**Discussion paper for September 2015 Crab Plan Team meeting:**
**Random effects approach to modeling NMFS EBS slope survey area-swept biomass estimates for Pribilof Islands golden king crab.**

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## **Introduction.**

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

In May 2105 the CPT recommended that, "*a preliminary Tier 4 assessment be brought to the September 2015 meeting using available slope survey data and applying a Kalman filter approach (e.g., the program developed by Jim Ianelli for groundfish stock assessments)*" (report of May 2015 CPT meeting). In June 2015, the SSC supported "*the CPT recommendation that a preliminary Tier 4 assessment be brought to the September 2015 meeting, using existing slope data and applying a Kalman filter approach*" (report of the June 2015 SSC meeting). The SSC also requested that the assessment include "*a discussion … of what stock delineation was chosen (what slope data were used) and the reason for that delineation*," and that "*a Stock Structure Template be completed for PI GKC*" (report of the June 2015 SSC meeting).

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

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

**<u>The NMFS EBS slope survey</u>**.

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

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

**<u>Methods</u>**.

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

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

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

***Model estimates of biomass and projections to 2016***.[1] The program "re.exe" was used to estimate biomass from the area-swept estimates in surveyed years and to project biomass estimates for unsurveyed years into 2016 via a state-space random walk plus noise model. The state-space random walk plus noise is formulated as a random effect model. The random effects model considers the process errors as "random effects" (i.e., drawn from an underlying distribution) and integrated out of the likelihood. The method was developed by the NPFMC groundfish plan team's survey averaging working group as a smoothing technique similar to the Kalman Filter, but which provides more flexibility with non-linear processes and non-normal error structures.

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

> "*Because the stock structure is unknown, the SSC recommends that the authors examine maps of catch-per-unit-effort by survey year to identify natural breaks in the spatial distribution of golden king crab along the slope. If no obvious breaks exist, the SSC recommends that the authors bring forward biomass estimates for the Pribilof canyon region and for the slope as a whole. However, we note that the Pribilof Canyon stations do not encompass the historical catches, which occurred inside and to the north of Pribilof Canyon. Therefore, the authors should consider a biomass estimate for an area that encompasses the majority of historical catches*."

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

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

Figure 7 shows the distribution of all 6,104 pot lifts sampled by observers with locations recorded during 1992–2014 Bering Sea golden king crab fisheries (including the Saint Matthew section of the Northern District, which is north of the Pribilof District) relative to the borders of the Pribilof District and of the survey subareas. Only one of those locations is within the portion of subarea 5 that is within the Pribilof District, none are within the portion of subarea 1 that is within the Pribilof District, and none are within subarea 3.

Figure 8 shows the 26 statistical areas with reported catch during the 1985–2014 Pribilof District golden king crab fisheries relative to the borders of the Pribilof District and of the survey subareas: one (accounting for 0.7% of the 1985–2014 total catch) lies largely in subarea 4, but extends into subarea 5; four (2.9% of the total catch) include portions of subarea 4; six (1.5% of total catch) include portions of subarea 3; one (8.9% of total catch) includes portions of subareas 3 and 2; four (83.9% of total catch) are in or extend into subarea 2; one (0.7% of total catch) includes portions of subareas 2 and 1; one (<0.1% of total catch) is largely within subarea 1; and eight (1.4% of total catch) are outside of the survey area (some of those may be errors in recording of statistical area).

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

**Results**.

Size frequency distributions of golden king crab captured within subareas 2, 3, and 4 during the 2008, 2010, and 2012 NMFS EBS slope surveys are shown in Figures 9–12.

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

Estimates and projections through 2016 of total, mature male, and legal male biomass in survey subareas 2-4 and survey subarea 2 from the state-space random walk plus noise model are plotted in Figures 13 and 14, respectively. More detailed results produced by re.exe are provided in Appendices A and B.

**References**.


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Pengilly, D. 2012. Pribilof Islands golden king crab. [*in*]: Stock Assessment and fishery Evaluation report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions: 2012 Crab SAFE. NPFMC, Anchorage, September 2012.

Pengilly, D. 2014. Pribilof Islands golden king crab. [*in*]: Stock Assessment and fishery Evaluation report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions: 2014 Crab SAFE. NPFMC, Anchorage, September 2014.

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

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

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

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

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

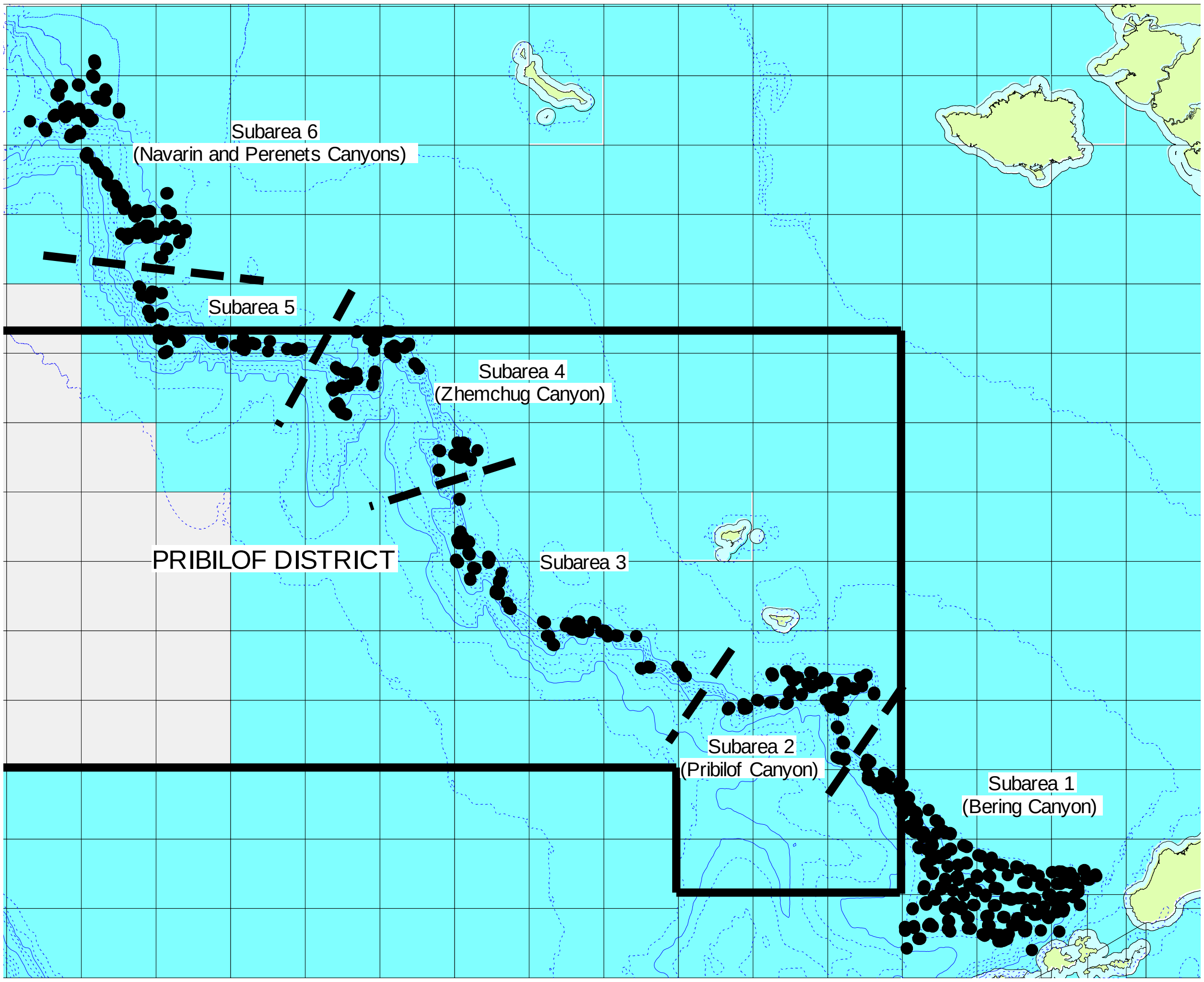


Figure 1. Pribilof District boundaries, slope survey subareas, and 2002–2012 slope survey tow locations; squares are 1° longitude x 30' latitude State statistical areas.

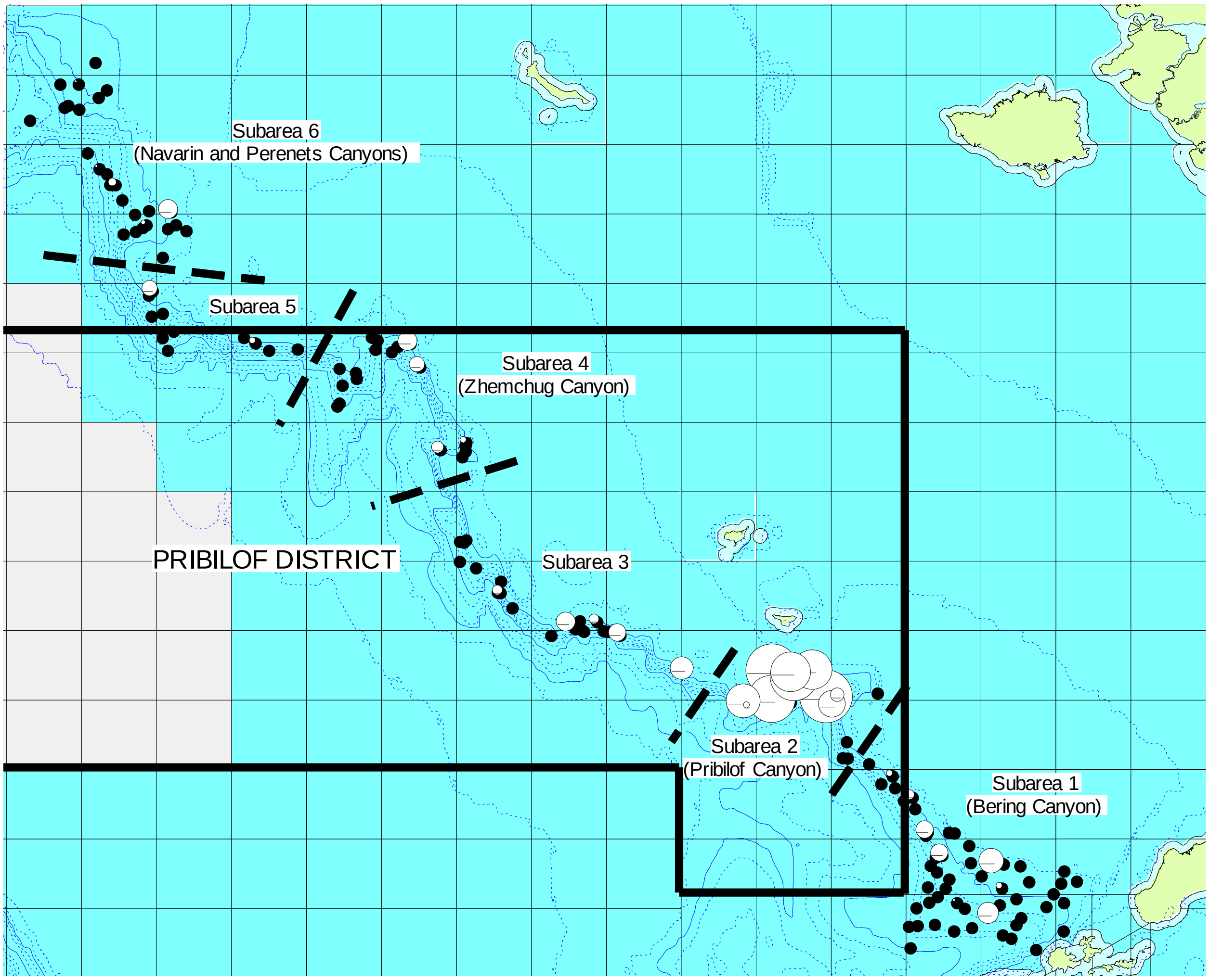


Figure 2. 2002 slope survey tow locations (black circles) and golden king crab CPUE (kg/sq-km; white circles; largest circle = 510 kg/sq-km); squares are 1° longitude x 30' latitude State statistical areas.

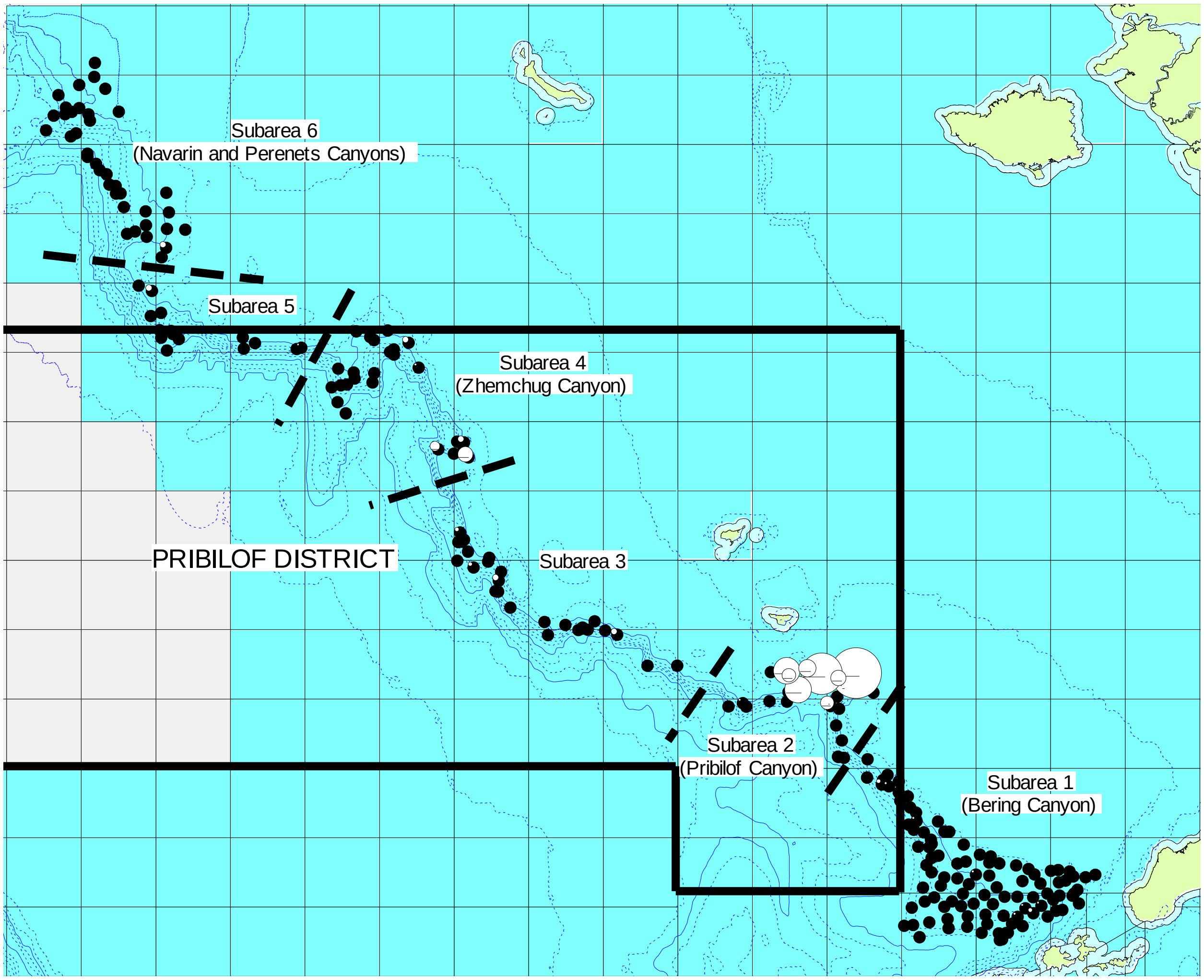


Figure 3. 2004 slope survey tow locations (black circles) and golden king crab CPUE (kg/sq-km; white circles; largest circle = 2,300 kg/sq-km); squares are 1° longitude x 30' latitude State statistical areas.

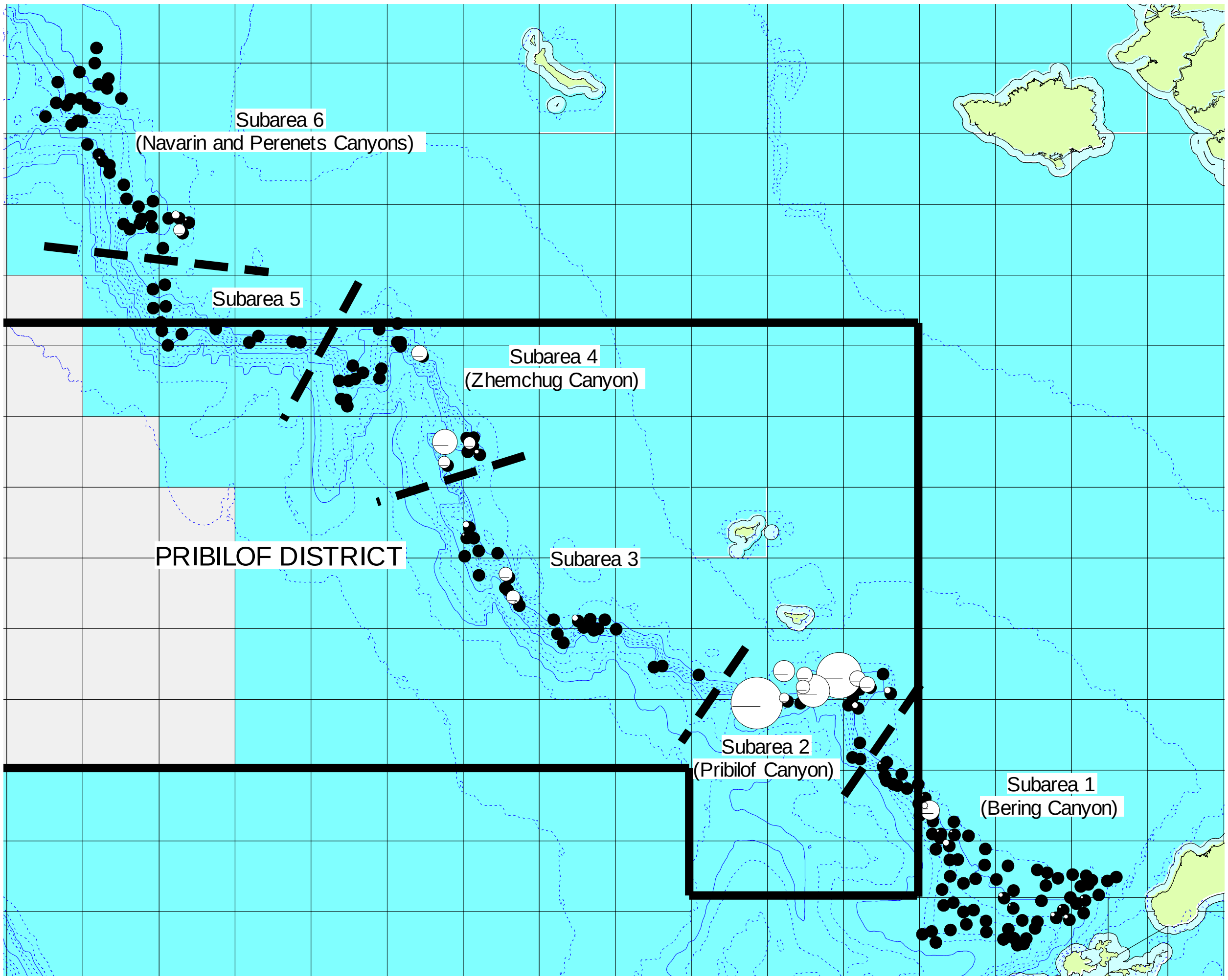


Figure 4. 2008 slope survey tow locations (black circles) and golden king crab CPUE (kg/sq-km; white circles; largest circle = 1,700 kg/sq-km); squares are 1° longitude x 30' latitude State statistical areas.

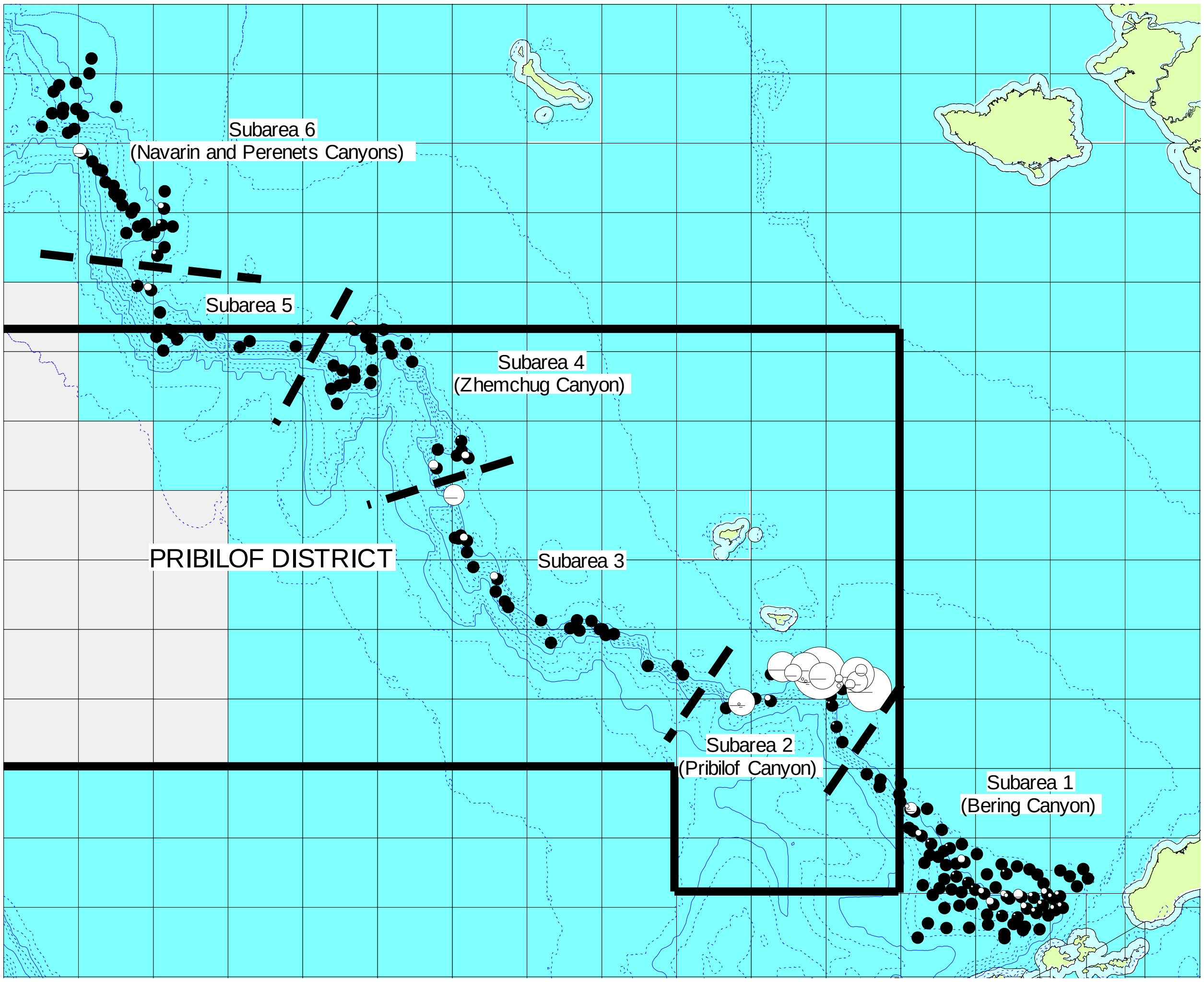


Figure 5. 2010 slope survey tow locations (black circles) and golden king crab CPUE (kg/sq-km; white circles; largest circle = 2,700 kg/sq-km); squares are 1° longitude x 30' latitude State statistical areas.

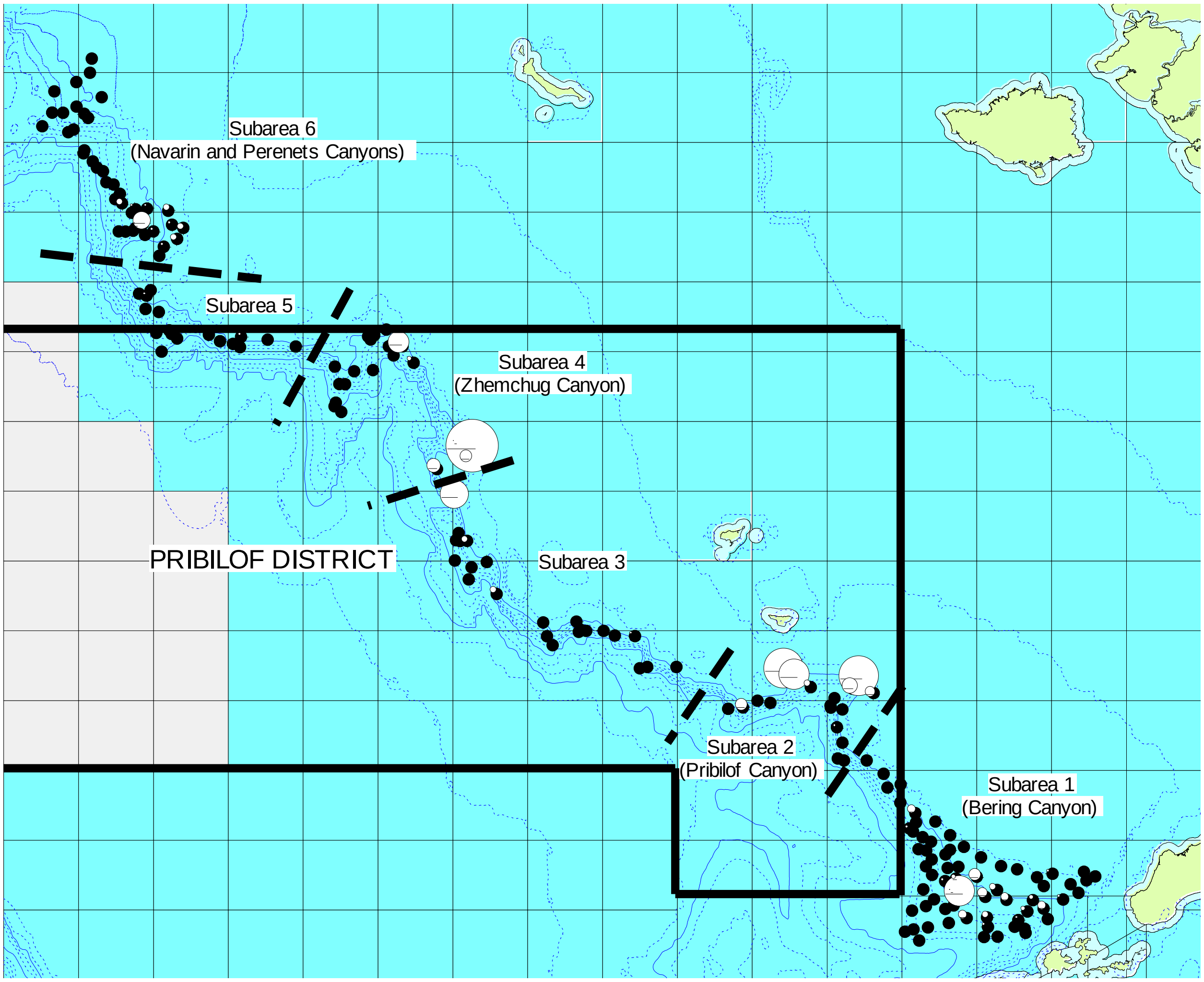


Figure 6. 2012 slope survey tow locations (black circles) and golden king crab CPUE (kg/sq-km; white circles; largest circle = 2,000 kg/sq-km); squares are 1° longitude x 30' latitude State statistical areas.

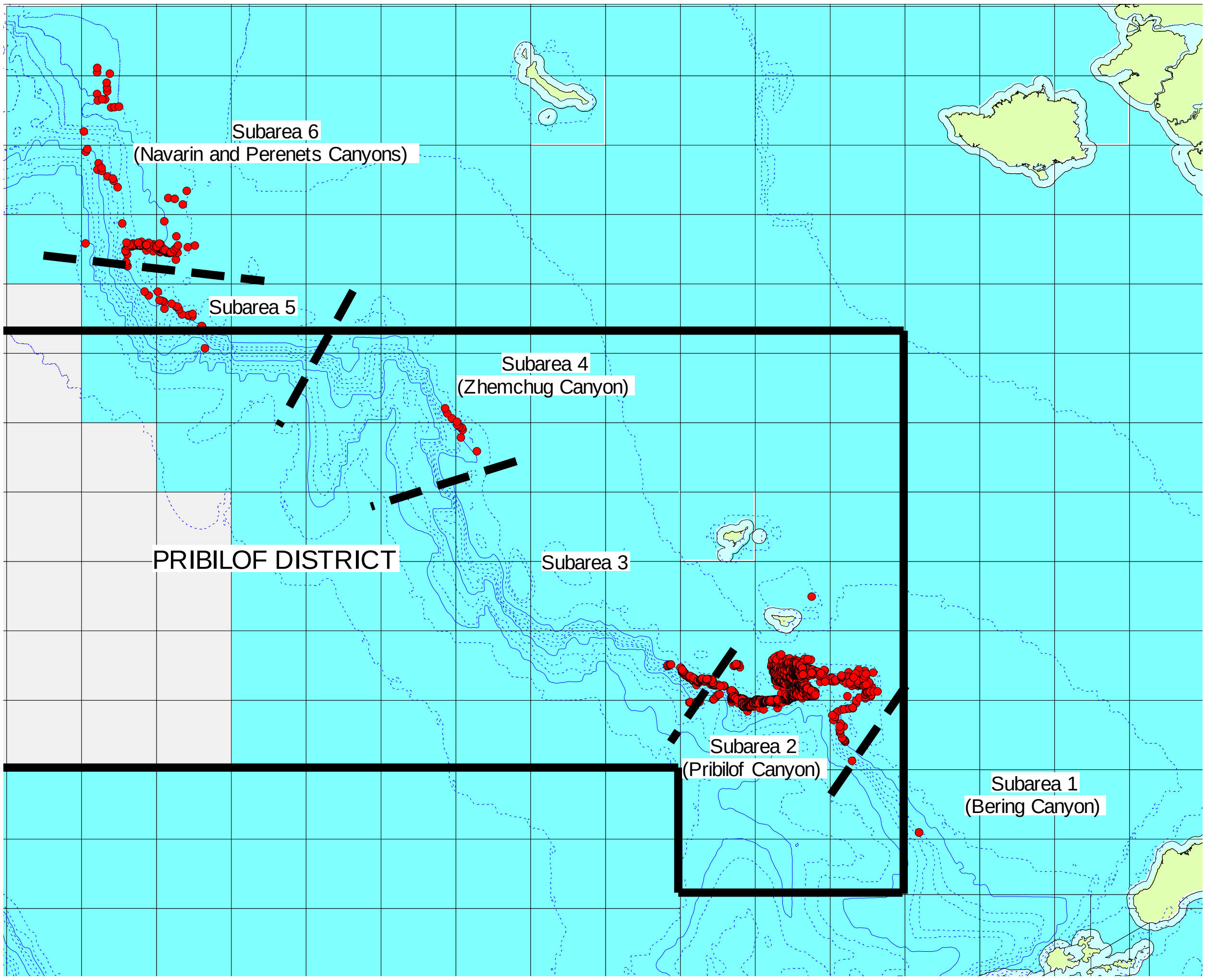


Figure 7. Locations of all pots sampled by observers during Bering Sea golden king crab fisheries (n = 6,104), 1992–2014; pots north of the Pribilof District northern boundary were fished during the Northern District – Saint Matthew Island Section fishery; squares are 1° longitude x 30' latitude State statistical areas.

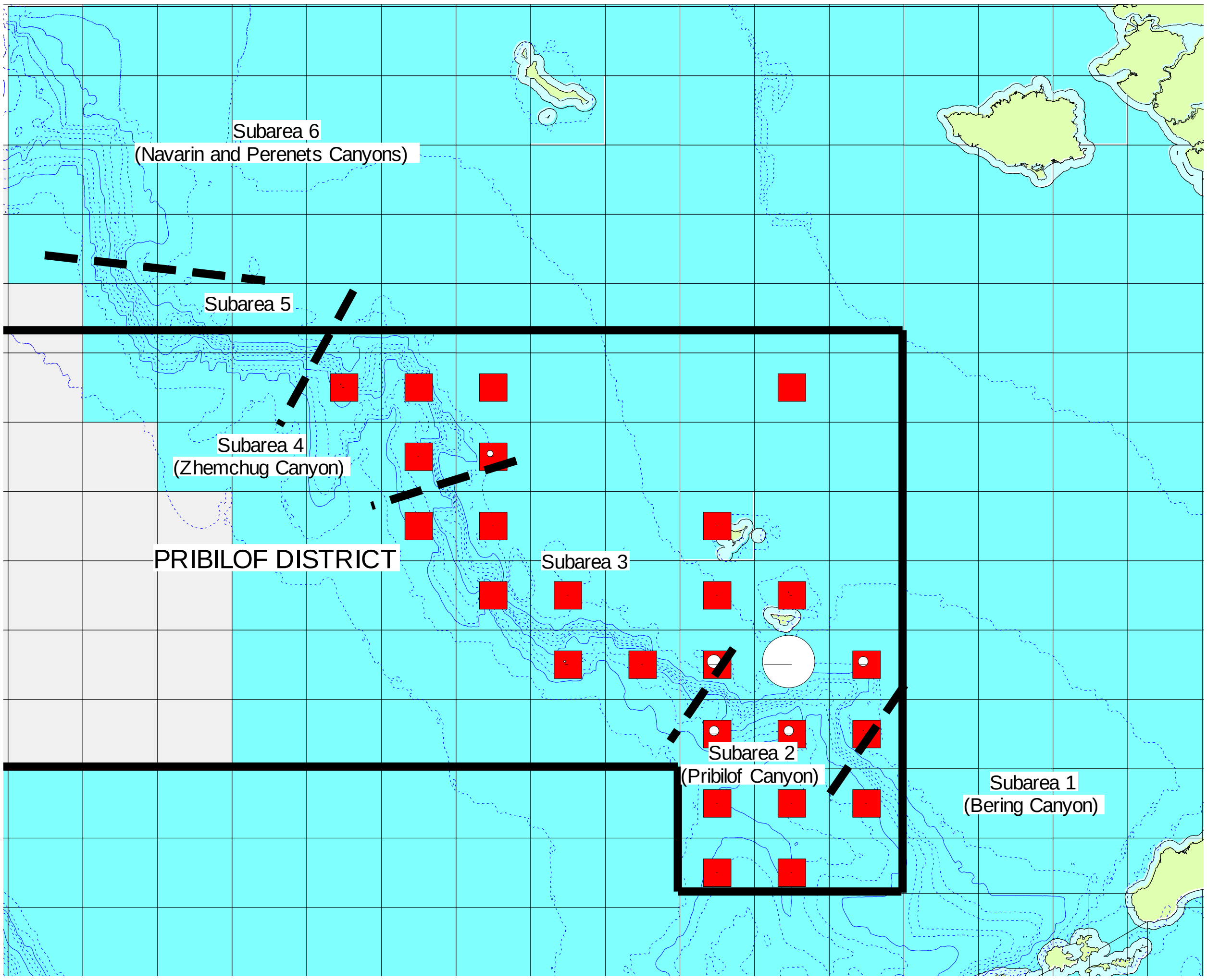


Figure 8. Statistical areas with reported catch during the 1985–2014 Pribilof District golden king crab fisheries: filled red squares denote statistical areas with reported catch; size of overlain white circles are proportional to the percentage of the total 1985–2014 catch reported from statistical area (biggest circle = 68% of total); squares are 1° longitude x 30' latitude State statistical areas.

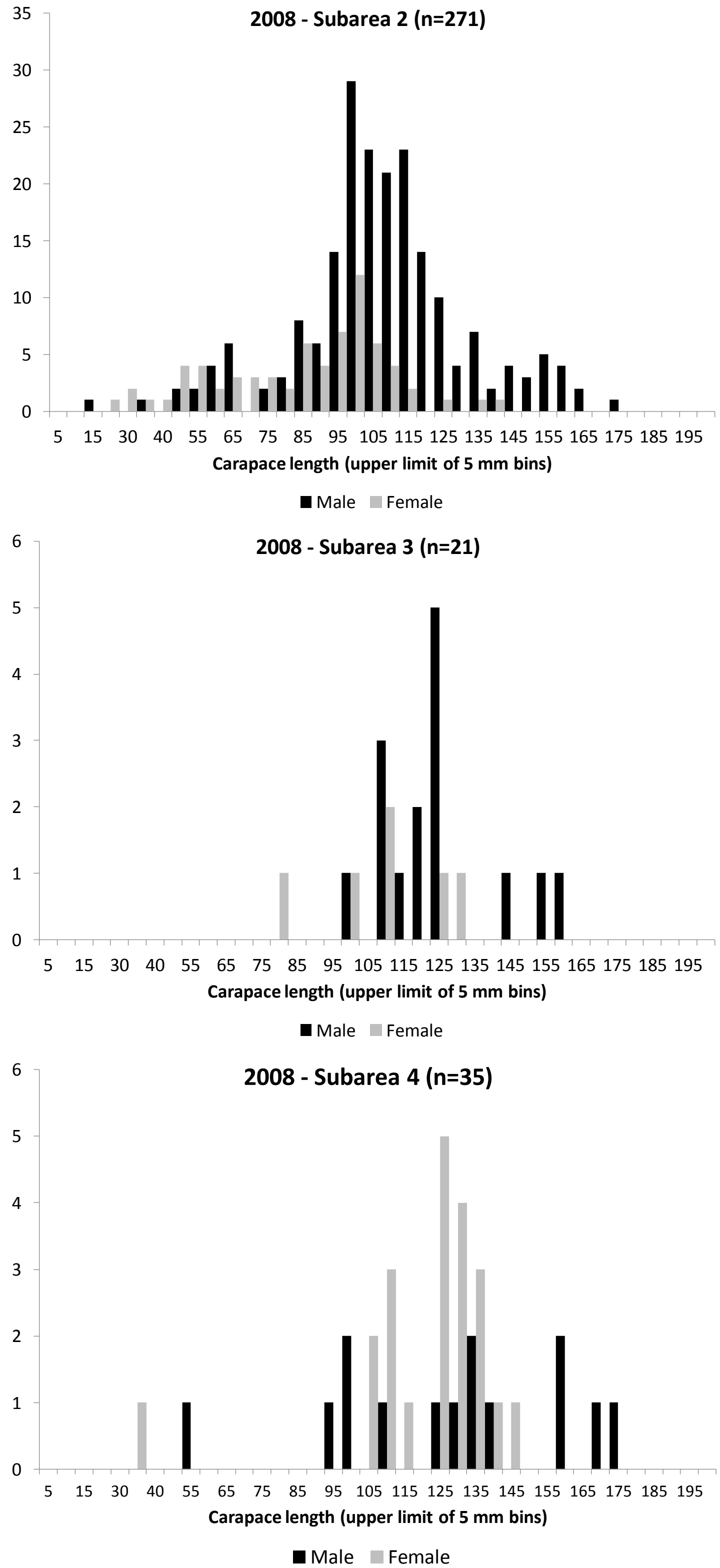


Figure 9. Size distribution of measured golden king crab during the 2008 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.

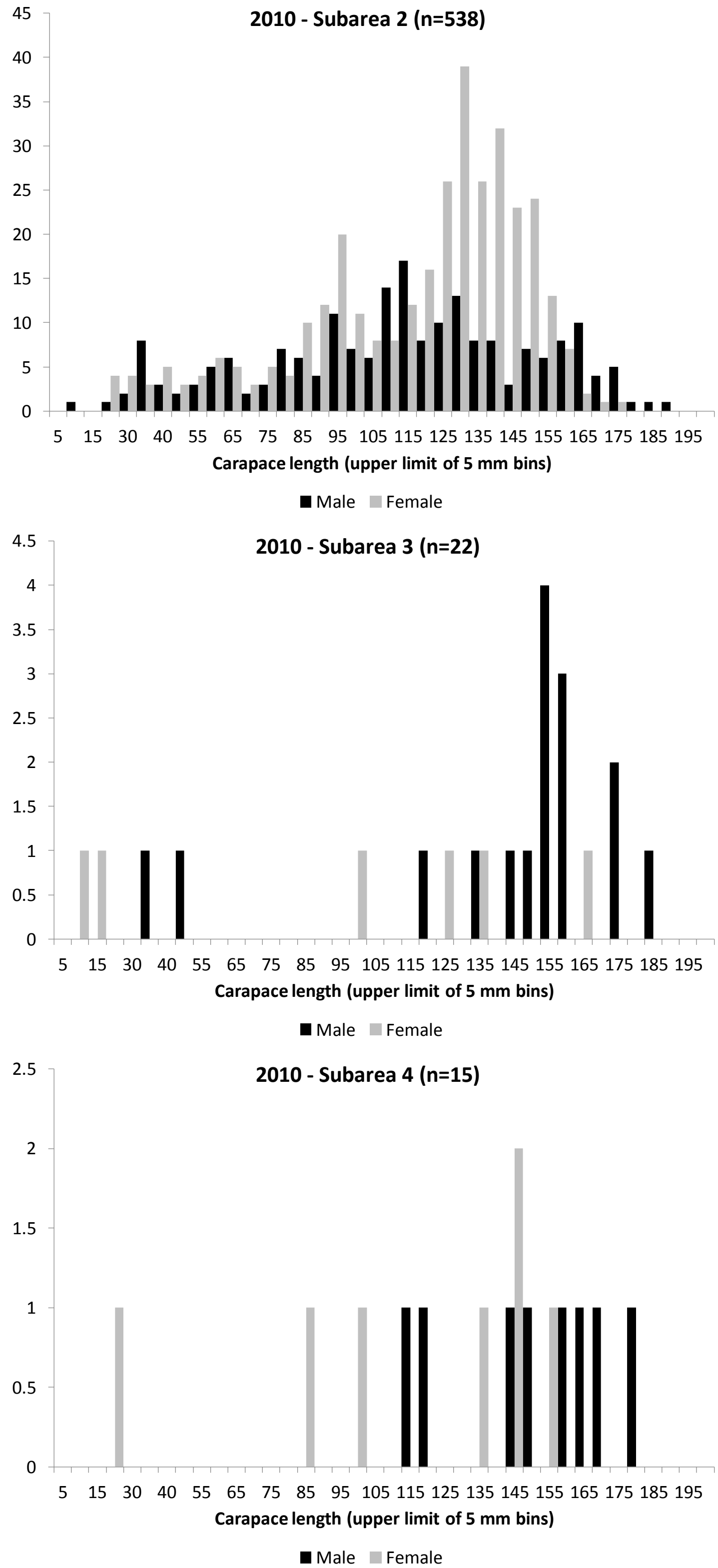


Figure 10. Size distribution of measured golden king crab during the 2010 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.

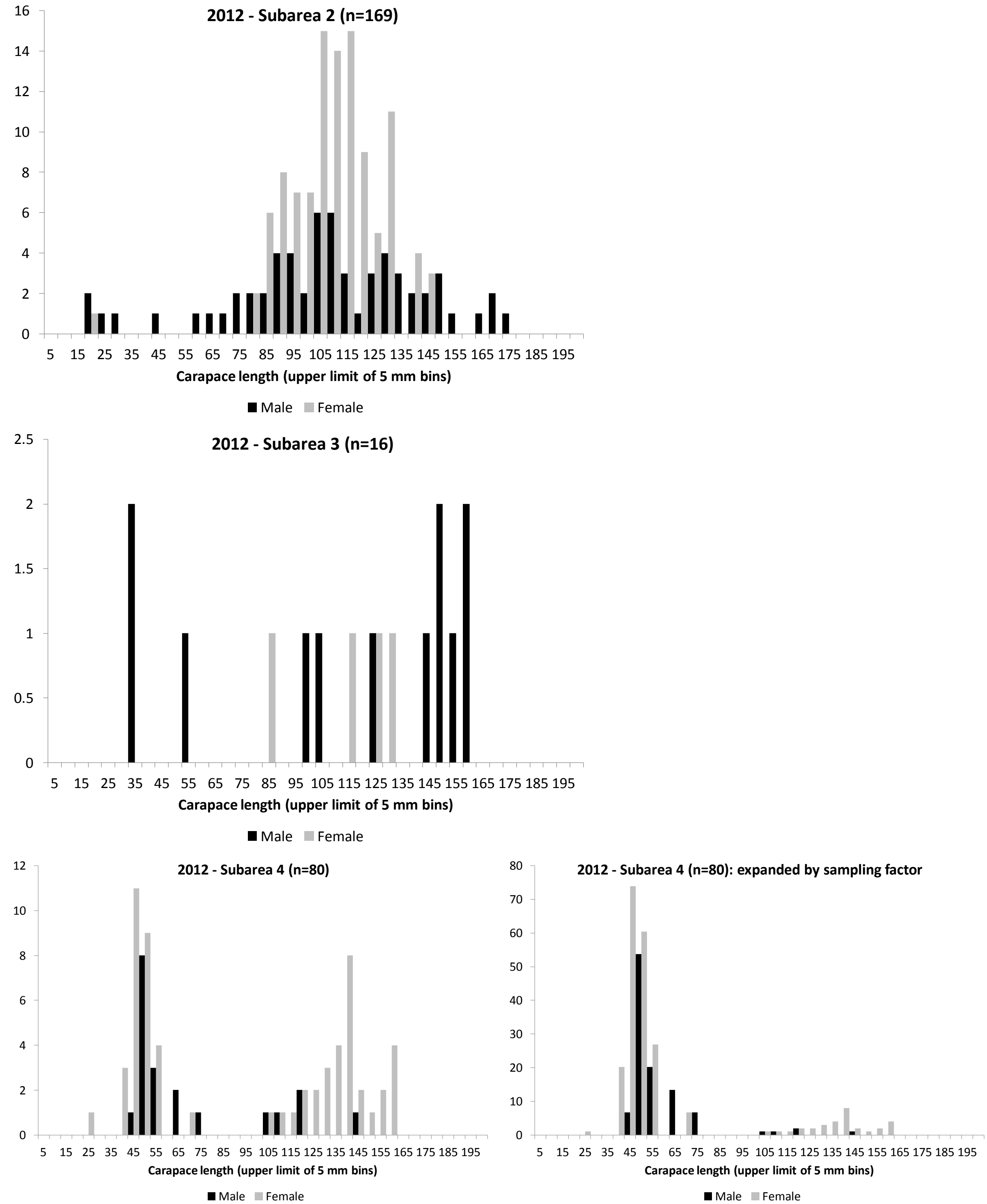


Figure 12. Size distribution of measured golden king crab during the 2012 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.

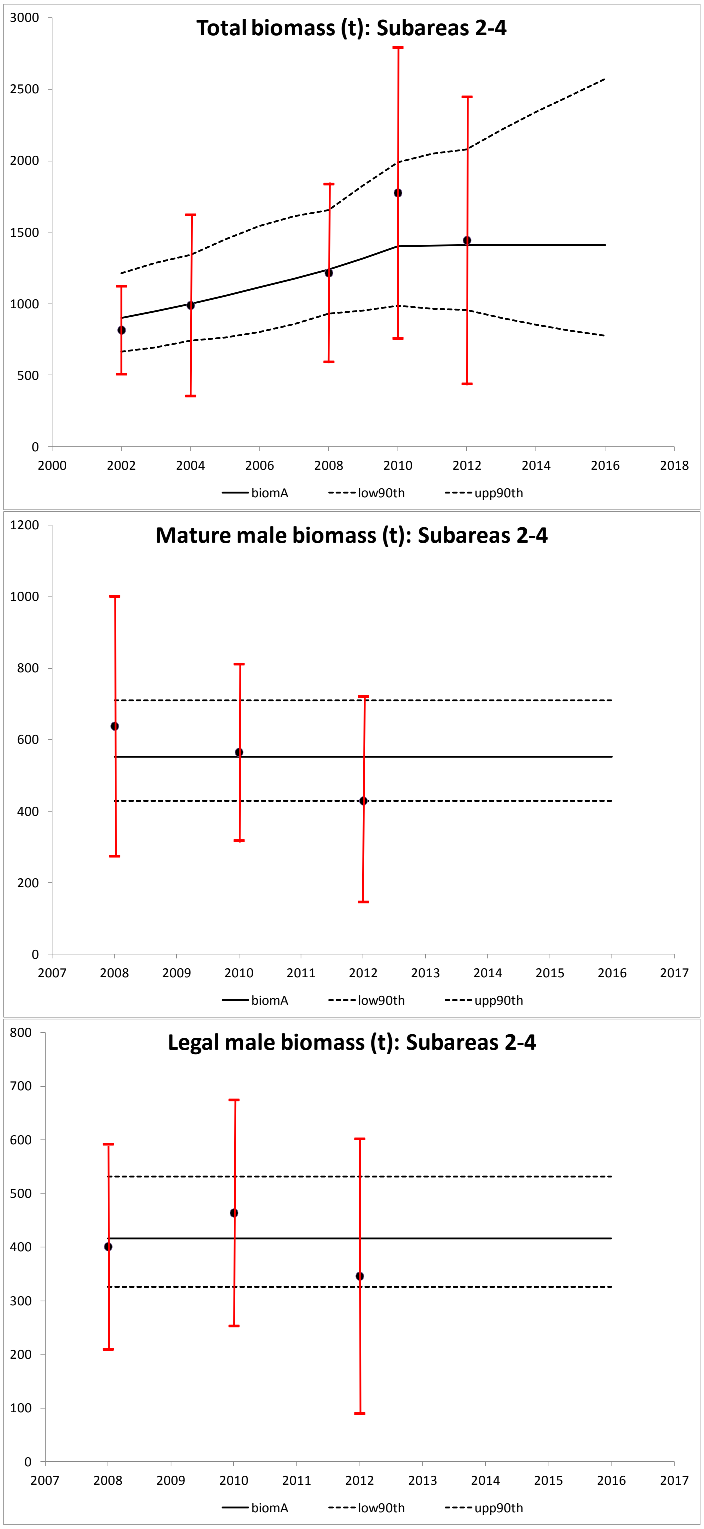


Figure 13. Plots of estimated and projected-into-2016 biomass of total, mature male, and legal male golden king crab in NMFS slope survey Subareas 2–4 with 90% confidence intervals and survey area-swept estimates; red bars are survey estimate plus/minus 2 standard errors.

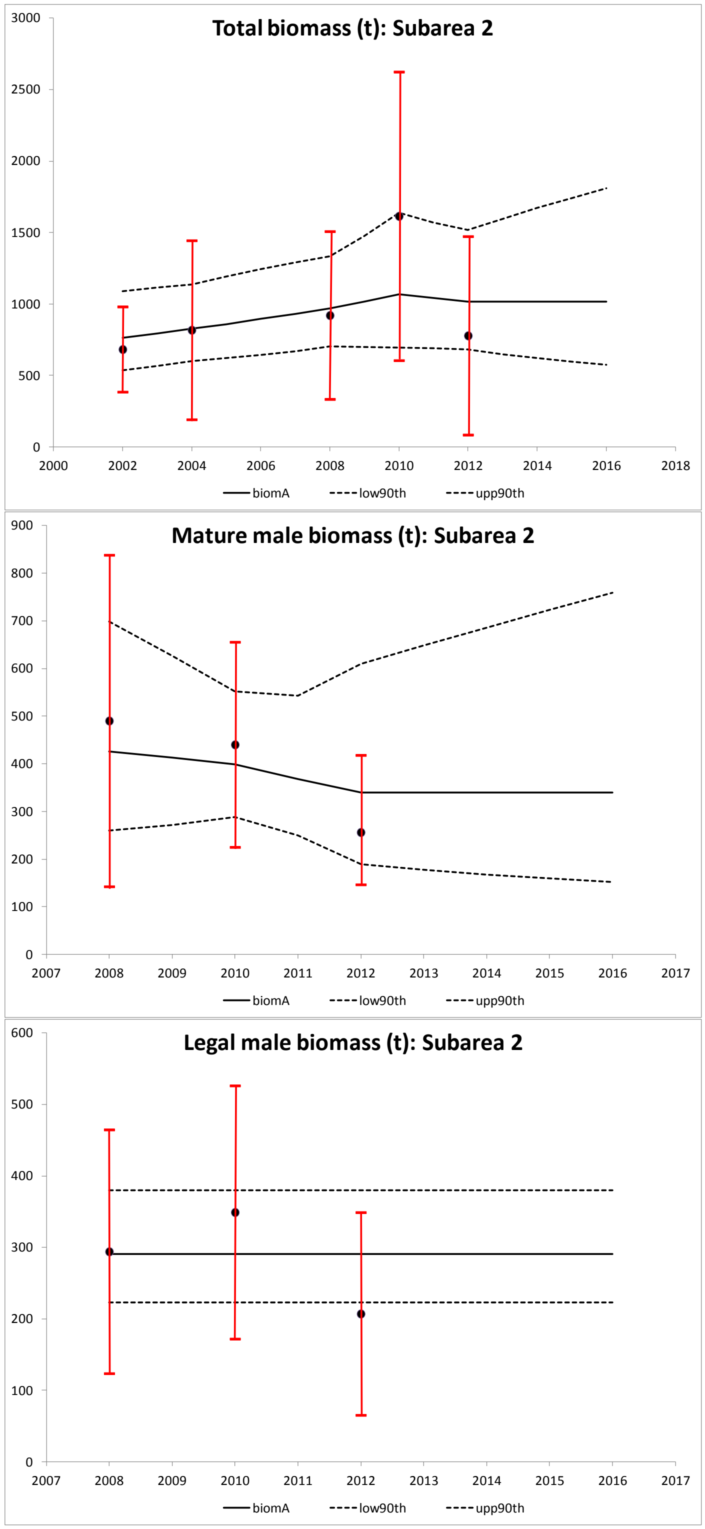


Figure 14. Plots of estimated and projected-into-2016 biomass of total, mature male, and legal male golden king crab in NMFS slope survey Subarea 2 with 90% confidence intervals and survey area-swept estimates; red bars are survey estimate plus/minus 2 standard errors.

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

**Total biomass (t) estimates for subareas 2-4, 2002-2012 slope surveys**

| **re.dat file** | | | | |
|---|---|---|---|---|
| 2002 | #Start year of model | | | |
| 2016 | #End year of model | | | |
| 5 | #number of survey estimates | | | |
| #Years of survey | | | | |
| 2002 | 2004 | 2008 | 2010 | 2012 |
| #Biomass estimates | | | | |
| 816 | 989 | 1216 | 1776 | 1444 |
| #Coefficients of variation for biomass estimates | | | | |
| 0.19 | 0.32 | 0.26 | 0.29 | 0.35 |

| **rwout.rep file** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| yrs_srv | | | | | | | | | | | | | | | |
| | 2002 | 2004 | 2008 | 2010 | 2012 | | | | | | | | | | |
| srv_est | | | | | | | | | | | | | | | |
| | 816 | 989 | 1216 | 1776 | 1444 | | | | | | | | | | |
| srv_sd | | | | | | | | | | | | | | | |
| | 0.188318 | 0.312233 | 0.25576 | 0.284166 | 0.339939 | | | | | | | | | | |
| yrs | | | | | | | | | | | | | | | |
| | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
| LCI | | | | | | | | | | | | | | | |
| | 629.437 | 656.433 | 701.98 | 720.12 | 754.662 | 806.877 | 882.1 | 894.822 | 923.012 | 898.032 | 888.492 | 825.005 | 773.028 | 728.958 | 690.711 |
| biomA | | | | | | | | | | | | | | | |
| | 898.729 | 947.241 | 998.371 | 1054.23 | 1113.21 | 1175.49 | 1241.26 | 1318.69 | 1400.94 | 1406.26 | 1411.6 | 1411.6 | 1411.6 | 1411.6 | 1411.6 |
| UCI | | | | | | | | | | | | | | | |
| | 1283.23 | 1366.88 | 1419.91 | 1543.35 | 1642.11 | 1712.51 | 1746.66 | 1943.33 | 2126.34 | 2202.12 | 2242.7 | 2415.29 | 2577.69 | 2733.52 | 2884.89 |
| low90th | | | | | | | | | | | | | | | |
| | 666.517 | 696.286 | 742.863 | 765.61 | 803.314 | 857.176 | 931.878 | 952.361 | 987.031 | 965.15 | 957.12 | 899.382 | 851.578 | 810.642 | 774.792 |
| upp90th | | | | | | | | | | | | | | | |
| | 1211.84 | 1288.65 | 1341.76 | 1451.65 | 1542.66 | 1612.02 | 1653.36 | 1825.92 | 1988.42 | 2048.98 | 2081.89 | 2215.55 | 2339.92 | 2458.08 | 2571.82 |
| biomsd | | | | | | | | | | | | | | | |
| | 6.80098 | 6.85355 | 6.90613 | 6.96056 | 7.015 | 7.06944 | 7.12388 | 7.18439 | 7.2449 | 7.24869 | 7.25248 | 7.25248 | 7.25248 | 7.25248 | 7.25248 |
| biomsd.sd | | | | | | | | | | | | | | | |
| | 0.181712 | 0.187108 | 0.179704 | 0.194463 | 0.198334 | 0.191976 | 0.174274 | 0.19784 | 0.212886 | 0.228819 | 0.236202 | 0.274026 | 0.307228 | 0.337176 | 0.364673 |

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

**Mature (>=107 mm CL) male biomass (t) estimates for subareas 2-4, 2008-2012 slope surveys**

| **re.dat file** | | |
|---|---|---|
| 2008 | #Start year of model | |
| 2016 | #End year of model | |
| 3 | #number of survey estimates | |
| #Years of survey | | |
| 2008 | 2010 | 2012 |
| #Biomass estimates | | |
| 638 | 565 | 429 |
| #Coefficients of variation for biomass estimates | | |
| 0.29 | 0.22 | 0.34 |

| **rwout.rep file** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| yrs_srv | | | | | | | | | |
| | 2008 | 2010 | 2012 | | | | | | |
| srv_est | | | | | | | | | |
| | 638 | 565 | 429 | | | | | | |
| srv_sd | | | | | | | | | |
| | 0.284166 | 0.217406 | 0.330745 | | | | | | |
| yrs | | | | | | | | | |
| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
| LCI | | | | | | | | | |
| | 408.72 | 408.738 | 408.744 | 408.724 | 408.686 | 408.673 | 408.661 | 408.649 | 408.636 |
| biomA | | | | | | | | | |
| | 551.765 | 551.76 | 551.755 | 551.749 | 551.743 | 551.743 | 551.743 | 551.743 | 551.743 |
| UCI | | | | | | | | | |
| | 744.872 | 744.828 | 744.803 | 744.824 | 744.878 | 744.9 | 744.923 | 744.945 | 744.967 |
| low90th | | | | | | | | | |
| | 428.915 | 428.93 | 428.936 | 428.917 | 428.882 | 428.871 | 428.861 | 428.85 | 428.839 |
| upp90th | | | | | | | | | |
| | 709.8 | 709.764 | 709.743 | 709.759 | 709.8 | 709.818 | 709.836 | 709.854 | 709.872 |
| biomsd | | | | | | | | | |
| | 6.31312 | 6.31311 | 6.3131 | 6.31309 | 6.31308 | 6.31308 | 6.31308 | 6.31308 | 6.31308 |
| biomsd.sd | | | | | | | | | |
| | 0.153107 | 0.153081 | 0.153069 | 0.153089 | 0.153131 | 0.153146 | 0.153162 | 0.153177 | 0.153193 |

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

**Legal (>=124 mm CL) male biomass (t) estimates for subareas 2-4, 2008-2012 slope surveys**

| **re.dat file** | | |
|---|---|---|
| 2008 | #Start year of model | |
| 2016 | #End year of model | |
| 3 | #number of survey estimates | |
| #Years of survey | | |
| 2008 | 2010 | 2012 |
| #Biomass estimates | | |
| 401 | 464 | 346 |
| #Coefficients of variation for biomass estimates | | |
| 0.24 | 0.23 | 0.37 |

| **rwout.rep file** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| yrs_srv | | | | | | | | | |
| | 2008 | 2010 | 2012 | | | | | | |
| srv_est | | | | | | | | | |
| | 401 | 464 | 346 | | | | | | |
| srv_sd | | | | | | | | | |
| | 0.236648 | 0.227042 | 0.358197 | | | | | | |
| yrs | | | | | | | | | |
| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
| LCI | | | | | | | | | |
| | 310.83 | 310.831 | 310.832 | 310.829 | 310.823 | 310.819 | 310.814 | 310.809 | 310.805 |
| biomA | | | | | | | | | |
| | 416.246 | 416.246 | 416.247 | 416.246 | 416.244 | 416.244 | 416.244 | 416.244 | 416.244 |
| UCI | | | | | | | | | |
| | 557.413 | 557.412 | 557.412 | 557.415 | 557.42 | 557.429 | 557.437 | 557.445 | 557.454 |
| low90th | | | | | | | | | |
| | 325.766 | 325.767 | 325.768 | 325.765 | 325.76 | 325.756 | 325.752 | 325.748 | 325.744 |
| upp90th | | | | | | | | | |
| | 531.856 | 531.855 | 531.855 | 531.857 | 531.862 | 531.868 | 531.875 | 531.882 | 531.888 |
| biomsd | | | | | | | | | |
| | 6.03128 | 6.03128 | 6.03128 | 6.03128 | 6.03127 | 6.03127 | 6.03127 | 6.03127 | 6.03127 |
| biomsd.sd | | | | | | | | | |
| | 0.148995 | 0.148994 | 0.148992 | 0.148997 | 0.149004 | 0.149011 | 0.149019 | 0.149027 | 0.149034 |

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

**Total biomass (t) estimates for subarea 2, 2002-2012 slope surveys**

| **re.dat file** | | | | |
|---|---|---|---|---|
| 2002 | #Start year of model | | | |
| 2016 | #End year of model | | | |
| 5 | #number of survey estimates | | | |
| #Years of survey | | | | |
| 2002 | 2004 | 2008 | 2010 | 2012 |
| #Biomass estimates | | | | |
| 682 | 817 | 920 | 1614 | 778 |
| #Coefficients of variation for biomass estimates | | | | |
| 0.22 | 0.38 | 0.32 | 0.31 | 0.45 |

| **rwout.rep file** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| yrs_srv | | | | | | | | | | | | | | | |
| | 2002 | 2004 | 2008 | 2010 | 2012 | | | | | | | | | | |
| srv_est | | | | | | | | | | | | | | | |
| | 682 | 817 | 920 | 1614 | 778 | | | | | | | | | | |
| srv_sd | | | | | | | | | | | | | | | |
| | 0.217406 | 0.367261 | 0.312233 | 0.302917 | 0.429421 | | | | | | | | | | |
| yrs | | | | | | | | | | | | | | | |
| | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
| LCI | | | | | | | | | | | | | | | |
| | 501.727 | 530.855 | 565.671 | 582.598 | 603.885 | 629.85 | 661.103 | 651.433 | 639.392 | 639.842 | 632.362 | 595.772 | 564.672 | 537.6 | 513.629 |
| biomA | | | | | | | | | | | | | | | |
| | 765.392 | 795.334 | 826.446 | 859.928 | 894.766 | 931.015 | 968.733 | 1016.4 | 1066.42 | 1042.21 | 1018.54 | 1018.54 | 1018.54 | 1018.54 | 1018.54 |
| UCI | | | | | | | | | | | | | | | |
| | 1167.62 | 1191.58 | 1207.44 | 1269.27 | 1325.76 | 1376.18 | 1419.51 | 1585.86 | 1778.65 | 1697.6 | 1640.55 | 1741.31 | 1837.22 | 1929.73 | 2019.79 |
| low90th | | | | | | | | | | | | | | | |
| | 536.964 | 566.491 | 601.209 | 620.218 | 643.275 | 670.677 | 702.97 | 699.711 | 694.179 | 692.03 | 682.709 | 649.397 | 620.824 | 595.745 | 573.37 |
| upp90th | | | | | | | | | | | | | | | |
| | 1091 | 1116.62 | 1136.07 | 1192.28 | 1244.58 | 1292.41 | 1334.97 | 1476.44 | 1638.28 | 1569.58 | 1519.57 | 1597.52 | 1671.04 | 1741.39 | 1809.35 |
| biomsd | | | | | | | | | | | | | | | |
| | 6.64039 | 6.67876 | 6.71714 | 6.75685 | 6.79656 | 6.83628 | 6.87599 | 6.92403 | 6.97206 | 6.9491 | 6.92613 | 6.92613 | 6.92613 | 6.92613 | 6.92613 |
| biomsd.sd | | | | | | | | | | | | | | | |
| | 0.215476 | 0.206262 | 0.19343 | 0.198649 | 0.200602 | 0.199385 | 0.194939 | 0.226966 | 0.260994 | 0.248915 | 0.243196 | 0.273606 | 0.300959 | 0.326026 | 0.349298 |

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

**Mature (>=107 mm CL) male biomass (t) estimates for subarea 2, 2008-2012 slope surveys**

| **re.dat file** | | | |
|---|---|---|---|
| 2008 | #Start year of model | | |
| 2016 | #End year of model | | |
| 3 | #number of survey estimates | | |
| #Years of survey | | | |
| 2008 | 2010 | 2012 | |
| #Biomass estimates | | | |
| 490 | 440 | 256 | |
| #Coefficients of variation for biomass estimates | | | |
| 0.36 | 0.24 | 0.32 | |

| **rwout.rep file** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| yrs_srv | | | | | | | | | |
| | 2008 | 2010 | 2012 | | | | | | |
| srv_est | | | | | | | | | |
| | 490 | 440 | 256 | | | | | | |
| srv_sd | | | | | | | | | |
| | 0.34909 | 0.236648 | 0.312233 | | | | | | |
| yrs | | | | | | | | | |
| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
| LCI | | | | | | | | | |
| | 236.563 | 250.548 | 271.48 | 231.49 | 168.758 | 156.739 | 146.522 | 137.661 | 129.86 |
| biomA | | | | | | | | | |
| | 426.017 | 412.406 | 399.23 | 367.956 | 339.133 | 339.133 | 339.133 | 339.133 | 339.133 |
| UCI | | | | | | | | | |
| | 767.196 | 678.825 | 587.094 | 584.872 | 681.513 | 733.775 | 784.941 | 835.466 | 885.654 |
| low90th | | | | | | | | | |
| | 260.02 | 271.441 | 288.838 | 249.389 | 188.79 | 177.438 | 167.678 | 159.125 | 151.522 |
| upp90th | | | | | | | | | |
| | 697.987 | 626.577 | 551.811 | 542.894 | 609.201 | 648.175 | 685.902 | 722.769 | 759.037 |
| biomsd | | | | | | | | | |
| | 6.05448 | 6.02201 | 5.98954 | 5.90796 | 5.82639 | 5.82639 | 5.82639 | 5.82639 | 5.82639 |
| biomsd.sd | | | | | | | | | |
| | 0.300135 | 0.254263 | 0.196759 | 0.236443 | 0.356084 | 0.393781 | 0.428172 | 0.459999 | 0.489763 |

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

**Legal (>=124 mm CL) male biomass (t) estimates for subarea 2, 2008-2012 slope surveys**

| **re.dat file** | | | |
|---|---|---|---|
| 2008 | #Start year of model | | |
| 2016 | #End year of model | | |
| 3 | #number of survey estimates | | |
| #Years of survey | | | |
| 2008 | 2010 | 2012 | |
| #Biomass estimates | | | |
| 294 | 349 | 207 | |
| #Coefficients of variation for biomass estimates | | | |
| 0.29 | 0.25 | 0.34 | |

| **rwout.rep file** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| yrs_srv | | | | | | | | | |
| | 2008 | 2010 | 2012 | | | | | | |
| srv_est | | | | | | | | | |
| | 294 | 349 | 207 | | | | | | |
| srv_sd | | | | | | | | | |
| | 0.284166 | 0.246221 | 0.330745 | | | | | | |
| yrs | | | | | | | | | |
| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
| LCI | | | | | | | | | |
| | 211.81 | 211.814 | 211.818 | 211.805 | 211.755 | 211.744 | 211.733 | 211.723 | 211.712 |
| biomA | | | | | | | | | |
| | 291.091 | 291.091 | 291.09 | 291.083 | 291.075 | 291.075 | 291.075 | 291.075 | 291.075 |
| UCI | | | | | | | | | |
| | 400.047 | 400.038 | 400.029 | 400.033 | 400.107 | 400.128 | 400.148 | 400.168 | 400.189 |
| low90th | | | | | | | | | |
| | 222.914 | 222.918 | 222.922 | 222.909 | 222.864 | 222.854 | 222.845 | 222.835 | 222.826 |
| upp90th | | | | | | | | | |
| | 380.119 | 380.112 | 380.105 | 380.106 | 380.163 | 380.18 | 380.196 | 380.212 | 380.228 |
| biomsd | | | | | | | | | |
| | 5.67364 | 5.67363 | 5.67363 | 5.67361 | 5.67358 | 5.67358 | 5.67358 | 5.67358 | 5.67358 |
| biomsd.sd | | | | | | | | | |
| | 0.162218 | 0.162207 | 0.162196 | 0.162214 | 0.162322 | 0.162348 | 0.162374 | 0.1624 | 0.162426 |

Appendix C. Draft Pribilof Islands (Pribilof District) golden king crab stock structure template (adapted from Spencer et al. 2010). Page 1 of 2.

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

Appendix C. Page 2 of 2.

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