**PRIBILOF ISLANDS GOLDEN KING CRAB**

**TIER 4 STOCK ASSESSMENT CONSIDERATIONS**

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**Introduction**

The Pribilof Islands (Pribilof District) golden king crab (PIGKC) stock is currently assessed using Tier-5 methods (2012 Crab SAFE); however, the SSC (June 2012 minutes) has encouraged investigation into the use of results from the (nominally) biennial NMFS-AFSC eastern Bering Sea (EBS) upper continental slope survey (Hoff and Britt 2011) for developing a Tier-4 assessment, which presupposes a reliable estimate of “current survey biomass” in terms of which to define proxy values of BMSY stock size and minimum stock size threshold MSST (2012 Crab SAFE Introduction). This document presents some important considerations associated with implementing a Tier-4 PIGKC stock assessment and sketches a possible Tier-4 assessment strategy.

**The EBS upper continental slope survey**

Details on the EBS continental slope survey methods are provided in Hoff and Britt (2011). Standardized surveys have been conducted in 2002, 2004, 2008, 2010, and 2012; although intended to be biennial, no survey was performed in 2006. The survey occurs during June–July and the surveyed region consists of a swath of (trawlable[[1]](#footnote-1)) ocean bottom at depths of 200–1,200 m extending northwest from near Dutch Harbor some 600 mi along the EBS continental slope (Figure 1). The survey area is divided into 6 geographic subareas running north-to-south in the survey area: Bering Canyon area, Pribilof Canyon area, the inter-canyon area between Pribilof Canyon and Zhemchug Canyon, the Zhemchug Canyon area, the inter-canyon area between Zhemchug and Pervenets Canyon, and the Pervenets and Navarin Canyons area. The subareas are partitioned into five 200-m depth zones, from 200 to 1,200 m. The survey samples approximately 200 locations by stratified simple random sampling from the 30 area-by-depth-zone strata. In 2010 sampling densities within strata ranged from one haul per 112.39 km2 to one haul per 368.96 km2 (survey tow sampling is denser at depths < 800 m), and the mean sampling density over the total surveyed area of 32,723 km2 was one haul per 204.48 km2. That sampling density compares to one haul per 400 nmi2 (1,372 km2) for the standard stations in the eastern Bering Sea continental shelf survey. The survey uses a Poly Nor’eastern high-opening bottom trawl equipped with mud-sweep roller gear; the mudsweep roller gear was constructed of 203 mm solid rubber disks strung over 16 mm high-tensile chain. The standard tow is 30 minutes at 2.5 knots.

**Key Considerations**

Preliminary to the development of a Tier-4 PIGKC stock assessment methodology, at least four issues should be considered.

1. ***Limited biennial data series***. The set of available EBS slope-survey results useful for such an assessment consists only of those for 2008, 2010, and 2012, resulting in an extremely limited time series of abundance and biomass estimates by which to understand stock history and dynamics and to use in formulating credible management quantities. Length measurements on individual crab were not recorded during the first survey in 2002 (Claire Armistead, NMFS-AFSC Kodiak Laboratory, 18 March 2013 email) and incompletely so in 2004 (250 of 321 captured GKC in successful tows; Hoff and Britt 2005), precluding necessary Tier-4 sex-by-size-class estimates for those surveys, and no EBS slope survey was conducted in 2006. Moreover, how the mud-sweep roller gear used in the survey affects survey selectivity by size or sex is unknown, as is how such selectivity compares with that realized by the continental shelf survey gear, which does not use mud-sweep roller gear.
2. ***Determination of stock boundaries for assessment***. The boundaries of the PIGKC fishery are defined by the boundaries of the Pribilof District of Registration Area Q and, within that area, the fishery has occurred mostly in the Pribilof Canyon area to the south of the Pribilof Islands (Figure 1). By contrast, the surveyed area extends north into the Northern District of Registration Area Q (north of 58° 39’ N) and south into the Aleutian Islands Registration Area O (south of 54° 36' N). Though a large proportion of the GKC encountered in the slope survey are caught in the Pribilof Canyon area, some GKC crab are captured sporadically throughout the surveyed area (Hoff and Britt 2003, 2005, 2009, 2011), and a Northern District GKC fishery has been successfully prosecuted historically, mostly to the west of St. Matthew Island in the area of the northern-most extent of the slope survey, with a peak harvest of 414,000 lb in 1987 (Fitch et al. 2012). All of this serves to underscore the fact that the PIGKC “stock” is, like some other fisheries stocks, an artificial construct, depending for its existence on the reification of administrative boundaries rather than on biological reality. It is thus inherently unclear how slope-survey results should be used for its assessment.
3. ***Fishing season, stock-assessment schedule, and survey schedule.*** The PIGKC fishery takes place from January 1 to December 31 under the conditions of a Commissioner’s permit, as mandated by State of Alaska regulation **5 AAC 34.910 (b) (3)**. This poses a number of timing difficulties given the existing CPT assessment cycle, especially as the fishery can potentially occur, and historically has occurred, throughout the year (Table 1) and may be in progress at the time of either the Spring or Fall CPT meetings. Under the present Tier-5 assessment methodology this problem is handled by determining both overfishing status in year *t-1* and the OFL for year *t+1* at the time of the Spring CPT meeting of year *t* so that the status of the current year’s fishery is immaterial. Under a Tier-4 approach, however, year-*t* catch and bycatch data are needed in projecting stock biomass into year *t+1* for subsequent OFL calculations. In addition, the survey’s biennial cycle is in itself problematic because “off-year” assessment computations would be dependent on multi-year projections of the most recent survey-based estimates. Given the lack of other relevant data and the limited knowledge about PIGKC biology and population dynamics, such lengthy projections will necessarily be crude and can be expected to contribute substantial, and mostly unquantifiable, extra uncertainty to the assessment process.
4. ***Confidentiality of directed fishery data.*** The limited vessel participation of the PIGKC fishery, especially in recent years, means that confidentiality requirements can routinely obstruct communication of fishery data and assessment methods and results. This problem has plagued assessment efforts under the present Tier-5 approach, but the additional complexities of a Tier-4 approach would likely exacerbate it, making assessment documentation and presentation even more awkward.

In the author’s view, the considerations enumerated above conspire to raise doubt about whether the tradeoffs involved in moving to a Tier-4 approach would lead to a more meaningful or scientifically defensible assessment of the PIGKC stock. Nevertheless, a possible Tier-4 approach is sketched in what follows.

**Tier-4 Assessment Outline**

Under the approach presented here only the mature male component of the population is directly subject to assessment, with male PIGKC measuring at least 107 mm carapace length (CL) classified as mature, based on Otto and Cummiskey (1985). By State of Alaska regulation **5 AAC 34.920 (a)** the minimum legal size for PIGKC is 5.5 in carapace width, including spines, but a CL measurement of 124 mm is currently recognized as a proxy for legal size when no legal measurement is available (Table 3-5 in NPFMC 2007). PIGKC fishery observer data support the appropriateness of the surrogate legal measurement (Figure 2), and it is thus adopted here. Necessary length-to-weight conversions are computed using the equation $w=αl^{β}$ relating carapace length $l$ in millimeters to weight $w$ in grams, with α = 0.0002988 and β = 3.135 for males and α = 0.001424 and β = 2.781 for (ovigerous) females (Table 3-5, NPFMC 2007). These allometric models provide reasonably good descriptions of recent EBS slope-survey data (e.g. Figure 3). Instantaneous natural mortality M is set at the postulated default value of 0.18 yr-1 for BSAI king crab (NPFMC 2007) . The measure of stock biomass is taken to be mature male biomass (MMB) at the time of mating MMBmating, quantified in terms of estimated MMB with respect to Dec 31, as opposed to the standard Feb 15 date in place for some other BSAI stocks. This modification of the reference date so that it coincides with the end of the PIGKC fishery year simplifies assessment timing details; and in light of the fact that the available evidence suggests that golden king crab are best characterized as asynchronous and aseasonal spawners (Pengilly 2012 SAFE), the modified reference date is as defensible as, or at least no more arbitrary than, the standard date. Finally, the OFL and ABC are developed and reported with respect to MMB; that is, the OFL is a mature male OFL rather than a total or total male OFL. This ties the ABC to mature male biomass, as well, via $ABC=\left(1-0.2\right)OFL$, where the 20% buffer might be invoked for establishment of even-year limits to account for the biennial nature of the slope survey. These various conventions are summarized in Table 2.

For assessment purposes, the EBS slope survey, which takes place in June and July of even years, is assigned a nominal date of July 1. In recent years the PIGKC fishery, when prosecuted, tends to occur in the first half of the calendar year but has extended into September (Table 1). Because little is known about PIGKC molting and growth and the slope survey provides limited information about recruitment of juvenile crab, mature male stock dynamics are determined entirely by natural mortality and fishery removals between surveys, which might be considered a conservative or worst case (i.e. recruitment failure) provision. Observed/estimated removals can be extracted based on available timing information or at the end of the PIGKC fishery year for the default case in which little information is at hand (e.g. groundfish fishery bycatch mortality). In the directed fishery, for instance, it would be possible to account for catch and bycatch removals on a monthly basis using fish-ticket information. Then, given availability of results from the 2014 and subsequent biennial slope-surveys by August 15, availability of data on fishery removals through June 30 by August 15, suitable proxies for BMSY and MSST, and an agreed-upon, reasonable approach to forecasting fishery removals between 1 July and December 31, implementation of the Tier-4 assessment would begin with the Fall 2014 CPT. The steps in the Tier-4 assessment cycle (depicted schematically in Figure 5), through complete transition from the existing Tier-5 approach, are as follows:

1. Spring 2013 CPT

* Establish Tier-5 OFL for 2014

2. Fall 2014 CPT

* Do catch accounting to determine if overfishing occurred in 2013 (i.e. if total catch during Jan 1 – Dec 31 2013 exceeded the 2013 Tier-5 OFL).
* Set BMSY equal to mean of estimated MMB on Dec 31 of 2008, 2010, and 2012 and put MSST equal to ½ BMSY. (MMB on Dec 31 is obtained from survey MMB by applying natural mortality and estimated fishery removals during 1 July – Dec 31.)
* Project 2014 survey MMB to Dec 31 2014 to obtain 2014 MMBmating,projected. Determine if stock is approaching overfished condition (i.e. if MMB is projected to be below MSST on Dec 31 2014).
* Apply Tier-4 overfishing control rule to 2015 MMB0,projected (= 2014 MMBmating,projected) to get Tier-4 OFL for 2015.

3. Fall 2015 CPT

* Do catch accounting to determine if overfishing occurred in 2014 (i.e. if total catch during Jan 1 – Dec 31 2014 exceeded the 2014 Tier-5 OFL).
* Estimate MMB on Dec 31 2014 (= 2014 MMBmating) using 2014 survey data and applying natural mortality and estimated fishery removals during 1 July – Dec 31 2014. Determine if stock is overfished (i.e. if estimated 2014 MMBmating < MSST).
* Consider re-establishing BMSY and MSST with incorporation of estimated 2014 MMBmating.
* Project 2015 MMB0 (=2014 MMBmating) to Dec 31 2015 to obtain 2015 MMBmating,projected. Determine if stock is approaching overfished condition (i.e. if MMB is projected to be below MSST on Dec 31 2015).
* Apply Tier-4 overfishing control rule to 2016 MMB0,projected (= 2015 MMBmating,projected) to get Tier-4 OFL for 2016.

4. Fall 2016 CPT

* Do catch accounting to determine if overfishing occurred in 2015 (i.e. if total catch during Jan 1 – Dec 31 2015 exceeded the 2015 Tier-4 OFL).
* Estimate MMB on Dec 31 2015 (= 2015 MMBmating) using 2015 MMB0 (=2014 MMBmating) and applying natural mortality and estimated fishery removals during 1 Jan – Dec 31 2015. Determine if stock is overfished (i.e. if estimated 2015 MMBmating < MSST).
* Project 2016 survey MMB to Dec 31 2016 to obtain 2016 MMBmating,projected. Determine if stock is approaching overfished condition (i.e. if MMB is projected to be below MSST on Dec 31 2016).
* Apply Tier-4 overfishing control rule to 2017 MMB0,projected (= 2016 MMBmating,projected) to get Tier-4 OFL for 2017.

5. Fall 2017 CPT

* Do catch accounting to determine if overfishing occurred in 2016 (i.e. if total catch during Jan 1 – Dec 31 2016 exceeded the 2016 Tier-4 OFL).
* Estimate MMB on Dec 31 2016 (= 2016 MMBmating) using 2016 survey data and applying natural mortality and estimated fishery removals during 1 July – Dec 31 2016. Determine if stock is overfished (i.e. if estimated 2016 MMBmating < MSST).
* Consider re-establishing BMSY and MSST with incorporation of estimated 2016 MMBmating.
* Project 2017 MMB0 (=2016 MMBmating) to Dec 31 2017 to obtain 2017 MMBmating,projected. Determine if stock is approaching overfished condition (i.e. if MMB is projected to be below MSST on Dec 31 2017).
* Apply Tier-4 overfishing control rule to 2018 MMB0,projected (= 2017 MMBmating,projected) to get Tier-4 OFL for 2018.

The process for overfishing and overfished determinations and for establishing OFLs in subsequent Fall CPT meetings would follow odd and even year processes established for the Fall 2016 and 2017 meetings.

The OFL is computed by applying FOFL determined via the Tier-4 overfishing control rule (2012 SAFE Introduction) to MMB in accordance with the Baranov catch equation:

$OFL=\frac{F\_{OFL}}{\left(F\_{OFL}+ M\right)}[1-e^{-(F\_{OFL}+ M)}]MMB$.

Expected mature male bycatch mortality in nontarget fisheries is then removed to obtain OFL\*, allowing computation of the retained catch portion of the OFL as $OFL\_{ret}=\frac{OFL^{\*}}{(p+1)}$, where ρ denotes an estimate of the expected ratio of mature male discard mortality biomass to retained catch in the directed fishery. This makes the contribution of directed-fishery discard mortality biomass to the OFL equal to $\frac{ρOFL^{\*}}{(ρ+1)}$. With the OFL in hand, the ABC can then be set at

 $\left(1-b\right)OFL$ for suitable buffer $bϵ(0,1)$.

**Biomass estimates and other results from the 2012, 2010, and 2008 surveys**

Estimates of mature male biomass necessary for the sketched Tier-4 assessment, along with estimates of mature male abundance and legal male, total male and total female biomass and abundance, were calculated by the author from 2012, 2010 and 2008 NMFS-AFSC EBS slope-survey data supplied by the NMFS-AFSC Kodiak Laboratory. All estimates were calculated for both the full survey area (Table 3) and for the Pribilof Canyon subarea of the survey region (Table 4) assuming the survey’s stratified simple-random-sample design (Hoff and Britt 2011). Survey-recorded CL measurements of individual crab (Figure 4) were used to delineate sex-by-size classes and to model individual crab weights in class biomass estimation. In a few instances (5 of 416 captured crab in 2008 and 1 of 427 in 2012) missing CL measurements were imputed by averaging over recorded CL measurements within the same haul and sex; sex had also to be imputed for the 1 unsized animal in the 2012 dataset. By contrast, Hoff and Britt (2011, 2009, 2005, 2003) report only total (all sizes and both sexes combined) GKC abundance and biomass estimates based on haul total-catch numbers and weights (G.R. Hoff, NMFS-AFSC Seattle, 13 Mar 2013 email) from the 2002, 2004, 2008 and 2010 slope surveys (Table 5). Some discrepancies between the comparable sets of estimates are evident. So far as the author is aware, 2012 slope-survey results have yet to be reported.

**References**

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Table 1: Percent of annual harvest by month of landing, 1993–2012 Pribilof Islands golden king

crab fishery.



Table 2: Proposed Tier-4 PIGKC assessment conventions.

|  |  |  |
| --- | --- | --- |
| Assessment Feature | Convention | Source |
| biomass and abundance estimates | stratified simple random sample(Hoff and Britt 2011) | EBS slope-survey data (NMFS-AFSC Kodiak Lab) |
| mature male size | CL >= 107 mm | Otto and Cummiskey (1985) |
| legal male size | CL >= 124 mm | NPFMC 2007 |
| male length-to-weight model | $$w=0.0002988l^{3.135}$$ | NPFMC 2007 |
| female length-to-weight model | $$w=0.001424l^{2.781}$$ | NPFMC 2007 |
| natural mortality | 0.18 yr-1 | NPFMC 2007 |
| measure of stock biomass | Dec-31 mature male biomass | author recommendation |
| OFL type | mature male biomass | author recommendation |
| ABC type | mature male biomass | author recommendation |
| ABC buffer | 10% (20%) | author recommendation(odd-year assessments) |
| survey catchability and selectivity | Q = 1; $S≡1$ | default |

Table 3: EBS slope-survey estimates of golden king crab

abundance and biomass for the full survey region.

|  |  |
| --- | --- |
|  | Abundance (1000s) and CV |
| year | female | male | mature male | legal male |
| 2012 | 1,282 | 0.33 | 1,061 | 0.21 | 540 | 0.24 | 378 | 0.28 |
| 2010 | 1,743 | 0.26 | 1,083 | 0.14 | 508 | 0.16 | 348 | 0.17 |
| 2008 | 748 | 0.25 | 1,187 | 0.26 | 593 | 0.30 | 257 | 0.22 |
|  | Biomass (1000 lb) and CV |
|   | female | male | mature male | legal male |
| 2012 | 2,120 | 0.43 | 2,124 | 0.24 | 1,791 | 0.26 | 1,478 | 0.28 |
| 2010 | 2,812 | 0.33 | 2,042 | 0.15 | 1,692 | 0.17 | 1,384 | 0.18 |
| 2008 | 943 | 0.25 | 2,173 | 0.26 | 1,624 | 0.25 | 997 | 0.22 |

Table 4: EBS slope-survey estimates of golden king crab

abundance and biomass for the Pribilof Canyon subarea.

|  |  |
| --- | --- |
|  | Abundance (1000s) and CV |
| year | female | male | mature male | legal male |
| 2012 | 592 | 0.53 | 360 | 0.42 | 174 | 0.32 | 113 | 0.36 |
| 2010 | 1,295 | 0.34 | 633 | 0.20 | 288 | 0.24 | 185 | 0.25 |
| 2008 | 395 | 0.43 | 908 | 0.34 | 403 | 0.43 | 167 | 0.29 |
|  | Biomass (1000 lb) and CV |
|   | female | male | mature male | legal male |
| 2012 | 866 | 0.54 | 701 | 0.34 | 565 | 0.32 | 456 | 0.34 |
| 2010 | 2,219 | 0.41 | 1,200 | 0.22 | 970 | 0.24 | 770 | 0.25 |
| 2008 | 340 | 0.54 | 1,546 | 0.36 | 1,080 | 0.36 | 648 | 0.29 |

Table 5: Hoff and Britt (2011, 2009, 2005, 2003) reported EBS slope-survey estimates

of total (all sizes and both sexes combined) golden king crab abundance and biomass.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Full survey region |  | Pribilof Canyon subarea |
| year | Abundance (1000s) | Biomass (1000 lb) |  | Abundance (1000s) | Biomass (1000 lb) |
| 2012 | NAa | NAa |  | NAa | NAa |
| 2010 | 2,830 | 5,070 |  | 1,930 | 3,560 |
| 2008 | 1,860 | 3,150 |  | 1,300 | 2,030 |
| 2004 | 1,240 | 2,430 |  | 862 | 1,800 |
| 2002 | 1,800 | 2,230 |  | 1,300 | 1,500 |

a Not yet available.

Figure 1. Locations of observer-sampled pots (red) from the 2001–2005 and 2010–2012 PIGKC fisheries and of the 189 tows of the 2012 EBS slope-survey (black/purple) used to construct abundance and biomass estimates. Locations of the 19 tows in the Pribilof Canyon subarea are colored purple.



Figure 2: “Retained” proportion of observer-sampled male GKC as a function

of CL, for 2001–2005 and 2010–2012 PIGKC fisheries. (Note: the CL proxy

for legal size is 124 mm.)



Figure 3: Fit of 2010 slope-survey GKC data to length-to-weight relationships used in this

assessment: $w=0.0002988l^{3.135}$ (males); $w=0.001424l^{2.781}$ (females).



Figure 4: Size-frequency distributions of male (left panels) and female (right panels) GKC captured in the 2012 (189 tows; 427 crab), 2010 (200 tows; 790 crab) and 2008 (200 tows; 416 crab) EBS slope surveys.

 **2016 MMBsurvey**

**2014 MMBsurvey**

**2014 MMBmating**

 ***2016 MMBmating***

 ***2014 MMBmating***

***2015 MMBmating***

 **2015 MMBmating**

 ***2015 OFL***

 ***2016 OFL***

 **CPT CPT CPT**

 1Jan2015 1Jan2016 1Jan2017

Figure 5. Schematic of proposed Tier-4 PIGKC stock assessment cycle, implemented as of the Fall 2014

CPT meeting. Projected assessment outputs (italicized, purple) are indicated by dashed lines/arrows;

assessment outputs estimated from fully available data (non-italicized, green) are indicated by solid

lines/arrows. Dotted lines place surveys and CPT meetings along time line. The EBS slope-survey is

assumed to occur July 1 of even years. See text for further details.

1. A site was considered trawlable “when the depth changed less than 50 m over the 2-nmi transect and there were no detectable obstacles in the trawl path.” (Hoff and Britt 2011, p.4) [↑](#footnote-ref-1)