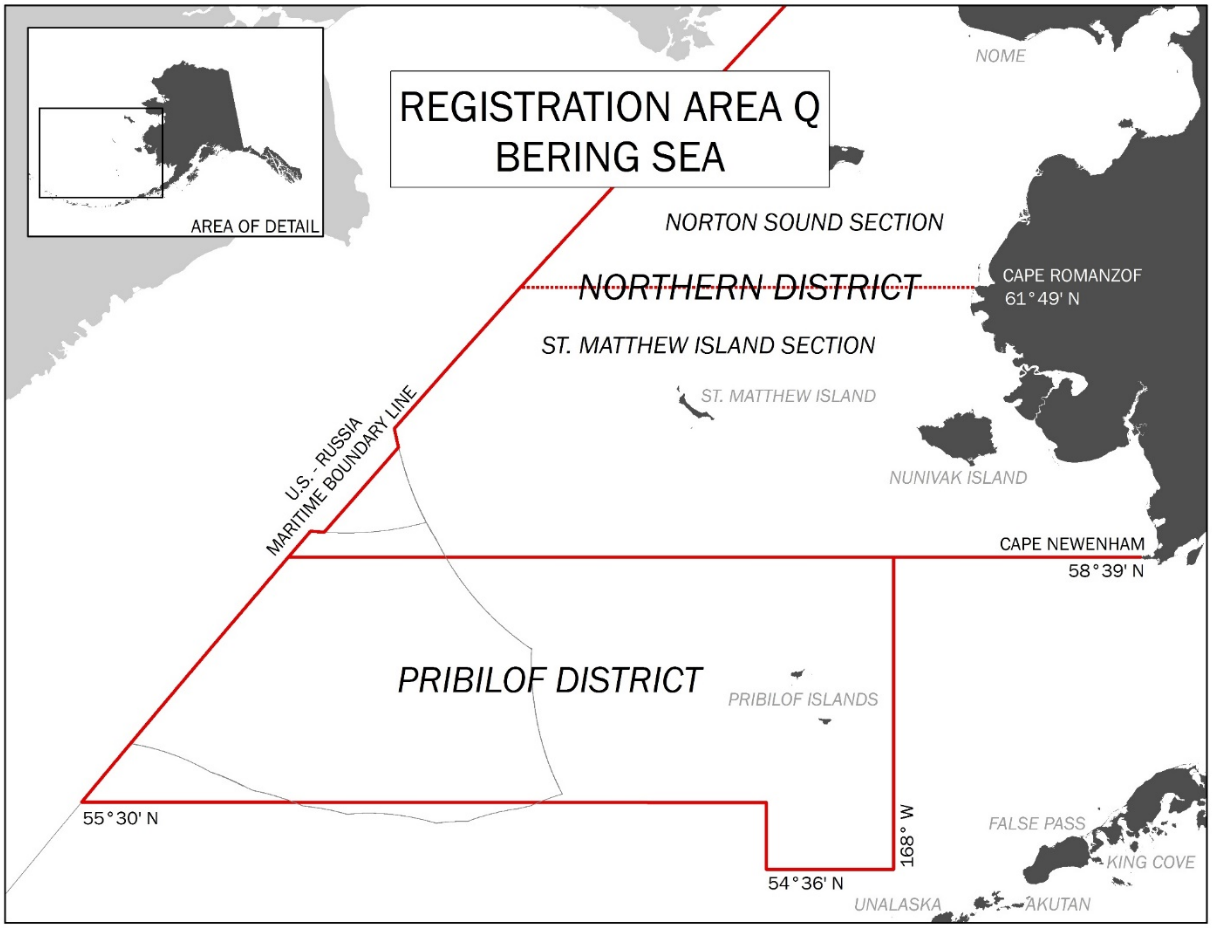

Figure 1. Bering Sea Registration Area Q, subdivided into the Northern District and Pribilof District management areas.

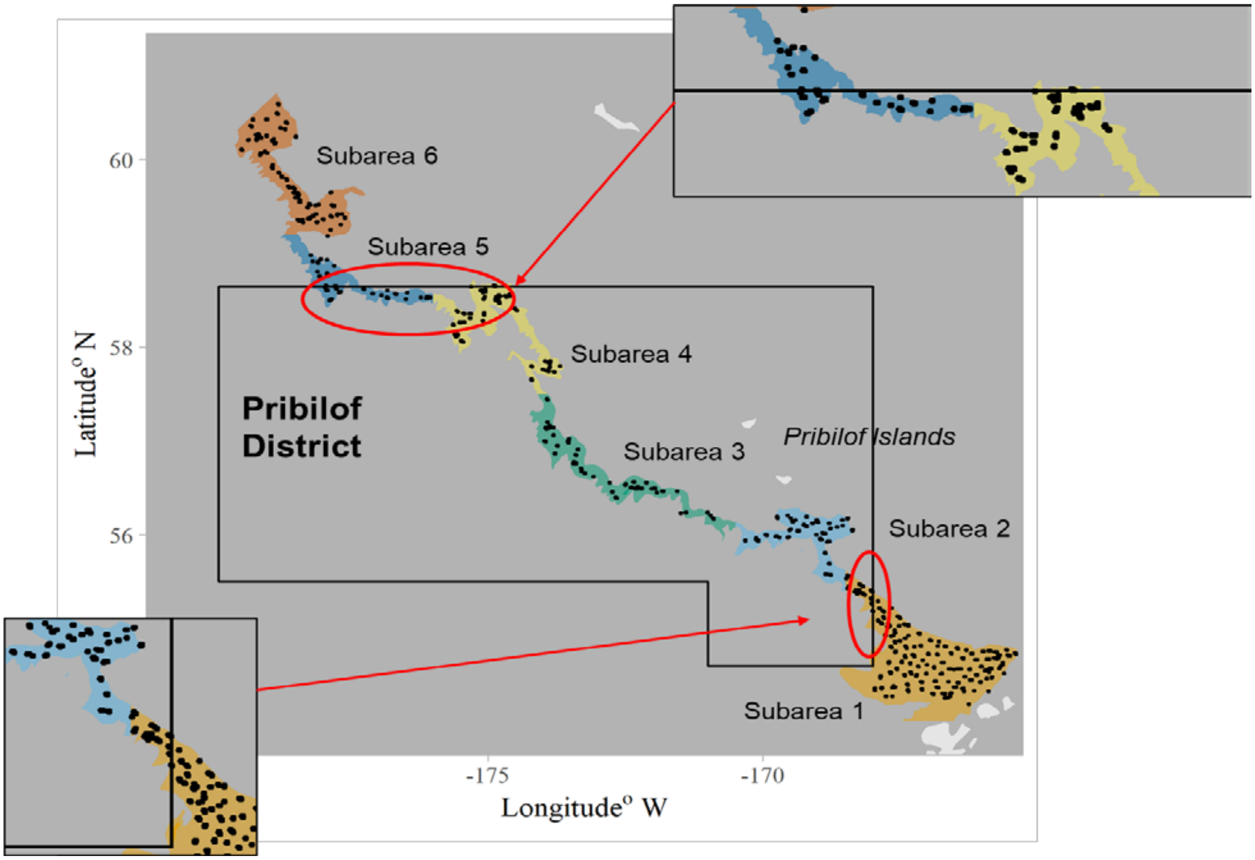

Figure 2. Map of survey subareas, with locations of all possible stations for surveys between 2002 – 2016. Portions of subareas 1 and 5 fall within the Pribilof District Management Area.

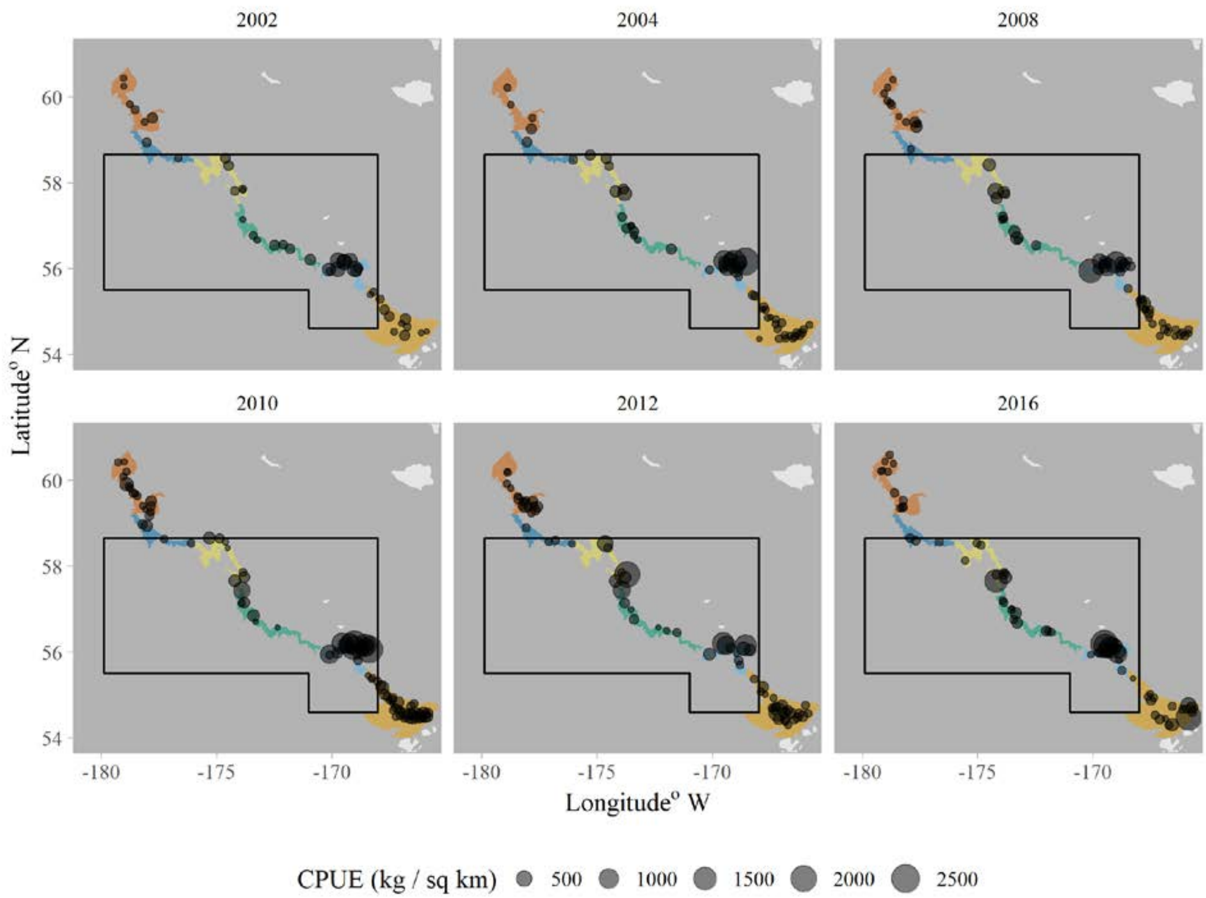

Figure 3. NMFS Eastern Bering Sea upper continental slope bottom trawl survey golden king crab CPUE (kg km^{-2}) total catch biomass for 2002-2016 surveys. Different color polygons correspond to the six different survey subareas with subarea numbering in progressing order from north to south. The black line depicts the Pribilof District Management Area boundary.

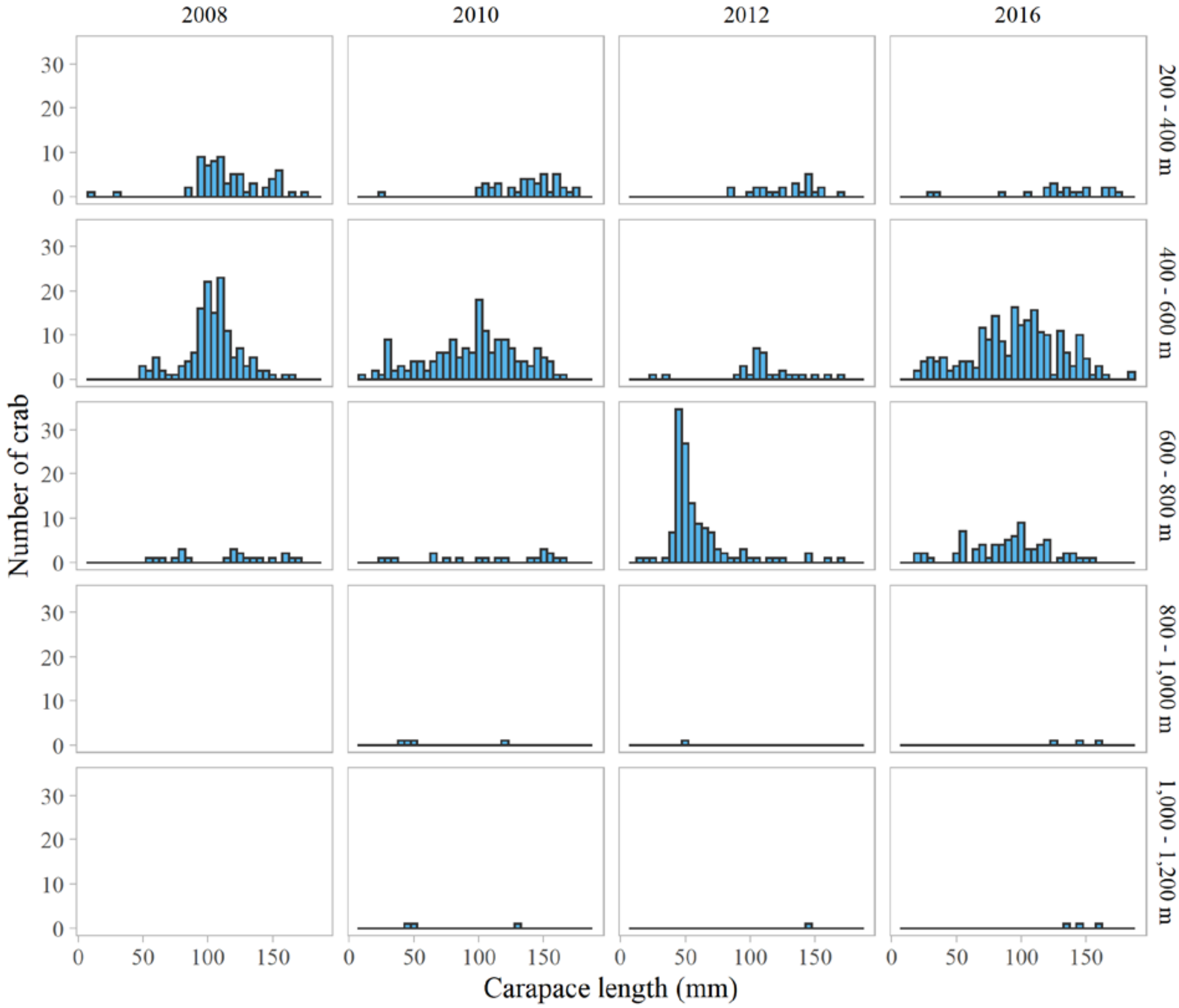

Figure 4. Size frequency of male golden king crab captured in the Pribilof District Management Area during the 2008, 2010, 2012, and 2016 NMFS Eastern Bering Sea upper continental slope bottom trawl survey.

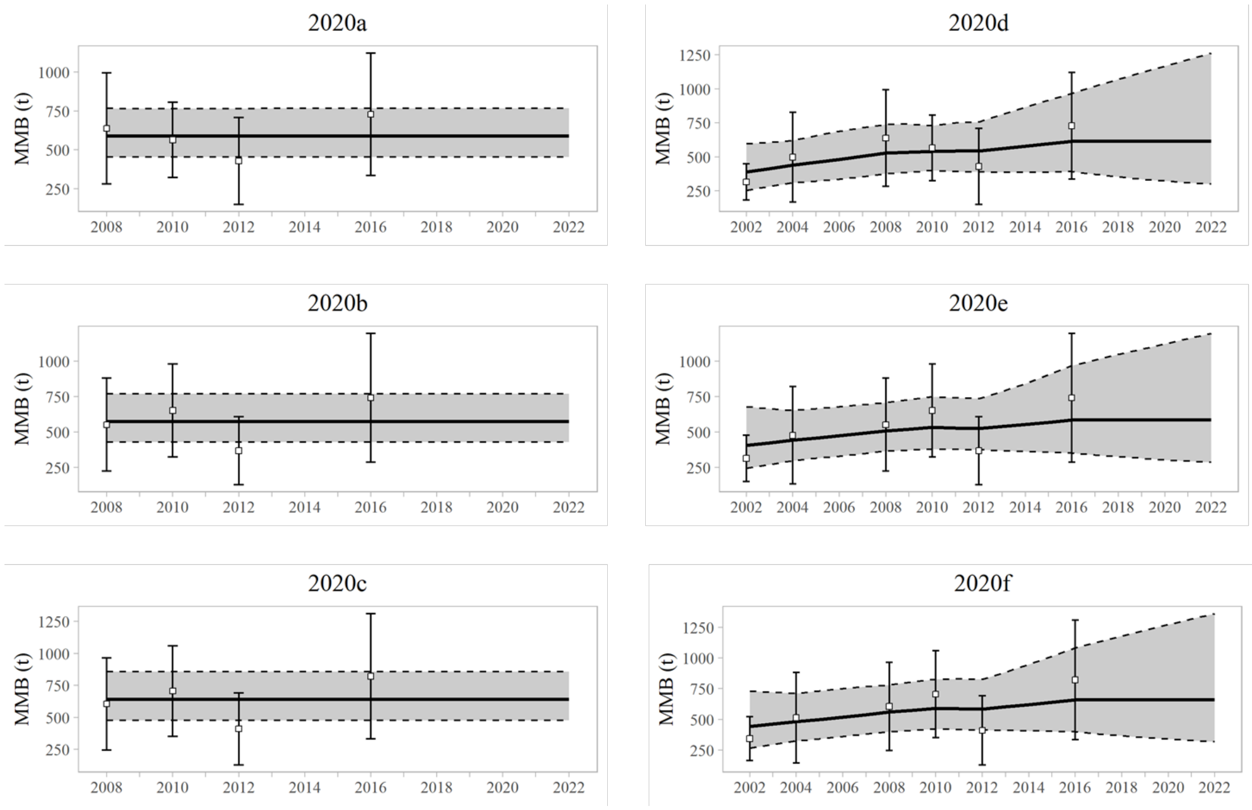

Figure 5. Model fits for PIGKC MMB, with panels referring to different model scenarios. Points correspond to the survey mature male biomass estimates ±95% CI and the black line corresponds to fitted biomass by random effects model ±95% CI (shaded area).

Appendix B

Updated discussion paper for May 2017 Crab Plan Team meeting:
Random effects approach to modeling NMFS EBS slope survey area-swept biomass estimates for Pribilof Islands golden king crab.

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Introduction

The Pribilof Islands golden king crab stock has been defined by the geographic borders of the Pribilof District (Figure 1) and has been managed as a Tier 5 stock (i.e., no reliable estimates of biomass and only historical catch data available) for determination of federal overfishing limits and annual catch limits (Pengilly 2014). Since 2011, the Council's Crab Plan Team (CPT) and the Scientific and Statistical Committee (SSC) have expressed interest in utilizing data collected during NMFS eastern Bering Sea (EBS) upper continental slope surveys (Hoff 2013) to establish an annual overfishing limit (OFL) and acceptable biological catch (ABC) on the basis of biomass estimates as an alternative to the standard Tier 5 historical-catch approach (see: reports of the June 2011, June 2012, June 2013, and October 2013 SSC meetings; reports of the May 2013 and September 2013 CPT meetings). Reviews of the EBS slope survey relative to the data collected on golden king crab, summaries of those data, and area-swept biomass estimates (Pengilly 2012, Gaeuman 2013a, 2013b), a Tier 4 approach to establishing OFL and ABC (Gaeuman 2013b), and "modified Tier 5" approach to establishing OFL and ABC (Gaeuman 2013a) have been presented to the CPT and SSC. Cancellation of the EBS biennial slope survey scheduled for 2014 precluded application of Gaeuman's (2013a) approach to establishment of OFL and ABC (see: report of the May 2015 CPT meeting; report of the June 2015 SSC meeting); however, the completion of the 2016 slope survey allows opportunity to revisit this approach.

In May 2015 the CPT recommended that, "*a preliminary Tier 4 assessment be brought to the September 2015 meeting using available slope survey data and applying a Kalman filter approach (e.g., the program developed by Jim Ianelli for groundfish stock assessments)*" (report of May 2015 CPT meeting). In June 2015, the SSC supported "*the CPT recommendation that a preliminary Tier 4 assessment be brought to the September 2015 meeting, using existing slope data and applying a Kalman filter approach*" (report of the June 2015 SSC meeting). The SSC also requested that the assessment include "*a discussion … of what stock delineation was chosen (what slope data were used) and the reason for that delineation,*" and that "*a Stock Structure Template be completed for PI GKC*" (report of the June 2015 SSC meeting). In September 2016 the CPT "*recommends the random effects model be re-evaluated after results from the 2016 slope survey are available.*" The SSC confirmed that request: "*The SSC concurs with the CPT* *recommendation"* ["*that the random effects model be re-evaluated after results from the 2016 slope survey are available*"].

This report provides: results of applying the program developed for groundfish stock assessments to the slope survey area-swept biomass estimates of golden king crab; a discussion of the stock delineation chosen (what slope data were used and why); and a Stock Structure Template for Pribilof Islands golden king crab (Appendix C) that was prepared with the guidance of Spencer et al. (2010).

This report does not provide a Tier 4 assessment, however (i.e., no OFLs or ABCs are computed from the results of this exercise). Prior to computation of an OFL or ABC, the author would like to review the biomass estimates with the CPT so that the CPT can evaluate the results relative to the Tier 4 and Tier 5 criteria (i.e., Do the biomass estimates meet the "reliability" criterion for removing the stock from Tier 5? Do the results meet the Tier 4 criterion of having sufficient information for simulation modeling that captures the essential population dynamics of the stock?). Additionally, the term "Tier 4 assessment" in application to this stock since 2013 has lost its clarity, making it unclear if the requested assessment was to be made according to Tier 4 as defined in the FMP, according to the "modified Tier 5" approach of Gaeuman (2014a), or according to some modification to a Tier 4 assessment. Dependent on the evaluation of results and after clarification of the assessment approach, the computations of OFL and ABC can be performed with the results presented here.

The NMFS EBS slope survey.

Only data from NMFS EBS slope trawl surveys performed in 2002 and later are used here. Although a pilot slope survey was also performed in 2000 and triennial surveys using a variety of nets, methods, vessels, and sampling locations were performed during 1979–1991 (Hoff and Britt 2011), Hoff and Britt (2011) noted that, "Comparisons between the post-2000 surveys and those conducted from 1979–1991 remain confounded due to differences in sampling gear, survey design, sampling methodology, and species identification." Starting in 2002, the slope survey was nominally a biennial survey, but no survey was performed in 2006 or 2014. Details on the methods and survey gear used in the 2002, 2004, 2008, 2010, 2012, and 2016 NMFS EBS slope surveys are provided in Hoff and Britt (2003, 2005, 2009, 2011) and Hoff (2013, 2016), respectively. Those methods and the applicability of the slope survey data to golden king crab abundance and biomass estimation have also been summarized by Pengilly (2012) and Gaeuman (2013a,b).

Briefly, the survey samples from an area of 32,723 km^2 in the 200–1,200 m depth zone. The surveyed area is divided into six subareas (Figure 2). Each subarea is divided into strata defined by 200 m depth zones and tows are performed at randomly-selected locations within each stratum, with target sampling density within strata proportional to the area in each subarea and stratum. Number of stations towed per survey ranged from 156 in 2002 to 231 in 2004; mean sampling density within strata ranged from approximately one tow per 162 km^2 in 2004 to approximately one tow per 255 km^2 in 2002. With regard to survey catchability of golden king crab by size and sex, the survey uses a Poly Nor'eastern high-opening bottom trawl equipped with mud-sweeper roller gear and the opinion of ASFC scientists was conveyed to the CPT during the May meeting that, with respect to golden king crab, "… the catchability of the slope net is less than 1.0 and probably considerably lower than the shelf net due to the differences in the foot rope and surveyed habitat" (report of the May 2013 CPT meeting).

Methods

Data available by survey. Data on golden king crab that are available from the 2002, 2004, 2006, 2008, 20010, 2012 and 2016 NMFS EBS slope surveys are summarized in Table 1.

Although the CPT and SSC both suggested that NMFS would "*provide the author with slope survey CPUE data based on State statistical areas or other stratification instead of the entire slope survey area because the entire survey extends beyond the Pribilof management area*" (reports of the May 2015 CPT meeting and June 2015 SSC meeting), the author did not find it necessary or useful for this exercise to receive the data stratified by State statistical area or by any other stratification besides that defined by the survey design.

Data summarization: area-swept biomass estimates. Area-swept estimates of total (male and female, all sizes) biomass and variances of estimates within strata within survey subarea for 2002, 2004, 2008, 2010, and 2012 were obtained directly from the tables presented in Hoff and Britt (2003, 2005, 2009, 2011) and Hoff (2013). For area-swept biomass estimation of mature males and legal males from the 2008, 2010, 2012, and 2016 survey data, 107 mm CL was used as a proxy for size at maturity (Somerton and Otto 1986) and 124 mm CL was used as a proxy for the 5.5 in carapace width (including spines) legal size (NPFMC 2007); weight of males was estimated from the CL measured during the survey by weight (g) = $(0.0002988) \times (CL)^{3.135}$ (NPFMC 2007). An area-swept estimate of biomass and of the variance of the biomass estimate was computed for each stratum within a survey subarea and summed over strata within the subarea to obtain area-swept estimates of biomass within a subarea and of the variance of that biomass estimate; estimates of the biomass and of variances of estimates within subareas were summed over subareas to obtain estimates of biomass in aggregates of subareas and of the variances of those estimates.

Model estimates of biomass and projections to 2018.[3] The program "re.exe" was used to estimate biomass from the area-swept estimates in surveyed years and to project biomass estimates for unsurveyed years into 2018 via a state-space random walk plus noise model. The state-space random walk plus noise is formulated as a random effect model. The random effects model considers the process errors as "random effects" (i.e., drawn from an underlying distribution) and integrated out of the likelihood. The method was developed by the NPFMC groundfish plan team's survey averaging working group as a smoothing technique similar to the Kalman Filter, but which provides more flexibility with non-linear processes and non-normal error structures.

Stock delineation chosen (what slope data were used). The author followed the guidance provided by the SSC in June 2013 (report of the June 2013 SSC meeting):

> "*Because the stock structure is unknown, the SSC recommends that the authors examine maps of catch-per-unit-effort by survey year to identify natural breaks in*

[3] The author acknowledges help from Martin Dorn, Jim Ianelli, and Paul Spencer, AFSC, in getting this paragraph completed.

the spatial distribution of golden king crab along the slope. If no obvious breaks exist, the SSC recommends that the authors bring forward biomass estimates for the Pribilof canyon region and for the slope as a whole. However, we note that the Pribilof Canyon stations do not encompass the historical catches, which occurred inside and to the north of Pribilof Canyon. Therefore, the authors should consider a biomass estimate for an area that encompasses the majority of historical catches."

Figures 3–8 show CPUE (kg km^{-2}) of golden king crab (males and females, all sizes) by tow and survey subarea during the 2002, 2004, 2008, 2010, 2012, and 2016 NMFS EBS slope surveys relative to the boundaries of the Pribilof District. Highest survey CPUE occurs at tows within survey subareas 2–4 (particularly in subarea 2; i.e., Pribilof Canyon). Tows performed in the portion of subarea 5 that lie within the Pribilof District have produced little or no catch of golden king crab, indicating a gap in golden king crab distribution between subarea 4 and the portion of the surveyed area north of the Pribilof District boundary (i.e., the portion of subarea 5 that is north of the Pribilof District boundary and all of subarea 6). Tows performed in subarea 1 that are within the Pribilof District have produced little or no catch of golden king crab, indicating a gap in distribution between Pribilof Canyon and the area east of the Pribilof District within subarea 1. It appears that the areas of subareas 1 and 5 that lie within the Pribilof District support limited densities of golden king crab. Subarea 3 appears to support only low-to-moderate densities of golden king crab relative to subarea 4 and – especially – subarea 2; tows with catch of golden king crab occurred sporadically within subarea 3, with highest densities occurring near the border of subarea 4 in 2010 and 2012 and near the border of subarea 2 in 2002.

Figure 9 shows the distribution of all 6,104 pot lifts sampled by observers with locations recorded during 1992–2014 Bering Sea golden king crab fisheries (including the Saint Matthew section of the Northern District, which is north of the Pribilof District) relative to the borders of the Pribilof District and of the survey subareas. Only one of those locations is within the portion of subarea 5 that is within the Pribilof District, none are within the portion of subarea 1 that is within the Pribilof District, and none are within subarea 3.

Figure 10 shows the 26 statistical areas with reported catch during the 1985–2014 Pribilof District golden king crab fisheries relative to the borders of the Pribilof District and of the survey subareas: one (accounting for 0.7% of the 1985–2014 total catch) lies largely in subarea 4, but extends into subarea 5; four (2.9% of the total catch) include portions of subarea 4; six (1.5% of total catch) include portions of subarea 3; one (8.9% of total catch) includes portions of subareas 3 and 2; four (83.9% of total catch) are in or extend into subarea 2; one (0.7% of total catch) includes portions of subareas 2 and 1; one (<0.1% of total catch) is largely within subarea 1; and eight (1.4% of total catch) are outside of the survey area (some of those may be errors in recording of statistical area).

This review of survey distribution and fishery catch and effort distribution shows that golden king crab in the Bering Sea and the fishery for golden king crab in the Bering Sea are concentrated in the Pribilof Canyon area (survey subarea 2). Nonetheless, golden king crab do occur more sporadically and at lower densities in survey subareas 3 and 4 and there has been some limited catch and effort during Pribilof District fisheries within survey subareas 3 and 4. Portions of survey subareas 1 and 5 that lie within the Pribilof District appear to be largely devoid of golden king crab, have produced little or no catch during the Pribilof District fishy, and have received little or no fishery effort. The golden king crab that occur in survey subarea 6 are exploited by the Saint Matthew section fishery when it is prosecuted. Accordingly, the following analyses to estimate trends in the Pribilof District stock were performed using survey data from only survey subareas 2, 3, and 4. Because of the high concentration of fishery effort and fishery catch in Pribilof Canyon and the high CPUE of golden king crab within Pribilof Canyon during the slope surveys, data summaries and analyses were also performed using data only from survey Subarea 2.

Results

Size frequency distributions of golden king crab captured within subareas 2, 3, and 4 during the 2008, 2010, 2012, 2016 NMFS EBS slope surveys are shown in Figures 11–14.

Area-swept biomass estimates by survey subarea, for the total surveyed area (pooled subareas 1–6), and for pooled subareas 2–4 for 2002, 2004, 2008, 2010, 2012 and 2016 are in Table 2.

Estimates and projections through 2018 of total, mature male, and legal male biomass in survey subareas 2-4 and survey subarea 2 from the state-space random walk plus noise model are plotted in Figures 15 and 16, respectively. More detailed results produced by re.exe are provided in Appendices A and B.

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Tables

Table 1. Data on golden king crab recorded during the 2002, 2004, 2008, 2010, 2012, and NMFS EBS slope surveys.

Survey	Weight in tow	Count in tow	Sex/CL/shell con/fem repro	Individual weights
2002	YES	YES	NO	NO
2004	YES	YES	NO	NO
2008	YES	YES	YES	285 of 416 meas'd
2010	YES	YES	YES	NO
2012	YES	YES	YES[a]	495 of 899 meas'd
2016	YES	YES	YES[b]	NO

a. Golden king crab <100 mm CL were subsampled for data recording at one tow in subarea 4 during the 2012 survey.
b. Golden king crab were subsampled for data recording at one tow in subarea 2 during the 2016 survey.

Table 2. Area-swept biomass (t) estimates of total (sexes combined), mature-sized males, and legal male golden king crab computed from 2002, 2004, 2008, 2010, 2012, and 2016 NMFS eastern Bering Sea slope survey data, by survey subarea, and with coefficients of variation (CV = standard error of estimate divided by the estimate).

		Total (males and females)		Mature males (males ≥ 107 mm CL)		Legal males (males ≥ 124 mm CL)	
Survey Year	Subarea	Biomass (t)	CV	Biomass (t)	CV	Biomass (t)	CV
2002	1	131	0.39	–	–	–	–
2002	2	682	0.22	–	–	–	–
2002	3	81	0.40	–	–	–	–
2002	4	53	0.40	–	–	–	–
2002	5	19	0.86	–	–	–	–
2002	6	44	0.69	–	–	–	–
2002	1–6	1,010	0.16	–	–	–	–
2002	2–4	816	0.19	–	–	–	–
2004	1	65	0.22	–	–	–	–
2004	2	817	0.38	–	–	–	–
2004	3	51	0.41	–	–	–	–
2004	4	121	0.36	–	–	–	–
2004	5	20	0.73	–	–	–	–
2004	6	24	0.73	–	–	–	–
2004	1–6	1,098	0.29	–	–	–	–
2004	2–4	989	0.32	–	–	–	–
2008	1	146	0.40	47	0.35	11	0.70
2008	2	920	0.32	490	0.36	294	0.29
2008	3	91	0.44	64	0.44	28	0.54
2008	4	205	0.46	85	0.53	78	0.52
2008	5	2	1.00	22	1.00	22	1.00
2008	6	66	0.50	30	0.63	19	0.61
2008	1–6	1,431	0.22	737	0.25	452	0.22
2008	2–4	1,216	0.26	638	0.29	401	0.24
2010	1	363	0.20	168	0.20	145	0.23
2010	2	1,614	0.31	440	0.24	349	0.25
2010	3	89	0.63	79	0.72	71	0.75
2010	4	72	0.41	46	0.47	44	0.50
2010	5	37	0.45	10	0.76	7	1.00
2010	6	122	0.43	25	0.51	12	1.00
2010	1–6	2,298	0.22	768	0.17	628	0.18
2010	2–4	1,776	0.29	565	0.22	464	0.23
2012	1	421	0.37	328	0.45	280	0.50
2012	2	778	0.45	256	0.32	207	0.34
2012	3	172	0.75	146	0.83	131	0.81
2012	4	494	0.69	26	0.48	8	1.00
2012	5	12	0.43	6	0.74	4	1.00
2012	6	149	0.40	49	0.33	40	0.38
2012	1–6	2,025	0.26	812	0.26	670	0.28
2012	2–4	1,444	0.35	429	0.34	346	0.37
2016	1	217	0.35	116	0.37	98	0.40
2016	2	1060	0.27	475	0.30	336	0.30
2016	3	100	0.34	74	0.42	65	0.47
2016	4	304	0.79	191	0.77	165	0.73
2016	5	23	0.48	10	0.72	4	1.00
2016	6	50	0.30	31	0.46	18	0.75
2016	1–6	1,754	0.22	897	0.24	685	0.24
2016	2–4	1,464	0.26	740	0.28	565	0.28

Figures

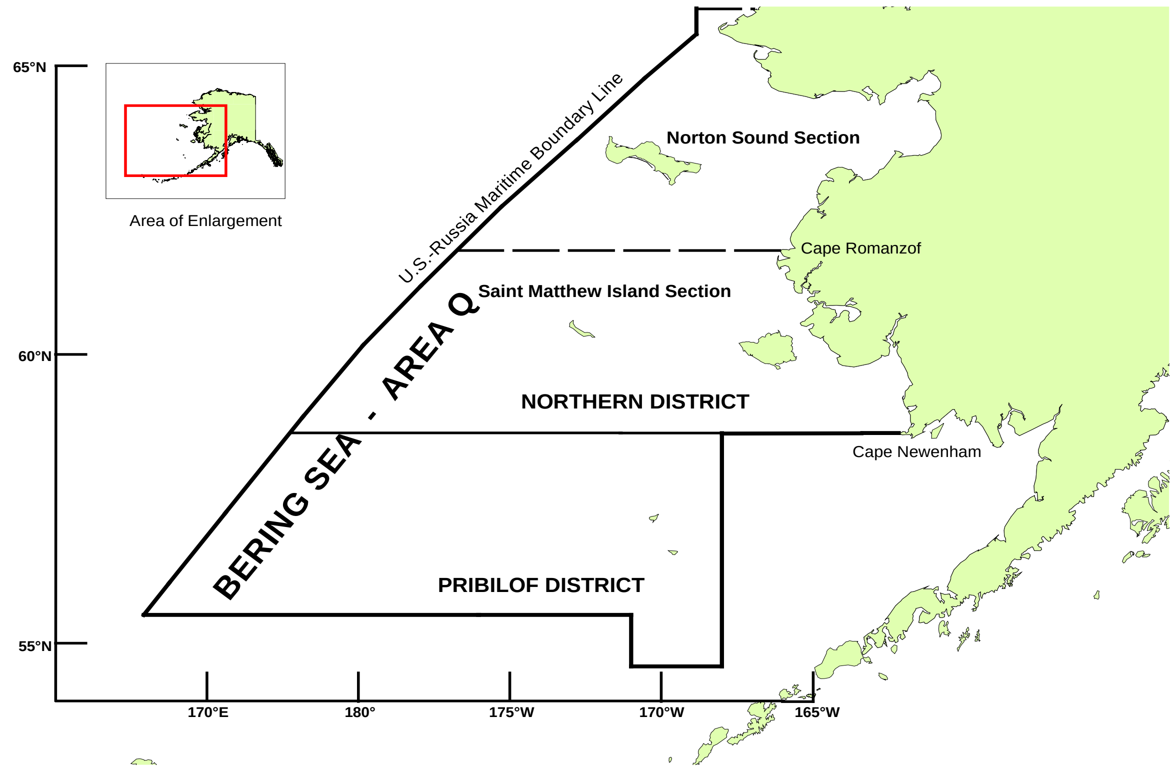

Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District.

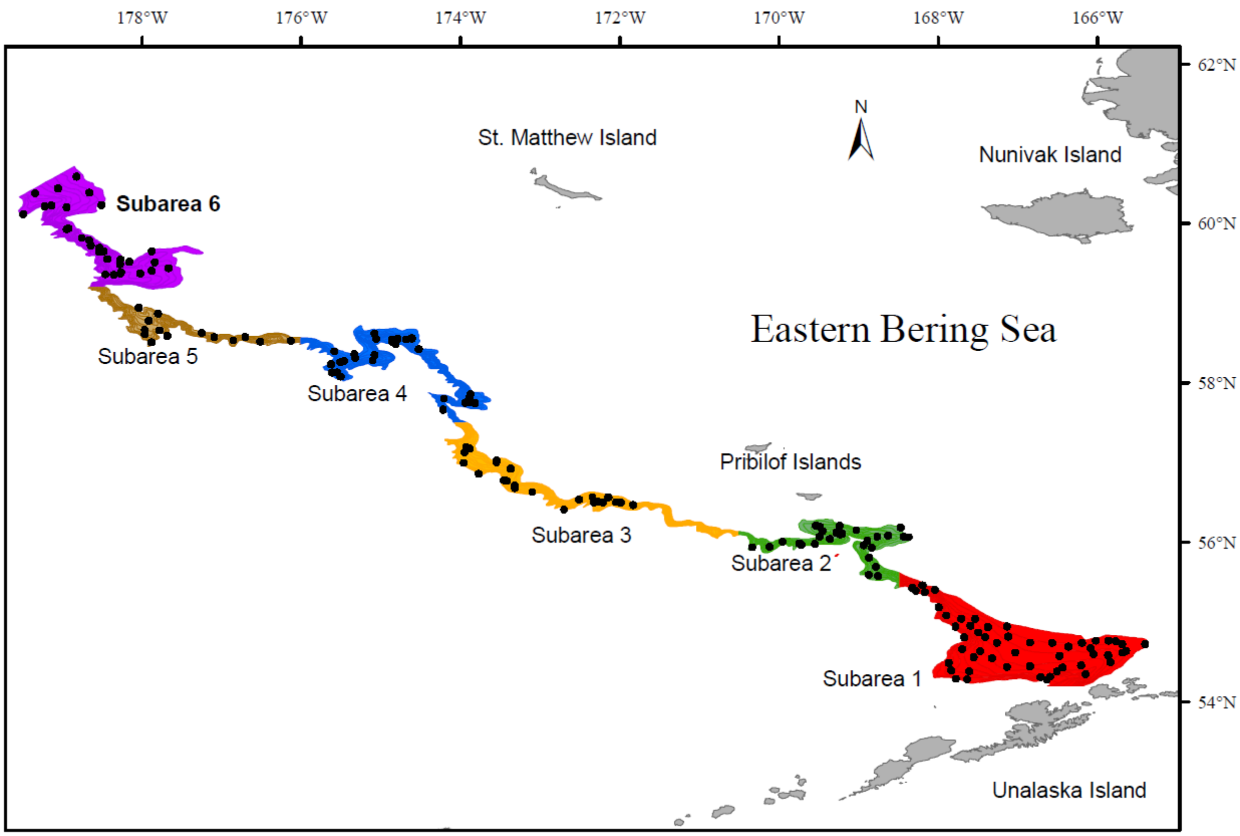

Figure 2. Map of standard survey area and the six subareas. Indicated are the 175 successful trawl stations (black dots) completed during the 2016 EBSS survey (taken form Hoff 2016).

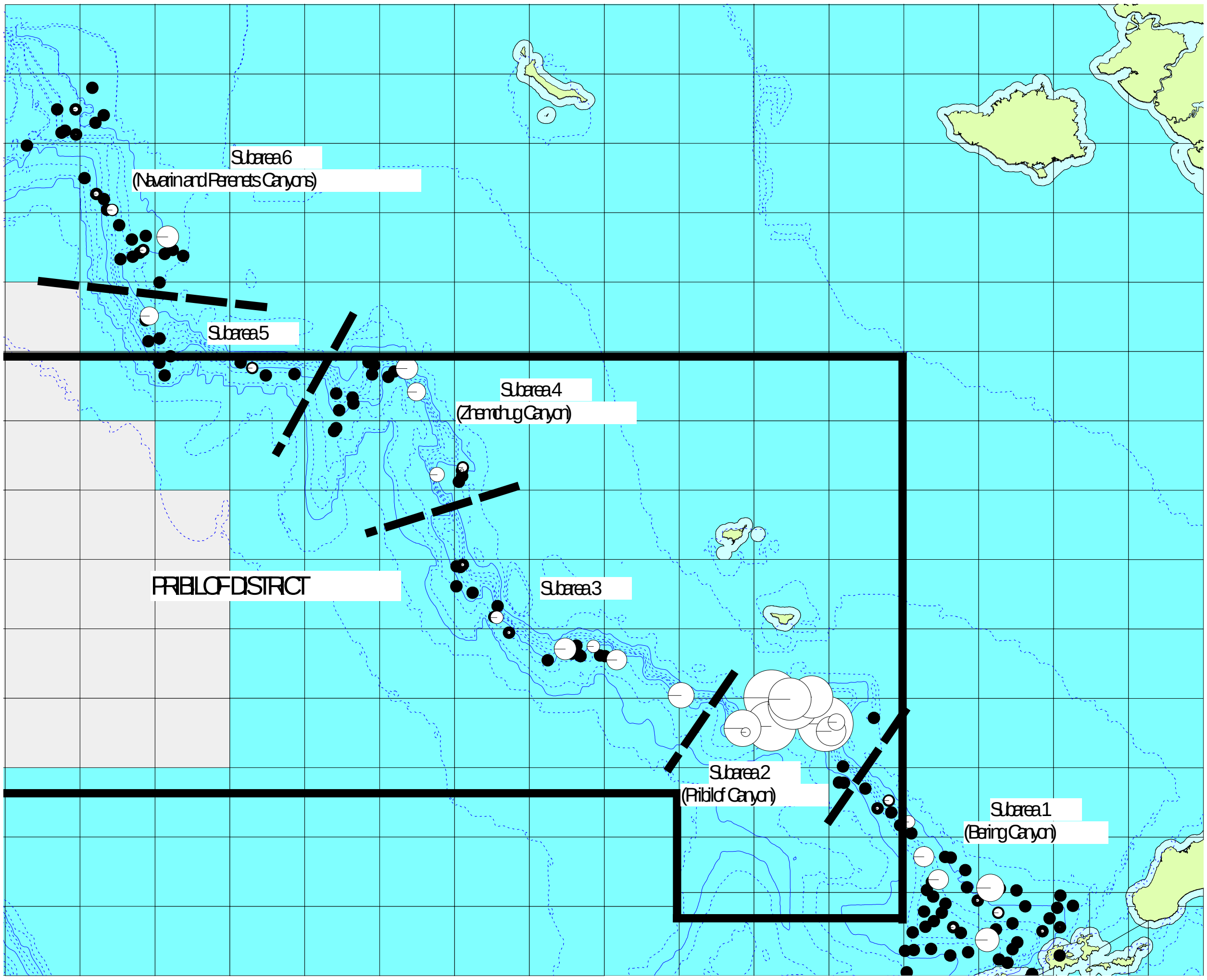

Figure 3. 2002 slope survey tow locations (black circles) and golden king crab CPUE (kg/sq-km; white circles; largest circle = 510 kg/sq-km); squares are 1° longitude x 30' latitude State statistical areas.

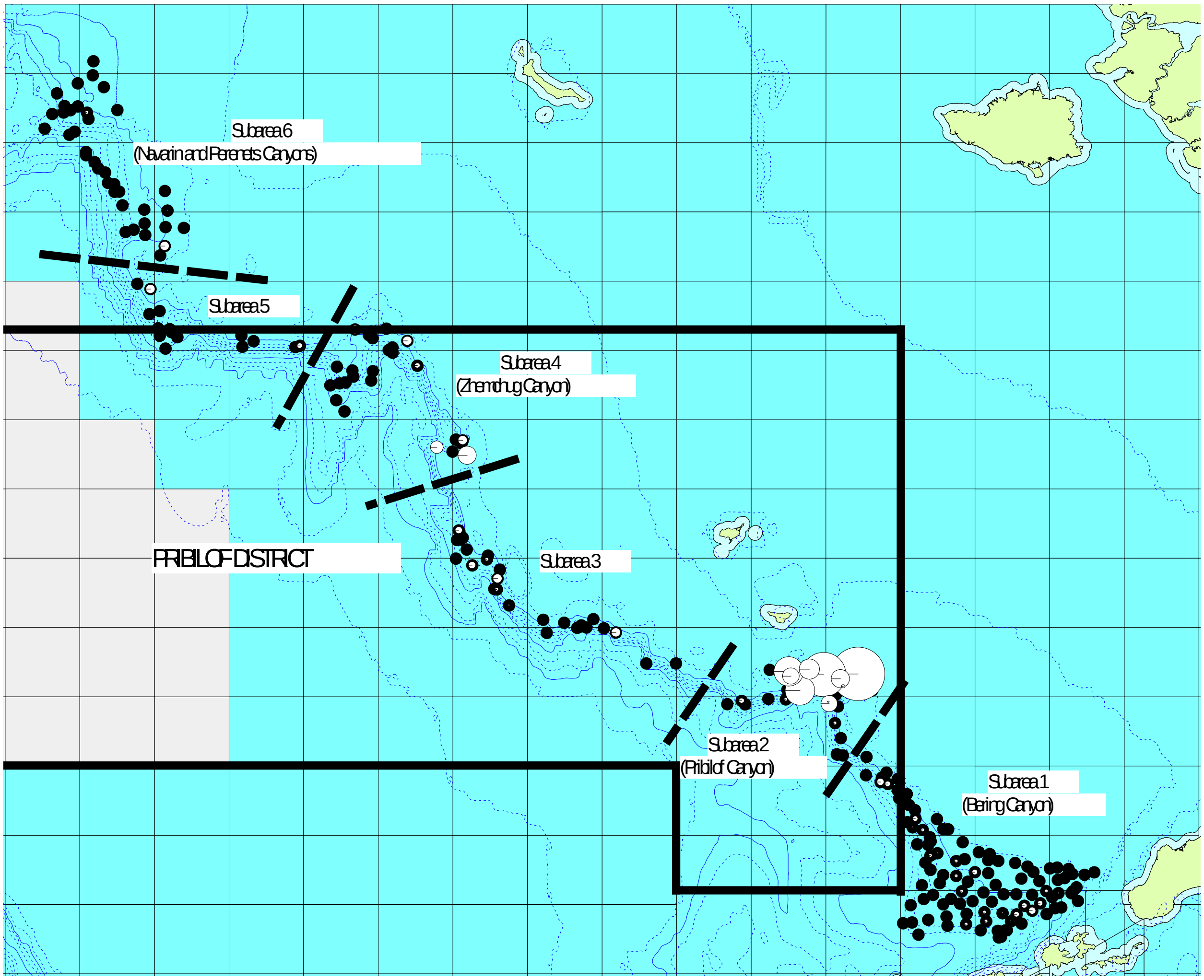

Figure 4. 2004 slope survey tow locations (black circles) and golden king crab CPUE (kg/sq-km; white circles; largest circle = 2,300 kg/sq-km); squares are 1° longitude x 30' latitude State statistical areas.

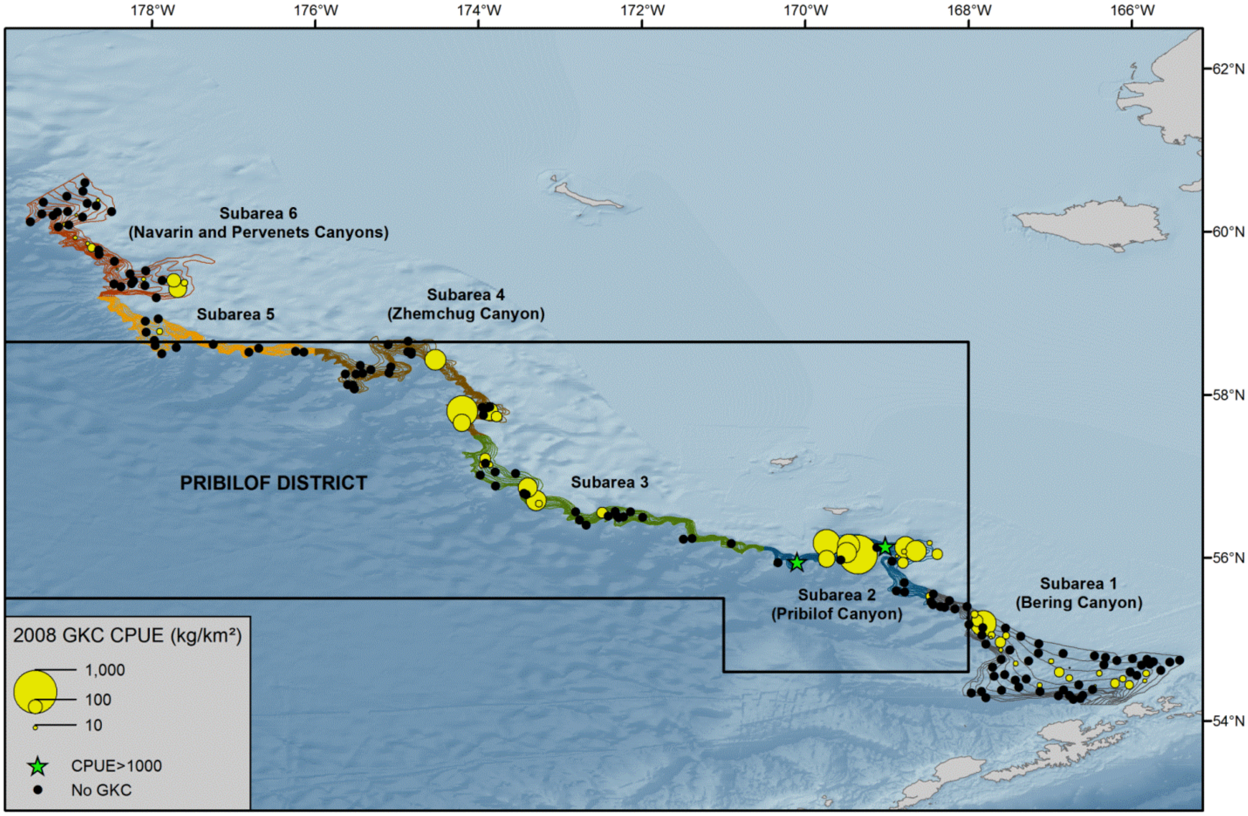

Figure 5. 2008 slope survey tow locations (black circles) and golden king crab CPUE (kg km^{-2}; yellow circles, green stars indicate values outside the normal range).

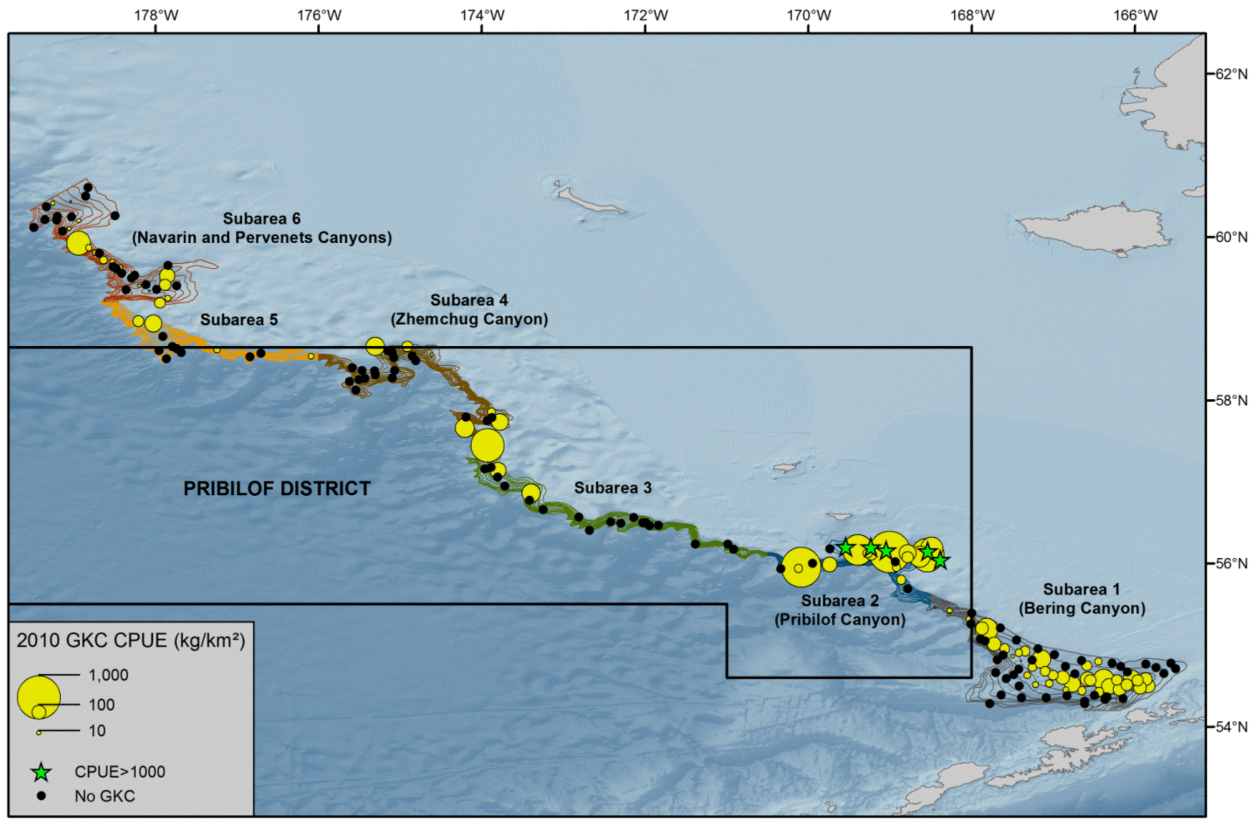

Figure 6. 2010 slope survey tow locations (black circles) and golden king crab CPUE (kg km^{-2}; yellow circles, green stars indicate values outside the normal range).

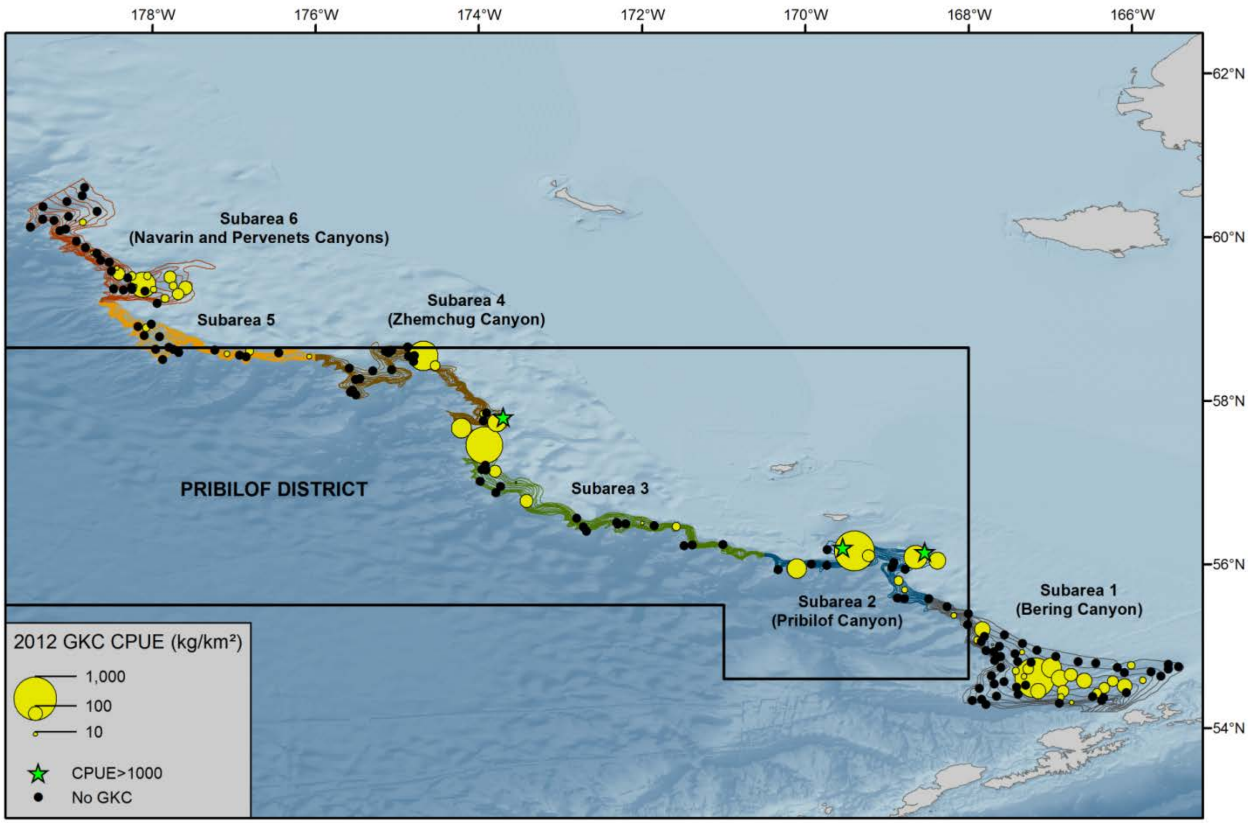

Figure 7. 2012 slope survey tow locations (black circles) and golden king crab CPUE (kg km^{-2}; yellow circles, green stars indicate values outside the normal range).

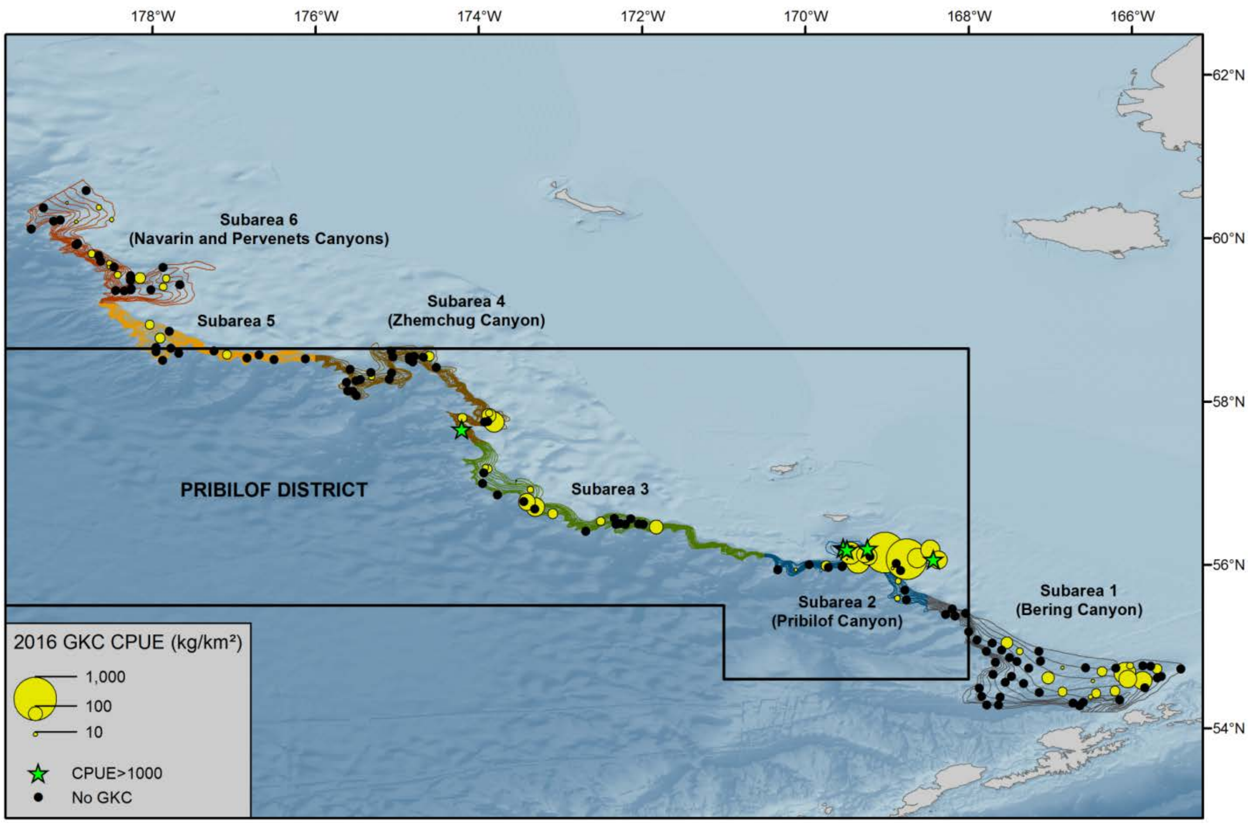

Figure 8. 2016 slope survey tow locations (black circles) and golden king crab CPUE (kg km^{-2}; yellow circles, green stars indicate values outside the normal range).

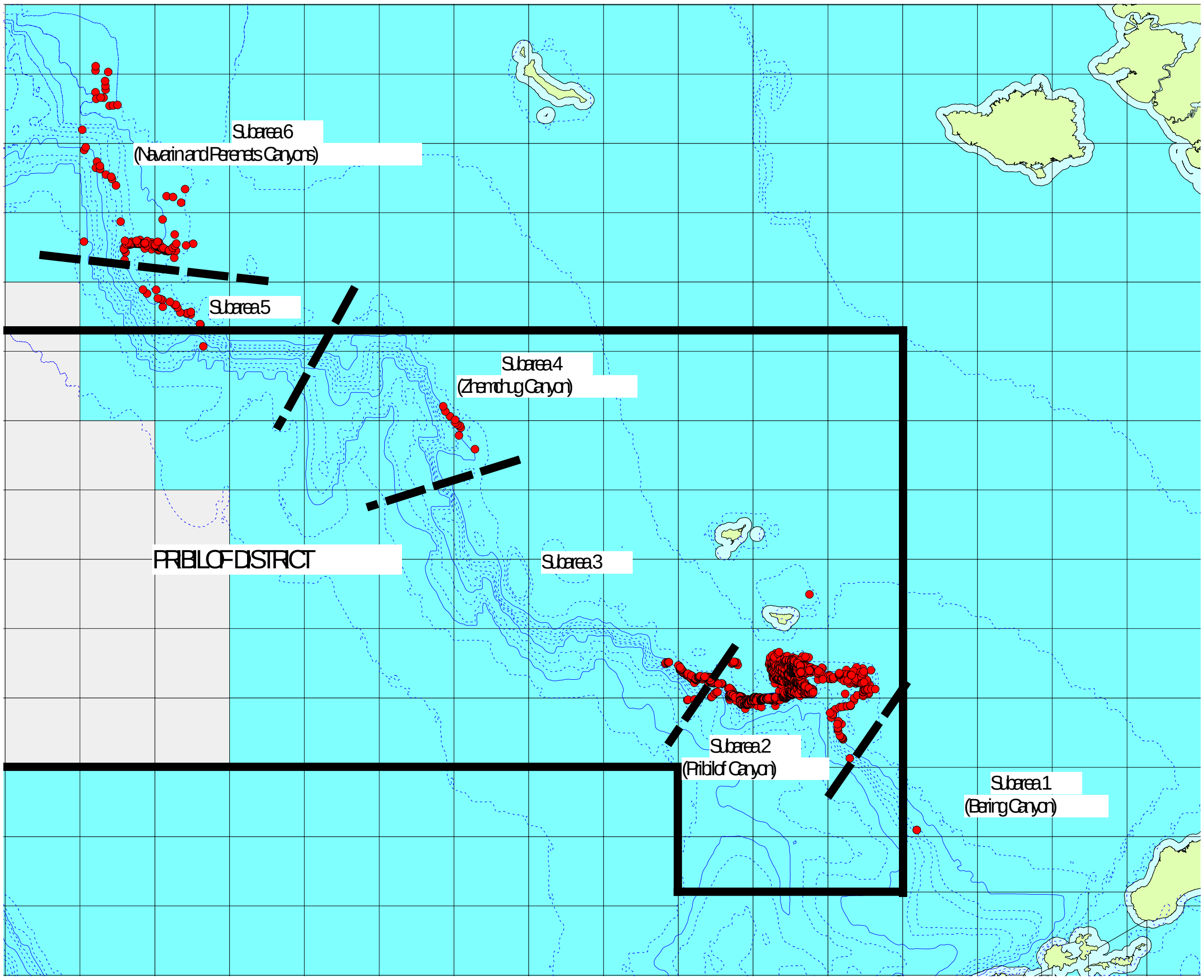

Figure 9. Locations of all pots sampled by observers during Bering Sea golden king crab fisheries (n = 6,104), 1992–2014; pots north of the Pribilof District northern boundary were fished during the Northern District – Saint Matthew Island Section fishery; squares are 1° longitude x 30' latitude State statistical areas.

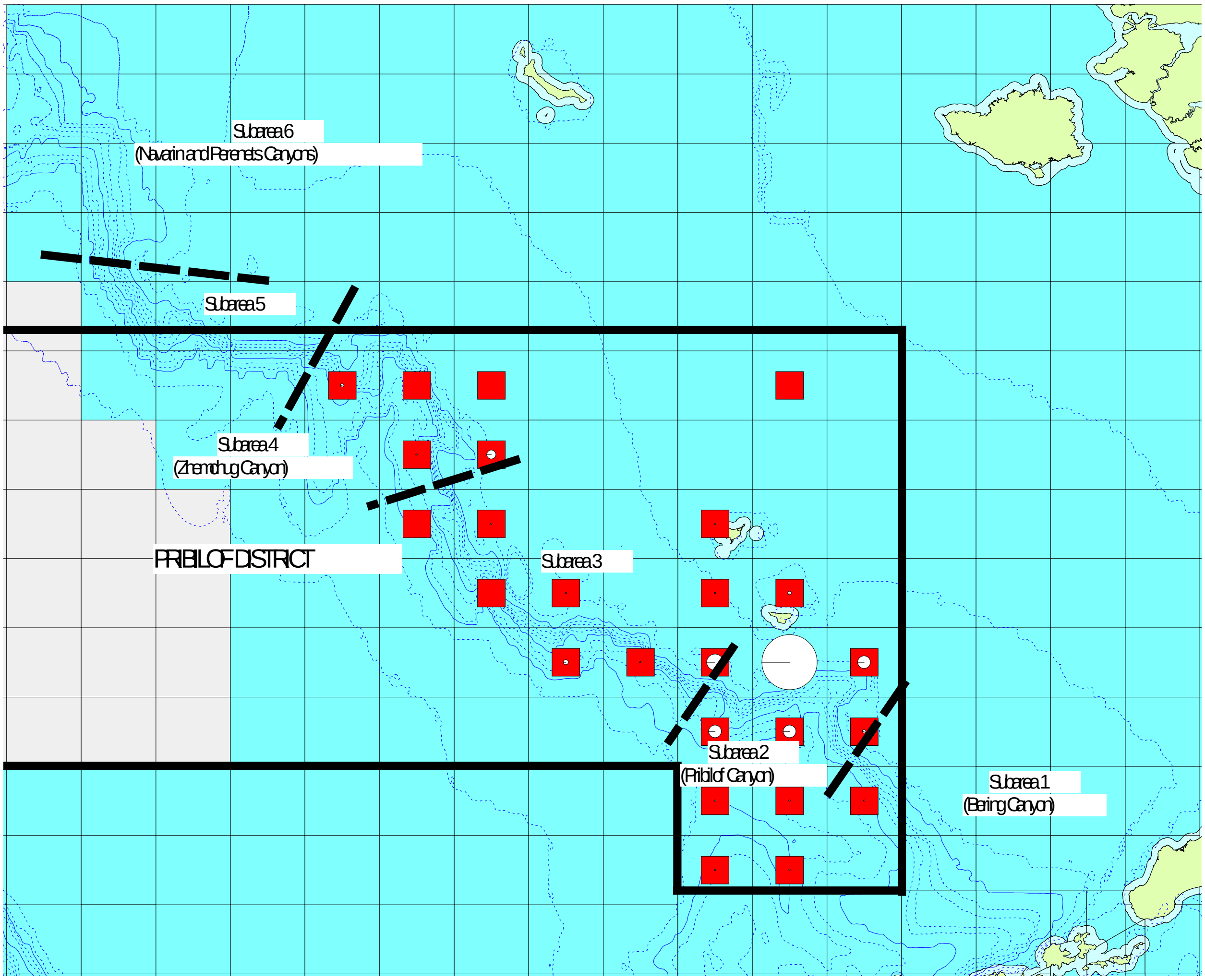

Figure 10. Statistical areas with reported catch during the 1985–2014 Pribilof District golden king crab fisheries: filled red squares denote statistical areas with reported catch; size of overlain white circles are proportional to the percentage of the total 1985–2014 catch reported from statistical area (biggest circle = 68% of total); squares are 1° longitude x 30' latitude State statistical areas.

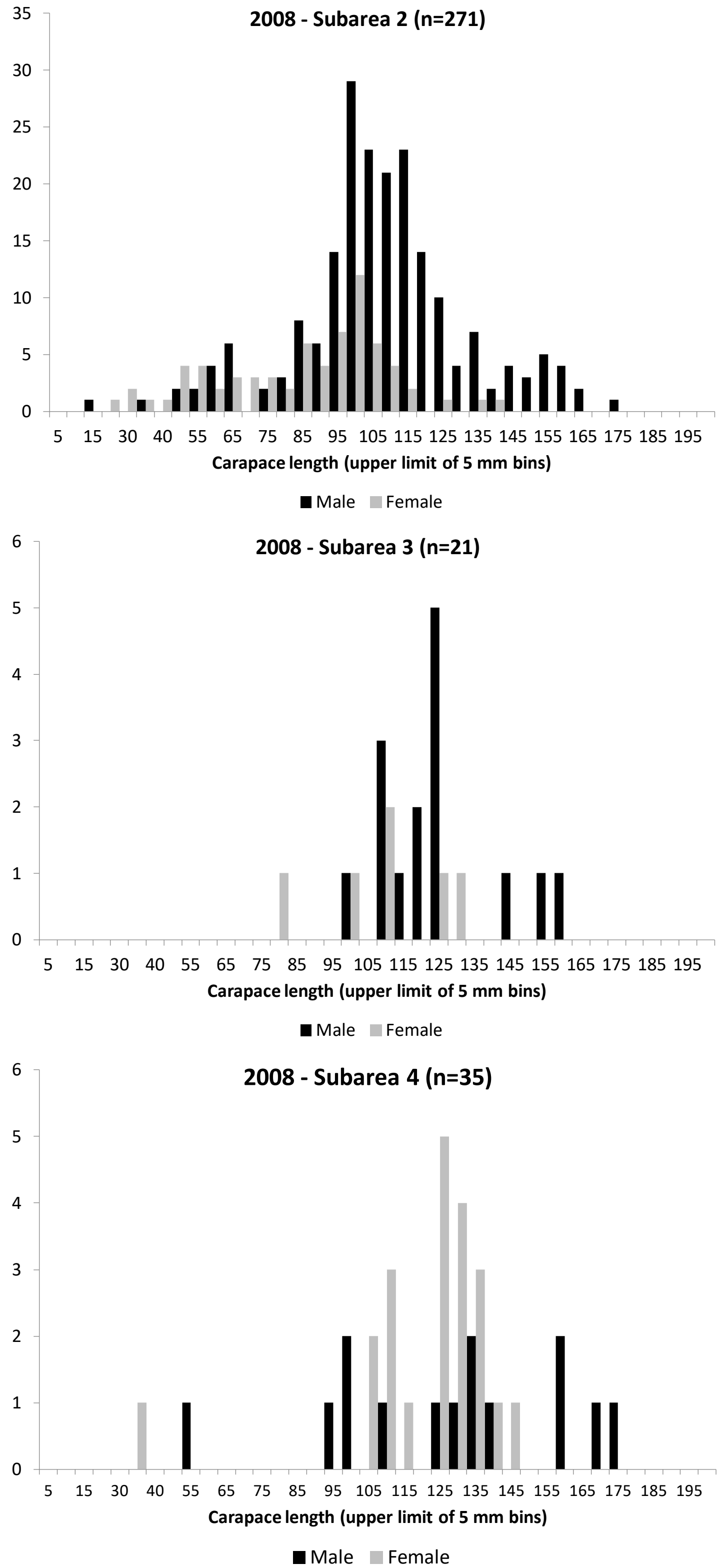

Figure 11. Size distribution of measured golden king crab during the 2008 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.

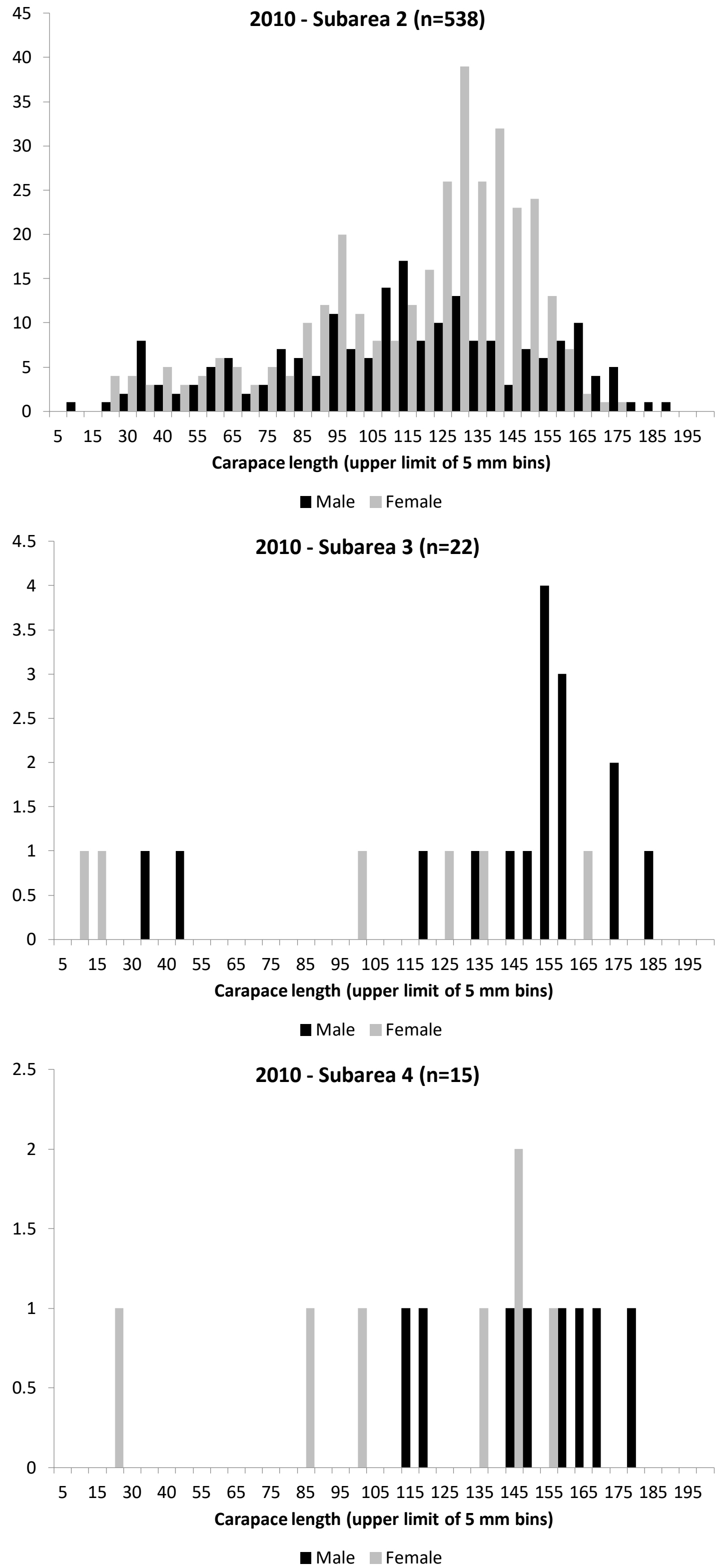

Figure 12. Size distribution of measured golden king crab during the 2010 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.

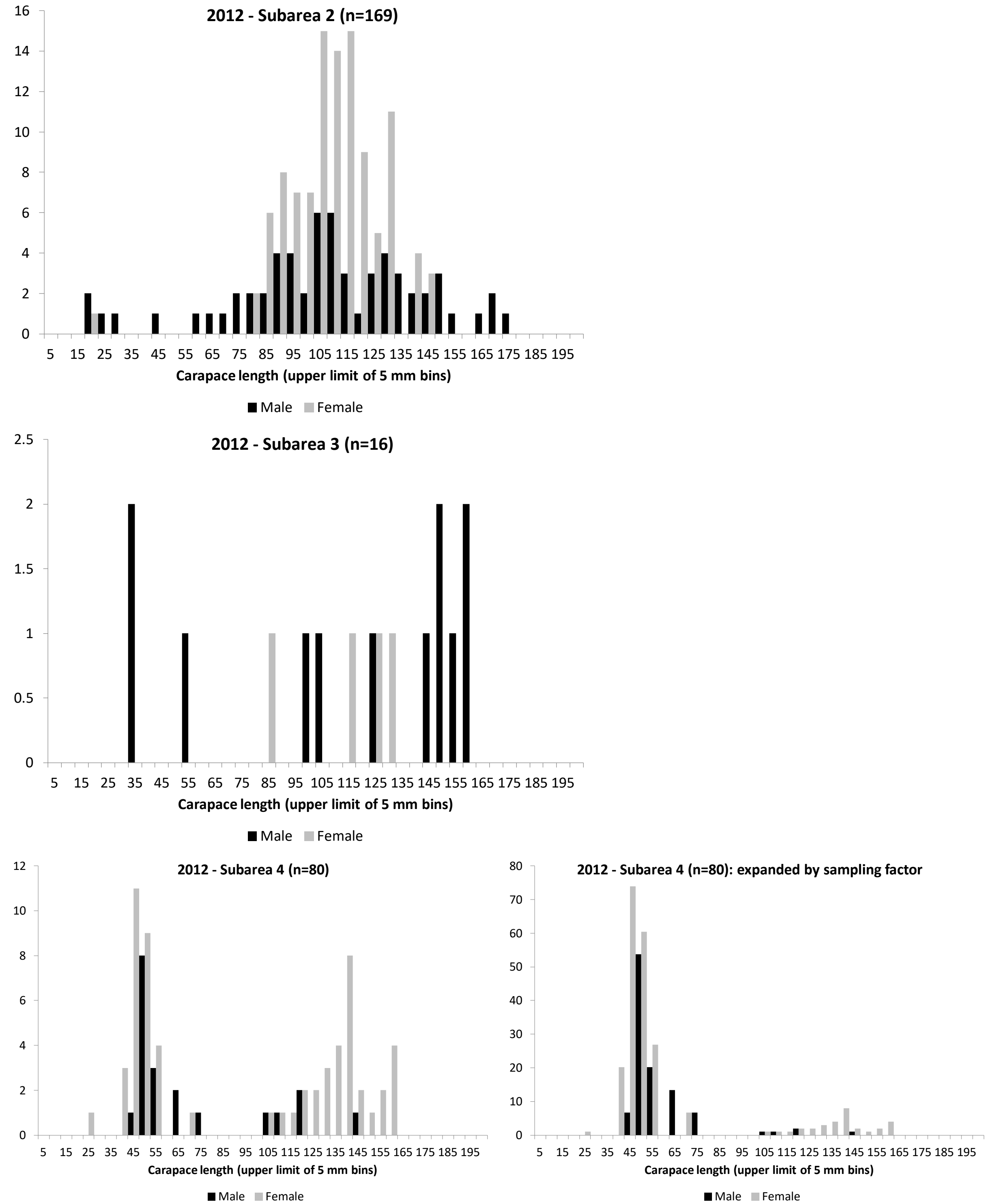

Figure 13. Size distribution of measured golden king crab during the 2012 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.

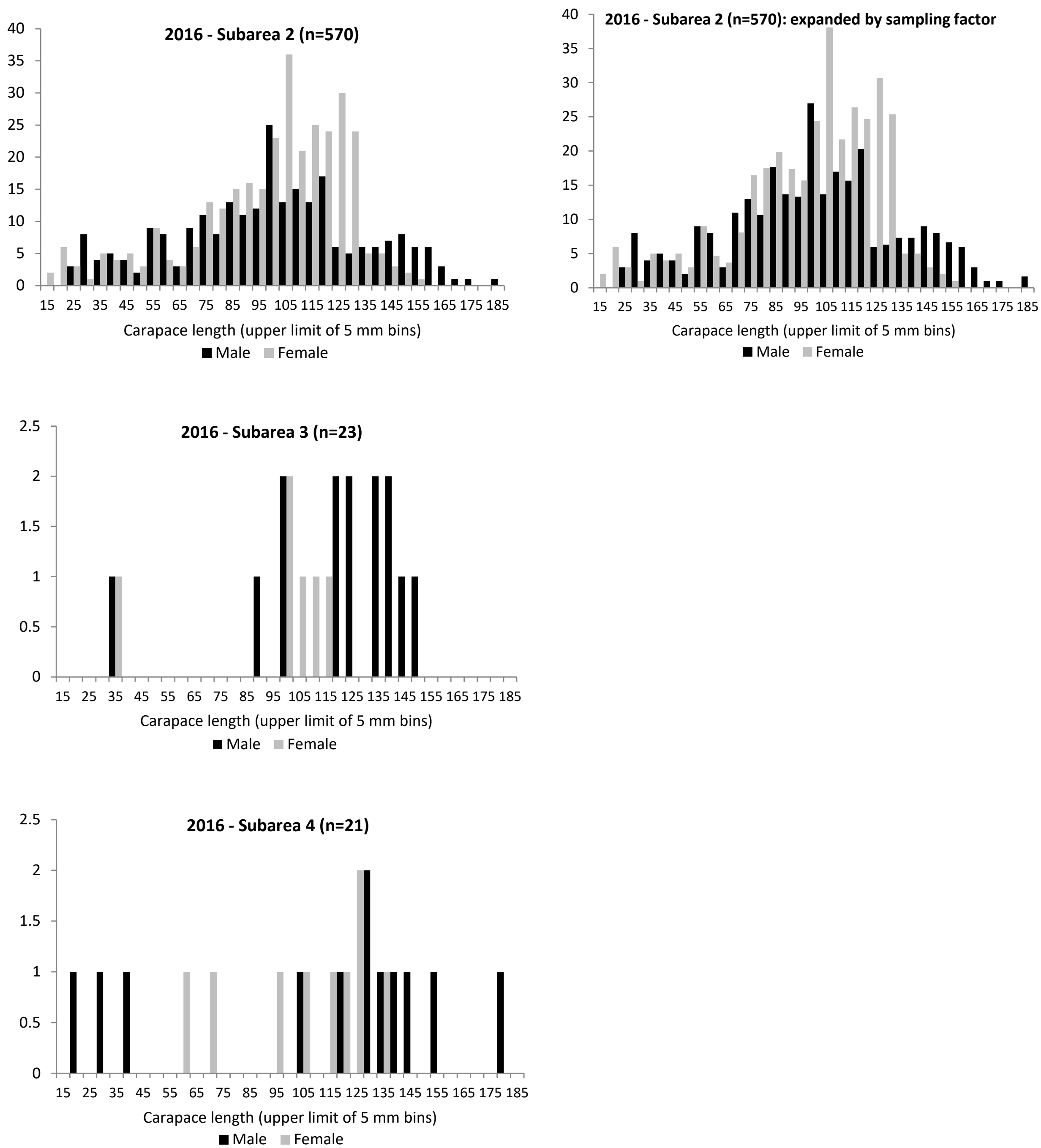

Figure 14. Size distribution of measured golden king crab during the 2016 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.

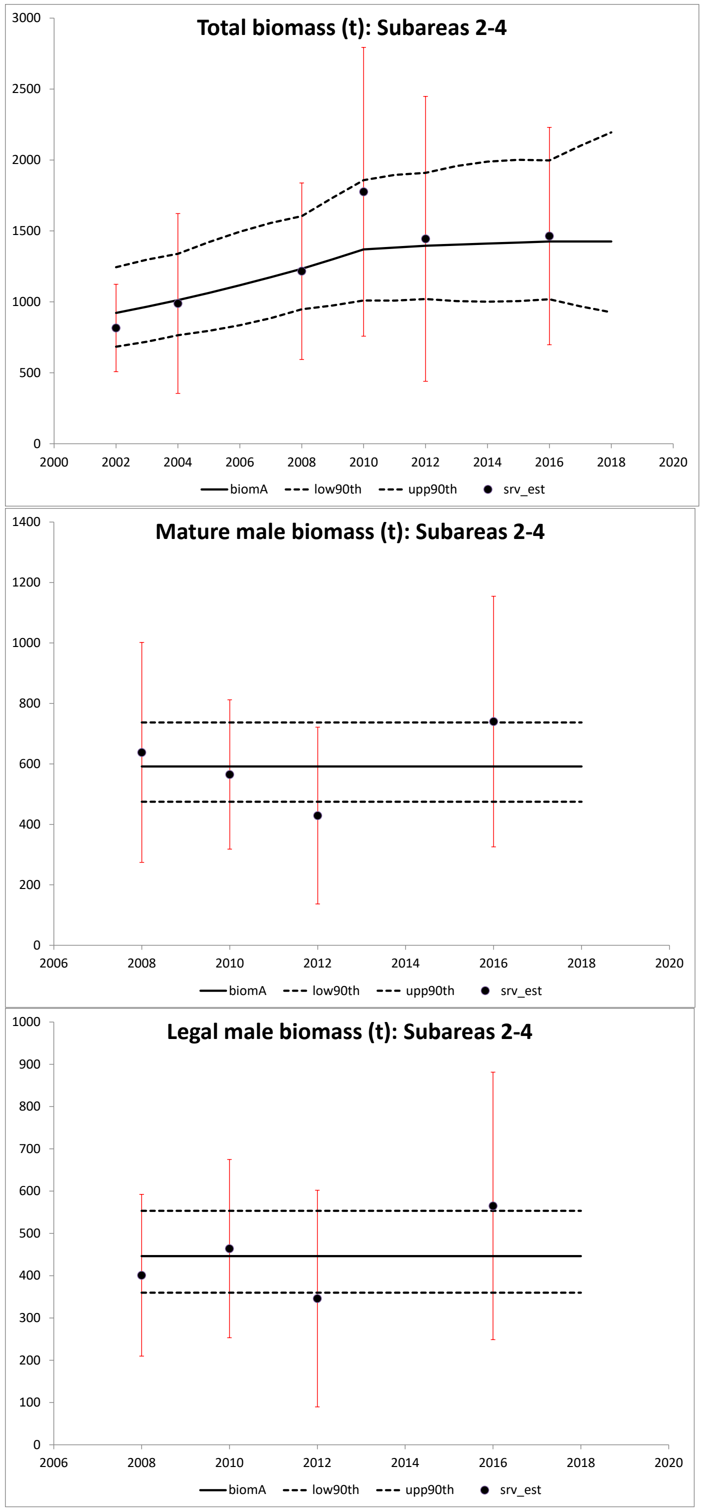

Figure 15. Plots of estimated and projected-into-2018 biomass of total, mature male, and legal male golden king crab in NMFS slope survey Subareas 2–4 with 90% confidence intervals and survey area-swept estimates; red bars are survey estimate plus/minus 2 standard errors.

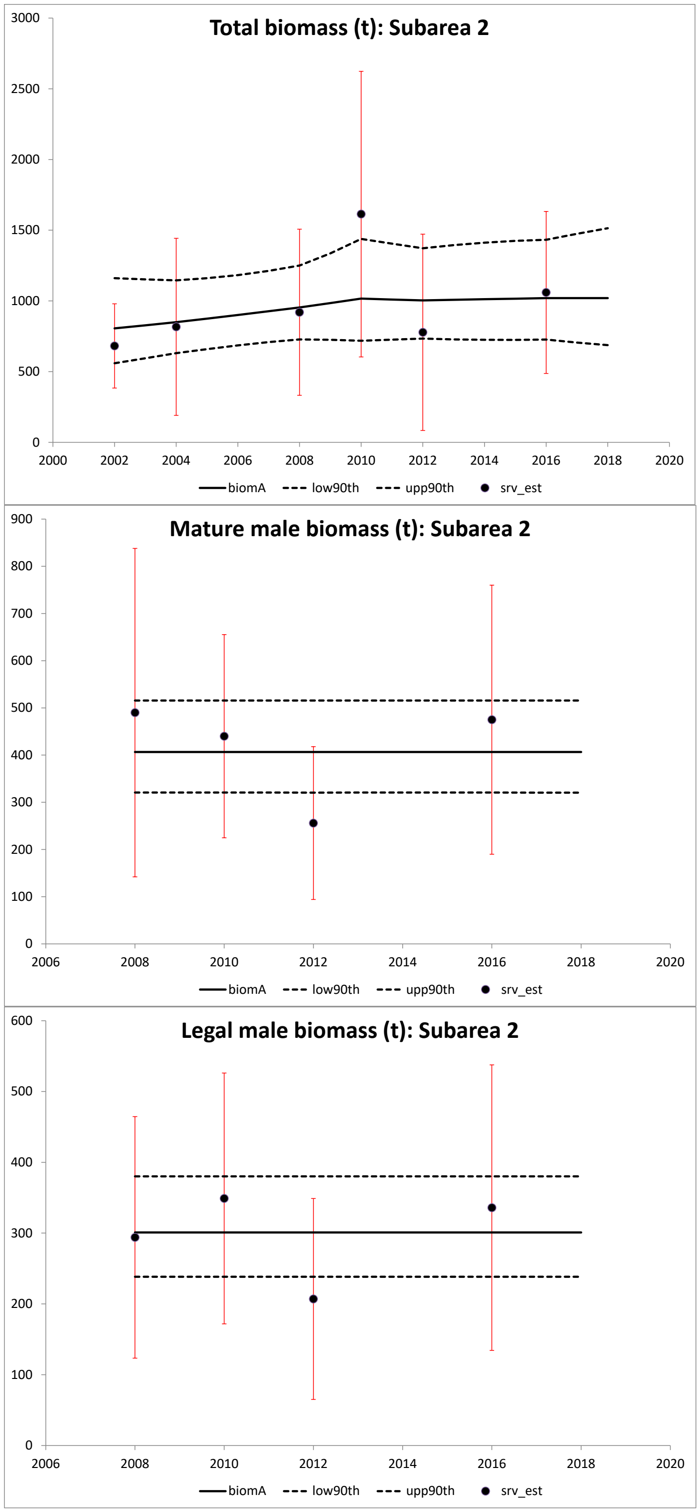

Figure 16. Plots of estimated and projected-into-2018 biomass of total, mature male, and legal male golden king crab in NMFS slope survey Subarea 2 with 90% confidence intervals and survey area-swept estimates; red bars are survey estimate plus/minus 2 standard errors.

Appendix A1. Input file (re.dat) for total golden king crab biomass in NMFS EBS slope survey Subareas 2-4 and results file (rwout.rep) produced by re.exe.

re.dat file

```
      2002 #Start year of model
      2018 #End year of model
         6 #number of survey estimates
#Years of survey
      2002      2004      2008      2010      2012      2016
#Biomass estimates
       816       989      1216      1776      1444      1464
#Coefficients of variation for biomass estimates
      0.19      0.32      0.26      0.29      0.35      0.26
```

rwout.rep file

yrs_srv																	
	2002	2004	2008	2010	2012	2016											
srv_est																	
	816	989	1216	1776	1444	1464											
srv_sd																	
	0.188318	0.312233	0.25576	0.284166	0.339939	0.25576											
yrs																	
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI																	
	645.592	679.925	725.189	752.615	790.057	838.815	901.75	922.256	952.61	949.698	960.644	943.422	937.229	940.902	954.447	899.215	853.018
biomA																	
	922.492	966.221	1012.02	1063.35	1117.29	1173.96	1233.5	1299.86	1369.79	1382.64	1395.6	1403.14	1410.71	1418.33	1425.99	1425.99	1425.99
UCI																	
	1318.16	1373.07	1412.31	1502.39	1580.05	1643	1687.3	1832.06	1969.66	2012.94	2027.5	2086.87	2123.4	2138.02	2130.5	2261.36	2383.83
low90th																	
	683.706	719.43	765.09	795.604	835.309	885.377	948.313	974.552	1009.87	1008.79	1020.07	1005.57	1000.89	1005.05	1018.06	968.382	926.452
upp90th																	
	1244.67	1297.67	1338.66	1421.21	1494.45	1556.59	1604.45	1733.75	1857.98	1895.02	1909.38	1957.89	1988.34	2001.55	1997.37	2099.84	2194.87
biomsd																	
	6.82708	6.87339	6.91971	6.96918	7.01866	7.06813	7.11761	7.17001	7.22241	7.23175	7.24108	7.24647	7.25185	7.25724	7.26262	7.26262	7.26262
biomsd.sd																	
	0.182097	0.179291	0.170039	0.176341	0.176813	0.171502	0.159833	0.175096	0.185309	0.191634	0.19055	0.202527	0.208635	0.209386	0.204842	0.235255	0.262163

Appendix A2. Input file (re.dat) for mature male golden king crab biomass in NMFS EBS slope survey Subareas 2-4 and results file (rwout.rep) produced by re.exe.

re.dat file				
2008	#Start year of model			
2018	#End year of model			
4	#number of survey estimates			
#Years of survey				
2008	2010	2012	2016	
#Biomass estimates				
638	565	429	740	
#Coefficients of variation for biomass estimates				
0.29	0.22	0.34	0.28	

rwout.rep file											
yrs_srv											
	2008	2010	2012	2016							
srv_est											
	638	565	429	740							
srv_sd											
	0.284166	0.217406	0.330745	0.274733							
yrs											
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI											
	455.113	455.114	455.115	455.114	455.114	455.115	455.113	455.109	455.103	455.099	455.095
biomA											
	591.486	591.485	591.484	591.484	591.485	591.486	591.488	591.49	591.492	591.492	591.492
UCI											
	768.721	768.718	768.715	768.716	768.718	768.721	768.728	768.74	768.756	768.762	768.768
low90th											
	474.693	474.694	474.694	474.694	474.693	474.694	474.693	474.69	474.684	474.681	474.678
upp90th											
	737.014	737.011	737.009	737.01	737.011	737.014	737.02	737.03	737.043	737.048	737.053
biomsd											
	6.38264	6.38264	6.38264	6.38264	6.38264	6.38264	6.38264	6.38265	6.38265	6.38265	6.38265
biomsd.sd											
	0.13372	0.133718	0.133717	0.133718	0.133718	0.133719	0.133722	0.133728	0.133737	0.133741	0.133745

Appendix A3. Input file (re.dat) for legal male golden king crab biomass in NMFS EBS slope survey Subareas 2-4 and results file (rwout.rep) produced by re.exe.

re.dat file

2008	#Start year of model			
2018	#End year of model			
4	#number of survey estimates			
#Years of survey				
2008	2010	2012	2016	
#Biomass estimates				
401	464	346	565	
#Coefficients of variation for biomass estimates				
0.24	0.23	0.37	0.28	

rwout.rep file

yrs_srv											
	2008	2010	2012	2016							
srv_est											
	401	464	346	565							
srv_sd											
	0.236648	0.227042	0.358197	0.274733							
yrs											
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI											
	345.148	345.153	345.158	345.158	345.158	345.156	345.151	345.143	345.132	345.129	345.126
biomA											
	446.173	446.174	446.175	446.176	446.177	446.178	446.18	446.182	446.184	446.184	446.184
UCI											
	576.768	576.762	576.758	576.759	576.761	576.769	576.781	576.799	576.822	576.828	576.834
low90th											
	359.687	359.692	359.696	359.696	359.696	359.695	359.691	359.684	359.675	359.672	359.669
upp90th											
	553.454	553.45	553.446	553.448	553.449	553.456	553.467	553.481	553.5	553.505	553.509
biomsd											
	6.10071	6.10071	6.10071	6.10071	6.10071	6.10072	6.10072	6.10073	6.10073	6.10073	6.10073
biomsd.sd											
	0.130986	0.13098	0.130975	0.130975	0.130976	0.130981	0.13099	0.131004	0.131022	0.131027	0.131032

Appendix B1. Input file (re.dat) for total golden king crab biomass in NMFS EBS slope survey Subarea 2 and results file (rwout.rep) produced by re.exe.

re.dat file

2002	#Start year of model				
2018	#End year of model				
6	#number of survey estimates				
#Years of survey					
2002	2004	2008	2010	2012	2016
#Biomass estimates					
682	817	920	1614	778	1060
#Coefficients of variation for biomass estimates					
0.22	0.38	0.32	0.31	0.45	0.27

rwout.rep file

yrs_srv																	
	2002	2004	2008	2010	2012	2016											
srv_est																	
	682	817	920	1614	778	1060											
srv_sd																	
	0.217406	0.367261	0.312233	0.302917	0.429421	0.265265											
yrs																	
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI																	
	521.757	558.084	595.708	624.797	650.996	673.321	691.078	684.518	671.956	681.957	691.351	684.38	680.48	679.379	680.946	657.937	637.299
biomA																	
	805.904	827.675	850.035	874.937	900.568	926.95	954.105	984.827	1016.54	1010.12	1003.74	1007.86	1011.99	1016.14	1020.31	1020.31	1020.31
UCI																	
	1244.8	1227.5	1212.94	1225.22	1245.82	1276.12	1317.24	1416.89	1537.82	1496.2	1457.29	1484.23	1505.01	1519.84	1528.81	1582.27	1633.51
low90th																	
	559.517	594.576	630.736	659.541	685.85	708.818	727.844	725.728	718.182	726.402	734.044	728.306	725.297	724.789	726.67	706.005	687.371
upp90th																	
	1160.79	1152.16	1145.58	1160.68	1182.51	1212.21	1250.7	1336.43	1438.84	1404.65	1372.53	1394.72	1412.01	1424.62	1432.61	1474.54	1514.52
biomsd																	
	6.69196	6.71862	6.74528	6.77415	6.80303	6.8319	6.86077	6.89247	6.92416	6.91782	6.91149	6.91558	6.91968	6.92377	6.92786	6.92786	6.92786
biomsd.sd																	
	0.221818	0.201078	0.181392	0.171798	0.165572	0.163101	0.164552	0.185587	0.211207	0.200438	0.190226	0.197485	0.202489	0.205403	0.206316	0.223854	0.240114

Appendix B2. Input file (re.dat) for mature male golden king crab biomass in NMFS EBS slope survey Subarea 2 and results file (rwout.rep) produced by re.exe.

re.dat file

2008	#Start year of model			
2018	#End year of model			
4	#number of survey estimates			
#Years of survey				
2008	2010	2012	2016	
#Biomass estimates				
490	440	256	475	
#Coefficients of variation for biomass estimates				
0.36	0.24	0.32	0.3	

rwout.rep file

yrs_srv											
	2008	2010	2012	2016							
srv_est											
	490	440	256	475							
srv_sd											
	0.34909	0.236648	0.312233	0.29356							
yrs											
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI											
	306.329	306.333	306.335	306.332	306.325	306.327	306.328	306.328	306.327	306.323	306.319
biomA											
	406.596	406.595	406.594	406.592	406.59	406.591	406.592	406.594	406.595	406.595	406.595
UCI											
	539.683	539.674	539.666	539.666	539.673	539.672	539.674	539.678	539.684	539.691	539.698
low90th											
	320.592	320.595	320.597	320.593	320.587	320.589	320.59	320.59	320.589	320.586	320.582
upp90th											
	515.674	515.666	515.66	515.659	515.664	515.664	515.665	515.669	515.674	515.68	515.685
biomsd											
	6.00782	6.00782	6.00782	6.00781	6.0078	6.00781	6.00781	6.00781	6.00782	6.00782	6.00782
biomsd.sd											
	0.14447	0.144463	0.144457	0.14446	0.144469	0.144466	0.144466	0.144468	0.144473	0.144479	0.144486

Appendix B3. Input file (re.dat) for legal male golden king crab biomass in NMFS EBS slope survey Subareas 2 and results file (rwout.rep) produced by re.exe.

re.dat file				
2008	#Start year of model			
2018	#End year of model			
4	#number of survey estimates			
#Years of survey				
2008	2010	2012	2016	
#Biomass estimates				
294	349	207	336	
#Coefficients of variation for biomass estimates				
0.29	0.25	0.34	0.3	

rwout.rep file											
yrs_srv											
	2008	2010	2012	2016							
srv_est											
	294	349	207	336							
srv_sd											
	0.284166	0.246221	0.330745	0.29356							
yrs											
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI											
	227.905	227.906	227.907	227.906	227.905	227.905	227.905	227.904	227.903	227.902	227.901
biomA											
	301.019	301.02	301.02	301.019	301.018	301.019	301.019	301.019	301.02	301.02	301.02
UCI											
	397.589	397.588	397.587	397.587	397.587	397.588	397.59	397.592	397.594	397.596	397.599
low90th											
	238.328	238.329	238.33	238.329	238.328	238.328	238.327	238.327	238.326	238.325	238.324
upp90th											
	380.202	380.201	380.2	380.199	380.2	380.201	380.202	380.203	380.205	380.207	380.209
biomsd											
	5.70717	5.70718	5.70718	5.70717	5.70717	5.70717	5.70717	5.70718	5.70718	5.70718	5.70718
biomsd.sd											
	0.141961	0.14196	0.141958	0.141959	0.141961	0.141961	0.141963	0.141964	0.141966	0.14197	0.141973

Appendix C

Draft Pribilof Islands (Pribilof District) golden king crab stock structure template

(adapted from Spencer et al. 2010). Page 1 of 2.

Factor and criterion	**Justification**
	Harvest and trends
Fishing mortality (5-year average percent of F_{abc} or F_{ofl})	F, F_{ABC}, and F_{OFL} are not estimated for Tier 5 stock. Total catch annual catch is confidential, but has been below the OFLs and ABCs established for season.
Spatial concentration of fishery relative to abundance (Fishing is focused in areas << management areas)	Fishery effort and catch is concentrated in Pribilof Canyon, a very small area of the Pribilof District, but also an area of concentrated golden king crab density (see EBS slope survey data).
Population trends (Different areas show different trend directions)	Uncertain. Standardized trawl surveys in the Pribilof District have only been performed in 2002, 2004, 2008, 2010, 2012, and 2016. Total biomass estimates generally increased from 2002 through 2012; with no substantial increase in 2016.
	Barriers and phenotypic characters
Generation time (e.g., >10 years)	Unknown, but likely >10 years.
Physical limitations (Clear physical inhibitors to movement)	Species occurs primarily in the 200-1000 m depth zone. No known physical barriers exist in the Pribilof District, although survey and fishery data suggest low densities in the 200-1000 m depth zone of the EBS slope between Pribilof Canyon and Zhemchug Canyon.
Growth differences (Significantly different LAA, WAA, or LW parameters)	No data for estimating size at age. Spatial differences in length-weight relationship within Pribilof District have not been investigated. Within the Bering Sea males at higher latitudes have been estimated to be heavier than equal-sized males at lower latitudes.
Age/size-structure (Significantly different size/age compositions)	Age structure data is lacking. Spatial trends within Pribilof District in size structure have not been investigated, but trend of latitudinal decrease in mean size may exist over the Bering Sea due to latitudinal decrease in size at maturity.
Spawning time differences (Significantly different mean time of spawning)	Species is known to exhibit an asynchronous reproductive cycle lacking distinct seasonal variation; mean spawning time within Pribilof District has not been estimated.

Factor and criterion	Justification
Maturity-at-age/length differences (Significantly different mean maturity-at-age/ length)	No data for estimating maturity at age. Spatial differences in size at maturity within Pribilof District have not been investigated. Within Bering Sea, estimates of size at maturity decrease south-to-north.
Morphometrics (Field identifiable characters)	Spatial trends within Pribilof District in morphometrics have not been investigated. Latitudinal trends in male morphometrics (chela size at length) may exist over the Bering Sea that are related to latitudinal trends in size at maturity.
Meristics (Minimally overlapping differences in counts)	N/A.
Behavior & movement	
Spawning site fidelity (Spawning individuals occur in same location consistently)	Not likely: ovigerous females tend to occur in the shallower depth zones at sites throughout the Pribilof District within the species depth distribution.
Mark-recapture data (Tagging data may show limited movement)	Mark-recapture data not available.
Natural tags (Acquired tags may show movement smaller than management areas)	Unknown.
Genetics	
Isolation by distance (Significant regression)	Unknown.
Dispersal distance (<<Management areas)	Unknown.
Pairwise genetic differences (Significant differences between geographically distinct collections)	Unknown.