Estimating Sustainable Yield for the Dungeness Crab Stock in Puget Sound

[This is a rough draft at this point and is more a proof of concept than anything else. Ideally parameter values for model runs would be identified by a group of Tribal (and possibly state) experts. Also, a discussion section is needed to discuss the strengths and weaknesses of each method and to contrast differences in the results. Finally, a recommendation|conclusion section is needed.]

Introduction

Over the last two decades the harvest of Dungeness Crab in Puget Sound by commercial and recreational fishers has increased more than three-fold[1]. The average annual harvest for the five-year period from 1987-1991 was 2.8 million lbs compared to the most recent five-year (2009-2013) average annual harvest of 9.3 million lbs. Figure 1 shows the estimated annual harvests since 1970 by each of the three user groups (Tribal, non-tribal commercial, and recreational) harvesting crab in Puget Sound. There was a rapid increase in total harvest during the period 1991 to 2001 after which annual harvests have fluctuated between 7.8 and 10.1 million lbs.

---

[1] Harvest estimates are for male crab only ≥ 6.25".

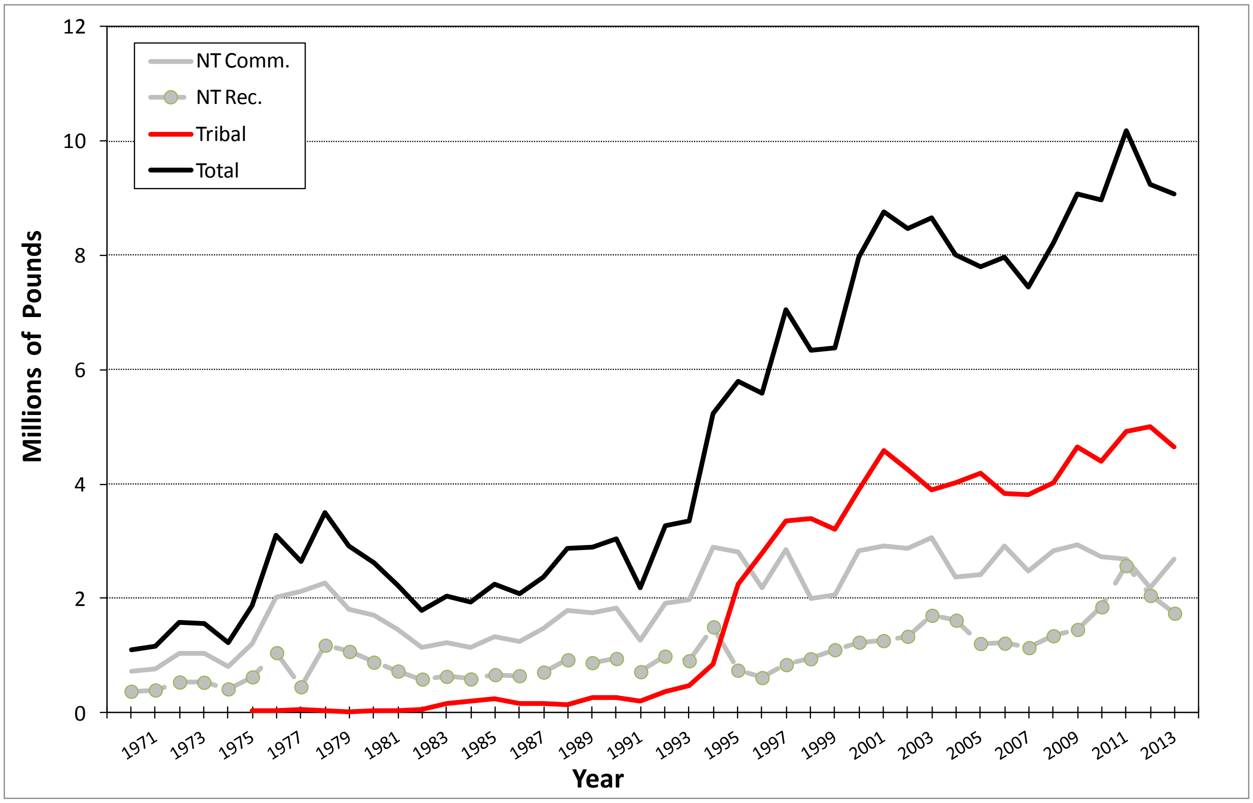

Figure 1. Annual harvest of Dungeness Crab in Puget Sound by non-tribal (NT) commercial, NT recreational, and Tribal fisheries.

While there have been no overt signs of over-harvest of this resource to date, it is unclear whether current harvest levels are sustainable. Effective management of fisheries requires estimates of the sustainable yield of the resource, i.e., a level of harvest that can be maintained without causing the stock to drastically decrease in abundance and productivity. Although the goal is often to estimate maximum sustainable yield (MSY), the amount of information required for an MSY estimate is not available for many stocks (Berkson et al. 2011, Wiedenmann et al. 2013, Carruthers et al. 2014). These are typically referred to as "data poor" stocks and a number of analytical methods have recently been developed to estimate either a proxy for MSY or a level of sustainable yield that results in a low probability of overfishing but is close to MSY. The stock of Dungeness crab in Puget Sound qualifies as a data poor stock (e.g., there are no estimates of annual abundance). The primary data source for this stock is the catch history for both commercial and recreational fisheries.

The goal of this project is to apply some of the methods developed for data poor stocks to the Dungeness crab stock in Puget Sound in order to: (1) estimate sustainable yield, (2) evaluate each of the methods as to applicability to the Dungeness crab stock, and (3) recommend a sustainable harvest level for fishery managers.

Methods

Four data-poor methods were evaluated for application to the Dungeness crab stock in Puget Sound:

1. the depletion-corrected average catch (DCAC) method described by MacCall (2009),
2. the "Only Reliable Catch Stocks" (ORCS) method described by Berkson et al. (2011),
3. the depletion-based stock reduction analysis (DB-SRA) method described by Dick and MacCall (2011), and
4. feasible *r-k* combinations (*r-k*) method described by Martell and Froese (2012).

We briefly describe the data requirements for each method, major assumptions, and ranges of input values used in the analyses (where appropriate).

Depletion-corrected average catch (DCAC)

MacCall (2009) developed the DCAC method as a "data-poor" method for identifying "a moderately high yield that is likely to be sustainable, while having a low probability that the estimated yield level greatly exceeds MSY and hence risks inadvertent overfishing and possible resource depletion before the error can be detected...". In addition to the time series of historical removals, the following inputs are required for a DCAC analysis:

- natural mortality (*M*) and a standard deviation (SD) for ln(*M*) (a SD = 0.50 is recommended by MacCall),
- the ratio between F_{MSY} and *M* (or *c* as defined by MacCall) and its SD (*c* = 1.00 with a SD of 0.2 is suggested by MacCall),
- depletion delta (*Δ*) or the relative decline in stock abundance between the first year and last year of the catch time series and its SD,
    - $\Delta = \frac{\hat{B}_{first\ year} - \hat{B}_{last\ year}}{\hat{B}_0}$ where $\hat{B}_0$ = unfished stock abundance,
- the ratio B_{MSY} / B_0 and its SD (values of 0.4 to 0.6 are suggested by MacCall with SD of 0.2).

MacCall shows how sustainable yield ($\hat{Y}_{sust}$) can be estimated using the equation:

$$\hat{Y}_{sust} = \frac{\sum_1^n catches}{n + {}^{\Delta}/_{(0.4\ x\ c\ x\ M)}}$$

where *n* = the number of years in the catch history. By incorporating the uncertainty of the parameters *M*, *Δ*, and *c*, (using standard deviations and assumed distributions), Monte Carlo simulations can be used to produce a large number of feasible estimates of $\hat{Y}_{sust}$. DCAC software uses a lognormal distribution to specify uncertainty around *M*, either a lognormal or a normal distribution to specify uncertainty around *c*, and either a bounded beta, lognormal, or a normal distribution to specify uncertainty around Δ. Mean or median values from the simulation results can then be used to define $\hat{Y}_{sust}$ and its approximate confidence interval.

MacCall (2009) does not recommend DCAC for stocks where M is greater than ~0.2/year because at higher natural mortality rates depletion correction becomes small. However, Wiedenmann et al. (2013) found that DCAC performed adequately for stocks with $M > 0.2$/year as long as the stocks were under- or fully exploited. When a stock was over-exploited at the time of analysis then Wiedenmann et al. (2013) found MacCall's guideline was appropriate. DCAC[2] was also one of the methods examined in a comprehensive management strategy evaluation by Carruthers et al. (2014). One of the six life-history types they evaluated was butterfish - a species with an expected range for M similar to Dungeness crab (between 0.7 and 0.9). In their evaluation, DCAC performed adequately for butterfish as long as the starting biomass for the catch time series was ≥ 50% B_{MSY}.

DCAC analyses were conducted with Version 2.1 of DCAC available from the NOAA Fisheries Toolbox (http://nft.nefsc.noaa.gov).

Only Reliable Catch Stocks (ORCS)

Berkson et al. (2011) provide a review of methods (including DCAC and DB-SRA) for setting catch limits for data poor stocks (i.e., where the only reliable data is a catch history). As part of that review, they developed an approach for developing catch limits for ORCS when DCAC or DB-SRA are not appropriate. Their method:

1. Uses expert opinion to assign a stock to one of three exploitation categories using an evidence-based scoring system;
2. Produces an over-fishing limit (OFL)[3] by multiplying a statistical measure of catch (e.g., mean, median, minimum, maximum, etc.) by a scalar that depends on the assigned exploitation category; and
3. Defines an allowable biological catch (ABC)[3] as a proportion (< 1.0) of the OFL to reflect a policy decision on acceptable risk, which may be a function of the productivity of the stock.

The three exploitation rate categories are: lightly exploited, moderately exploited, and heavily exploited. Berkson et al. (2011) provide a table of attributes for determining the exploitation rate category and provide guidance on scoring (1, 2, or 3) each attribute. Final assignment to a category is based on the mean score across all attributes. They recommend exploitation status be assigned as:

- mean score < 1.5 - lightly exploited,
- 1.5 ≤ mean score ≤ 2.5 - moderately exploited, and

---

[2] The version of DCAC we evaluated is referred to as static DCAC by Carruthers et al. (2014).

[3] OFL and ABC are requirements specified in National Standard 1 Guidelines specified by the National Marine Fisheries Service in response to the reauthorization of the Magnuson-Stevens Act in 2006.

- mean score > 2.5 - heavily exploited.

OFLs are then established as: 2.0 X catch statistic for lightly exploited stocks,
1.0 X catch statistic for moderately exploited stocks, and
0.5 X catch statistic for heavily exploited stocks.

Again, the catch statistic can be the mean, median, minimum, or maximum catch based on catch data from a series of years. Expert opinion is used to determine the appropriate catch statistic for this calculation.

Berkson et al. also provide recommendations for calculating ABC based on the OFL, stock productivity, and acceptable risk. We applied the ORCS method to the Puget Sound Dungeness crab stock based on the expert opinion of X shellfish biologists involved in Dungeness crab management in Puget Sound. ***(This is at least something that should be considered).***

Depletion-based stock reduction analysis (DB-SRA)

Dick and MacCall (2011) describe DB-SRA as a data-poor approach that combines DCAC with the modeling framework of stock reduction analysis. Unlike DCAC, DB-SRA incorporates a production function into its framework. Dick and MacCall developed a novel production function that is a hybrid of the Schaefer production function and the Pella-Tomlinson-Fletcher (PTF) production function. Their production function has the form of a PTF production model for stock abundances above a specified biomass level (B_{join}) and a Schaefer model for abundances below B_{join}.

Similarly to DCAC, in addition to the historical catch series, a DB-SRA analysis begins with a set of four Monte Carlo-drawn input parameters. The four input parameters specified (including standard deviations) are:

1. natural mortality (M),
2. the ratio between F_{MSY} and M (MacCall's c),
3. the relative biomass at maximum latent productivity (B_{mnpl}) defined as the ratio B_{MSY} / K (MacCall refers to K *as* B_0), and
4. the relative depletion level (B_T / K) for a specific year T, where T does not have to be the last year in the catch series.

Not all combinations of input parameters allow the DB-SRA model to end with the assumed relative stock depletion in the target year. Trajectories that predict negative biomass in any year are not included in the results. Means, medians, and percentiles for K, B_{MSY}, F_{MSY}, OFL (over-fishing limit), and MSY are obtained from the successful trajectories. MSY being the estimated long-term average catch that can be taken from the stock under current ecological and environmental conditions on a sustainable basis. OFL is the best estimate of the maximum amount of a stock that can be caught without resulting in overfishing[4]. Catch equal to OFL results in a 50% probability of overfishing.

DB-SRA analyses were conducted using R code (R Development Core Team 2012) provided by E.J. Dick (NMFS).

Feasible *r-k* combinations (*r-k*)

The feasible *r-k* combinations method of Martell and Froese (2012) approximates MSY using catch data, resilience[5] of the species, and simple assumptions about stock sizes relative to carrying capacity for the first year and final year of catch data. A time series of historical removals is required for the *r-k* method. In addition, the following ranges are specified and treated as uniform distributions:

- a range for *r* (maximum rate of population increase) depending upon the resilience of the species. Martell and Froese recommend:
    - $0.015 \le r \le 0.1$ for stocks thought to have "very low" resilience
    - $0.05 \le r \le 0.5$ for stocks thought to have "low" resilience,
    - $0.2 \le r \le 1.0$ for stocks thought to have "medium" resilience, and
    - $0.6 \le r \le 1.5$ for stocks thought to have "high" resilience.
- a range for *k* (carrying capacity[6]) defined by observed maximum catch and a multiple of observed maximum catch (e.g., 100).
- a range for the ratio of stock abundance (*N*) to *k* at the beginning of the catch time series (e.g., $0.6 \le N/k \le 0.9$).
- a range for the ratio of stock abundance to *k* at the end of the catch time series (e.g., $0.3 \le N/k \le 0.7$).

From these uniform distributions, random *r-k* pairs are drawn and used to calculate annual biomass trajectories over the series of catch years using a Schaefer production function. The annual catch history is applied to each year's starting biomass calculation to update biomass before projection of the next year's biomass using the Schaefer production model. The trajectory of the stock is followed and only those *r-k* combinations that have:

i. never collapsed the stock (driven it to zero),
ii. exceeded carrying capacity, and
iii. that result in a final relative biomass calculation (*N/k*) that falls within the assumed range of final depletion

---

[4] Overfishing is defined as a level of fishing mortality or total annual catch that jeopardizes the capacity of a stock to produce MSY on a continuing basis.

[5] Resilience refers to resilience to fishing pressure and is analogous to productivity, i.e., high resilience implies high productivity relative to other stocks.

[6] Carrying capacity (*k*) is analogous to B_0 in DCAC and DB-SRA.

are accepted (similarly to DB-SRA). Additional process errors can be specified for the model if desired; setting additional process error to 0 results in an observation error only model that is deterministic (Martell and Froese 2012).

For each *r*-*k* combination that is accepted, MSY is calculated as:

$$MSY = \frac{r\,k}{4}$$

(Haddon 2011). Martell and Froese's recommendation to use the geometric mean of the MSY estimates from accepted *r*-*k* combinations was followed for our analyses. The *r*-*k* combinations analyses were conducted using R code (R Development Core Team 2012) developed by Martell and Froese which is available at http://www.fishbase.de/rfroese/.

Results

A number of input parameters are common to more than one model. The next section briefly describes the derivation of the values used, the standard deviation for the parameter (where appropriate), and range (where appropriate) for these parameters.

Input Parameters

Natural Mortality: One of the key parameters for two of the methods (DCAC and DB-SRA) is *M*. Siddeek et al. (2004) examined reference points for two Dungeness crab populations (southeast Alaska and western Canada) and provided estimates of *M* for each. The estimate of *M* for the western Canada stock was based on the Fraser River delta fishery which is proximate to Puget Sound; estimated *M* for post-recruit males (based on unpublished data referenced in Siddeek et al. 2004) was 0.75. This value of *M* was used for the Dungeness crab stock in Puget Sound.

F_{MSY} / M: Both MacCall (2009) and Dick and MacCall (2011) summarize recent scientific opinion on typical values for this ratio. They determined that $F_{MSY} / M = 0.8$ (with SD = 0.2) was reasonable for most species. Because of the apparently high productivity of Dungeness crab in Puget Sound a value of 0.9 (with SD = 0.2) was also explored in the appropriate analyses.

Current Level of Depletion: Defined as current biomass / K (or B_0 depending upon the model) - it specifies the view of current biomass for the stock relative to carrying capacity (or stock size prior to any fishing). A point value plus plausible range was established based on expert opinion (using the same set of biologists that participated in the ORCS method). We defined current depletion as 0.5 (50% of carrying capacity) and explored a range from 0.25 to 0.75.

B_{MSY} / B_0: A value of 0.4 is often used for groundfish and 0.25 for flatfish (NOAA Fisheries Toolbox documentation). A range of values from 0.25 to 0.50 were explored.

Depletion-corrected average catch (DCAC)

DCAC model runs were conducted with the input parameters specified in Table 1 and the catch series displayed in Figure 1. A total of 10,000 model iterations (parameter draws) were run for each analysis. Mean and median DCAC catches estimated by the model are presented in Table 2. Figure 2 compares the distributions of the 10,000 model estimates of DCAC catch for run DCAC A to run DCAC J.

Table 1. Input parameters for each DCAC model run (highlighted values are changes from model run A).

Model Label	Catch Series	Average Catch (lbs)	M	F_{MSY} / M	Δ	B_{MSY} / B_0
DCAC A	1970 - 2013	4,817,280	0.75 (0.50)	0.80 (0.20)	0.50 (0.20)	0.40 (0.20)
DCAC B	1970 - 2013	4,817,280	0.75 (0.50)	0.90 (0.20)	0.50 (0.20)	0.40 (0.20)
DCAC C	1970 - 2013	4,817,280	0.75 (0.50)	0.90 (0.20)	0.40 (0.20)	0.40 (0.20)
DCAC D	1970 - 2013	4,817,280	0.75 (0.50)	0.90 (0.20)	0.65 (0.20)	0.40 (0.20)
DCAC E	1970 - 2013	4,817,280	0.75 (0.50)	0.90 (0.20)	0.65 (0.20)	0.25 (0.20)
DCAC F	1970 - 2013	4,817,280	0.75 (0.50)	0.90 (0.20)	0.65 (0.20)	0.50 (0.20)
DCAC G	1991 - 2013	7,179,685	0.75 (0.50)	0.90 (0.20)	0.50 (0.20)	0.50 (0.20)
DCAC H	1991 - 2013	7,179,685	0.75 (0.50)	0.90 (0.20)	0.65 (0.20)	0.40 (0.20)
DCAC I	1991 - 2013	7,179,685	0.75 (0.50)	0.90 (0.20)	0.65 (0.20)	0.25 (0.20)
DCAC J	1991 - 2013	7,179,685	0.75 (0.50)	0.90 (0.20)	0.65 (0.20)	0.50 (0.20)

Table 2. Mean and median DCAC catches for each DCAC model run.

Model Label	Mean DCAC (lbs)	Median DCAC (lbs)
DCAC A	4,431,339	4,555,868
DCAC B	4,467,516	4,583,504
DCAC C	4,530,235	4,634,270
DCAC D	4,379,398	4,510,371
DCAC E	3,886,293	4,266,185
DCAC A	4,494,996	4,577,047
DCAC B	6,298,333	6,541,419
DCAC C	6,093,448	6,352,727
DCAC D	5,183,288	5,756,995
DCAC E	6,347,233	6,524,553

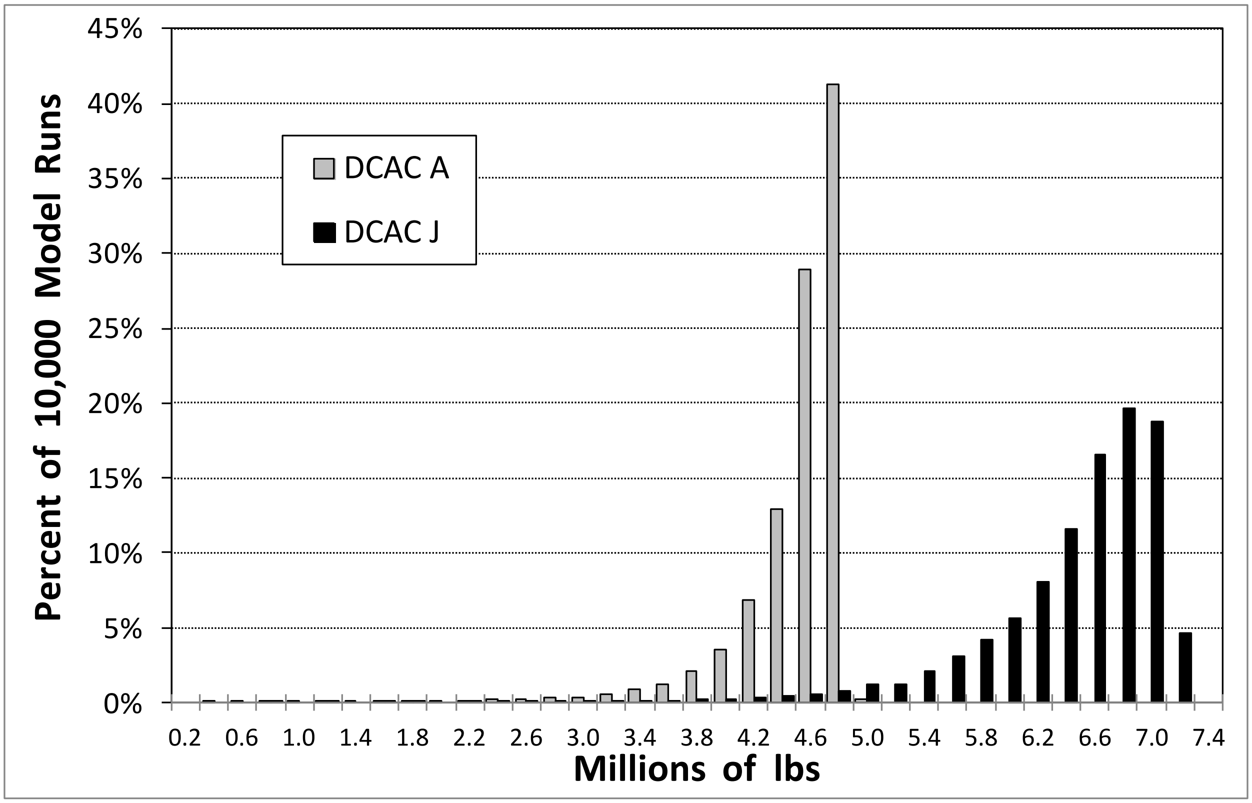

Figure 2. Comparison of the distributions of the 10,000 model estimates of DCAC catch for runs DCAC A and DCAC J

Only Reliable Catch Stocks (ORCS)

TO BE COMPLETED

Depletion-based stock reduction analysis (DB-SRA)

DB-SRA model runs were conducted with the input parameters specified in Table 5 and the catch series displayed in Figure 1. All model runs used the complete catch series. A total of 10,000 model iterations (parameter draws) were run for each analysis. Mean and median MSY and OFL estimates by the model are presented in Table 6. Figure 3 compares the distributions of the 10,000 model estimates of MSY catch for run DB-SRA A to run DB-SRA J.

Table 5. Input parameters for each DB-SRA model run (highlighted values are changes from model run A).

Model Label	***M***	***F_{MSY} / M***	**Depletion *1 - (B_{2013} / B_0)***	***B_{MSY} / B_0***
DB-SRA A	0.75 (0.40)	0.80 (0.10)	0.50 (0.10)	0.40 (0.05)
DB-SRA B	0.75 (0.40)	0.90 (0.10)	0.50 (0.10)	0.40 (0.05)
DB-SRA C	0.75 (0.40)	0.90 (0.10)	0.50 (0.10)	0.25 (0.05)
DB-SRA D	0.75 (0.40)	0.90 (0.10)	0.75 (0.10)	0.40 (0.05)
DB-SRA E	0.75 (0.40)	0.90 (0.10)	0.25 (0.10)	0.40 (0.05)
DB-SRA F	0.85 (0.40)	0.90 (0.10)	0.60 (0.10)	0.40 (0.05)
DB-SRA G	0.65 (0.40)	0.90 (0.10)	0.60 (0.10)	0.40 (0.05)
DB-SRA H	0.75 (0.40)	0.90 (0.10)	0.60 (0.10)	0.40 (0.05)
DB-SRA I	0.75 (0.40)	0.90 (0.10)	0.60 (0.10)	0.35 (0.05)
DB-SRA J	0.85 (0.40)	0.90 (0.10)	0.60 (0.10)	0.40 (0.05)

Table 6. Mean and median MSY and OFL catches for each DB-SRA model run.

Model Label	**Mean MSY (lbs)**	**Median MSY (lbs)**	**Mean OFL (lbs)**	**Median OFL (lbs)**
DB-SRA A	8,435,507	8,158,446	11,023,207	10,191,963
DB-SRA B	8,592,164	8,315,813	11,256,339	10,419,234
DB-SRA C	8,979,038	8,663,779	19,251,612	17,462,863
DB-SRA D	6,719,803	6,667,991	4,436,069	4,038,587
DB-SRA E	16,546,746	14,476,037	33,189,759	27,641,745
DB-SRA F	8,484,927	8,202,093	11,086,333	10,252,974
DB-SRA G	8,529,970	8,260,428	11,176,307	10,344,281
DB-SRA H	7,578,411	7,429,866	7,872,913	7,360,921
DB-SRA I	7,656,724	7,475,171	9,160,503	8,490,850
DB-SRA J	7,630,215	7,474,857	7,958,020	7,455,739

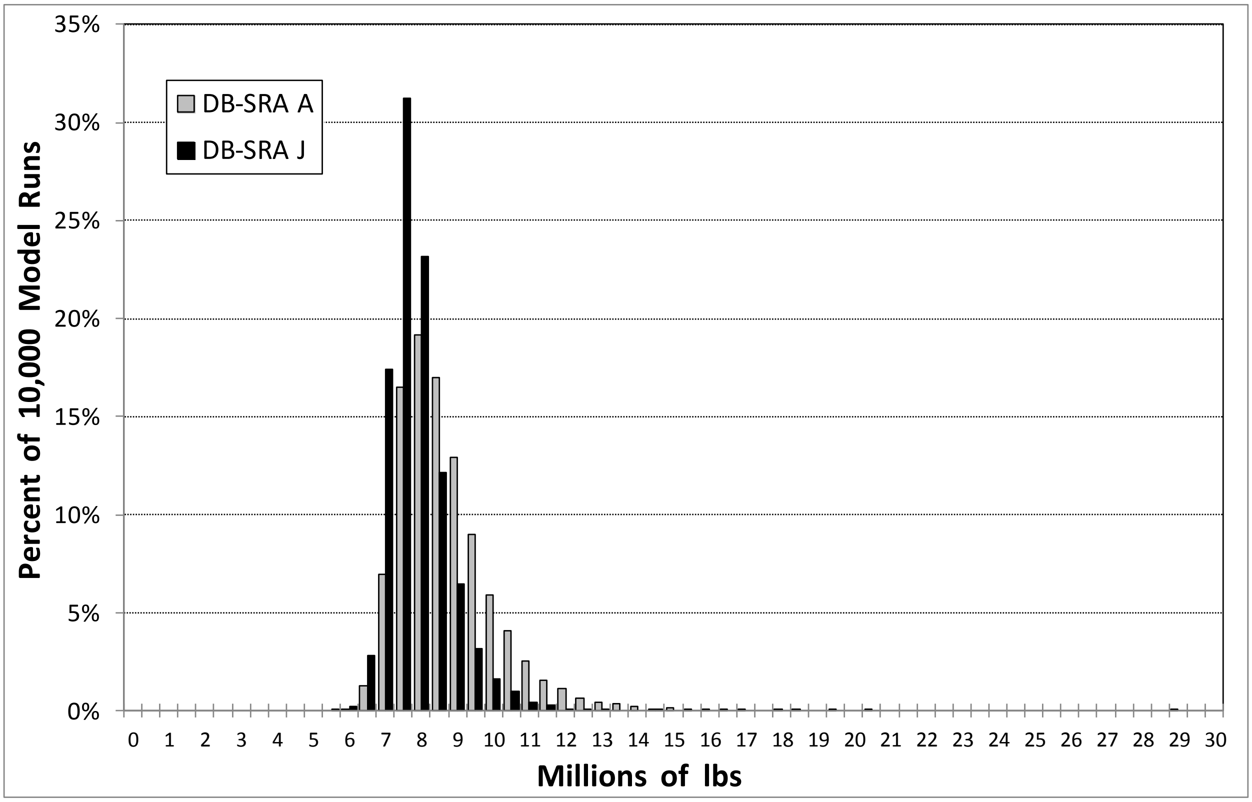

Figure 3. Comparison of the distributions of the 10,000 model estimates of MSY catch for runs DB-SRA A and DB-SRA J.

Feasible *r-k* combinations (*r-k*)

Model runs for the *r-k* analyses were conducted with the input parameters specified in Table 7 and the catch series displayed in Figure 1. All model runs used the complete catch series. Because of a lower rate of occurrence of feasible trajectories compared to DCAC and DB-SRA, a total of 50,000 model iterations (parameter draws) were run for each analysis.

Table 7. Input parameters for each *r-k* model run (highlighted values are changes from model run A).

Model Label	**Range for *r***	**Process Error**	**Range for $B_{Initial} / K$**	**Range for B_{Final} / K**	**Range for K^a**
r-k A	0.6 - 1.5	0	0.5 - 0.9	0.3 - 0.7	MaxC - 50 *x* MaxC
r-k B	0.6 - 1.5	0	0.5 - 0.9	0.2 - 0.5	MaxC - 50 *x* MaxC
r-k C	0.6 - 1.5	0	0.75 - 0.9	0.3 - 0.7	MaxC - 50 *x* MaxC
r-k D	0.6 - 1.5	0	0.5 - 0.9	0.3 - 0.7	MaxC - 10 *x* MaxC
r-k E	0.6 - 1.5	0	0.5 - 0.9	0.2 - 0.5	MaxC - 10 *x* MaxC
r-k F	0.6 - 1.5	0	0.75 - 0.9	0.3 - 0.7	MaxC - 10 *x* MaxC
r-k G	0.6 - 1.5	0	0.75 - 0.9	0.2 - 0.5	MaxC - 10 *x* MaxC
r-k H	0.2 - 1.0	0	0.5 - 0.9	0.3 - 0.7	MaxC - 10 *x* MaxC
r-k I	0.2 - 1.0	0	0.5 - 0.9	0.2 - 0.5	MaxC - 10 *x* MaxC
r-k J	0.2 - 1.0	0	0.75 - 0.9	0.3 - 0.7	MaxC - 10 *x* MaxC

[a] Expressed as a function of maximum catch (MaxC) in the time series.

Table 8. Mean, geometric mean, and median MSY estimates for each *r-k* model run.

Model Label	**Geometric Mean (lbs)**	**Mean (lbs)**	**Median (lbs)**	**Feasible Trajectories**
r-k A	9,295,688	9,254,255	9,235,841	13,537
r-k B	8,221,266	8,214,110	8,231,359	5,110
r-k C	9,224,881	9,184,314	9,127,954	12,320
r-k D	9,296,419	9,255,019	9,234,595	13,674
r-k E	8,225,469	8,218,304	8,237,055	5,126
r-k F	9,227,706	9,187,048	9,130,772	12,487
r-k G	8,213,190	8,206,341	8,225,107	5,024
r-k H	8,687,543	8,606,619	8,669,404	11,070
r-k I	7,301,666	7,265,189	7,377,739	4,918
r-k J	8,687,543	8,606,619	8,669,404	11,070

Figure 4 compares the distributions of *r-k* model estimates of MSY catch for runs *r-k* A to *r-k* B.

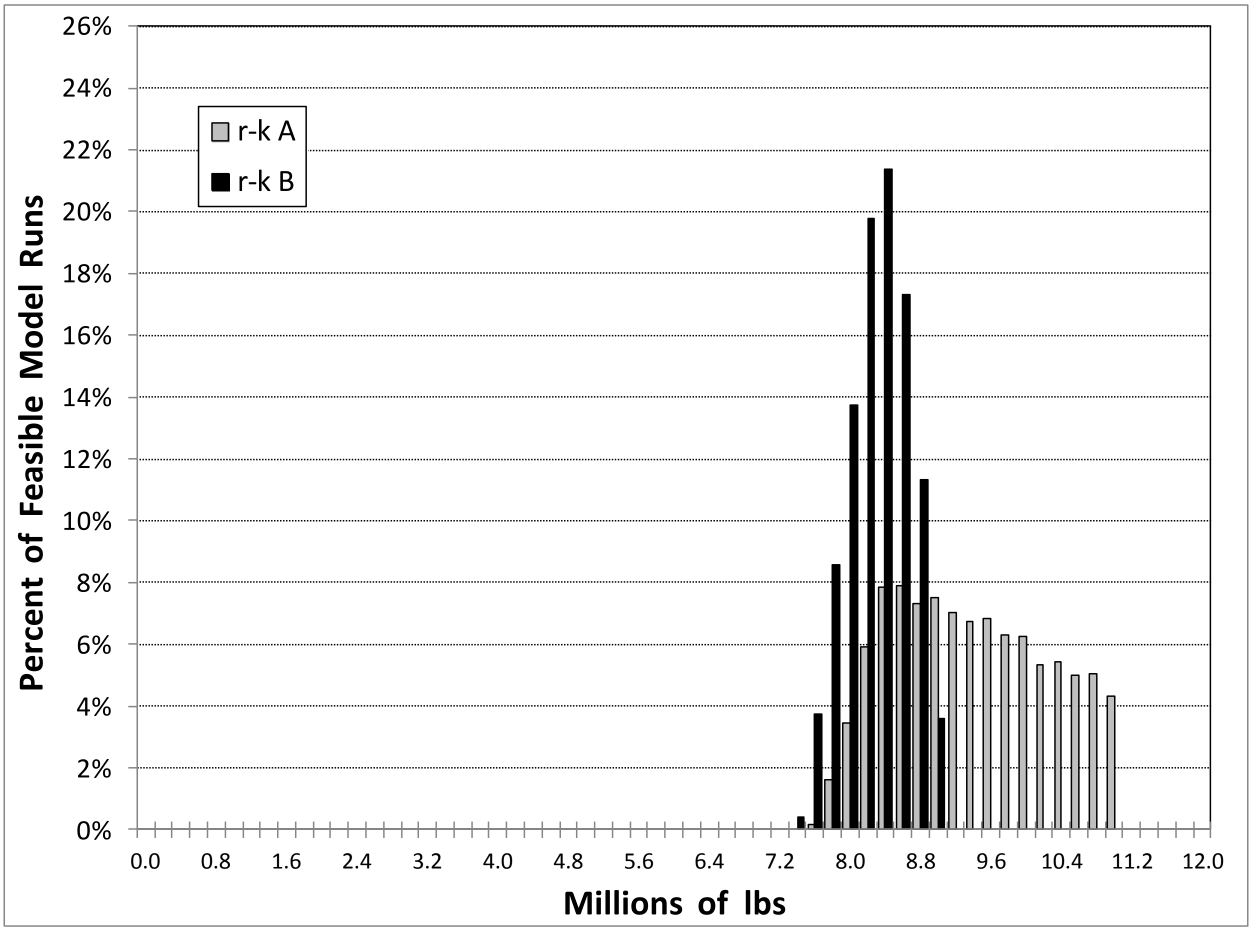

Figure 4. Comparison of the distributions of *r-k* model estimates of MSY catch for runs *r-k* A and *r-k* B.

Discussion

Box-and-whiskers plots were used to compare results from different model runs. Box-and-whiskers plots encompass the central quartiles of the data (the central 50% of the data values) in a shaded box with the median value indicated by a heavy black line in the box. Box whiskers include all data values not considered outliers or extreme values. Outliers are marked with open circles and are values between 1.5 and 3 box lengths from the upper or lower edges of the box (Hoaglin et al. 1983). Extreme values are marked by asterisks and are more than three box lengths from the upper or lower edges of the box.

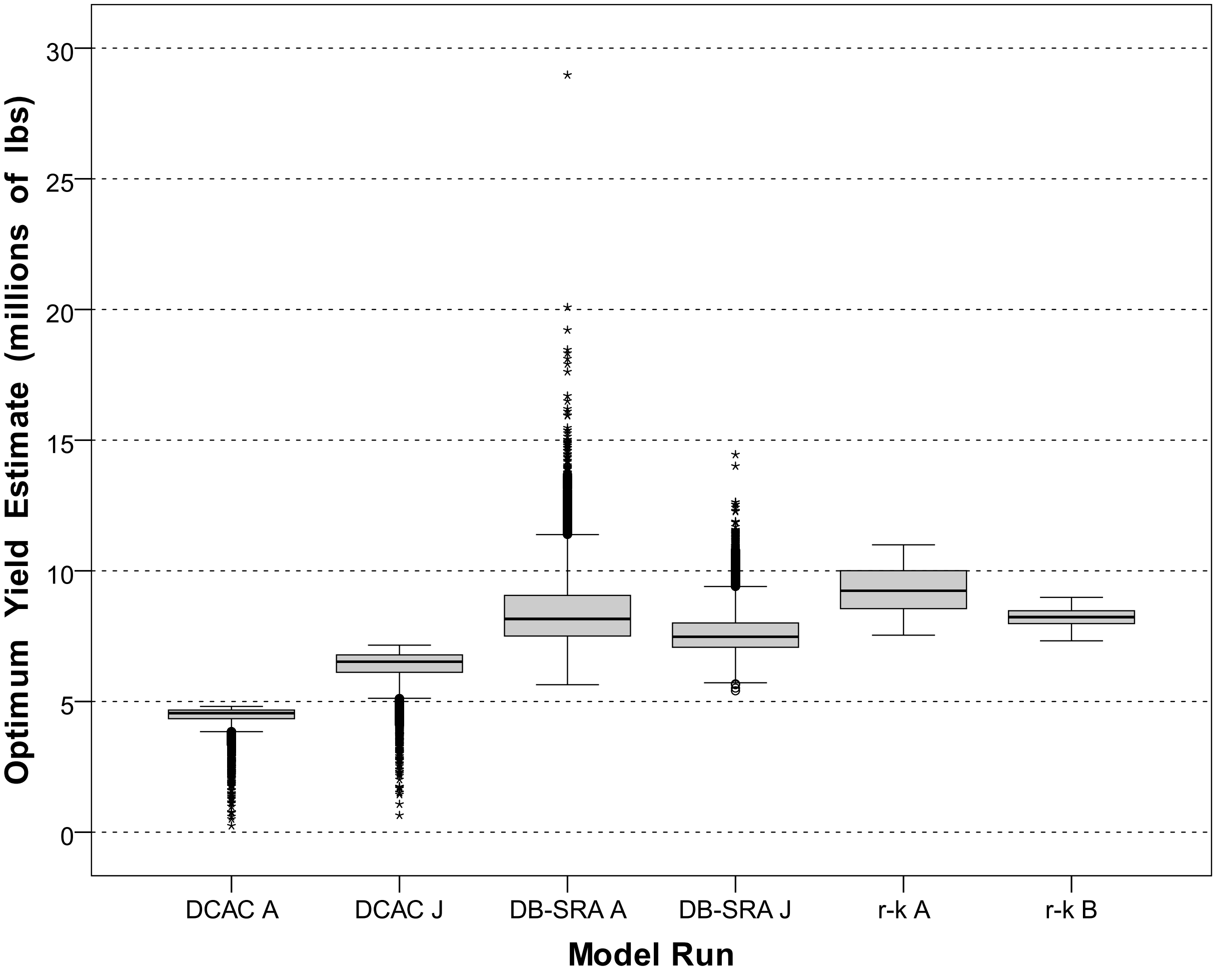

Figure 5. Box-and-whiskers plots comparing optimum catch estimates from stochastic runs for models DCAC, DB-SRA, and *r-k* (model runs shown correspond to those presented in the Results section).

References

Berkson, J., L. Barbieri, S. Cadrin, S. Cass-Calay, P. Crone, P. Dorn, C. Friess, D. Kobayashi, T.J. Miller, W.S. Patrick, S. Pautzke, S. Ralston, and M.Trianni, M. 2011. Calculating acceptable biological catch for stocks that have reliable catch data only. NOAA Technical Memorandum, NMFS-SEFSC-616.

Carruthers, T.R., A.E. Punt, C.J. Walters, A. MacCall, M.K. McAllister, E.J. Dick, and J. Cope. 2014. Evaluating methods for setting catch limits in data-limited fisheries. Fisheries Research 153:48-68.

Dick, E.J. and A.D. MacCall. 2011. Depletion-based stock reduction analysis: a catch-based method for determining sustainable yields for data-poor fish stocks. Fish. Res. 110: 331–341.

Haddon, M. 2011. Modelling and Quantitative Methods in Fisheries. Chapman and Hall/ CRC Press, New York.

Hoaglin, D. C., F. Mosteller, and J. W. Tukey. 1983. *Understanding Robust and Exploratory Data Analysis*. John Wiley and Sons, New York.

MacCall, A.D. 2009. Depletion-corrected average catch: a simple formula for estimating sustainable yields in data-poor situations. ICES J. Mar. Sci. 66:2267–2271.

Martell, S., and R. Froese. 2012. A simple method for estimating MSY from catch and resilience. Fish and Fisheries DOI: 10.1111/j.1467-2979.2012.00485.x.

R Development Core Team. 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rodríguez-Domínguez, G., S.G. Castillo-Vargasmachuca, R. Pérez-González, and E.A. Aragón - Noriega. 2014. Catch—maximum sustainable yield method applied to the crab fishery (*Callinectes* spp.) in the Gulf of California. J. Shellfish Res. 33(1):45-51.

Siddeek, M. S. M., B. Sainte-Marie, J. Boutillier, and G. Bishop. 2004. Comparison of reference points estimated using a side-based method for two high-latitude crab species in the United States and Canada. Can. J. Fish. Aquat. Sci. 61:1404‑1430.

Wiedenmann, J., M.J. Wilberg, and T.J. Miller. 2013. An evaluation of harvest control rules for data-poor fisheries. North American Journal of Fisheries Management, 33(4):845-860.