Pribilof Islands Golden King Crab Stock Assesssment 2023 DRAFT

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Executive Summary

1. **Stock**: Golden king crab, *Lithodes aequispinus*, Pribilof Islands (Pribilof District), Alaska.
2. **Catch**: 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 856,475 lb (388 t). 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 there being none in the ten years that no vessels participated (1984, 1986, 1990–1992, 2006–2009, 2015, and 2016) to 341,908 lb (155 t) in 1995, when seven vessels made landings. The fishery is not rationalized and there is no state harvest strategy in regulation. A guideline harvest level (GHL) was first established for the fishery in 1999 at 200,000 lb (91 t). The GHL was reduced to 150,000 lb (68 t) for 2000–2014 and reduced to 130,000 lb (59 t) in 2015. No vessels participated in the directed fishery and no landings were made during 2006–2009 or 2015-2016. Catch data from 2003–2005, 2010–2014, and 2017-2019 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, 2017-2019 fisheries were not closed by emergency order. Four vessels participated in both 2020 and 2021, harvesting 107,679 lb (48.8 t) and 34,216 lb (15.5 t), respectively.

   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 discard mortality during 2001–2021 due to crab fisheries range from 0 lb (0 t) to 16,251 lb (7.4 t), with an average of 4,695 lb (2.1 t). Estimates of annual fishery mortality during 1991/92–2019 due to groundfish fisheries range from 198 lb (0.1 t) to 19,489 lb (8.8 t), with an average of 5,013 lb (2.3 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 2021).
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 1,790,154 lb (812 t) in 2012 to 1,916,329 lb (869 t) in 2016, and from 564,383 lb (256 t) in 2012 to 1,021,602 lb (463 t 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). Four vessels participated in both 2020 and 2021, harvesting 107,679 lb (48.8 t) and 34,216 lb (15.5 t), respectively. Bycatch mortality in groundfish fisheries during 2020-2022 was 4,387 (2 t), 4,630(2 t), 4,453 (2 t), respectively. Overfishing did not occur in 2020, 2021, 2022. The GHL for the 2020-2022 seasons was 59 t. The 2024, 20252, and 2026 OFL and ABC in the table below are the author's recommendations, which follow previous determinations.

Management Performance (values in t)

Fishery Year	MSST	Biomass (MMB)	GHL[a]	Retained Catch	Total Catch[b]	OFL	ABC
2016	N/A	N/A	59	0	0	91.0	68.0
2017	N/A	N/A	59	CF	CF	93.0	70.0
2018	N/A	N/A	59	CF	CF	93.0	70.0
2019	N/A	N/A	59	CF	CF	93.0	70.0
2020	N/A	N/A	59	48.8	52.3	93.0	70.0
2021	N/A	N/A	59	15.5	21.6	93.0	70.0
2022	N/A	N/A	59			93.0	70.0
2023	N/A	N/A				93.0	70.0
2024	N/A	N/A				94.7	71.1
2025	N/A	N/A				94.7	71.1
2026	N/A	N/A				94.7	71.1

[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.

6. **Basic for the OFL and ABC**: The values for 2021-2023 are the author's recommendation.

Fishery Year	Tier	Reference Years	Natural Mortality	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%
2024	5	1993-1998[a]	0.18 yr^{-1}	25%
2025	5	1993-1998[a]	0.18 yr^{-1}	25%
2026	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 these years multiplied by a factor of 1.052 to account for the estimated bycatch mortalityoccurring 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 94.7 t (CV = 0.3; section G).

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

Changes in management of the fishery

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 2023.

Changes to the input data

- Retained catch and discarded catch data in the directed fishery have been updated through the 2021 season.
- Bycatch estimates from non-directed crab fisheries have been updated through the 2022 season. time series estimates have been updated using reproducible methods consistent with other Bering Seas crab stocks.
- Bycatch estimates from groundfish fisheries have been updated through the 2022 season.

Changes to the assessment methodology

This assessment follows the methodology recommended by the CPT since May 2012 and the SSC since June 2012.

Changes to the assessment results

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 2013–2023 Tier 5 OFLs; computations resulted in minor changes due to updates made to discard and bycatch time series.

B. Responses to SSC and CPT Comments

SSC June 2020

Comment: "*For the next full assessment, the SSC requests the authors provide three assessment alternatives:*

- *The current Tier 5 assessment methodology.*
- *A Tier 4 assessment. A key issue with the Tier 4 approach will be selecting an appropriate BMSY proxy and determining whether the estimates of biomass are sufficiently reliable to warrant a Tier 4 status for the stock. The SSC notes that estimates of MMB from the slope survey may only be sporadically available in the future, which complicates status determination under Tier 4 (i.e., stock status relative to MSST).*
- *A Tier 5 methodology that uses Tier 4 methods for calculating the OFL/ABC. This approach would use the historical EBS slope survey estimates (based on a reference period) and use F=M for OFL calculation (or perhaps a different F value). An example of this approach was used for spiny dogfish (see October 2010 SSC report)."*

Response: We present all three options in this document and appendices.

Comment: "*The SSC notes that assessing trends in catch is not currently possible because of confidential data. The SSC recommends that the authors consider rescaling catch across years (e.g., min/max or z-score) such that relative catch trends could potentially be displayed without violating confidentiality rules.*"

Response: We were advised by ADF&G staff not to do so as catch numbers could be reasonably approximated given the trend and known values of non-confidential seasons.

Comment: "*For the assessment alternatives using a survey reference period, the SSC recommends the authors and CPT provide a rationale for the preferred reference period, and clearly specify the objective associated with the chosen period (e.g., target the current productivity regime or the range of potential productivity).*"

Response: For tier 4 calculations in Appendix A, we chose to use all of the survey years available for two reasons: 1) survey data is limited to only 4-6 years over a 14 year time period, and 2) this is the best available fishery independent data to capture the range of potential productivity of the stock.

Comment: "*The SSC supports the CPT recommendation to evaluate EBS slope survey variance for the early survey years (2002 and 2004) and to continue investigating whether additional length and sex composition data are available for 2004.*"

Response: We were unable to recover additional biological data for 2002 and 2004, but variance in MMB proxies are now computed as suggested by the CPT.

Comment: "*The SSC supports continued efforts by ADF&G to coordinate with industry to conduct a pot survey, and reiterates its past recommendation to explore VAST model fits to the EBS slope survey data, recognizing that this method may not be successful given the spatial characteristics of the survey.*"

Response: We were unable to explore VAST model fits during this reporting period.

Comment: "*The SSC recommends the authors and CPT consider whether the Aleutians Islands estimate of M (0.21) is appropriate for the PIGKC stock (M=0.18).*"

Response: Authors ackowledge that a species specific estimate of natural mortality is likely appropriate and both values of M are considered in Tier 4 calculations (Appendix A).

CPT May 2020

Comment: "*Continue to explore the existence of 2004 survey size composition data.*"

Response: We were unable to recover new 2004 survey data.

Comment: "*Improve CV calculations for 2002 and 2004 MMB estimates.*"

Response: CVs were computed using variance of the division of two random variables.

Comment: "*Explore a simplified GMACS model.*"

Response: We were unable to explore a GMACS model during this reporting period, but are gathering data for future efforts.

SSC October 2019

Comment: "*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.*"

Response: We further explored RE modelling. An industry-cooperative survey is in development.

Comment: *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.*

Response:Included 2002 and 2004 estimates in Tier 4 scenario 2. Did not change process error lower bound, as model appeared to converge.

CPT October 2019

Comment: *Explore the feasibility of a simplified Gmacs model to assess the stock.*

Response: Work started; data is being compiled.

Comment: *Consider initiating an industry cooperative survey to assess abundance trends.*

Response: In the works.

SSC June 2017

Comment: *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.*

Response: Inquired. No progress in obtaining confidentiality waivers from processors.

Comment: *The SSC would appreciate additional insights from the assessment author into the performance of the random effects model.*

Response: We further explored the random effects model performance and provide details in Appendix A.

CPT May 2017

Comment: *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.*

Response: 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.

Comment: *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.

Comment: *Put bounds on the process error and rerun the model.*

Response: After investigating the model performance in the .par file, it appears the model did converge (maximum gradient component is <0.0001).

C. Introduction

1. **Scientific name**: *Lithodes aequispinus* J. E. Benedict, 1895.
2. **Description of general distribution**: 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 (approximately 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 most recent Pribilof District golden king crab fishery (2021) was 189 fathoms (346 m), based on observer data.

3. **Evidence of stock structure**: 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 1 - 2). 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 lb (0 t) to 341,908 lb (155 t), and the number of vessels participating annually has ranged from 0 to 8, but 1-2 on average since rationalization of other Bering Sea crab fisheries (2005).

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

   Despite confidentiality requirements under SOA statute Sec. 16.05.815, it can be noted, 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) $\geq$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 $\leq$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

Summary of new information

Retained catch, directed fishery discards and bycatch during non-directed crab fisheries and groundfish fisheries have been added up through the 2022 season.

Data presented as time series

1. The 1981/82-1983/84, 1984-2022 time series of retained catch (number and weight of crab, including deadloss), effort (vessels and pot lifts), CPUE (number of landed crab captured per pot lift), and average weight of landed crab is presented in Tables 1 - 2.

2. The 2001-2022 time series of discarded catch and estimated discard mortality during the directed fishery is presented in Tables 3 - 4. Observer data on size distributions and estimated catch numbers of discarded catch were used to estimate the weight of discarded catch 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. Following Siddeek et al. (2014), the bycatch mortality rate of golden king crab captured and discarded during the directed fishery was assumed to be 0.2.
3. The 1990-2022 time series of discarded bycatch in non-directed crab fisheries (i.e., Bering Sea snow crab and Bering Sea grooved Tanner crab fisheries) is presented in Tables **??** - **??**. 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 Pribilof District golden king crab seasons. 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.
4. 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 Tables 7 - 8. 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.
5. Tables 1 - 8 summarizes the available data on retained catch weight and the available estimates of discarded catch weight.
6. **Catch-at-length**: Not used in a Tier 5 assessment; none are presented.
7. **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.
8. **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.
9. **Other data time series**: None.

Data which may be aggregated over time

1. **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 $\geq$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 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).

2. **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, $Weight = A * CL^B$ are: A = 0.0002712 and B = 3.168 for males (ADF&G, unpublished data) and A = 0.0014240 and B = 2.781 for females(from Table 3-5, NPFMC 2007).

3. **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.

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

1. 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.
2. 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

History of modeling approaches for this stock

Gaeuman (2013a, 2013b), Pengilly (2015), and Pengilly and Daly (2017; 2020) 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 2021-2023, as had been recommended by NPFMC (2007) and by the CPT and SSC in 2008-2020.

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] then 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 2024-2026.

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 nondirected 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 2024-2026 Tier 5 OFL recommended here uses the same approach as used for the 2013–2023 Tier 5 OFLs.

Model selection and evaluation

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.,

$$\mathrm{OFL}_{2024-2026} = (1 + R_{2001-2010})RET_{1993-1998} + BM_{NC,1994-1998} + BM_{GF,92/93-98/99} \tag{1}$$

where,

- $R_{2001-2010}$ = average of the estimated ratio of bycatch mortality to retained catch in the directed fishery during 2001-2010.
- $RET_{1993-1998}$ = average retained catch in the directed crab fishery during 1993-1998.
- $BM_{NC,1994-1998}$ = estimated average bycatch mortality in non-directed crab fisheries during 1994–1998.
- $BM_{GF,92/93-98/99}$ = estimated average 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 $RET_{1993-1998}$, $R_{2001-2010}$, $BM_{NC,1994-1998}$, and $BM_{GF,92/93-98/99}$ are provided in Table 9; the column means in Table 9 are the calculated values of $RET_{1993-1998}$, $R_{2001-2010}$, $BM_{NC,1994-1998}$, and $BM_{GF,92/93-98/99}$. Using the calculated values of $RET_{1993-1998}$, $R_{2001-2010}$, $BM_{NC,1994-1998}$, and $BM_{GF,92/93-98/99}$, the calculated value of OFL_{2018} is,

$$\text{OFL}_{2021-2023} = (1 + 0.063)78.8 \text{ t} + 7.19 \text{ t} + 3.79 \text{ t} = 94.7 \text{ t } (208,876 \text{ lbs}) \tag{2}$$

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)
status quo	Total-catch	1993-1998	93
recommended/updated crab bycatch	Total-catch	1993-1998	94.7

The recommended approach uses the same time period and uses the sample calculation as supported by the CPT and SSC since 2013. Updating the time series of bycatch in non-directed crab fisheries (above) resulted in a slightly higher OFL.

Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models

See Section E, above.

Convergence status and convergence criteria for the base-case model (or proposed base-case model)

Not applicable.

Table (or plot) of the sample sizes assumed for the compositional data

Not applicable.

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. Establishment of consistent and reproducible methods for estimating bycatch in crab fisheries has improved credibility of the existing time series, but may have greater uncertainty due to the nature of the low-effort directed 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.

Description of criteria used to evaluate the model or to choose among alternative models, including the role (if any) of uncertainty

See section E, above.

Residual analysis (e.g. residual plots, time series plots of observed and predicted values or other approach)

Not applicable.

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, above.

Results (best models)

List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties

Not applicable for Tier 5 stock.

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 Table 9.

Graphs of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible)

Not applicable for Tier 5 stock.

Evaluation of the fit to the data

Not applicable for Tier 5 stock.

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.

Uncertainty and sensitivity analyses (this section should highlight unresolved problems andmajor 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

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 2010-2023. 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.

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.

Specification of the total-catch OFL

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."

Basis for projecting MMB to the time of mating

Not applicable for Tier 5 stock.

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. Fishery statistics from 2020 - 2021 were not confidential, and overfishing did not occur. Values for the 2024-2026 OFL and ABC are the author's recommendations.

Management Performance (values in t)

Fishery Year	MSST	Biomass (MMB)	GHL[a]	Retained Catch	Total Catch[b]	OFL	ABC
2016	N/A	N/A	59	0	0	91.0	68.0
2017	N/A	N/A	59	CF	CF	93.0	70.0
2018	N/A	N/A	59	CF	CF	93.0	70.0
2019	N/A	N/A	59	CF	CF	93.0	70.0
2020	N/A	N/A	59	48.8	52.3	93.0	70.0
2021	N/A	N/A	59	15.5	21.6	93.0	70.0
2022	N/A	N/A	59			93.0	70.0
2023	N/A	N/A				93.0	70.0
2024	N/A	N/A				94.7	71.1
2025	N/A	N/A				94.7	71.1
2026	N/A	N/A				94.7	71.1

[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.

Management Performance (values in lb)

Fishery Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch[a]	OFL	ABC
2016	N/A	N/A	130,000	0	0	200,621	149,914
2017	N/A	N/A	130,000	CF	CF	205,030	154,324
2018	N/A	N/A	130,000	CF	CF	205,030	154,324
2019	N/A	N/A	130,000	CF	CF	205,030	154,324
2020	N/A	N/A	130,000	107,679	115,195.5	205,030	154,324
2021	N/A	N/A	130,000	34,216	47,713.5	205,030	154,324
2022	N/A	N/A	130,000			205,030	154,324
2023	N/A	N/A				205,030	154,324
2024	N/A	N/A				208,778	156,749
2025	N/A	N/A				208,778	156,749
2026	N/A	N/A				208,778	156,749

[a] 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.

Specification of the retained-catch portion of the total-catch OFL

Retained-catch portion is the average retained catch during 1993-1998 (79 t). Note that a retained catch of 79 t would exceed the author's recommended ABC for 2024, 2025, and 2026 (71.1 t); see G.4, below.

Recommended F_{OFL}, OFL total catch and the retained portion for the coming year

See above; no F_{OFL} is recommended for a Tier 5 stock.

G. Calculation of ABC

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 9 to calculate $R_{2001-2010}$, $RET_{1993-1998}$, $BM_{NC,1994-1998}$, $BM_{GF,92/93-98/99}$, and OFL_{2023}). The mean and CV computed from the 1,000 replicates are 94.7 t and 0.26, 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).

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 2023 is unknown.

List of additional uncertainties for alternative sigma-b

Not applicable to this Tier 5 assessment.

Author recommended ABC

25% buffer on OFL; i.e., ABC = (1-0.25)(94.7 t) = 71.1 t (1.56657×10^5 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.

J. Literature Cited

Barnard, D. R., and R. Burt. 2004. Alaska Department of Fish and Game summary of the 2002 mandatory shellfish observer program database for the general and CDQ crab fisheries. Alaska Department of Fish and Game, Regional Information Report No. 4K04-27, Kodiak.

Barnard, D. R., and R. Burt. 2006. Alaska Department of Fish and Game summary of the 2005 mandatory shellfish observer program database for the non-rationalized crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 06-36, Anchorage.

Blau, S. F., and D. Pengilly. 1994. Findings from the 1991 Aleutian Islands golden king crab survey in the Dutch Harbor and Adak management areas including analysis of recovered tagged crabs. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 4K94-35, Kodiak.

Blau, S. F., L. J. Watson, and I. Vining. 1998. The 1997 Aleutian Islands golden king crab survey. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 4K98-30, Kodiak.

Bowers, F.B., B. Failor-Rounds, and M.E. Cavin. 2005. Annual management report for the commercial shellfish fisheries of the Bering Sea, 2004. Pages 71-186 in Bowers, F.R., K.L. Bush, M. Schwenzfeier, J. Barnhart, M. Bon, M.E. Cavin, S. Coleman, B. Failor-Rounds, K. Milani, and M. Salmon. 2005. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea and the Westward Region's Shellfish Observer Program, 2004. Alaska Department of Fish and Game, Fishery Management Report No. 05-51, Anchorage.

Burt, R., and D. R. Barnard. 2005. Alaska Department of Fish and Game summary of the 2003 mandatory shellfish observer program database for the general and CDQ fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 05-05, Anchorage.

Burt, R., and D. R. Barnard. 2006. Alaska Department of Fish and Game summary of the 2004 mandatory shellfish observer program database for the general and CDQ fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 06-03, Anchorage.

Byrne, L. C., and D. Pengilly. 1998. Evaluation of CPUE estimates for the 1995 crab fisheries of the Bering Sea and Aleutian Islands based on observer data. Pages 61-74 *in*: Fishery stock assessment models, edited by F. Funk, T.J. Quinn II, J. Heifetz, J.N. Iannelli, J.E. Powers, J.F. Schweigert, P.J. Sullivan, and C.-I Zhang, Alaska Sea Grant College Program Report No. AK-SG-98-01, University of Alaska Fairbanks, 1998.

Foy, R. J., 2013. 2013 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Red King Crab Fisheries of the Bering Sea and Aleutian Islands Regions. *in*: Stock Assessment and fishery Evaluation report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions: 2013 Crab SAFE. NPFMC, Anchorage, September 2013.

Gaeuman, W. B. 2011. Summary of the 2010/2011 Mandatory Crab Observer Program Database for the Bering Sea/Aleutian Islands commercial crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 11-73, Anchorage.

Gaeuman, W. B. 2013a. Pribilof Islands golden king crab Tier 4 stock assessment considerations. Report to the North Pacific Fishery Management Council Bering Sea-Aleutian Island Crab Plan Team, 30 April - 3 May 2013 meeting, Anchorage, AK.

Gaeuman, W. B. 2013b. Alternative Pribilof Islands golden king crab stock assessment strategy. Report to the North Pacific Fishery Management Council Bering Sea-Aleutian Island Crab Plan Team, 17-20 September 2013 meeting, Seattle, WA.

Gaeuman, W. B. 2013c. Summary of the 2011/2012 Mandatory Crab Observer Program Database for the Bering Sea/Aleutian Islands commercial crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 13-21, Anchorage.

Gaeuman, W. B. 2014. Summary of the 2013/14 Mandatory Crab Observer Program Database for the Bering Sea/Aleutian Islands commercial crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 14-49, Anchorage.

Haaga, J. A., S. Van Sant, and G. R. Hoff. 2009. Crab abundance and depth distribution along the continental slope of the eastern Bering Sea. Poster presented at the 25th Lowell Wakefield Fisheries Symposium (Biology and Management of Exploited Crab Populations under Climate Change), Anchorage, AK, March 2009. Available online at: $ftp://ftp.afsc.noaa.gov/posters/pJHaaga01_ebs-crab.pdf$

Hiramoto, K. 1985. Overview of the golden king crab, Lithodes aequispina, fishery and its fishery biology in the Pacific waters of Central Japan. in: Proc. Intl. King Crab Symp., University of Alaska Sea Grant Rpt. 85-12, Fairbanks.

Hiramoto, K., and S. Sato. 1970. Biological and fisheries survey on an anomuran crab, *Lithodes aequispina* Benedict, off Boso Peninsula and Sagami Bay, central Japan. Jpn. J. Ecol. 20:165-170. In Japanese with English summary.

Hoff, G. R. 2013. Results of the 2012 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFSAFSC-258.

Hoff, G. R. 2016. Results of the 2016 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFSAFSC-339.

Hoff, G. R., and L. Britt. 2003. Results of the 2002 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-141.

Hoff, G .R., and L. Britt. 2005. Results of the 2004 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-156.

Hoff, G. R., and L. Britt. 2009. Results of the 2008 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-197.

Hoff, G. R., and L. Britt. 2011. Results of the 2010 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-224.

Jewett, S. C., Sloan, N. A., and Somerton, D. A. 1985. Size at sexual maturity and fecundity of the fjord-dwelling golden king crab *Lithodes aequispina* Benedict from northern British Columbia. Journal of Crustacean Biology 5(3):377-385.

Leon, J. M., J. Shaishnikoff, E. Nichols, and M. Westphal. 2017. Annual management report for shellfish fisheries of the Bering Sea–Aleutian Islands management area, 2015/16. Alaska Department of Fish and Game, Fishery Management Report No. 17-10, Anchorage.

McBride, J., D. Fraser, and J. Reeves. 1982. Information on the distribution and biology of the golden (brown) king crab in the Bering Sea and Aleutian Islands area. NOAA, NWAFC Proc. Rpt. 92-02.

National Marine Fisheries Service (NMFS). 2004. Bering Sea Aleutian Islands Crab Fisheries Final Environmental Impact Statement. DOC, NOAA, National Marine Fisheries Service, AK Region, P.O. Box 21668, Juneau, AK 99802-1668, August 2004.

Neufeld, G., and D. R. Barnard. 2003. Alaska Department of Fish and Game summary of the 2001 mandatory shellfish observer program database for the general and CDQ fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 4K03-2, Kodiak.

North Pacific Fishery Management Council (NPFMC). 2007. Public Review Draft: Environmental Assessment for proposed Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner Crabs to Revise Overfishing Definitions. 14 November 2007. North Pacific Fishery Management Council, Anchorage. Nyblade, C.F. 1987. Phylum or subphylum Crustacea, class Malacostraca, order Decopoda, Anomura. in: M.F. Strathman (ed.), Reproduction and development of marine invertebrates on the northern Pacific Coast. Univ. Wash. Press, Seattle, pp.441-450. Otto, R. S., and P. A. Cummiskey. 1985. Observations on the reproductive biology of golden king crab (Lithodes aequispina) in the Bering Sea and Aleutian Islands. Pages 123–136 in Proceedings of the International King Crab Symposium. University of Alaska Sea Grant Report No. 85-12, Fairbanks.

Paul, A. J., and J. M. Paul. 2000. Changes in chela heights and carapace lengths in male and female golden king crabs Lithodes aequispinus after molting in the laboratory. Alaska Fishery Research Bulletin 6:70-77.

Paul, A. J., and J. M. Paul. 2001a. Growth of juvenile golden king crabs Lithodes aequispinus in the laboratory. Alaska Fishery Research Bulletin 8: 135-138.

Paul, A. J., and J. M. Paul. 2001b. The reproductive cycle of golden king crab *Lithodes aequispinus* (Anomura: Lithodidae). Journal of Shellfish Research 20:369-371.

Pengilly, D. 2015. Discussion paper for September 2015 Crab Plan Team meeting: Random effects approach to modelling NMFS EBS slope survey area-swept estimates for Pribilof Islands golden king crab. Report to the North Pacific Fishery Management Council Bering Sea Aleutian Island Crab Plan Team, 14-17 September 2015 meeting, Seattle, WA.

Pengilly, D. and B. Daly. 2017. Updated discussion paper for May 2017 Crab Plan Team meeting: Random effects approach to modelling NMFS EBS slope survey area-swept estimates for Pribilof Islands golden king crab. Report to the North Pacific Fishery Management Council Bering Sea-Aleutian Island Crab Plan Team, 2-5 May 2017 meeting, Juneau, AK.

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

Siddeek, M. S. M., J. Zheng, and D. Pengilly. 2014. Aleutian Islands golden king crab (*Lithodes aequispinus*) model-based stock assessment in spring 2015. http://www.npfmc.org/wpcontent/PDFdocuments/membership/PlanTeam/Crab/May2015/AIGKC.pdf

Sloan, N.A. 1985. Life history characteristics of fjord-dwelling golden king crabs *Lithodes aequispina*. Mar. Ecol. Prog. Ser. 22:219-228.

Somerton, D. A., and R.S. Otto. 1986. Distribution and reproductive biology of the golden king crab, *Lithodes aequispina*, in the eastern Bering Sea. Fish. Bull. 84:571-584.

Watson, L. J., D. Pengilly, and S. F. Blau. 2002. Growth and molting probability of golden king crabs (*Lithodes aequispinus*) in the eastern Aleutian Islands, Alaska. Pages 169-187 *in* 2002. A. J. Paul, E. G. Elner, G. S. Jamieson, G. H. Kruse, R. S. Otto, B. Sainte-Marie, T. C. Shirley, and D. Woodby (eds.). Crabs in coldwater regions: Biology, Management, and Economics. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks.

Webb. J. 2014. Reproductive ecology of commercially important Lithodid crabs. Pages 285-314 in B.G. Stevens (ed.): King Crabs of the World: Biology and Fisheries Management. CRC Press, Taylor &

Francis Group, New York.

K. Tables

Table 1: Commercial fishery history for the Pribilof District golden king crab fishery: number of guideline harvest level (GHL; lb), vessels, weight of retained catch (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.'CF' denotes confidential fishery data.

Season	GHL	Vessels	Retained (lb)[a]	Retained (crab)[a]	Pot lifts	CPUE	Avg. wt.
1981/82		2	CF	CF	CF	CF	CF
1982/83		10	69,970	15,330	5,252	2.92	4.6
1983/84		50	856,475	253,162	26,035	9.72	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		2	CF	CF	CF	CF	CF
1989		2	CF	CF	CF	CF	CF
1990		0	0	0	0		
1991		0	0	0	0		
1992		0	0	0	0		
1993		5	67,458	17,643	15,395	1.15	3.8
1994		3	CF	CF	CF	CF	CF
1995		7	341,908	82,489	9,551	8.64	4.1
1996		6	329,009	91,947	9,952	9.24	3.6
1997		7	179,249	43,305	4,673	9.27	4.1
1998		3	CF	CF	CF	CF	CF
1999	200,000	3	CF	CF	CF	CF	CF
2000	150,000	7	131,816	29,145	5,450	5.35	4.5
2001	150,000	6	145,876	33,723	4,262	7.91	4.3
2002	150,000	8	150,434	34,860	5,279	6.6	4.3
2003	150,000	3	CF	CF	CF	CF	CF
2004	150,000	5	CF	CF	CF	CF	CF
2005	150,000	4	CF	CF	CF	CF	CF
2006	150,000	0	0	0	0		
2007	150,000	0	0	0	0		
2008	150,000	0	0	0	0		
2009	150,000	0	0	0	0		
2010	150,000	1	CF	CF	CF	CF	CF
2011	150,000	2	CF	CF	CF	CF	CF
2012	150,000	1	CF	CF	CF	CF	CF
2013	150,000	1	CF	CF	CF	CF	CF
2014	150,000	1	CF	CF	CF	CF	CF
2015	130,000	0	0	0	0		
2016	130,000	0	0	0	0		
2017	130,000	2	CF	CF	CF	CF	CF
2018	130,000	1	CF	CF	CF	CF	CF
2019	130,000	2	CF	CF	CF	CF	CF
2020	130,000	4	107,679	24,301	2,960	8.21	4.4
2021	130,000	4	34,216	7,021	2,361	2.97	4.9

[a]Deadloss included.
CF = Confidential

Table 2: Commercial fishery history for the Pribilof District golden king crab fishery: number of guideline harvest level (GHL; t), vessels, weight of retained catch (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.'CF' denotes confidential fishery data.

Season	GHL	Vessels	Retained (t)[a]	Retained (crab)[a]	Pot lifts	CPUE	Avg. wt.
1981/82		2	CF	CF	CF	CF	CF
1982/83		10	31.7	15,330	5,252	2.92	2.1
1983/84		50	388.5	253,162	26,035	9.72	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		2	CF	CF	CF	CF	CF
1989		2	CF	CF	CF	CF	CF
1990		0	0	0	0		
1991		0	0	0	0		
1992		0	0	0	0		
1993		5	30.6	17,643	15,395	1.15	1.7
1994		3	CF	CF	CF	CF	CF
1995		7	155.1	82,489	9,551	8.64	1.9
1996		6	149.2	91,947	9,952	9.24	1.6
1997		7	81.3	43,305	4,673	9.27	1.9
1998		3	CF	CF	CF	CF	CF
1999	91	3	CF	CF	CF	CF	CF
2000	68	7	59.8	29,145	5,450	5.35	2.1
2001	68	6	66.2	33,723	4,262	7.91	2
2002	68	8	68.2	34,860	5,279	6.6	2
2003	68	3	CF	CF	CF	CF	CF
2004	68	5	CF	CF	CF	CF	CF
2005	68	4	CF	CF	CF	CF	CF
2006	68	0	0	0	0		
2007	68	0	0	0	0		
2008	68	0	0	0	0		
2009	68	0	0	0	0		
2010	68	1	CF	CF	CF	CF	CF
2011	68	2	CF	CF	CF	CF	CF
2012	68	1	CF	CF	CF	CF	CF
2013	68	1	CF	CF	CF	CF	CF
2014	68	1	CF	CF	CF	CF	CF
2015	59	0	0	0	0		
2016	59	0	0	0	0		
2017	59	2	CF	CF	CF	CF	CF
2018	59	1	CF	CF	CF	CF	CF
2019	59	2	CF	CF	CF	CF	CF
2020	59	4	48.8	24,301	2,960	8.21	2
2021	59	4	15.5	7,021	2,361	2.97	2.2

[a]Deadloss included.
CF = Confidential

Table 3: Weight (lb) of estimated discarded catch of Pribilof District golden king crab (PIGKC) during the PIGKC directed fishery, 1993-2021, with total fishery mortality (lb) estimated by applying a bycatch mortality rate of 0.2 to the discarded catch.

	Males		Females	
Season	Discards (lb)	Mortality	Discards (lb)	Mortality
2001	21,220.6	4,244.1	21,076.2	4,215.2
2002	50,656.6	10,131.3	13,954.2	2,790.8
2003	CF	CF	CF	CF
2004	CF	CF	CF	CF
2005	CF	CF	CF	CF
2006	NE	NE	NE	NE
2007	NE	NE	NE	NE
2008	NE	NE	NE	NE
2009	NE	NE	NE	NE
2010	CF	CF	CF	CF
2011	CF	CF	CF	CF
2012	CF	CF	CF	CF
2013	CF	CF	CF	CF
2014	CF	CF	CF	CF
2015	NE	NE	NE	NE
2016	NE	NE	NE	NE
2017	CF	CF	CF	CF
2018	CF	CF	CF	CF
2019	CF	CF	CF	CF
2020	4,086.3	817.3	11,229.4	2,245.9
2021	11,112.8	2,222.6	29,218.2	5,843.6

NE = No Effort

CF = Confidential

Table 4: Weight (t) of estimated discarded catch of Pribilof District golden king crab (PIGKC) during the PIGKC directed fishery, 1993-2021, with total fishery mortality (t) estimated by applying a bycatch mortality rate of 0.2 to the discarded catch.

	Males		Females	
Season	Discards (t)	Mortality	Discards (t)	Mortality
2001	9.63	1.93	9.56	1.91
2002	22.98	4.6	6.33	1.27
2003	CF	CF	CF	CF
2004	CF	CF	CF	CF
2005	CF	CF	CF	CF
2006	NE	NE	NE	NE
2007	NE	NE	NE	NE
2008	NE	NE	NE	NE
2009	NE	NE	NE	NE
2010	CF	CF	CF	CF
2011	CF	CF	CF	CF
2012	CF	CF	CF	CF
2013	CF	CF	CF	CF
2014	CF	CF	CF	CF
2015	NE	NE	NE	NE
2016	NE	NE	NE	NE
2017	CF	CF	CF	CF
2018	CF	CF	CF	CF
2019	CF	CF	CF	CF
2020	1.85	0.37	5.09	1.02
2021	5.04	1.01	13.25	2.65

NE = No Effort
CF = Confidential

Table 5: Weight (lb) of estimated discarded bycatch of Pribilof golden king crab (PIGKC) during non-directed crab fisheries (i.e. Bering Sea snow and grooved Tanner crab) from 1990 - 2021 with total fishery mortality (lb) estimated by applying a bycatch mortality rate of 0.5 to the discarded catch.

	Snow Crab		Grooved Tanner crab		Total	
Season	Bycatch	Mortality	Bycatch	Mortality	Bycatch	Mortality
1993	0	0	ND	ND	0	0
1994	0	0	2,682.1	1,341	2,682.1	1,341
1995	0	0	37,987.9	18,994	37,987.9	18,994
1996	1,920.1	960	14,006.2	7,003.1	15,926.3	7,963.2
1997	2,105.9	1,052.9	NE	NE	2,105.9	1,052.9
1998	10,317	5,158.5	NE	NE	10,317	5,158.5
1999	89,516.2	44,758.1	NE	NE	89,516.2	44,758.1
2000	0	0	CF	CF	CF	CF
2001	0	0	CF	CF	CF	CF
2002	3,877.3	1,938.6	NE	NE	3,877.3	1,938.6
2003	833.1	416.5	CF	CF	CF	CF
2004	0	0	CF	CF	CF	CF
2005	0	0	CF	CF	CF	CF
2006	0	0	NE	NE	0	0
2007	0	0	NE	NE	0	0
2008	0	0	NE	NE	0	0
2009	2,633	1,316.5	NE	NE	2,633	1,316.5
2010	0	0	NE	NE	0	0
2011	574.5	287.3	NE	NE	574.5	287.3
2012	642.1	321	NE	NE	642.1	321
2013	843.1	421.5	NE	NE	843.1	421.5
2014	135	67.5	NE	NE	135	67.5
2015	0	0	NE	NE	0	0
2016	0	0	NE	NE	0	0
2017	0	0	CF	CF	CF	CF
2018	0	0	NE	NE	0	0
2019	0	0	CF	CF	CF	CF
2020	0	0	NE	NE	0	0
2021	0	0	CF	CF	CF	CF
2022	2,088.2	1,044.1	CF	CF	CF	CF

ND = No Data
NE = No Effort
CF = Confidential

Table 6: Weight (t) of estimated discarded bycatch of Pribilof golden king crab (PIGKC) during non-directed crab fisheries (i.e. Bering Sea snow and grooved Tanner crab) from 1990 - 2021 with total fishery mortality (t) estimated by applying a bycatch mortality rate of 0.5 to the discarded catch.

	Snow Crab		Grooved Tanner crab		Total	
Season	Bycatch	Mortality	Bycatch	Mortality	Bycatch	Mortality
1993	0	0	ND	ND	0	0
1994	0	0	1.22	0.61	1.22	0.61
1995	0	0	17.23	8.62	17.23	8.62
1996	0.87	0.44	6.35	3.18	7.22	3.61
1997	0.96	0.48	NE	NE	0.96	0.48
1998	4.68	2.34	NE	NE	4.68	2.34
1999	40.6	20.3	NE	NE	40.6	20.3
2000	0	0	CF	CF	CF	CF
2001	0	0	CF	CF	CF	CF
2002	1.76	0.88	NE	NE	1.76	0.88
2003	0.38	0.19	CF	CF	CF	CF
2004	0	0	CF	CF	CF	CF
2005	0	0	CF	CF	CF	CF
2006	0	0	NE	NE	0	0
2007	0	0	NE	NE	0	0
2008	0	0	NE	NE	0	0
2009	1.19	0.6	NE	NE	1.19	0.6
2010	0	0	NE	NE	0	0
2011	0.26	0.13	NE	NE	0.26	0.13
2012	0.29	0.15	NE	NE	0.29	0.15
2013	0.38	0.19	NE	NE	0.38	0.19
2014	0.06	0.03	NE	NE	0.06	0.03
2015	0	0	NE	NE	0	0
2016	0	0	NE	NE	0	0
2017	0	0	CF	CF	CF	CF
2018	0	0	NE	NE	0	0
2019	0	0	CF	CF	CF	CF
2020	0	0	NE	NE	0	0
2021	0	0	CF	CF	CF	CF
2022	0.95	0.47	CF	CF	CF	CF

ND = No Data
NE = No Effort
CF = Confidential

Table 7: Estimated annual weight (lb) 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 (lb) estimated by assuming bycatch mortality rate = 0.5 for fixedgear fisheries and bycatch mortality rate = 0.8 for trawl fisheries. 1991/92-2008/09 is listed by crab fishery year, while 2009-2022 are listed by calendar year.

	Bycatch in groundfish fisheries (no mortality rate applied)			
Fishery Year	Fixed	Trawl	Total	Total Mortality
1991-1992	110.2	13,470.3	13,580.5	10,824.7
1992-1993	7,694.1	19,555.0	27,249.2	19,488.9
1993-1994	1,124.4	21,252.6	22,376.9	17,570.9
1994-1995	551.2	7,120.9	7,672.1	5,974.5
1995-1996	903.9	4,188.8	5,092.7	3,814.0
1996-1997	44.1	1,918.0	1,962.1	1,565.3
1997-1998	2,998.3	1,080.3	4,078.6	2,358.9
1998-1999	14,925.3	396.8	15,322.1	7,782.3
1999-2000	10,560.2	1,433.0	11,993.2	6,437.5
2000-2001	3,593.5	4,144.7	7,738.2	5,114.7
2001-2002	3,306.9	771.6	4,078.6	2,270.8
2002-2003	1,234.6	463.0	1,697.6	992.1
2003-2004	529.1	396.8	925.9	573.2
2004-2005	352.7	859.8	1,212.5	859.8
2005-2006	198.4	132.3	330.7	198.4
2006-2007	2,954.2	242.5	3,196.7	1,675.5
2007-2008	18,673.2	352.7	19,025.9	9,612.2
2008-2009	8,818.5	3,439.2	12,257.7	7,165.0
2009	5,886.3	5,621.8	11,508.1	7,451.6
2010	4,695.9	2,226.7	6,922.5	4,122.6
2011	1,873.9	2,932.2	4,806.1	3,284.9
2012	1,609.4	1,807.8	3,417.2	2,248.7
2013	1,102.3	5,489.5	6,591.8	4,938.4
2014	1,344.8	1,168.5	2,513.3	1,609.4
2015	1,785.7	4,166.7	5,952.5	4,232.9
2016	507.1	352.7	859.8	529.1
2017	374.8	2,954.2	3,329.0	2,557.4
2018	264.6	3,505.4	3,769.9	2,932.2
2019	132.3	10,846.8	10,979.0	8,752.4
2020	88.2	5,511.6	5,599.7	4,453.3
2021	66.1	5,445.4	5,511.6	4,387.2
2022	22.0	5,776.1	5,798.2	4,629.7
Average	3,064.4	4,343.1	7,407.5	5,004.5

Table 8: 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 fixedgear fisheries and bycatch mortality rate = 0.8 for trawl fisheries. 1991/92-2008/09 is listed by crab fishery year, while 2009-2022 are listed by calendar year.

	Bycatch in groundfish fisheries (no mortality rate applied)			
Fishery Year	Fixed	Trawl	Total	Total Mortality
1991-1992	0.05	6.11	6.16	4.91
1992-1993	3.49	8.87	12.36	8.84
1993-1994	0.51	9.64	10.15	7.97
1994-1995	0.25	3.23	3.48	2.71
1995-1996	0.41	1.90	2.31	1.73
1996-1997	0.02	0.87	0.89	0.71
1997-1998	1.36	0.49	1.85	1.07
1998-1999	6.77	0.18	6.95	3.53
1999-2000	4.79	0.65	5.44	2.92
2000-2001	1.63	1.88	3.51	2.32
2001-2002	1.50	0.35	1.85	1.03
2002-2003	0.56	0.21	0.77	0.45
2003-2004	0.24	0.18	0.42	0.26
2004-2005	0.16	0.39	0.55	0.39
2005-2006	0.09	0.06	0.15	0.09
2006-2007	1.34	0.11	1.45	0.76
2007-2008	8.47	0.16	8.63	4.36
2008-2009	4.00	1.56	5.56	3.25
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	0.17	1.34	1.51	1.16
2018	0.12	1.59	1.71	1.33
2019	0.06	4.92	4.98	3.97
2020	0.04	2.50	2.54	2.02
2021	0.03	2.47	2.50	1.99
2022	0.01	2.62	2.63	2.10
Average	1.39	1.97	3.36	2.27

Table 9: 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 2, values under $R_{2001-2010}$ were computed from the retained catch data and the directed fishery discarded catch estimates in Tables 2 and 4 (assumed bycatch mortality rate = 0.2), values under $BM_{NC,1994-1998}$ were computed from the nondirected crab fishery discarded catch estimates in Table 6 (assumed bycatch mortality rate = 0.5) and values under $BM_{GF,92/93-98/99}$ are from Table 8.

Year	Crab Season	$RET_{1993-1998}$	$R_{2001-2010}$	$BM_{NC,1994-1998}$	$BM_{GF,92/93-98/99}$
1993	1993/94	30.6			8.84
1994	1994/95	CF		0.61	7.97
1995	1995/96	155.09		9.05	2.71
1996	1996/97	149.24		3.65	1.73
1997	1997/98	81.31		2.34	0.71
1998	1998/99	CF		20.30	1.07
1999	1999/00				3.53
2000	2000/01				
2001	2001/02		0.058		
2002	2002/03		0.086		
2003	2003/04		CF		
2004	2004/05		CF		
2005	2005/06		CF		
2006	2006/07				
2007	2007/08				
2008	2008/09				
2009	2009/10				
2010	2010/11		CF		
	N	6	6	5	7
	Mean	78.80	0.063	7.19	3.79
	SE	24.84	0.005	3.57	1.25
	CV	0.32	0.08	0.50	0.33

J. Figures

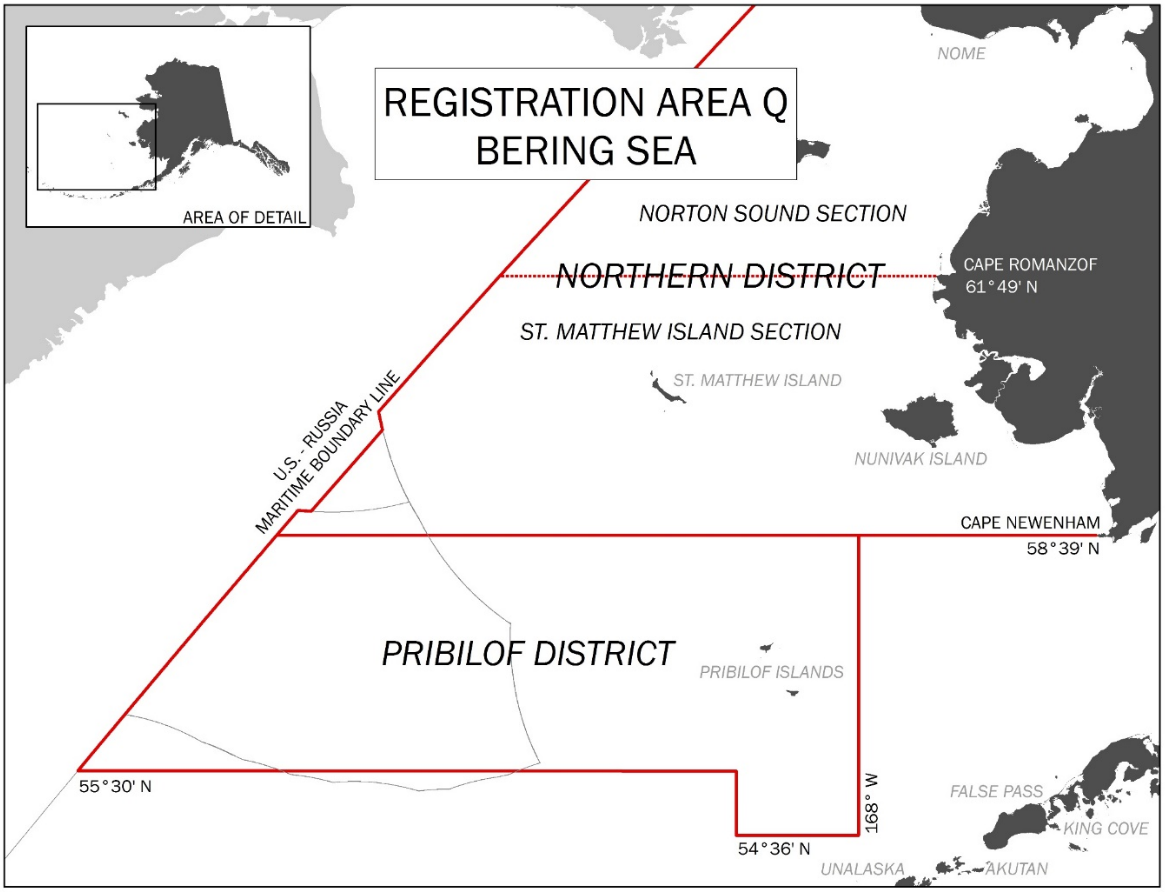

Figure 1: King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District.

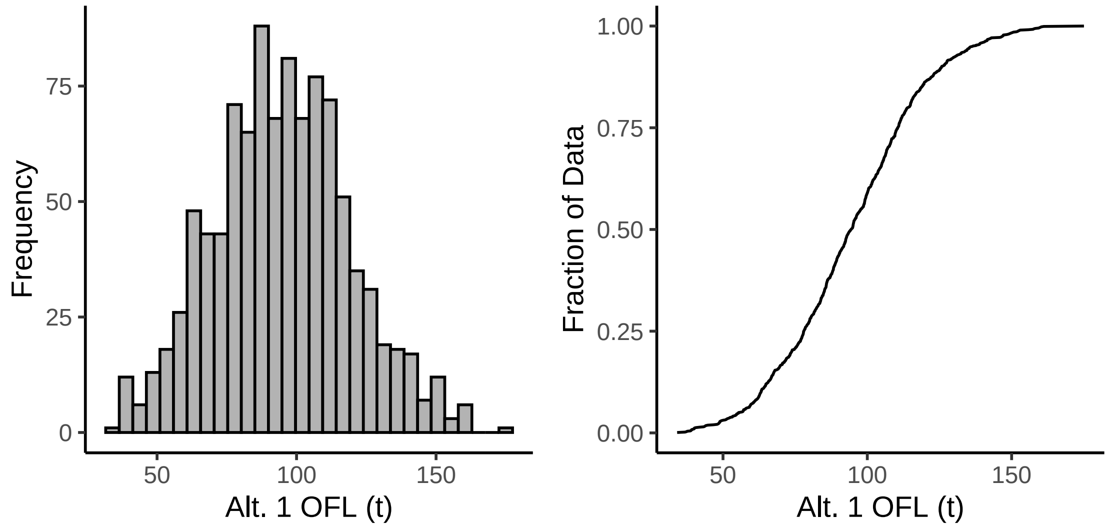

Figure 2: Bootstrap estimates of the sampling distribution of the 2024-2026 Alternative 1 Tier 5 OFL (total catch, t) for the Pribilof Islands golden king crab stock; histogram on left, quantile plot on right.

Appendix A: Pribilof Islands Golden King Crab Draft Tier 4 Assessment

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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 in 2002, 2004, 2008, 2010, 2012, and 2016. The slope survey was a multi-species survey stratified by subarea and depth (Hoff and Britt 2003, 2005, 2009, 2011; Hoff 2013, 2016), and is the sole fishery independent data source for estimating mature male biomass (MMB) of 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 within 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 (Figure 3). 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 to obtain to obtain biomass estimates in aggregate and the variances of those estimates. Since length composition data were not available for 2002 and 2004, MMB estimates were obtained by first estimating total biomass associated variance for 2002 and 2004, and then multiplying it by the ratio of MMB to total biomass in 2008-2016 ($r_{2008-2016}$). CVs for 2002 and 2004 were computed as the variance of the division of two random variables, using the variance of total biomass in those years and the variance in $r_{2008-2016}$.

Available data not used in analysis

- The 1981/82–1983/84, 1984–2021 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).
- The 1993–2022 time series of weight of retained catch (1993 - 2021) and estimated weight of discarded catch (2001 - 2010) and estimated weight of fishery mortality of Pribilof golden king crab during the directed fishery and non-directed crab fisheries (1993 - 2022).

- The groundfish fishery discarded catch data (grouped into crab fishery years from 1991/92–2008/09, and by calendar years from 2009–2022).
- Retained catch size composition data for 2001-2021.

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 $\geq$ 90 mm that were tagged in the Aleutian Islands and recovered during subsequent commercial fisheries (Watson et al. 2002); those results are not used in the OFL calculation and therefore not presented here.

Weight-at length (by sex)

Parameters (A and B) used for computing weight (g) from carapace length (CL, mm) of golden king crab by $Weight = A * CL^B$, were estimated using data collected as part of an ADF&G special collection during the directed fishery (not at-sea observer) for males (A = 0.0002712 and B = 3.168). Female specific parameters (A = 0.0014240 and B = 2.781) were those specified in the FMP (NPFMC 2007, Table 3-5).

Natural mortality rate

The default natural mortality rate assumed for king crab species by NPFMC (2007) is M = 0.18. Here, calculations using M = 0.21, consistent with Aleutian Island golden king crab (Siddeek et al., 2022), are also presented for comparison.

Analytic Approach

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 (RE) 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. The RE model approach was revisited in 2020, using proxy estimates of MMB for 2002 and 2004 based on the ratio of MMB to total biomass in other survey years. Again, the CPT recommended to use the Tier 5 assessment due to the lack of documentation associated with the particular version of the RE model used and uncertainty in the availability of future fishery independent data (CPT 2020). Here, we further explore the utility of the latest version of the RE model within the R package *rema* (Sullivan et al. 2022), though there has been no additional fishery-independent data since the 2016 survey, thus the time series used in this analysis is the same as in the 2020 assessment.

Model

Various versions of the RE model have been in use by the North Pacific Fisheries Management Council (NPFMC) Groundfish Plan Team (GPT) since 2013. State dynamics of the model follow a random walk, in which log-transformed biomass is a random effect with distribution $\mathcal{N}(0, \sigma^2_{pe})$ (Sullivan et al. 2022a and b). The R package *rema* was developed as a generalized, consensus version of RE model variations, and is implemented through Template Model Builder (TMB) (Kristensen et al. 2016). The GPT and SSC both endorsed use of *rema* for groundfish assessments in 2022. In this analysis, a univariate (i.e., single strata) model was fit to area swept MMB estimates (males $\geq$ 107 mm; Somerton and Otto 1986) from the NMFS-AFSC EBS slope survey. Each model has only a single estimable parameter, ln σ_{pe}.

Model Scenarios

Model scenarios evaluated were as follows:

- **23.0**: MMB and CV 2002-2016. MMB estimates and associated CVs were computed using the mean ratio of MMB:total biomass from 2008-2016.
- **23.0a**: Same as 23.0, but with CV = 0.4 for 2002. An arbitrarily high CV (approximately equal to the time series maximum) was evaluated in response to a CPT comment regarding the influence of a comparatively low CV in 2002.
- **23.1**: MMB and CV 2008-2016.
- **23.1a**: Same as 23.1, but adding a squared penalty term to the likelihood (i.e., NLL = NLL + $(\ln \sigma_{pe} + 1.5)^2$) to prevent process error from going to zero.
- **23.1b**: Same as 23.1, but adding a prior to $\ln \sigma_{pe}$, based on the $\ln \sigma_{pe}$ estimate of model 23.0 ($\mathcal{N}(-2.3, 1)$). Additional prior distributions $\mathcal{N}(-1.3, 1)$ and $\mathcal{N}(-3.3, 1)$ were also evaluated to examine sensitivity.

Model Evaluation

Arbitrarily increasing the 2002 survey biomass estimated CV (CV = 0.4; model 23.0a) resulted in a lower estimate of σ_{pe} and thus worse fit to the data than model 23.0. Without data from 2002 and 2004, model 23.1 estimated σ_{pe} to be approximately zero (i.e., the model was unable to discern a change in biomass throughout the time series), though without reaching optimal convergence (maximum gradient component = 9.22e^{-7}) (Table 2). Models 23.1a and 23.1b both produced non-zero estimates of σ_{pe}, despite excluding 2002 and 2004 biomass observations. Model 23.1b resulted in a seemingly better fit than 23.1a, but was sensitive to the prior distribution parameters (Table 3, Figure **??**).

Calculation of Reference Points

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

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

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), M = 0.18 yr^{-1} or M = 0.21 yr$\hat{}^{-1}$ (Siddeek et al. 2018), and $\alpha = 0.1$. The Tier 4 OFL (Table 4 and 5) was calculated by applying a fishing mortality determined by the harvest control rule (above) to the mature male biomass at the time of mating (MMB$_{proj}$), which remained constant starting in 2016 (i.e., the last data input year).

Author Recommendation

Our preferred model scenario is model 23.0. Despite using approximations of survey MMB in lieu of direct estimates, the approximations appear to capture the population trends indicated by total biomass survey estimates for these years. Hence, model 23.0 is a reasonable attempt to use all the available data. We also recommend reference point calculations using M = 0.21 yr^{-1} following Siddeek et al. (2018). The assumed natural mortality rate specified by the FMP (0.18 yr^{-1}; NPFMC 2007) was in reference to red king crab *Paralithodes camtschaticus*, whereas M = 0.21 yr^{-1} was based on Aleutian Islands golden king crab

(Siddeek et al. 2018), thus it is more likely to reflect the mortality rate of golden king crab in the Pribilof District.

Since it is unlikely that the NMFS-AFSC EBS slope survey will be conducted with regularity (if at all) in the future, we question the advantage of a tier 4 assessment approach that uses it as a primary biomass index. ADF&G has previously expressed interest in developing an industry-cooperative survey, which may become more feasible as there has been greater fishery participation during recent seasons. A pot survey would be a critical source of data should trawl surveys of the EBS slope be discontinued.

Data Gaps

The RE model implemented in *rema* is able to incorporate additional relative biomass indices (i.e., fishery catch per unit effort; CPUE) that are related to the primary biomass index by a scaling parameter, q (Sullivan et al. 2022). Although at-sea observers have been deployed in the Pribilof District golden king crab fishery since the 2001 season, a fishery CPUE index may be ineffectual due to the infrequency of data in this fishery. In the 15 seasons in which there has been fishing effort with observers onboard, the most any of the 21 participating vessels have fished is seven seasons (two seasons on average), thus population trends inferred from CPUE are highly confounded with participant. Moreover, there is little basis for comparison among vessels, since combinations of vessels that participate in a given year are highly variable and often sparse. Still, the value of these data could be explored in the absence of fishery independent data should consideration of a tier 4 assessment continue.

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We thank the Jerry Hoff for providing survey data, and the Crab Plan Team and Katie Palof for review, and Jane Sullivan for guidance on the use of *rema*.

Literature Cited

Crab Plan Team. 2020. crab Plan Team Report, May 4-7, 2020. North Pacific Fishery Management Council, Anchorage.

Hoff, G. R. 2013. Results of the 2012 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-258.

Hoff, G. R. 2016. Results of the 2016 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-339.

Hoff, G. R., and L. Britt. 2003. Results of the 2002 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-141.

Hoff, G .R., and L. Britt. 2005. Results of the 2004 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-156.

Hoff, G. R., and L. Britt. 2009. Results of the 2008 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-197.

Hoff, G. R., and L. Britt. 2011. Results of the 2010 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-224.

Kristensen, K., A. Nielsen, C.W. Berg, H. Skaug, B.M. Bell. 2016. TMB: Automatic Differentiation and Laplace Approximation. Journal of Statistical Software, 70(5), 1-21. doi:10.18637/jss.v070.i05

North Pacific Fishery Management Council (NPFMC). 2007. Public Review Draft: Environmental Assessment for proposed Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner Crabs to Revise Overfishing Definitions. 14 November 2007. North Pacific Fishery Management Council, Anchorage.

Pengilly, D. and B. Daly. 2017. Updated discussion paper for May 2017 Crab Plan Team meeting: Random effects approach to modelling NMFS EBS slope survey area-swept estimates for Pribilof Islands golden king crab. Report to the North Pacific Fishery Management Council Bering Sea-Aleutian Island Crab Plan Team, 2-5 May 2017 meeting, Juneau, AK.

Siddeek, M.S.M., J. Zheng, C. Siddon, B. Daly, J. Runnebaum, and M.J. Westphal. 2018. Aleutian Islands golden king crab model-based stock assessment. North Pacific Fishery Management Council, Anchorage, Alaska.

Somerton, D. A., and R.S. Otto. 1986. Distribution and reproductive biology of the golden king crab, Lithodes aequispina, in the eastern Bering Sea. Fish. Bull. 84:571-584.

Sullivan, J., C. Monnahan and P. Hulson. 2022a. rema: A random effects model for estimating biomass, with the option to include an additional survey index. https://afsc-assessments.github.io/rema/

Sullivan, J., C. Monnahan, P. Hulson, J. Ianelli, J. Thorson, and A. Havron. 2022b. REMA: a consensus version of the random effects model for ABC apportionment and Tier 4/5 assessments. Plan Team Report, Joint Groundfish Plan Teams, North Pacific Fishery Management Council. 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Tables

Table 1: Total biomass (t), mature male biomass (MMB; t), associated CV (t) and ratio of mature male biomass to total biomass by survey year.

Survey	Total Biomass (t)	MMB (t)[a]	CV	$r_{2008-2016}$
2002	715	314	0.29	
2004	1,085	476	0.39	
2008	972	551	0.31	0.57
2010	1,661	652	0.26	0.39
2012	1,213	368	0.34	0.30
2016	1,504	741	0.32	0.49
			Mean	0.44
			Var	0.01

[a]Estimates for 2002 and 2004 based on mean ratio from 2008-2016.

Table 2: Negative log-likelihoods and σ_{pe} estimates with associated standard error (SE) by model scenario.

Model	NLL	σ_{pe}	SE
23.0	2.55	0.101	0.10
23.0a	2.37	0.052	0.16
23.1	1.21	8.117e-06	2.54e-04
23.1a	1.68	0.166	0.10
23.1b	2.27	0.081	0.07

Table 3: Estimates of ln σ_{pe} from model 23.1b assuming different prior distributions with mean, μ and $\sigma^2 = 1$.

μ	ln σ_{pe}	SE
-1.3	-1.85	0.77
-2.3	-2.51	0.86
-3.3	-3.35	0.96

Table 4: Comparisons of tier 4 management quantities assuming $M = 0.18$ for each model scenarios.

Model	B_{MSY} (t)	MMB (t)	MMB$_{proj}$ (t)	MMB$_{proj}/B_{MSY}$	F_{OFL}	OFL (t)
23.0	507	584	521	1.03	0.18	85.9
23.0a	524	550	491	0.94	0.17	75.7
23.1	576	576	515	0.89	0.16	75.6
23.1a	573	633	566	0.99	0.18	91.9
23.1b	576	597	534	0.93	0.17	81.3

Table 5: Comparisons of tier 4 management quantities assuming $M = 0.21$ for each model scenarios.

Model	B_{MSY} (t)	MMB (t)	MMB$_{proj}$ (t)	MMB$_{proj}/B_{MSY}$	F_{OFL}	OFL (t)
23.0	507	584	512	1.01	0.21	96.9
23.0a	524	550	482	0.92	0.19	83.9
23.1	576	576	506	0.88	0.18	83.8
23.1a	573	633	555	0.97	0.20	101.8
23.1b	576	597	524	0.91	0.19	90.1

Figures

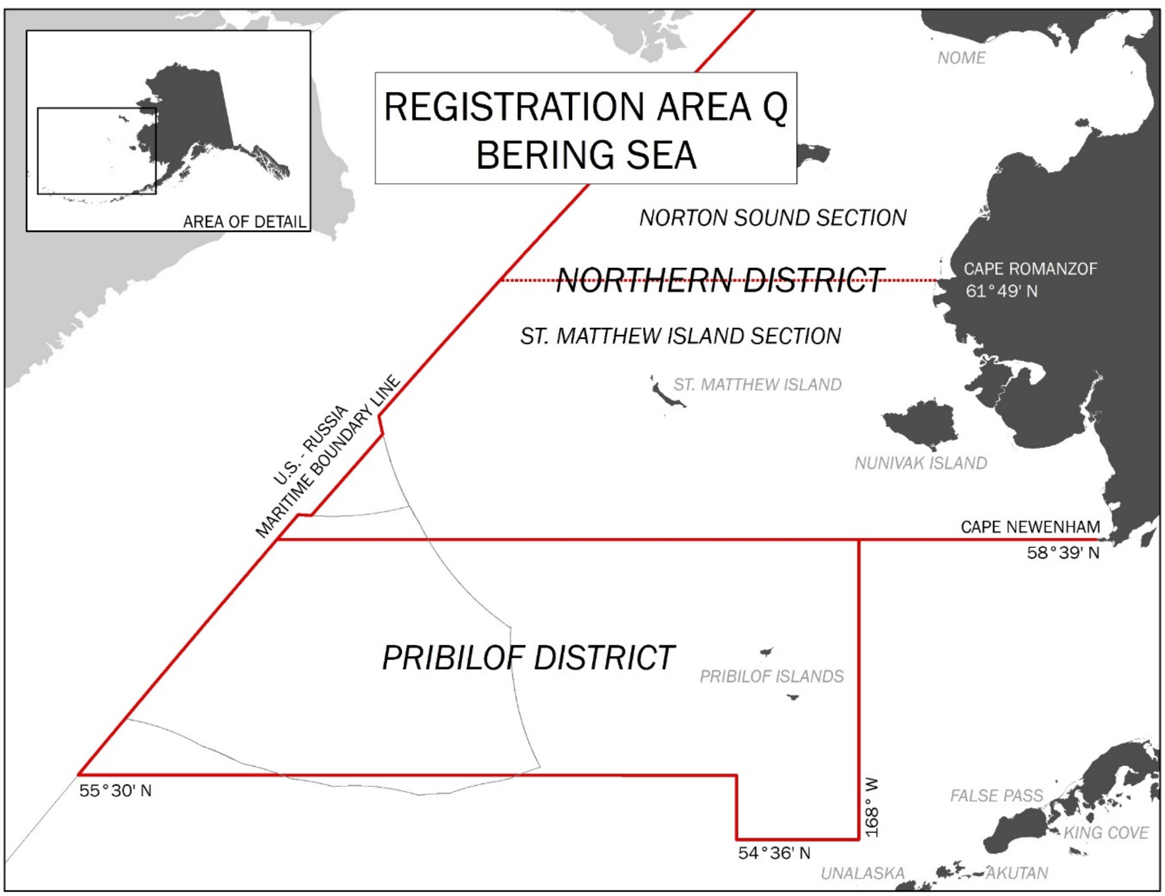

Figure 1: King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District.

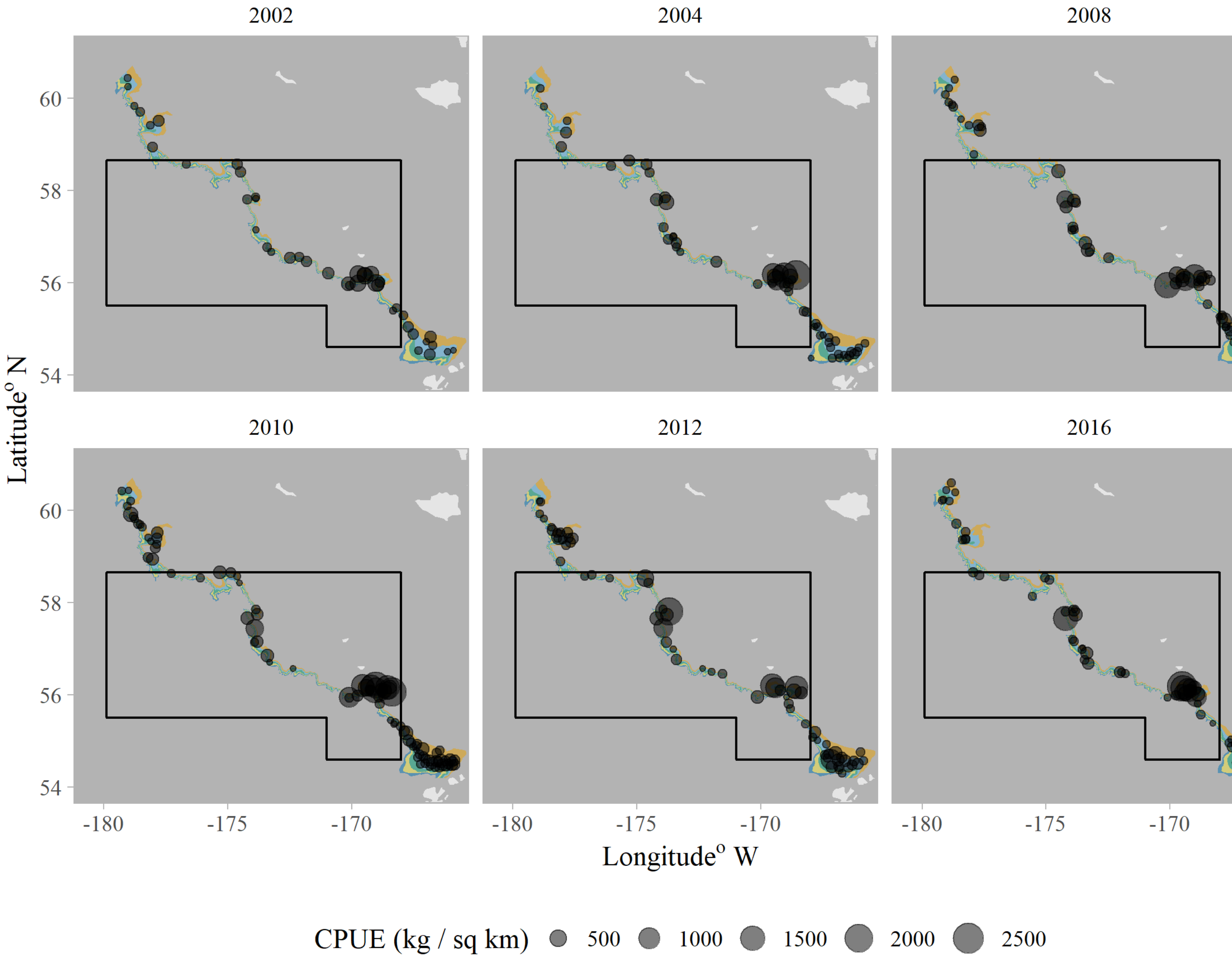

Figure 2: Location of golden king crab (all sizes and sex) catch during the NMFS-AFSC EBS slope survey by survey year. The black rectangluar shape represents the Pribilof District Management Area boundary.

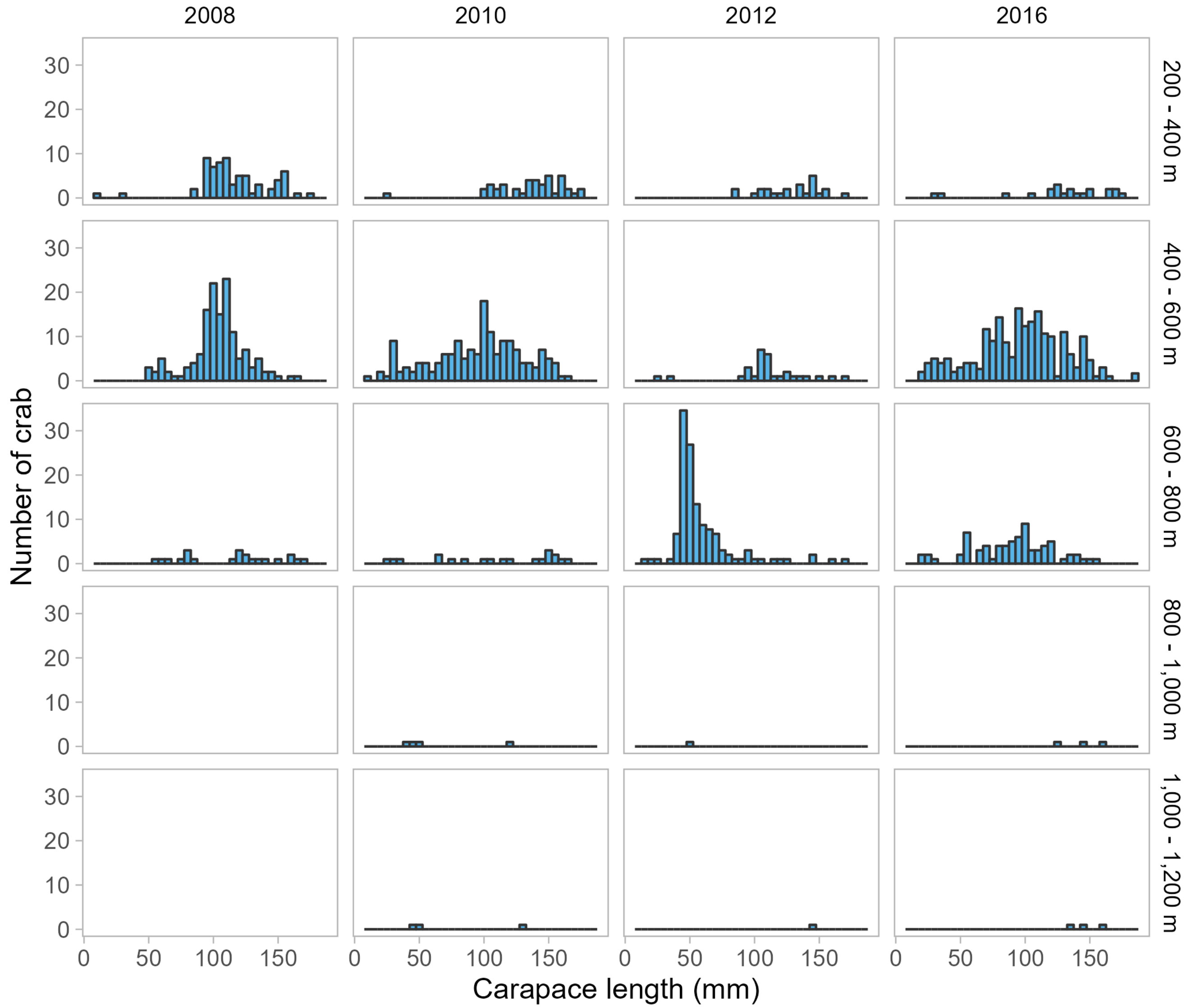

Figure 3: Size composition of male golden king crab by depth strata for survey years in which size data are available.

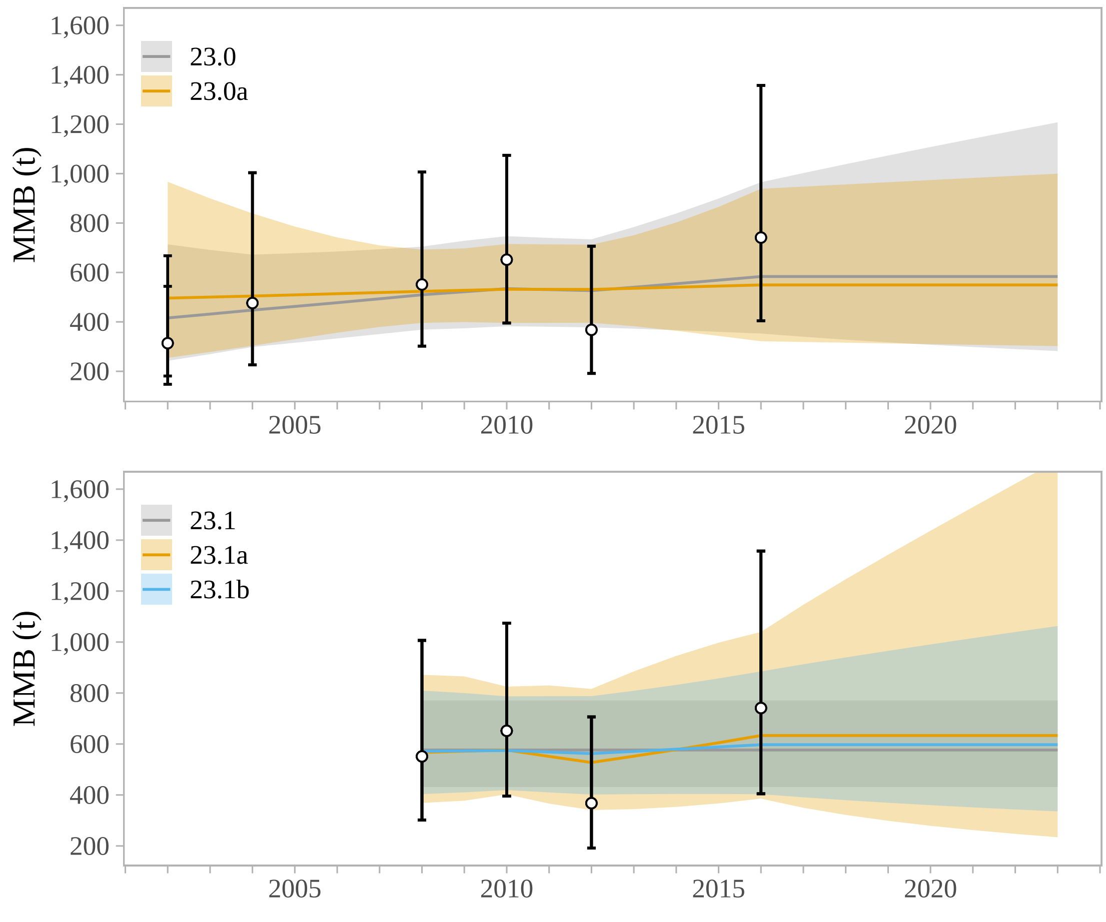

Figure 4: Fits to model scenarios that include data from 2002-2016 (top) and 2008-2016 only (bottom). Additional error bars on 2002 observed MMB indicate increased survey CV (model 23.0a).

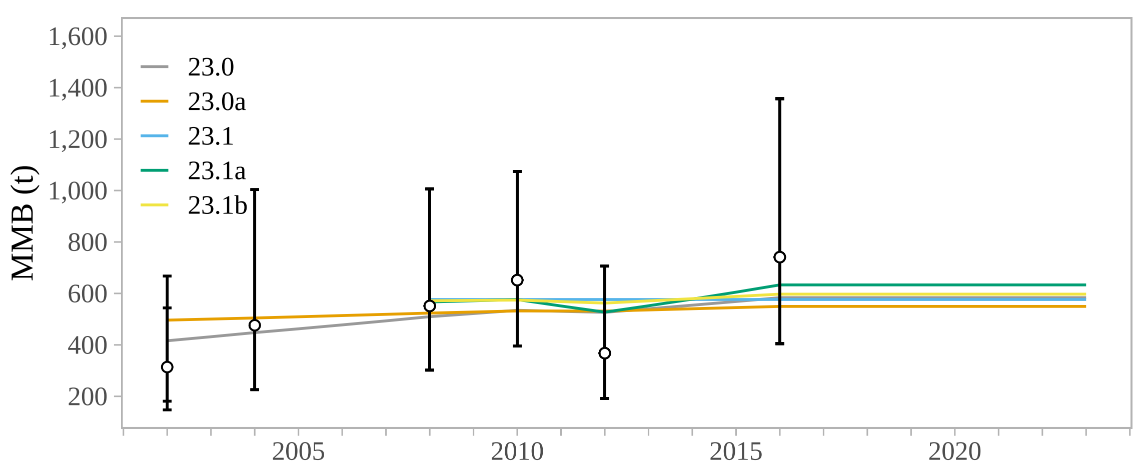

Figure 5: Fits to all model scenarios (confidence intervals not shown). Additional error bars on 2002 observed MMB indicate increased survey CV (model 23.0a).

Appendix B: Pribilof Islands Golden King Crab Alternative Tier 4/5 Assessment

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Purpose

This appendix offers alternative harvest specifications in response to the following comment in the 2020 June SSC report:

"*For the next full assessment, the SSC requests the authors provide...A Tier 5 methodology that uses Tier 4 methods for calculating the OFL/ABC. This approach would use the historical EBS slope survey estimates (based on a reference period) and use F=M for OFL calculation (or perhaps a different F value). An example of this approach was used for spiny dogfish (see October 2010 SSC report).*"

Data

Area swept estimates of mature male biomass (MMB) from the 2002, 2004, 2008, 2010, 2012, and 2016 NMFS-AFSC Eastern Bering sea slope survey were used to calculate management quantities (**??**). Details of survey methodology and biomass computations can be found in Appendix A, as well as Hoff and Britt (2003; 2005; 2009,; 2011) and Hoff (2013; 2016).

Calculation of Reference Points

The 2010 Gulf of Alaska spiny dogfish (*Squalus suckleyi*) assessment used groundfish tier 5 calculations in which OFL is computed as OFL = $M \times B$ where $F_{OFL} = M$ (NPFMC 2010) and authors used a model based M Tribuzio and Kruse (2011). For Pribilof District golden king crab, we computed OFL specifications using both $M = 0.18$ yr$\hat{}^{-1}$ (NPFMC 2007) and $M = 0.21$ yr$\hat{}^{-1}$ (Siddeek et al., 2018). In the absence of an updated survey MMB estimate, we computed biomass B as the average MMB for 2002-2016 surveys ($B = 517$ t) to capture the range of potential productivity of the stock. MMB estimates for 2002 and 2004 were estimated from the ratio of MMB to total biomass in 2008-2016 (see Appendix A for more details). We felt that inclusion of 2002 and 2004 was appropriate since the trend in total biomass throughout the time series indicated lower biomass, and thus lower productivity, in those years. ABC was computed a ABC = $(1 - 0.25)$OFL, consistent with tier 4 calculations for EBS crab stocks (NPFMC 2007).

Tables

Table 1: Mature male biomass estimates base on areas swept calculations for the NMFS-AFSC EBS slope survey within the Pribilof District Management Area. MMB estimates for 2002 and 2004 are proxies based on total biomass, and he ratio of MMB to total biomass in other survey years (Appendix A).

Survey	MMB (t)
2002	313.8
2004	476.2
2008	551.3
2010	651.7
2012	367.7
2016	741.1

Table 2: Comparisons of alternative tier 4 OFL specifications using $M = 0.18$ or $M = 0.21$, and B equal to the average survey MMB from 2002 - 2016.

M	B (t)	OFL (t)	ABC (t)
0.18	517.0	93.1	69.8
0.21	517.0	108.6	81.4

Literature Cited

Hoff, G. R. 2013. Results of the 2012 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-258.

Hoff, G. R. 2016. Results of the 2016 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-339.

Hoff, G. R., and L. Britt. 2003. Results of the 2002 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-141.

Hoff, G .R., and L. Britt. 2005. Results of the 2004 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-156.

Hoff, G. R., and L. Britt. 2009. Results of the 2008 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-197.

Hoff, G. R., and L. Britt. 2011. Results of the 2010 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-224.

North Pacific Fishery Management Council (NPFMC). 2007. Public Review Draft: Environmental Assessment for proposed Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner Crabs to Revise Overfishing Definitions. 14 November 2007. North Pacific Fishery Management Council, Anchorage.

Siddeek, M.S.M., J. Zheng, C. Siddon, B. Daly, J. Runnebaum, and M.J. Westphal. 2018. Aleutian Islands golden king crab model-based stock assessment. North Pacific Fishery Management Council, Anchorage, Alaska.

Tribuzio, C.A., K. Echave, C. Rodgveller, J. Heifetz, and K.J. Goldman. 2010. Chapter 18b: Assessment of the sharks in the Gulf of Alaska. NPFMC Gulf of Alaska SAFE. North Pacific Fishery Management Council, Anchorage, Alaska.

Tribuzio, C.A., G.H. Kruse. 2011. Demographic and risk analyses of spiny dogfish (*Squalus suckleyi*) in the Gulf of Alaska using ageand stage-based population models. Marine and Freshwater Research 62: 1395–1406.