# St Matthew Island Blue King Crab Survey-Based Assessment: Modifications and Preliminary Results

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## Introduction

For the Fall 2012 St Matthew Island blue king crab stock assessment, the current author used a simple survey-based approach to obtain abundance and biomass estimates required for State and federal management purposes. This document describes that approach. This document also presents revised methods for calculation of the OFL and for determination of the ABC. An alternative $B_{MSY}$-proxy reference period is proposed for use in the OFL control rule, and a more general simulation-based method is proposed for implementing P* specification of the ABC. All methods are illustrated using preliminary survey-based assessment results that rely on NMFS trawl-survey and groundfish observer data from the last year pending availability of the new numbers.

## Survey-Based Estimates of Management Quantities

For estimation of required management quantities, the approach used here relies primarily on directed-fishery reported catch (Table 1) and results from the annual NMFS EBS trawl survey (Table 2). ADF&G crab-observer data (Table 3) are used to develop estimates of discard mortality biomass in the directed fishery, whereas estimates of groundfish bycatch mortality are based on NMFS groundfish observer bycatch biomass data (Table 4).

State harvest strategy (5 AAC 34.917) requires estimates of assessment-year mature-male biomass $MMB_{survey}$ and mature and legal-male abundances $MMA_{survey}$ and $LMA_{survey}$ at the time of the survey. Such estimates are directly available from NMFS trawl-survey results (Table 2), as are measures of their uncertainty. Determination of the federal overfishing level (OFL), including specification of a $B_{MSY}$ proxy, requires estimation of mature-male biomass at time of mating $MMB_{mating}$, the Tier-4 proxy measure of stock biomass.

To estimate $MMB_{mating}$, the survey estimate of mature-male biomass $MMB_{survey}$ is first discounted to the midpoint $\tau$ of the fishery under natural mortality $M$, assumed equal to 0.18 yr$^{-1}$. Fishery-reported retained-catch biomass $B_{ret}$ (Table 1) is then subtracted, along with estimated directed-fishery mature-male discard mortality $MMB_{dis}$ (Table 3). After further discounting the resulting biomass to Feb 15, the assumed time of mating, estimated bycatch mortality $MMB_{GFmort}$ in the groundfish fisheries (Table 4) is additionally subtracted on the assumption that groundfish bycatch impacts primarily the mature population, approximately as a Feb 15 pulse effect. Figure 1 displays the four biomass time-series inputs. The calculation is given by

$$MMB_{mating} = (MMB_{survey}\exp(-\tau M) - B_{ret} - MMB_{dis})\exp[-(0.63-\tau)M] - MMB_{GFmort}. \qquad [1]$$

Directed fishery mature-male discard mortality $MMB_{dis}$ is estimated from fishery-reported retained catch and ADF&G crab-observer size-frequency sampling of animals in sampled pot lifts by the proportion of catch corresponding to the sample ratio $\rho$ (Table 3) of estimated mature-male discard weight to estimated total retained weight, assuming a 20% handling mortality. Length-to-weight computations employ coefficients developed by Chilton and Foy (2010). For fishery years lacking observer data, i.e. 1978/79 – 1989/90, and for the assessment year projection the ratio is imputed from years with data using the pre and post-rationalized fishery average value, respectively. Groundfish bycatch mortality $B_{GFmort}$ is estimated by ½ the sum of 80% of the blue king crab bycatch estimates reported for trawl, pelagic trawl, and non-pelagic trawl gear types and 50% of the estimates for all other gear types. The multipliers 0.80 and 0.50 represent assumed handling mortalities, whereas the factor ½ approximates (crudely) the male component of the bycatch.

As Figure 1 shows, the magnitudes of retained catch, discard mortality, and groundfish bycatch mortality are typically small by comparison with mature-male biomass so that [1] leads to the approximation

$$MMB_{mating} \cong \exp[-(0.63)M]MMB_{survey}, \qquad [2]$$

which allows variance estimation and construction of approximate confidence intervals under the assumption that the survey estimate is lognormally distributed around the true value. It follows in any case that

$$\widehat{var}(MMB_{mating}) \cong 0.8\widehat{var}(MMB_{survey}), \qquad [3]$$

with $M = 0.18\ yr^{-1}$ considered given.

Figure 2 shows trawl-survey estimates of "legal" (≥ 120mm CL), "sublegal mature" (105 – 119mm CL), and "recruit" (90 – 104mm CL) male abundance (Table 2). Also shown is the estimated exploitation rate relative to mature male biomass at the time of the survey, which was calculated by summing retained catch and estimated mature male discard and groundfish bycatch mortality and dividing by survey estimated mature male biomass. Evident in this display is an increasing trend in abundance beginning about half way through the 1999/00 – 2008/09 fishery closure, when the exploitation rate was near zero. Evident also are the generally cyclic nature of the three abundance time series and the strong positive correlation between them. In any case, it should be kept in mind that these three size classes only roughly represent their nominal legal and biological population analogues. In particular, recruitment for this stock is, by default, poorly characterized in terms of 90 – 104 mm CL male abundance, which is itself imprecisely estimated.

Figure 3 displays the 35-year time series of estimated mature-male biomass at time of mating $MMB_{mating}$, together with approximate 95% confidence intervals based on [2] and the further assumption that $MMB_{mating}$ inherits a median-unbiased lognormal distribution from the survey estimate; Table 5 provides the numbers. Consistent with the patterns observed in Figure 2, the time series indicates a period of low stock biomass after an abrupt 1998/99 decline prior to the fishery closure. Stock biomass appears to begin rebuilding about midway through the closure, estimated $MMB_{mating}$ showing a nearly monotone increasing trend from 2003/04 through the preliminary 2011/12 estimate of 16.8 million pounds. The time series also exhibits an overall periodic structure similar to that apparent in Figure 2, with statistically significant nontrivial autocorrelations at lags 1 (+), 6 (–), and 7 (–). In light of the high uncertainty associated with the biomass estimates, it is worth noting that the triennial ADF&G SMBKC pot survey data from 1995 – 2010 tell a similar story (Table 6): the 2001 and 2004 surveys signal a decline in stock biomass, followed by substantial increases in both 2007 and 2010. On the other hand, rather low CPUEs and harvests falling well short of the TAC in each of the three fisheries prosecuted since its reopening in 2009 (Table 1) give some reason to think there could be more to the story.

**Calculation of The OFL**

The overfishing level (OFL) is the fishery-related mortality biomass associated with fishing mortality $F_{OFL}$. The SMBKC stock is currently considered Tier 4 (2011 SAFE). Thus given stock estimates or suitable proxy values of $B_{MSY}$ and $F_{MSY}$, along with two additional parameters $\alpha$ and $\beta$, $F_{OFL}$ is determined by the control rule

$$a)\quad F_{OFL} = F_{MSY}\,,\ when\ \ B/B_{MSY} > 1;$$
$$b)\quad F_{OFL} = F_{MSY}\,(B/B_{MSY} - \alpha)/(1-\alpha),\ when\ \ \beta < B/B_{MSY} \le 1;$$
$$c)\quad F_{OFL} < F_{MSY}\ \ with\ directed\ \ fishery\ F = 0,\ when\ \ B/B_{MSY} \le \beta\,,$$

where $B$ is specified to be mature-male biomass at mating $MMB_{mating}$. Note that as $B$ is itself a function of $F_{OFL}$, here taken to be

$$B{=}MMB_{survey}exp(-0.63M)exp(-F_{OFL}), \qquad [4]$$

in case b) numerical approximation of $F_{OFL}$ is required. Previous recommendations for the stock are to use the years 1989/90 – 2009/10 to define a $B_{MSY}$ proxy in terms of average estimated $MMB_{mating}$ and to put $\gamma = 1.0$ with assumed stock natural mortality $M = 0.18$ in setting the $F_{MSY}$ proxy value $\gamma M$. The parameters $\alpha$ and $\beta$ are assigned their default values $\alpha = 0.10$ and $\beta = 0.25$.

With $F_{OFL}$ determined via the control rule, the total male catch OFL is then calculated as

$$OFL = TMB_{survey}\exp(-\tau M)[1-\exp(-F_{OFL})]\,, \qquad [5]$$

where $TMB_{survey}$ is the survey estimate of total male biomass and τ is the time from the survey to the midpoint of the directed fishery.

For this stock there are three catch biomass components to consider: 1) directed-fishery retained catch $B_{ret}$; 2) directed-fishery male discard mortality $B_{dis}$; and 3) male bycatch mortality $B_{GFTmort}$ and $B_{GFFmort}$ in the groundfish trawl and fixed-gear fisheries. Accordingly, the OFL can be partitioned as

$$OFL = B_{ret} + B_{dis} + B_{GFTmort} + B_{GFFmort}\ , \qquad [6]$$

with $B_{ret}$ constituting the retained catch portion of the OFL. For assessment year quantities, groundfish bycatch mortalities are imputed using the previous year's estimates $\hat{B}_{GFTmort}$ and $\hat{B}_{GFFmort}$, and total male discard mortality $B_{dis}$ is projected as $0.2\rho B_{ret}$, where $\rho$ is the ratio of male discard weight to retained-catch weight from the most recent crab-observer size-frequency data and 0.2 is the assumed handling mortality in the directed fishery. Substitution into [6] then yields a retained-catch OFL of

$$OFL_{ret} = B_{ret} = \frac{OFL - \hat{B}_{GFTmort} - \hat{B}_{GFFmort}}{1 + 0.2\rho}. \qquad [7]$$

Associated *OFL* directed-fishery discard mortality is back calculated as $0.2\rho OFL_{ret}$.

For the 2012/13 assessment year, the author recommends basing the $B_{MSY}$ proxy value on the years 1978/79 – 1998/99 rather than on the previously used period 1989/90 – 2009/10, which includes a10-year closure of the directed fishery and implementation of a rebuilding plan. The proposed period of time comprehends the full data series prior to the hypothesized 1998/99 stock collapse (Zheng and Kruse 2002), and estimates of $MMB_{mating}$ for these years represent the full range of values and appear to include a period of low stock biomass after which the stock appears successfully to rebound, even under continued moderate fishing pressure (Figure 2 and 3). This choice of reference years results in a $B_{MSY}$ proxy of 8.33 million pounds, as compared to the 2011 SAFE value of 6.85 million pounds based on the years 1989/90 – 2009/10. By contrast, overall 1978/79 – 2011/12 average estimated $MMB_{mating}$ is 7.53 million pounds. Using [4], and the 2011 $MMB_{survey}$ estimate in lieu of the not yet available 2012 value, then gives $B = MMB_{mating}$ = 15.7 million pounds and $B/B_{MSY}$ = 1.89 > 1 with $F_{OFL}$ at the $F_{MSY}$ proxy $M = 0.18\ yr^{-1}$, so that case a) of the control rule applies. Given $TMB_{survey}$ = 24.58 million pounds (2011 survey estimate), the total male catch *OFL* is thus 3.74 million pounds by [5], as determined in the 2011 assessment, with retained-catch portion equal to 3.35 million pounds by [7].

**Determination of The ABC**

For determining an acceptable biological catch (ABC), and hence the annual catch limit (ACL), current recommendations are to require that P(ABC > OFL) = P* with P* = 0.49. As implemented here, the maximum ABC is set equal to $\lambda \times ofl$, where *ofl* is the assessment calculated overfishing level from the control rule and the multiplier $\lambda$ is determined by the probability statement P[$\lambda$OFL > median(OFL)] = 0.49, which is evaluated in terms of a simulation-based empirical distribution designed to account for uncertainty in key assessment inputs. Specifically, lognormal distributions are used to model uncertainty in the assumed value of natural mortality *M,* including its use as the $F_{MSY}$ proxy; in assessment year estimates of mature male and total male biomass at the time of the survey; and in the estimates of mature male biomass at the time of mating over those years included in the author-recommended $B_{MSY}$-proxy reference period 1978/79 – 1998/99. Survey-based estimates and their CVs are used in specifying parameters for the biomass distributions, whereas *ln(M)* is assumed normal with mean *ln(0.18)* and standard deviation 0.5. The OFL empirical distribution is then obtained from a large number of replicate applications of the OFL control rule under simulated independent sampling from the hypothesized parametric distributions.

Using the preliminary 2012/13 assessment numbers, this procedure yields $\lambda$ = 0.983 and a maximum ABC of 0.983 × 3.74 million pounds = 3.68 million pounds (Figure 4). The R code used to implement the procedure is presented in Appendix A. As a conservative measure and in keeping with past CPT and SSC guidance, the author recommends that the ABC be set at no more than 90% of the maximum value. In this instance, the use of an additional 10% buffer leads to a provisional author-recommended ABC of 3.31 million pounds. By comparison, the recommended 2011 value, also based on a total male catch OFL of 3.74 million pounds, was 3.40 million pounds.

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Table 1. The 1978/79 – 2011/12 directed St. Matthew Island blue king crab pot fishery. (Source: Bowers et al. 2011; ADF&G Dutch Harbor staff, pers. comm.; ADF&G Crab Observer Database)

| | | | Harvest[b] | | | | | |
|---|---|---|---|---|---|---|---|---|
| Season | Dates | GHL/TAC[a] | Crab | Pounds | Pot Lifts | CPUE[c] | Avg Wt[d] | Avg CL[e] |
| 1978/79 | 07/15-09/03 | | 436,126 | 1,984,251 | 43,754 | 10 | 4.5 | 132.2 |
| 1979/80 | 07/15-08/24 | | 52,966 | 210,819 | 9,877 | 5 | 4.0 | 128.8 |
| 1980/81 | 07/15-09/03 | | | **CONFIDENTIAL** | | | | |
| 1981/82 | 07/15-08/21 | | 1,045,619 | 4,627,761 | 58,550 | 18 | 4.4 | NA |
| 1982/83 | 08/01-08/16 | | 1,935,886 | 8,844,789 | 165,618 | 12 | 4.6 | 135.1 |
| 1983/84 | 08/20-09/06 | 8 | 1,931,990 | 9,454,323 | 133,944 | 14 | 4.9 | 137.2 |
| 1984/85 | 09/01-09/08 | 2.0-4.0 | 841,017 | 3,764,592 | 73,320 | 11 | 4.5 | 135.5 |
| 1985/86 | 09/01-09/06 | 0.9-1.9 | 436,021 | 2,175,087 | 46,988 | 9 | 5.0 | 139.0 |
| 1986/87 | 09/01-09/06 | 0.2-0.5 | 219,548 | 1,003,162 | 22,073 | 10 | 4.6 | 134.3 |
| 1987/88 | 09/01-09/05 | 0.6-1.3 | 227,447 | 1,039,779 | 28,230 | 8 | 4.6 | 134.1 |
| 1988/89 | 09/01-09/05 | 0.7-1.5 | 280,401 | 1,236,462 | 21,678 | 13 | 4.4 | 133.3 |
| 1989/90 | 09/01-09/04 | 1.7 | 247,641 | 1,166,258 | 30,803 | 8 | 4.7 | 134.6 |
| 1990/91 | 09/01-09/07 | 1.9 | 391,405 | 1,725,349 | 26,264 | 15 | 4.4 | 134.3 |
| 1991/92 | 09/16-09/20 | 3.2 | 726,519 | 3,372,066 | 37,104 | 20 | 4.6 | 134.1 |
| 1992/93 | 09/04-09/07 | 3.1 | 545,222 | 2,475,916 | 56,630 | 10 | 4.5 | 134.1 |
| 1993/94 | 09/15-09/21 | 4.4 | 630,353 | 3,003,089 | 58,647 | 11 | 4.8 | 135.4 |
| 1994/95 | 09/15-09/22 | 3.0 | 827,015 | 3,764,262 | 60,860 | 14 | 4.9 | 133.3 |
| 1995/96 | 09/15-09/20 | 2.4 | 666,905 | 3,166,093 | 48,560 | 14 | 4.7 | 135.0 |
| 1996/97 | 09/15-09/23 | 4.3 | 660,665 | 3,078,959 | 91,085 | 7 | 4.7 | 134.6 |
| 1997/98 | 09/15-09/22 | 5.0 | 939,822 | 4,649,660 | 81,117 | 12 | 4.9 | 139.5 |
| 1998/99 | 09/15-09/26 | 4.0 | 635,370 | 2,968,573 | 91,826 | 7 | 4.7 | 135.8 |
| 1999/00-2008/09 | | | | **FISHERY CLOSED** | | | | |
| 2009/10 | 10/15-02/01 | 1.17 | 103,376 | 460,859 | 10,697 | 10 | 4.5 | 134.9 |
| 2010/11 | 10/15-02/01 | 1.60 | 298,669 | 1,263,982 | 29,344 | 10 | 4.2 | 129.3 |
| 2011/12 | 10/15-02/01 | 2.54 | 437,862 | 1,881,322 | 48,554 | 9 | 4.3 | 130.0 |

[a] Guideline Harvest Level/Total Allowable Catch in millions of pounds.
[b] Includes deadloss.
[c] Harvest number/pot lifts.
[d] Harvest weight/harvest number, in pounds.
[e] Average Carapace Length of retained crab in millimeters, from dockside sampling of delivered crab.

Table 2. NMFS EBS trawl-survey area-swept estimates of male crab abundance ($10^3$ crab) by size class and mature male (≥ 105 mm CL) biomass ($10^3$ lb) and estimated CV. Total number of captured male crab ≥ 90 mm CL is also given. (Source: J.Zheng, ADF&G; R.Foy, NMFS)

| Year | Recruit (90-104mm CL) | Sublegal Mature (105-119mm CL) | Mature (105mm+ CL) | Legal (120mm+ CL) | Mature Male Biomass | CV | Number of Crab |
|---|---|---|---|---|---|---|---|
| 1978 | 2.384 | 2.268 | 4.032 | 1.764 | 11.876 | 0.391 | 163 |
| 1979 | 2.939 | 2.225 | 4.448 | 2.223 | 12.864 | 0.391 | 187 |
| 1980 | 2.539 | 2.456 | 5.322 | 2.867 | 16.724 | 0.474 | 188 |
| 1981 | 0.477 | 1.233 | 3.579 | 2.346 | 12.833 | 0.404 | 140 |
| 1982 | 1.713 | 2.495 | 8.482 | 5.987 | 30.748 | 0.316 | 269 |
| 1983 | 1.078 | 1.663 | 5.027 | 3.363 | 17.921 | 0.282 | 231 |
| 1984 | 0.410 | 0.499 | 1.977 | 1.478 | 7.684 | 0.187 | 104 |
| 1985 | 0.381 | 0.376 | 1.500 | 1.124 | 5.750 | 0.217 | 93 |
| 1986 | 0.206 | 0.457 | 0.833 | 0.377 | 2.578 | 0.389 | 46 |
| 1987 | 0.325 | 0.631 | 1.346 | 0.715 | 4.060 | 0.285 | 71 |
| 1988 | 0.410 | 0.816 | 1.772 | 0.957 | 5.693 | 0.242 | 81 |
| 1989 | 2.164 | 1.158 | 2.951 | 1.792 | 9.675 | 0.250 | 211 |
| 1990 | 1.053 | 1.031 | 3.370 | 2.338 | 11.955 | 0.264 | 170 |
| 1991 | 1.135 | 1.680 | 3.916 | 2.236 | 12.255 | 0.245 | 198 |
| 1992 | 1.074 | 1.382 | 3.672 | 2.291 | 12.649 | 0.204 | 220 |
| 1993 | 1.521 | 1.828 | 5.104 | 3.276 | 16.959 | 0.163 | 324 |
| 1994 | 0.883 | 1.298 | 3.555 | 2.257 | 11.696 | 0.176 | 211 |
| 1995 | 1.025 | 1.188 | 2.929 | 1.741 | 9.843 | 0.173 | 178 |
| 1996 | 1.238 | 1.891 | 4.956 | 3.064 | 17.112 | 0.241 | 285 |
| 1997 | 1.165 | 2.228 | 6.017 | 3.789 | 20.143 | 0.329 | 296 |
| 1998 | 0.660 | 1.661 | 4.510 | 2.849 | 15.054 | 0.359 | 243 |
| 1999 | 0.223 | 0.222 | 0.780 | 0.558 | 2.871 | 0.182 | 52 |
| 2000 | 0.282 | 0.285 | 1.025 | 0.740 | 3.795 | 0.309 | 61 |
| 2001 | 0.419 | 0.502 | 1.440 | 0.938 | 5.064 | 0.255 | 91 |
| 2002 | 0.111 | 0.230 | 0.870 | 0.640 | 3.311 | 0.322 | 38 |
| 2003 | 0.449 | 0.280 | 0.745 | 0.465 | 2.483 | 0.316 | 65 |
| 2004 | 0.247 | 0.184 | 0.746 | 0.562 | 2.705 | 0.286 | 48 |
| 2005 | 0.319 | 0.310 | 0.811 | 0.501 | 2.812 | 0.360 | 42 |
| 2006 | 0.917 | 0.642 | 1.882 | 1.240 | 6.494 | 0.357 | 126 |
| 2007 | 2.518 | 2.020 | 3.212 | 1.193 | 9.157 | 0.348 | 250 |
| 2008 | 1.352 | 0.801 | 2.257 | 1.457 | 7.354 | 0.287 | 167 |
| 2009 | 1.573 | 2.161 | 3.571 | 1.410 | 10.189 | 0.264 | 251 |
| 2010 | 3.927 | 3.253 | 5.711 | 2.458 | 17.948 | 0.373 | 385 |
| 2011 | 1.693 | 3.215 | 6.467 | 3.252 | 21.073 | 0.525 | 315 |
| 2012 | NA | NA | NA | NA | NA | NA | NA |

Table 3. Observed proportion of crab by size class during ADF&G crab observer pot-lift sampling and estimated fishery mature male discard mortality (pounds). (Source: ADF&G Crab Observer Database)

| Year | Pot Lifts (Sampled/Total) | Number of Crab (90+ CL) | 90-104mm CL | 105-119mm CL | 120mm+ CL | $\rho$[a] | Mature Male Discard Mortality[b] |
|---|---|---|---|---|---|---|---|
| 1990/91 | 10/26,264 | 150 | 0.1133 | 0.3933 | 0.4933 | 0.587 | 202,559 |
| 1991/92 | 125/37,104 | 3,393 | 0.1329 | 0.1768 | 0.6902 | 0.188 | 126,675 |
| 1992/93 | 71/56,630 | 1,606 | 0.1905 | 0.2677 | 0.5417 | 0.309 | 153,353 |
| 1993/94 | 84/58,647 | 2,241 | 0.2806 | 0.2097 | 0.5095 | 0.263 | 158,152 |
| 1994/95 | 203/60,860 | 4,735 | 0.2941 | 0.2713 | 0.4344 | 0.397 | 298,629 |
| 1995/96 | 47/48,560 | 663 | 0.1478 | 0.212 | 0.6395 | 0.255 | 161,585 |
| 1996/97 | 96/91,085 | 489 | 0.1595 | 0.2229 | 0.6175 | 0.242 | 149,108 |
| 1997/98 | 133/81,117 | 3,195 | 0.1818 | 0.2053 | 0.6127 | 0.610 | 566,970 |
| 1998/99 | 135/91,826 | 1,322 | 0.1925 | 0.2162 | 0.5912 | 0.364 | 215,845 |
| 2009/10 | 989/10,484 | 19,802 | 0.1413 | 0.3235 | 0.5352 | 0.452 | 41,706 |
| 2010/11 | 2,419/29,356 | 45,466 | 0.1314 | 0.3152 | 0.5534 | 0.406 | 102,692 |
| 2011/12 | 3,359/48,554 | 58,666 | 0.1314 | 0.3051 | 0.5636 | 0.440 | 165,659 |

[a] Mature-discard to legal-retained weight ratio using crab observer size frequency data and SMBKC length-to-weight coefficient from Chilton and Foy 2010.
[b] Product of $\rho$, fishery reported retained catch weight, and assumed 20% handling mortality.

Table 4. Groundfish SMBKC male bycatch biomass (pounds) data. (Source: J.Zheng, ADF&G; R.Foy, NMFS)

| Year | Bycatch | | Total Groundfish |
|---|---|---|---|
| | Trawl[a] | Fixed Gear | Bycatch Mortality[b] |
| 1992/93 | 993 | 5,355 | 3,472 |
| 1993/94 | 5,232 | 57 | 4,214 |
| 1994/95 | 808 | 199 | 746 |
| 1995/96 | 2,191 | 446 | 1,976 |
| 1996/97 | 64 | 30 | 66 |
| 1997/98 | 18 | 769 | 399 |
| 1998/99 | 0 | 2,566 | 1,283 |
| 1999/00 | 24 | 6,922 | 3,480 |
| 2000/01 | 46 | 91 | 82 |
| 2001/02 | 70 | 4,380 | 2,246 |
| 2002/03 | 3,157 | 2,154 | 3,603 |
| 2003/04 | 3,510 | 4,914 | 5,265 |
| 2004/05 | 394 | 3,087 | 1,859 |
| 2005/06 | 0 | 2,845 | 1,423 |
| 2006/07 | 5,962 | 6,783 | 8,161 |
| 2007/08 | 286 | 299,895 | 150,176 |
| 2008/09 | 705 | 25,797 | 13,535 |
| 2009/10 | 1,722 | 18,281 | 10,518 |
| 2010/11 | 75 | 7,471 | 3,796 |
| 2011/12[c] | 75 | 7,471 | 3,796 |

[a] Trawl, pelagic trawl, and non-pelagic trawl gear types.
[b] Assuming handling mortalities of 0.8 for trawl and 0.5 for fixed gear.
[c] 2011/12 estimates, to be updated Fall 2012.

Table 5. Estimated mature male biomass ($10^6$ lb) at time of mating (Feb 15) with approximate 95% confidence intervals based on assuming median unbiased lognormality of the survey estimate of mature male biomass. The 2012 value is the 2012/13 OFL projection.

| Survey Year | MMBmating | Lower | Upper |
|---|---|---|---|
| 1978 | 8.677 | 3.563 | 21.134 |
| 1979 | 11.277 | 5.310 | 23.951 |
| 1980 | 14.783 | 6.059 | 36.064 |
| 1981 | 6.988 | 2.139 | 22.833 |
| 1982 | 18.882 | 7.997 | 44.583 |
| 1983 | 6.756 | 2.051 | 22.254 |
| 1984 | 3.191 | 1.492 | 6.823 |
| 1985 | 2.997 | 1.479 | 6.073 |
| 1986 | 1.315 | 0.391 | 4.417 |
| 1987 | 2.602 | 1.227 | 5.515 |
| 1988 | 3.866 | 2.101 | 7.113 |
| 1989 | 7.490 | 4.301 | 13.044 |
| 1990 | 8.904 | 4.855 | 16.331 |
| 1991 | 7.711 | 3.973 | 14.966 |
| 1992 | 8.882 | 5.382 | 14.659 |
| 1993 | 12.221 | 8.253 | 18.097 |
| 1994 | 6.696 | 3.944 | 11.366 |
| 1995 | 5.717 | 3.422 | 9.552 |
| 1996 | 12.307 | 6.926 | 21.868 |
| 1997 | 13.164 | 5.671 | 30.558 |
| 1998 | 10.504 | 4.449 | 24.798 |
| 1999 | 2.559 | 1.795 | 3.650 |
| 2000 | 3.388 | 1.872 | 6.129 |
| 2001 | 4.519 | 2.760 | 7.399 |
| 2002 | 2.952 | 1.592 | 5.474 |
| 2003 | 2.212 | 1.205 | 4.059 |
| 2004 | 2.413 | 1.391 | 4.186 |
| 2005 | 2.509 | 1.264 | 4.981 |
| 2006 | 5.709 | 2.930 | 11.395 |
| 2007 | 8.025 | 4.084 | 15.770 |
| 2008 | 6.551 | 3.767 | 11.395 |
| 2009 | 8.600 | 5.022 | 14.729 |
| 2010 | 14.699 | 6.820 | 31.684 |
| 2011 | 16.832 | 5.786 | 48.969 |
| 2012[a] | 15.292 | 4.978 | 48.740 |

[a] 2012 estimates assuming OFL catch, to be updated Fall 2012 using most recent NMFS trawl-survey and groundfish observer data.

Table 6. Size-class CPUE and estimates of mean pot biomass (pounds) and its CV from the 96 common stations surveyed during the six triennial ADF&G SMBKC pot surveys. (Source: D.Pengilly and R.Gish, ADF&G)

| Year | 90-104mm CL | 105-119mm CL | 120mm+ CL (legal) | Biomass | CV | Number of Crab |
|---|---|---|---|---|---|---|
| 1995 | 1.919 | 3.198 | 6.922 | 38.219 | 0.130 | 4,624 |
| 1998 | 0.964 | 2.763 | 8.804 | 44.458 | 0.062 | 4,812 |
| 2001 | 1.266 | 1.737 | 5.487 | 28.994 | 0.079 | 3,255 |
| 2004 | 0.112 | 0.414 | 1.141 | 5.886 | 0.152 | 640 |
| 2007 | 1.086 | 2.721 | 4.836 | 26.841 | 0.097 | 3,319 |
| 2010 | 1.326 | 3.276 | 5.607 | 34.255 | 0.125 | 3,920 |

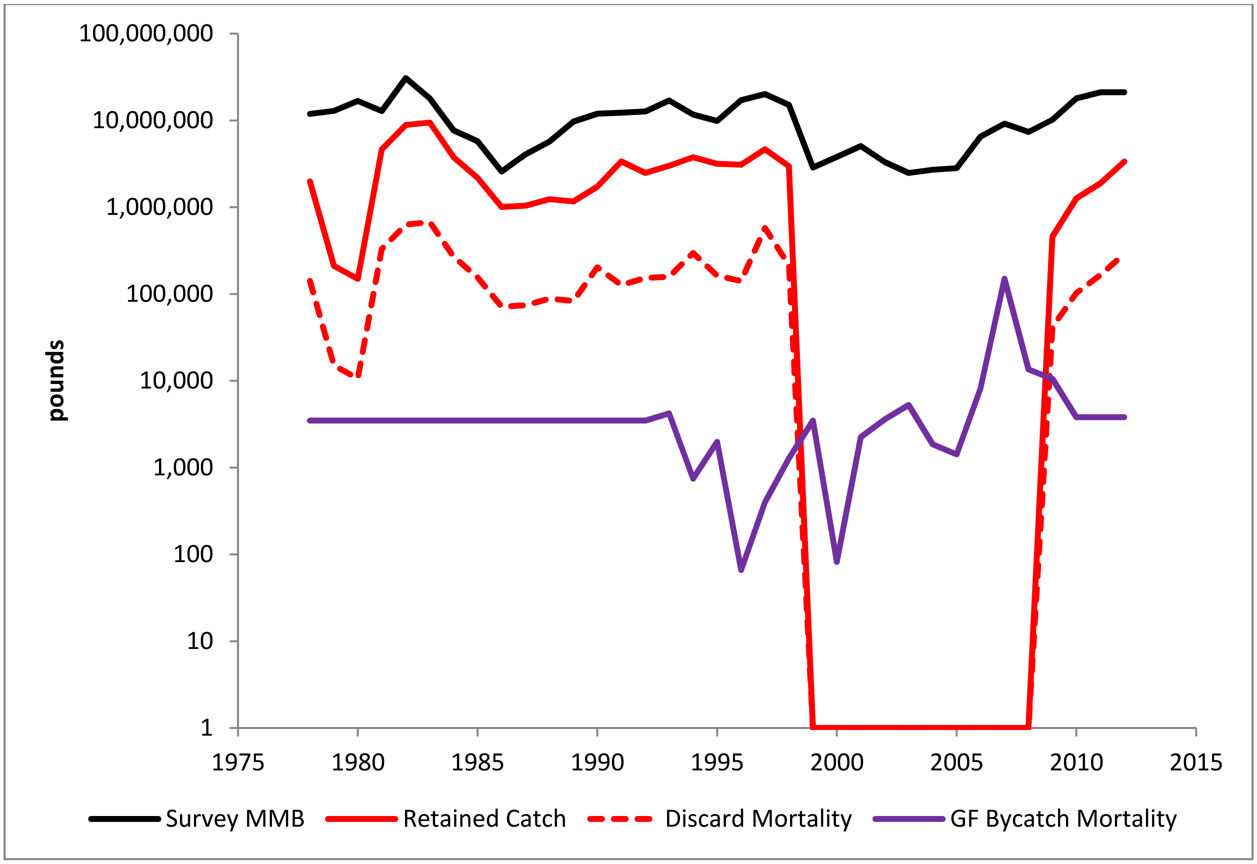


Figure 1. Inputs to computation of estimated 1978/79-2012/13 mature male biomass at time of mating (Feb 15). Retained catch and discard and bycatch mortality biomasses for the last survey year 2012 are 2012/13 OFL projections based on 2011 survey and NMFS observer estimates, to be updated Fall 2012. Note logarithmic scale on vertical axis.

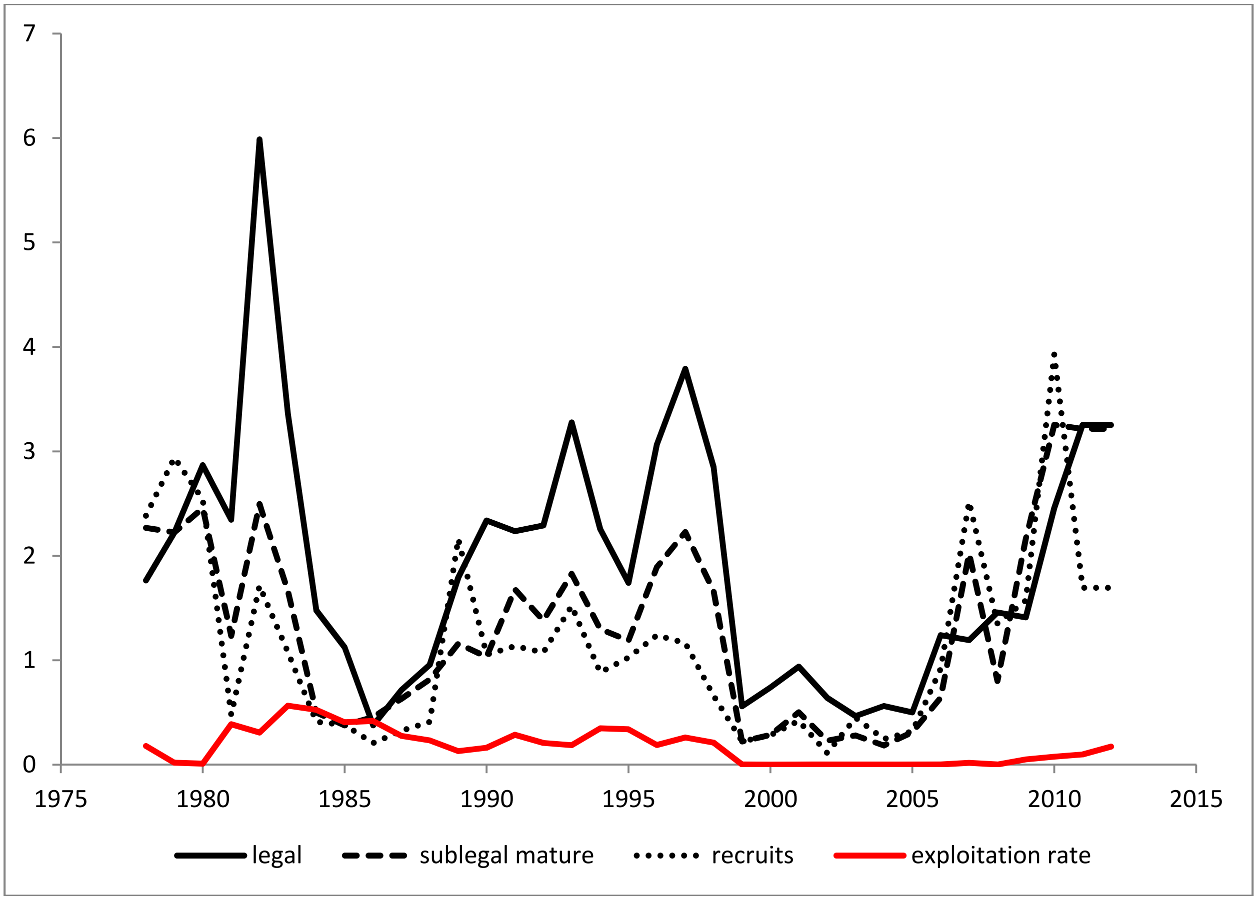


Figure 2. Trawl-survey estimated legal (≥ 120mm CL), sublegal mature (105 – 119mm CL), and recruit (90 – 104mm CL) abundance (millions of crab), together with estimated exploitation rate relative to mature male biomass at time of survey. Note that the directed fishery was closed 1999/20 – 2008/09. Survey year 2012 numbers are from 2011 survey and NMFS observer estimates and assume OFL catch, to be updated Fall 2012.

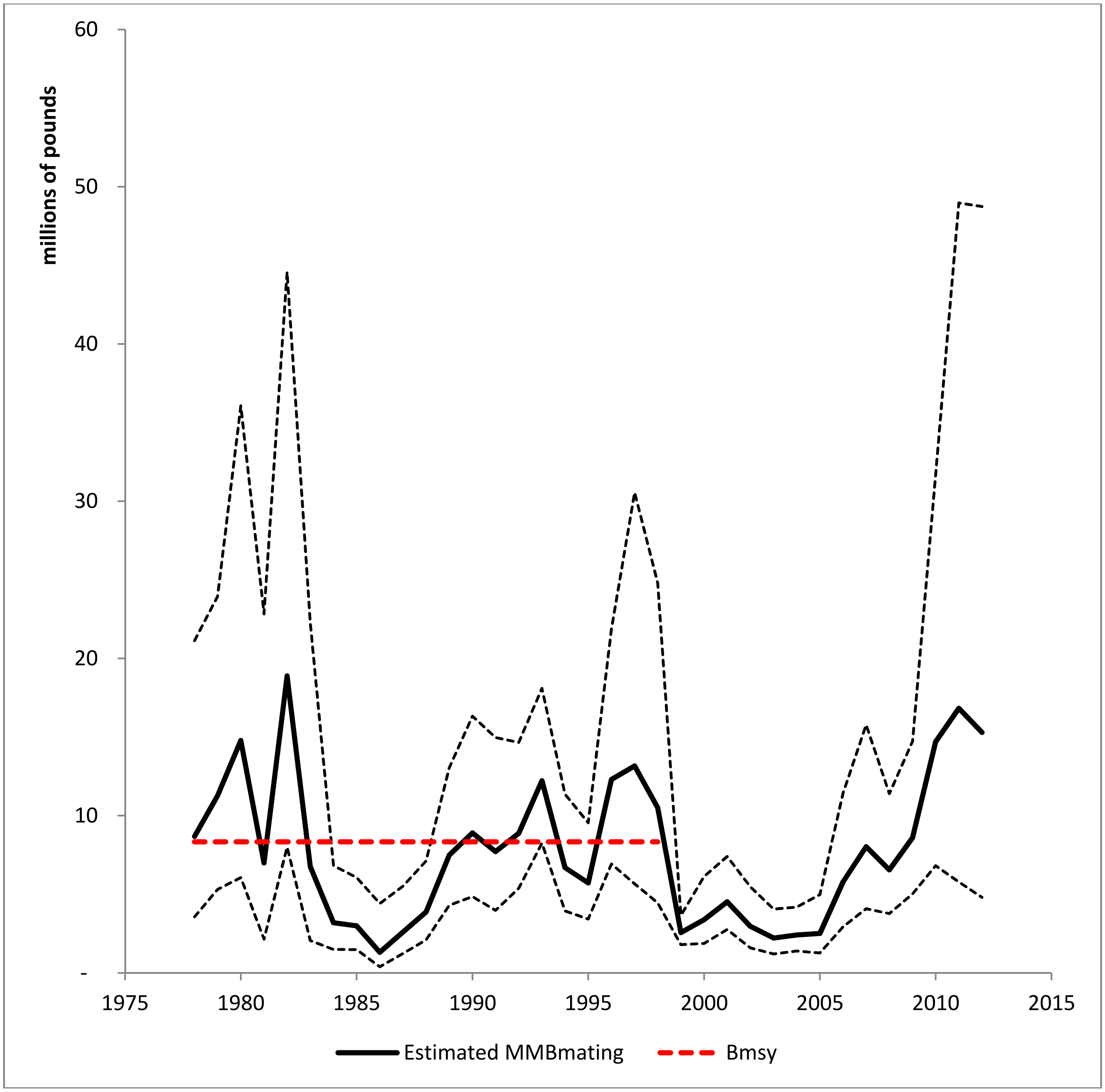

Figure 3. Estimated mature male biomass at time of mating (Feb 15) with approximate 95% confidence intervals based on [2] and assumed median-unbiased lognormality of the trawl-survey estimate of mature male biomass. The 2012 value is from the 2012/13 OFL projection based on 2011 survey and NMFS observer estimates, to be updated Fall 2012. Displayed $B_{MSY}$ proxy is 1978/79 – 1998/99 average.

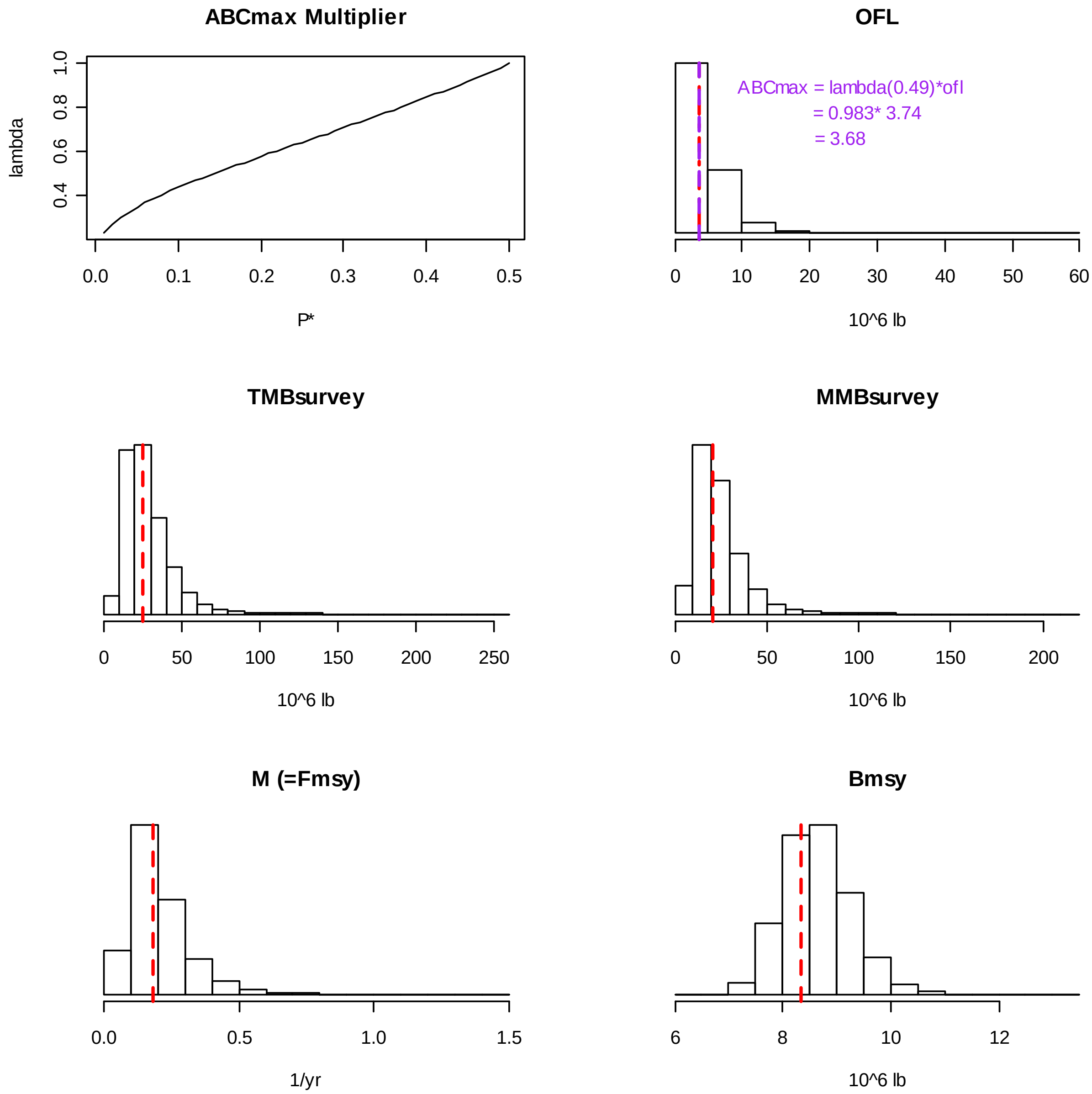


Figure 4. Determination of the maximum ABC (3.68 million pounds) using simulation-based OFL empirical probability distribution accounting for hypothesized uncertainty in key assessment inputs. The multiplier lambda (top left) is computed according to the probability statement P[lambda × OFL > median(OFL)] = P*. Dotted red lines indicate the assessment calculated overfishing level (top right) and associated inputs (lower four panels): total male and mature male biomass at the time of the survey, natural mortality, and the $B_{MSY}$ proxy based on the author-recommended time period 1978/79 – 1998/99.

## Appendix A: R Code for Maximum ABC Determination

```
# FUNCTION
get.Feb15MMB<-function(f,mmb,m){
#Compute MMBmating given fishing mort f, survey mmb, and natural mort m.
return(mmb*exp(-0.63*m-f))
}

# FUNCTION
G<-function(f,mmb,m,Fmsy,Bmsy,alpha){
# Control rule function of f given survey mmb, natural mort m, and control rule parameters Fmsy,
# Bmsy, and alpha.
b<-get.Feb15MMB(f,mmb,m)
return(Fmsy/(1-alpha)*(b/Bmsy-alpha))
}

# FUNCTION
get.Fofl<-function(mmb,m,Fmsy,Bmsy,alpha,beta){
# Iterative computation of f = Fofl using control rule
f1<-G(Fmsy,mmb,m,Fmsy,Bmsy,alpha)
if(f1>Fmsy)return(Fmsy) else
{
	for(k in 1:11)f1<-G(f1,mmb,m,Fmsy,Bmsy,alpha)
	return(ifelse(f1<Fmsy/(1-alpha)*(beta-alpha),0,f1))
}
}

# MAIN FUNCTION
dOFL<-function(tmb,Fmsy,alpha,beta,N,m,Msig,mmb,MMBsig,mmbm.k,MMBMsig.k){
# Generate empirical OFL distribution using simulation. Returns 6 component list of OFL, Fofl,
# M, assessment year survey MMB, Bmsy, and assessment year survey TMB simulated distributions.
# tmb = Estimated survey total male biomass [for TMB OFL]
# Fmsy (M), alpha (0.1), beta (0.25) = control rule parameters
# N = Empirical distribution sample size
# m = point estimate of M (0.18); Msig = sd (0.5) of log
# mmb = assessment year point estimate of survey MMB; MMBsig = sd of log
# mmbm.k = Bmsy reference year point estimates of MMBmating; MMBMsig.k = sds of logs

# Simulated sources of uncertainty:
# 1. Natural mortality (and Fmsy): M=m*exp(X), X~N(0,Msig)
# 2. Assessment year survey MMB: MMB=mmb*exp(X), X~N(0,MMBsig)
# [and assessment year survey TMB=tmb*exp(X)(same X) for TMB OFL]
# 3. Bmsy reference years estimated Feb15 MMB: MMBM.k=mmbm.k*exp(X),
# X~N(0,MMBMsig.k), k=1,2,...,K

K<-length(mmbm.k)
Fofl<-Bmsy<-OFL<-numeric(N)

#Sample
M<-m*exp(rnorm(N,0,Msig))
```

```
x<-rnorm(N,0,MMBsig); MMB<-mmb*exp(x); TMB<-tmb*exp(x)
MMBM.k<-matrix(exp(rnorm(K*N,0,rep(MMBMsig.k,each=N))),ncol=K)%*%diag(mmbm.k)

# Iteratively compute Fofl, and total male OFL, according to control rule
for(n in 1:N)
{
Bmsy[n]<-mean(MMBM.k[n,])
Fmsy=M[n]
Fofl[n]<-get.Fofl(MMB[n],M[n],Fmsy,Bmsy[n],alpha,beta)

OFL[n]<-TMB[n]*exp(-.44*M[n])*(1-exp(-Fofl[n]))
}

return(list(OFL,Fofl,M,MMB,Bmsy,TMB))
}
# END MAIN FUNCTION

# SCRIPT
# Assessment computed OFL
ofl<-3.74

# dOFL inputs
tmb<-24.58; mmb<-21.073; mmbcv<-0.525; Fmsy<-M<-0.18; Msig<-0.5; alpha<-0.1; beta<-0.25
mmbm.k<-c(8.677,11.277,14.783,6.988,18.882,6.756,3.191,2.997,1.315,2.602, 3.866,7.490,8.904,
7.711,8.882,12.221,6.696,5.717,12.307,13.164,10.504)
MMBMsig.k<-sqrt(.8)*c(.391,.391,.474,.404,.316,.282,.187,.217,.389,.285,.242,.25, .264,.245,.204,
.163,.176,.173,.241,.329,.359)
MMBMsig.k<-sqrt(log(1+MMBMsig.k^2))
N<-100000

# Run dOFL
out<-dOFL(tmb,Fmsy,alpha,beta,N,M,Msig,mmb,sqrt(log(1+mmbcv^2)),mmbm.k,MMBMsig.k)

# Iteratively obtain multiplier lambda as function of P* from empirical OFL distribution according
# to P[lambda*OFL > median(OFL)] = P*.
lambda<-numeric(50)
PSTAR<-(1:50)/100
m<-median(out[[1]])
for(j in 1:50){
lambdah<-1.0
lambdal<-0.0
for(k in 1:100)
{
	lambda[j]<-mean(c(lambdah,lambdal))
	pstar<-sum((lambda[j]*out[[1]])>m)/N
	if(pstar<PSTAR[j])lambdal<-lambda[j] else lambdah<-lambda[j]
}
}

# Obtain multiplier and max ABC under P* = 0.49
lambda.49<-lambda[49]
```

```
ABCmax<-lambda.49*ofl

# Generate Figure 4
par(mfcol=c(3,2))
plot(PSTAR,lambda,xlab="P*",ylab="lambda",type="l",main="ABCmax Multiplier")
hist(out[[6]],breaks=20,main="TMBsurvey",xlab="10^6 lb",yaxt="n",ylab="")
abline(v=24.58,col="red",lty=2,lwd=2)
hist(out[[3]],breaks=20,main="M (=Fmsy)",xlab="1/yr",yaxt="n",ylab="")
abline(v=.18,col="red",lty=2,lwd=2)
hist(out[[1]],breaks=20,main="OFL",xlab="10^6 lb",ylab="",yaxt="n")
text(26,60000,labels="ABCmax = lambda(0.49)*ofl",col="purple")
text(28.5,50000,labels=paste("= ",round(lambda.49,3),"*",ofl,sep=""),col="purple")
text(24.5,40000,labels=paste("= ",round(lambda.49*ofl,2),sep=""),col="purple")
abline(v=ofl,col="red",lty=4,lwd=2)
abline(v=ABC.49,col="purple",lwd=2,lty=2)
hist(out[[4]],breaks=20,main="MMBsurvey",xlab="10^6 lb",yaxt="n",ylab="")
abline(v=21.073,col="red",lty=2,lwd=2)
hist(out[[5]],breaks=20,main="Bmsy",xlab="10^6 lb",yaxt="n",ylab="")
abline(v=mean(mmbm.k),col="red",lwd=2,lty=2)
```