User Manual: Version 1.0

Evaluation of Alternative Catch Limits for Illex:

Estimation of Risk of Falling Below Candidate Escapement Thresholds and Exceeding F/M Thresholds

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1.0 Executive Summary

This user manual describes the model used to estimate the probability of falling below various candidate escapement rates for Illex squid, the probability of exceeding candidate ratios of fishing mortality to natural mortality, and joint probabilities of violating both thresholds. Source code for the model is listed in **Appendix 1**.

Given the uncertainty of the population biology, oceanographic conditions, and fishery dynamics one way of approaching the problem is to address the implications of the parameter uncertainty on estimated rates of escapement. Given plausible ranges of parameter uncertainty, what are the risks to the population? This model addresses the uncertainty with respect to parameters in a given year, the variability of actual catches and survey indices across years, and the potential consequences of alternative catch levels. Alternative catch levels are evaluated by computing the fishing mortality rate and escapement that would have occurred IF the alternative catch had been applied to the estimated stock size in year t.

The model theory is described in **Appendix 2** and is extended herein to include uncertainty related to the estimation of minimum swept area biomass estimated derived from NEFSC Bottom Trawl Surveys.

This user manual includes a worked example of the analyses used to prepare the report attached in Appendix 2. The model is written in R. Example input and output files are included, along with two Excel spreadsheets that are used to create summary tables for the assessment report. Finally, the graphs from the model are summarized in a pdf file with sequentially numbered plots. The captions for each plot are included in the documentation below.

2.0 Background

Illex squid are seasonally available to northeast US fisheries but the fraction of the population in fishing areas can only be approximated. Owing to their diel vertical migration patterns, efficiency of trawl gear can vary within a day. Illex squid are a sub-annual species with temperature dependent growth rates. Natural mortality rates (M) are poorly estimated and are strongly linked to maturation rates. Finally, measures of relative abundance via trawl surveys in the US typically occur after the primary fishing period. Collectively, these features make stock assessments of squid problematic around the world. Dynamic stock assessment models (i.e., models that links populations across years) of squid have generally not been successfully applied. Most assessments rely on some form of depletion model that follows one or more putative cohorts within a season based on changes in catches and effort of commercial harvesters. A depletion model provides estimates of an initial population size (B.0) and the total rate of mortality that is a function of fishing effort and natural mortality.

The model used herein also estimates the initial biomass necessary to support the observed catch. However, instead of fitting the time series of fishery CPUE, it seeks consistency with the terminal year abundance estimate and an assumed rate of natural mortality (M). For the Illex population in the Northeast US we have an estimate of the relative abundance (I_t) of Illex at the end of the fishing season and the observed total catch. The end of year biomass estimate B_t is

inversely proportional to the overall gear efficiency (q) of the trawl and the fraction of the total population (v) in the survey area during the sampling period. The standard error of the estimate, derived from sampling theory, also contributes to the uncertainty of B_t. To estimate the initial virtual biomass, it is necessary to assume a rate of natural mortality. Mathematical details of the model theory are described below. However, it is important to recognize that four sources of uncertainty are incorporated into the estimation of B.0:

- Efficiency of the trawl survey gear, q
- Fraction of the total population available to the survey area, v
- Standard error of the estimated relative abundance $SE(I_t)$
- Natural mortality M

Fortunately, it is possible to establish some bounds on q, v, M based on empirical studies and comparisons with the literature. The error of the survey estimate is obtained from sampling theory.

The virtual population biomass estimator for B.0 is obtained by rearranging the terms of Baranov's catch equation and estimating the overall fishing mortality rate F. Escapement can then be estimated as the ratio of the population size with the fishery relative to what the population would have been in the absence of the fishery (i.e., natural mortality only). The ratio of fishing mortality to natural mortality (F/M) has been used as a biological reference point for forage fish. Finally, given an estimate of B.0 it is possible to estimate the escapement that would have occurred if the alternative quota had been taken. Additional background on the theory and application of these methods may be found in **Appendix 2**.

In a nutshell, the methodology described herein estimates the initial biomass at the start of the fishing season over a broad range of assumed parameter values. It then computes the effect of the actual catch, and hypothetical alternative catches, on escapement and F/M ratios. The joint effects of parameter uncertainty and alternative catch levels are used to create probability density functions of biomass, fishing mortality rates, escapement levels, and F/M ratios.

3.0 Model Theory

3.1 Estimation of Initial Biomass, Fishing Mortality and Escapement

Let I_t represent observed index of biomass at time t and C_t represent the catch at time t. The estimated swept area total biomass consistent with the index is

$$B_t = \frac{I_t}{q}\frac{A}{a} \qquad (1)$$

where the catchability or efficiency **q**, is an assumed value. The average area swept per tow is **a** and the total area of the survey is **A**. To account for the fact that a sizable fraction of the Illex population lies outside of the survey area, an additional parameter **v** is introduced which represents the fraction of the resource measured by the survey. If the population is closed **v** is set to one and all of the population is assumed to be in the survey areas. Eq. 1 can be modified to account for this by dividing the right-hand side by **v** such that:

$$B_t = \frac{I_t}{q}\frac{A}{a}\frac{1}{v} = \frac{AI_t}{qav} \qquad (2)$$

The NEFSC fall bottom trawl survey occurs after most of the fishery occurs and therefore can be considered a measure of post-fishery abundance. In order to account for the potential swept area biomass that existed at the start of the season, it is necessary to add the total landings removed from the fishery. Thus, the estimate of abundance at the start of fishing season is what was left plus what was extracted. Since the removals take place over a period of time and the squid are subject to natural mortality during that period, it is further necessary to inflate those removals.

To "back up" the abundance estimate to what it would have been at the start of the season, one needs to adjust the actual catch for natural mortality and add it back into B_t

$$B_t = B_0 \ e^{-Zt} \qquad (3)$$

Where B_t is defined by Eq. 2.

The initial biomass consistent with observed catch can be obtained by rearranging the Baranov catch equation as

$$B_0 = \frac{C_t}{\frac{F}{F+M}(1-e^{-(F+M)})} \qquad (4)$$

Substitution of Eq. 3 into 4 and rearranging results in

$$B_t e^{(F+M)} = \frac{C_t}{\frac{F}{F+M}(1-e^{-(F+M)})} \qquad (5)$$

Further substitution of Eq 2 into 5 expresses B_t and B_0 as functions of observations of survey indices I_t and landings C_t and assumed values for q, v and M.

$$\frac{AI_t}{qav} e^{(F+M)} = \frac{C_t}{\frac{F}{F+M}(1-e^{-(F+M)})} \qquad (6)$$

Fishing mortality F can now be computed directly by numerical methods (see function uniroot in R). Direct estimation of F was used in this analysis rather than Pope's approximation in view of the potential consequences of violating the parameter range over which the Pope's method is appropriate. Direct estimation of F also simplifies consideration of escapement under alternative assumed quotas.

For the purposes of this work, escapement is defined as the ratio of the observed end of fishing season population B_t to that expected if no fishing mortality occurred. The projected population if no fishing occurred can be obtained by projecting B0 in Equation 10 by the fraction surviving natural mortality:

$$B_{t,without\ fishery} = B_0 e^{-Mt} \qquad (7)$$

The "escapement" is now computed as the ratio of the estimated B_t based on the survey divided by the projected biomass that would have occurred in the absence of the fishery.

$$Escapement = \frac{B_t}{B_{t,without\ fishery}} \tag{8}$$

Further substitution of Eq. 3 and 7 into Eq. 8 results in

$$Escapement = \frac{B_t}{B_{t,without\ fishery}} = \frac{B_0 e^{-(F+M)}}{B_0\ e^{-M}} = e^{-F} \tag{9}$$

Estimates of B_0 can also be used to evaluate the effects of alternative catch levels on escapement. Let C_H equal a hypothesized catch to be obtained from the estimated B_0. Substitution of C_H into Eq. 6 allows for estimation of the F necessary to obtain C_H, denoted as F_H.

$$B_0 = \frac{C_H}{\frac{F_H}{F_H+M}\left(1-e^{-(F_H+M)}\right)} \tag{10}$$

Thus, escapement given C_H is now defined as exp($-F_H$). To investigate the implications of alternative higher catches Equation 10 was applied to each year, 1997-2021 using hypothetical quotas of 24,000 to 60,000 mt in steps of 1,000 mt.

3.2 Stochastic Methods for Biomass, Fishing Mortality and Escapement

For a given set of assumed parameters {q,v,M} and fixed inputs for survey estimates and catch {$I_{f,t}$, $I_{s,t}$, C_t} it is possible to estimate $B_{0,t}$, F_t, Escapement$_t$ F/M and other outputs of possible utility for the assessment.

In this model formulation, catch is assumed to be measured without error but the survey value $I_{f,t}$ is also considered to be a random variable. This modification of the model presented in March 2022 is a response to the recommendation of the MAFMC SSC to consider the uncertainty of the point estimate of survey biomass. Survey theory dictates that the expected value of a mean quantity from a stratified random design will be normally distributed irrespective if the underlying distribution or patchiness of the animals. As a first approximation, the sampling variation of $I_{f,t}$ was evaluated over the 80% confidence interval by selecting n equal probability points specified by a normal distribution with probability values between Normal($\mu=I_{f,t}$, $\sigma=CV_{f,t}$ $I_{f,t}$, $\alpha=0.1$) and Normal($\mu=I_{f,t}$, $\sigma=CV_{f,t}$ $I_{f,t}$, $\alpha=0.9$).

The ranges of other parameters in Equation 2 and 6, i.e., **{q,v,M}** can be established by examining a range of parameters. By assuming that each of the parameters is drawn from an underlying distribution of values, it is possible to compute the resulting distribution of $B_{0,t}$, F_t, Escapement$_t$ etc. One way of efficiently sampling over the entire range of values is known as Latin hypercube sampling. In simple terms, one assigns an equal probability to each value

drawn from the underlying distribution by dividing the range of the parameter into equal probability intervals. The area under the curve (ie. the integral) for a probability density function over a define range e.g., (q_1, q_2) is the same for all intervals. Thus each observation, defined as the midpoint of (q_1, q_2) now has the same probability. For a uniform distribution this just means dividing the domain of the distribution (p_{min}, p_{max}) into equally spaced intervals.

This same principle can be applied to any hypothetical parameter, say r, (r_{min}, r_{max}) to obtain equal probability observations. By looping over the full range of r for every value of p you obtain a measure of the expected value of some function Y for p over every value of r. If there are N_q intervals for parameter q, N_v for v, N_M for M, and N_I for $I_{f,t}$ then the joint probability for any combination $\{q_i, v_j, M_k, I_{f,t}\}$ is $(1/N_q)(1/N_v)(1/N_M)(1/N_I)$. Looping over all possible combinations yields a probability density function for any function of q, v, M and $I_{f,t}$.

In this case, N was set to 25, 20, 20, and 25 for (N_q), (N_v), (N_M), and (N_I), respectively. This results in 250,000 evaluations of the function for each year. The model is written in R and the core code is listed in **Appendix 1.**

Probability levels for candidate thresholds can be computed by counting the proportion of realizations that fall above for below a criteria. For example, the average probability that a given alternative quota induces escapement below 50% can be found by estimating the proportion of cases that fall below 0.5 and averaging the probabilities over all years. This was done for each candidate quota level between 24,000 and 60,000 mt.

3.3 Constraints on parameters.

Catchability

The conversion Bigelow to Albatross is 1/1.4093 implies max q Albatross is 0.71 if Bigelow q=1 (Miller et al 2010). In addition, catch rates of Illex are higher during the day than at night. Diurnal differences in catch rates are known for many squid. For longfin squid Jacobson et al. (2015, cf Table 3, p. 1334) found a nearly two-fold difference between a composite median abundance and an estimate based on daytime tows only (0.74 B vs 1.5 B). A model adjusted estimate of median abundance was 2.0B. Together these estimates suggest an upper bound in the range of q to be 0.37 to 0.493 for longfin squid.

In another study, Benoit and Swain (2003) compared day vs night catches from the Canadian research vessels Alfred Needler and Lady Hammand, both of which used the Yankee 36 net or the period 1971 to 2001. Using estimated the log catch ratios of night to day tows for the research vessels) were -1.224 and -1.376 respectively (P<0.001; see their Table A1, p 1317). These imply day to night ratios of catch rates of 3.401 and 3.959. If roughly half the tows during the day, then the expected catch expressed in daytime equivalents would by 2.2 to 2.5 times higher. Using a model statistical method comparable to the "statististical control" model of Benoit and Swain (2003), Sagarese et al. (2016) computed an overall day night coefficient of 1.2 (log scale) for Illex in the Northeast US Continental Shelf Large Marine Ecosystem (P<0.005). The arithmetic day to night ratios is exp(1.2) = 3.32, similar to that found by Benoit and Swain (2003).

As noted in Hendrickson and Showell (2019) the Benoit and Swain (2003) did not find significant differences for Illex in pairwise comparison tests, but this may have been a function of sample size (about 67 stations each in 1988 and 1992). Brodziak and Hendrickson (1997) reported catch rates for pre-recruit (<10 cm mantle length) Illex illecebrosus to be 1.6 to 2.4 times higher in the day than during dusk and night, respectively (P<0.001). The same ratios for Illex recruits (>10 cm) had a significance value of 0.106 and was not reported.

Collectively, these studies suggest that night time catches are low by a factor of at least two. Combining this with the known information from the Bigelow to Albatross calibration coefficient (1/1.4093) results in reasonable upper bound of 0.5/1.4093=0.355. This compares favorably to the 95% upper bound (=0.325) proposed by Manderson et al for commercial vessels.

The likely lower bound on catchability has important implications for estimating the likely range of biomass bounds. Assuming very low values of q imply very high values of biomass. Manderson et al. (2021) reported a potential lower bound of 2% for q based expert opinion. While efficiencies may be this low for specific tows, it is unlikely to be the case over an entire survey within a year. The average estimate from the experts for commercial gear was 7.8%. Assuming that this is based on daytime tows, it would be reasonable to assume that research vessel tows, which are collected both day and night, the lower bound on research vessel tows should be less than 7.8%. It is not possible to determine if the differences in diel catch rates factored into the average defined by the expert panel.

Availability

Spatial analyses methods were used by Lowman et al. (2021) and Manderson et al. (2022) were used to compute estimates of likely availability of Illex to the US survey strata. Depending on the method used for the sensitivity-specificity threshold, availability estimates ranged from 34.5 to 46% with one method to 31-73% with another. The wider range (31-73%) was used in this report for setting bounds.

Natural Mortality

The lower bound of assumed weekly natural mortality rates (=0.01) was based on lowest assumed value in Hendrickson and Hart (2006). The upper bound of 0.13 week^{-1} was obtained from the predictive equation of Hewitt and Hoenig (2005) given a maximum age of 221 days in 2019-2020 samples.

Candidate Thresholds for Escapement and F/M

Escapement levels of 50%, 40% and 35% from literature and assessment reports. F/M ratio for forage species. F/M =1, 2/3. The candidate threshold levels are hardwired into estimation model. If a subsequent review suggests revision, the values could be updated or made part of the parameter stream for model specification.

3.4 Risk Analyses

Decisions by the MAFMC regarding catch levels are governed by its Risk Policy that attempts to avoid overfishing over all levels of stock biomass. The risk of overfishing is defined as the probability of exceeding the overfishing limit and is denoted as P* as depicted below.

Comparison of the current risk policy (status quo) and the modified alternative. The modified alternative depicted is now the MAFMC's policy. Source= https://static1.squarespace.com/static/511cdc7fe4b00307a2628ac6/t/5e56e0ccb8195137f6d160d7/1582751948674/1_Risk+Policy+memo+to+SSC.pdf Under the approved new risk policy (labeled as "Modified Alt" in the figure above, the probability of overfishing can reach 0.49 when the ratio of current to MSY stock levels exceeds 1.5. Below 1.5 the acceptable risk of overfishing declines to zero when B/Bmsy$\leq$0.1.

The risk of overfishing for Illex can be expressed as the probability of escapement falling below a specific threshold level (say 35%, 40%, 50%) or the probability of exceeding F/M =2/3, 1 or other values that attempt to preserve forage for available predators. Finally, one can estimate the joint probability of exceeding F/M threshold and falling below an escapement threshold.

To apply the Council risk policy it to guesstimate the likely current state of the Illex resource (i.e., Bt/Bmsy). For illustration, it has been assumed that the population is between 0.5 and 1.0 times the Bmsy level. See Figures 181-183, in the pdf plot output file.

4.0 Guide to Source Code

The model is implemented in R and is run under RStudio (Appendix 1). The code is broken up into 4 major blocks. The first block loads the necessary R libraries, reads in the catch and survey data, reads in the model parameters, reads in the list of alternative quotas, and creates the appropriately sized arrays. It also opens the output file for graphs. The second block is the computational engine that loops over the specified number of iterations and computes the

estimates for B.0, F, Escapement, and the F/M ratio. F is estimated from the catch equation using the function uniroot(). The computation time is proportional to the total number of evaluations (or problem size). The problem size parameter is the product of the number of intervals for each parameter. For the test example specified here, the number of evaluations per year is 25*25*20*20 = 250,000. This requires very large arrays in R. Each realization B.0 is also evaluated with respect to the effects of each alternative quota sizes. For the SSC example in 2022 the range of alternative quotas considered is between 24,000 mt and 60,000 mt in steps of 1,000 mt. For each of the 250,000 realizations B.0 in a given year, the potential effects of 37 alternative quotas on escapement and F/M is computed. Thus, there are 9.25 million evaluations per year.

The large number of evaluations are distilled by percentiles and stored in two separate data frames. One summarizes the estimates for the observed catches; the second summarizes the estimates for the hypothetical catches. Thus, escapement and F/M is computed for each realization (250K) with respect to the observed catch, and with respect to each of the hypothesized alternative quotas (i.e., 24,000 to 60,000 mt).

To facilitate visualization of the results a pdf file is created to contain various 3D and 2D plots. Each plot is numbered sequentially and can be extracted for inclusion in a final report.

The databases supporting these graphs are output to .csv files. These files are then copied into generalized Excel spreadsheets that automatically create all of the tables used in the report. The following schematic gives an overview of the information flows to and from the estimation odels and to the summary report.

Schematic of Estimation Model Structure: Inputs and Outputs
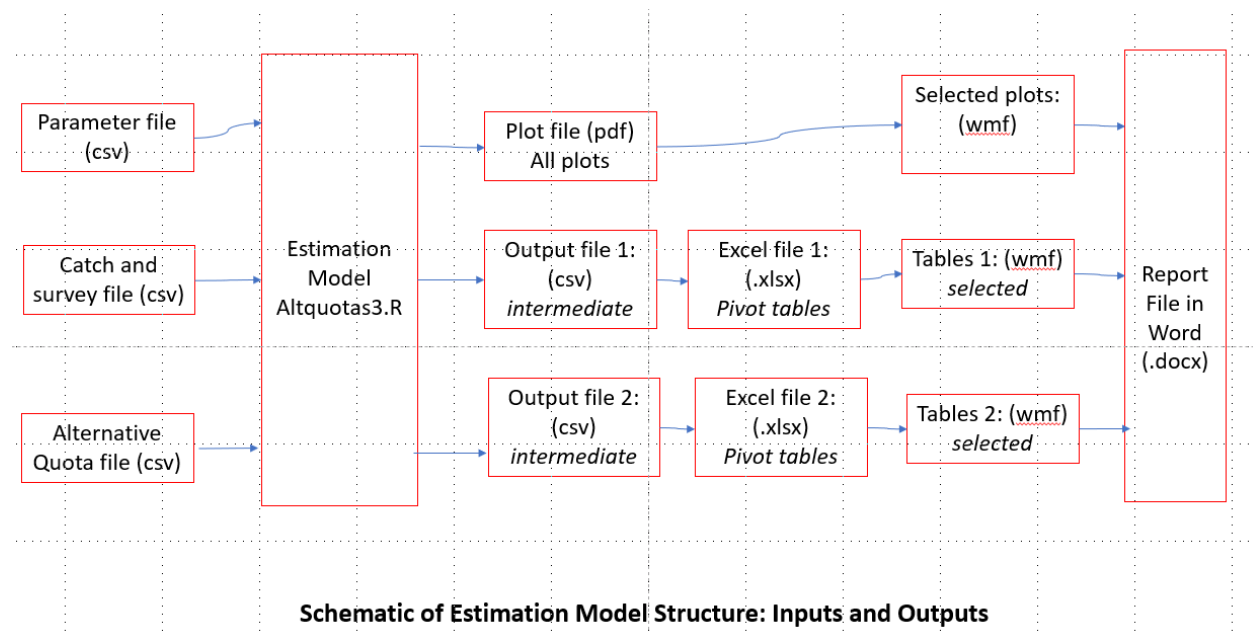
Table of file names

Type	Contents	Exten-sion	Filename (size KB)
Input	Parameters for controlling range of q, v, M, confidence interval for survey biomass uncertainty. The number of evaluations for each parameter are also specified	.csv	inputtests.csv (1 KB)
Input	Table of catch and survey biomass estimates based on NEFSC bottom trawl survey for spring and fall survey. Only the fall survey is used by this program; the spring survey is used for other computations related to mass balance approaches. Uncertainty is expressed as the coefficient of variation (CV) of the estimate. Values are the percent CV written as an integer. Thus CV=17 is a 17% CV; the standard error of the estimate is computed as the product of the mean estimate times the CV/100.	.csv	Catch_survey_data.csv (1 KB)
Input	This file is a list of the alternative quotas to be evaluated. Values are expressed in metric tons.	.csv	AlternativeQuotas.csv (1 KB)
Output	Database of probabilities of violating candidate reference points for each output variable.	.csv	Escapement_FMratio_probabilities_197-2022.csv (795 KB)
Output	Database of percentiles for each output variable.	.csv	RiskAnalysis_stats_1997-2022.csv (12,947 KB)
Output	The file Escapement_FMratio_probabilities_197-2022.csv is imported into this spreadsheet which contains pivot tables that are used to generate report ready tables for inclusion in the report	.xsls	Tables for Escapement_FMratio_probabilities_1997-2022.xlsx (932 KB)
Output	The file RiskAnalysis_stats_1997-2022.csv csv is imported into this spreadsheet which contains pivot tables that are used to generate report ready tables for inclusion in the report	.xlsx	Tables for RiskAnalysis_stats_1997-2022.xlsx (12,385 KB)
Output	This file contains all of the plots generated by the model. The structure of the plot file is summarized in the documentation	.pdf	RiskAnalysis_plots_1997-2022.pdf (26,805 KB)

Example Working directory of files:

Name	Date modified	Type	Size
AltQuotas2.R	1/31/2023 10:28 PM	Tinn-R	51 KB
Tables for Escapement_FMratio_probabilities_1997-2022.xlsx	1/31/2023 10:27 PM	Microsoft Excel W...	932 KB
Tables for RiskAnalysis_stats_1997-2022.xlsx	1/31/2023 3:59 PM	Microsoft Excel W...	12,384 KB
schematic of model structure.pptx	1/30/2023 11:32 PM	Microsoft PowerPo...	42 KB
PNG layout example in Word.docx	1/30/2023 11:20 AM	Microsoft Word D...	23 KB
RiskAnalysis_plots_1997-2022_132.png	1/30/2023 10:59 AM	PNG File	4 KB
RiskAnalysis_plots_1997-2022_131.png	1/30/2023 10:59 AM	PNG File	6 KB
RiskAnalysis_plots_1997-2022_1.png	1/30/2023 10:23 AM	PNG File	1 KB
RiskAnalysis_plots_1997-2022_77.png	1/30/2023 10:18 AM	PNG File	0 KB
RiskAnalysis_plots_1997-2022.pdf	1/29/2023 9:11 PM	Adobe Acrobat D...	26,805 KB
Escapement_FMratio_probabilities_1997-2022.csv	1/29/2023 9:10 PM	Microsoft Excel Co...	795 KB
RiskAnalysis_stats_1997-2022.csv	1/29/2023 9:10 PM	Microsoft Excel Co...	12,947 KB
inputtests.csv	1/29/2023 2:41 PM	Microsoft Excel Co...	1 KB
AltQuotas2 - Copy.R	1/27/2023 6:54 PM	Tinn-R	47 KB
catch_survey_data.csv	1/27/2023 4:16 PM	Microsoft Excel Co...	1 KB
Tables for Escapement_FMratio_probabilities_1997-2022_template.xlsx	1/27/2023 4:14 PM	Microsoft Excel W...	849 KB
Tables for RiskAnalysis_stats_1997-2022_template.xlsx	1/27/2023 3:53 PM	Microsoft Excel W...	11,865 KB
inputtests - Copy.csv	1/26/2023 9:15 AM	Microsoft Excel Co...	1 KB
AltQuotas_2023.Rproj	1/25/2023 4:22 PM	R Project	1 KB
misc R code test of multiple plots to single file.docx	1/20/2023 10:08 PM	Microsoft Word D...	24 KB
AltQuotas1.R	3/29/2022 9:43 AM	Tinn-R	31 KB
catch_survey_data Copy.xlsx	3/8/2022 2:34 AM	Microsoft Excel W...	13 KB
AlternativeQuotas.csv	2/28/2022 3:26 PM	Microsoft Excel Co...	1 KB

5.0 Input Data

5.1 Model Control Parameters: inputtest.csv

Here's the format of the inputtests.csv file used to generate the test case. The range of values considered for q, v, and M is the lower and upper bounds of a uniform distribution. For the fall survey, the range of I.f.alpha is the lower and upper bounds of the confidence interval desired. In the example below, an 80% confidence interval is evaluated given the 0.1 and 0.9 levels of alpha. The F.range parameter is simply the admissible range of fishing mortality rates in the search algorithm that estimates F in the catch equation (Eq. 4 and Eq. 6).

	A	B	C	D	E	F	G	H	I
1	Par.Name	Min	Max	N	Comment				
2	q	0.078	0.325	25	# Efficiency				
3	v	0.37	0.73	20	#Availability				
4	M	0.01	0.13	20	#Natural Mortality				
5	I.f.alpha	0.1	0.9	25	# 80%CI range for eval of observation error				
6	F.range	0.000001	5	1	# Admissible range of F to search in Newton Ralphson				
7									

Here's the format for the AlternativeQuotas.csv file that contains the range of alternative quotas evaluated for each year.

	A	B
1	AltQuota	
2	24000	
3	25000	
4	26000	
5	27000	
6	28000	
7	29000	
8	30000	

. . .

31	53000
32	54000
33	55000
34	56000
35	57000
36	58000
37	59000
38	60000

5.2 Survey and Catch Data

The catch and survey data file (catch_survey_data.csv)contains the catch for each year and the spring and fall NEFSC survey years for years where the surveys are done. Missing years are identified with an NA. Only the fall survey is used by this program. The spring survey, used for other computations related to mass balance approaches, is not considered by the SSC in its evaluation of risk of exceeding candidate biological thresholds. Uncertainty is expressed as the coefficient of variation (CV) of the estimate. Values are the percent CV written as an integer. Thus CV=17 is a 17% CV; the standard error of the estimate is computed as the product of the mean estimate times the CV/100. The table included values for 2022 that are equal to those in 2021. These are to be updated for the model update in 2023.

	A	B	C	D	E	F	
1	Year	Catch.t	l.s.t	cv.s.t	l.f.t	cv.f.t	
2	1997	14358	511	46	2730	17	
3	1998	24154	226	57	7725	51	
4	1999	8482	149	17	929	16	
5	2000	9117	35	14	3999	22	
6	2001	4475	110	38	1422	15	
7	2002	2907	68	55	2322	20	
8	2003	6557	23	34	10913	68	
9	2004	27499	139	72	2279	12	
10	2005	13861	14	24	3696	46	
11	2006	15500	121	32	14220	34	
12	2007	9661	147	32	7311	8	
13	2008	17429	54	34	5462	18	
14	2009	19090	404	38	5170	20	
15	2010	16394	101	30	2941	22	
16	2011	19487	294	29	2937	18	
17	2012	12211	1099	34	2895	12	
18	2013	4107	22	27	1827	13	
19	2014	9342	NA	NA	3592	11	
20	2015	2873	217	20	2795	14	
21	2016	7004	2641	38	3711	26	
22	2017	23371	314	26	NA	NA	
23	2018	25524	382	23	7146	13	
24	2019	28495	1901	59	3310	14	
25	2020	NA	NA	NA	NA	NA	
26	2021	30714	NA	NA	3531	17	
27	2022	30714	NA	NA	3531	17	
28							

6.0 Running the Model in RStudio

The source code for the model is contained in AltQuotas3_tidy.R. This file is equivalent functionally to the AltQuotas2.R but extraneous comments, test code and so forth have been eliminated to improve readability.

6.1 Creating a project file in R

The user should set up a separate project file for each parameter configuration. All output files generated will be sent to this file. The function getwd() is used to identify the path to the working directory. Outputs to this directory are made by appending the file name to the working directory as follows:

plotoutputfile=paste0(getwd(),"/RiskAnalysis_plots_1997-2022.pdf")   #specify plot output file

pdf(file=plotoutputfile,height=9.4545, width=5.5) #Open pdf file and specify plot area in inches(default)

6.2 Required R libraries

The model relies on a number of R libraries available from the R website. These include:

```
library(mgcv)
library(Hmisc)
library(contourPlot)
library(vioplot)
library(plyr)
library(sm)
library(EnvStats)
library(MASS)
library(akima)
library(Polychrome)
library(Rtools)
```

Each of the libraries can be installed using the install.packages() command as follows:

```
install.packages('EnvStats')
install.packages('Polychrome')
install.packages("Rtools")
etc.
```

6.3 Processing time

The run time for the model is proportional to the number of simulations per year. This variable in the code is denoted by n.sim. On my computer (Think Pad T580, ~2020) the run time for 1997-2022, with 250,000 estimates per year was 3.97 hours. This translates to 1.589 hours per 100,000 estimates.   See below.

```
> end_time=Sys.time()
> TotalRunTime=end_time-start_time
> Timeper100000Simulations=TotalRunTime/n.sim*100000
> print(paste("Total Elapsed Time for simulation = ",TotalRunTime))
[1] "Total Elapsed Time for simulation =  3.97342756470044"
> print(paste("Time per 100,000 simulations = ",Timeper100000Simulations))
[1] "Time per 100,000 simulations =  1.58937102588018"
> ###############################################End of simulations
>
```

Thus a simulation with 400,000 estimates per year would be 400,000/100,000 * 1.5893 = 6.35 hrs.

7.0 Output Data

7.1 RiskAnalysis_stats_1997-2022.csv

This file contains the primary simulation model output. Each year of the simulation requires n.sim evaluations where n.sim can be a very large number (e.g., 25*20*20*25 = 250,000). It is not feasible to store this much output so the estimates are distilled prior to saving the results to file. In this file the n.sim runs are summarized by computing the percentiles of each variable listed in column **vname**. These include B.0, F, Escapement, and F/M. The percentiles included are from 0 to 1 in steps of 0.01. The catch level can be of two types. If **catchtype**="Obs" then **catchlevel** is the actual catch. If **catchtype**="AltQuota" then catchlevel is the hypothetical catch being evaluated for risk analysis. The same principle is used to distinguish Escapement from that which is associated with the observed catch and that which is based on the hypothetical quota.

	A	B	C	D	E	F	G	H
1		x	year	vname	catchlevel	catchtype	percentile	
2	0%	27498.18	1997	B.0.catch	14358	Obs	0	
3	1%	36935.62	1997	B.0.catch	14358	Obs	0.01	
4	2%	40270.41	1997	B.0.catch	14358	Obs	0.02	
5	3%	42962.48	1997	B.0.catch	14358	Obs	0.03	
6	4%	45367.15	1997	B.0.catch	14358	Obs	0.04	
7	5%	47605.66	1997	B.0.catch	14358	Obs	0.05	
8	6%	49754.94	1997	B.0.catch	14358	Obs	0.06	

• • •

299	95%2	1.166056	1997	FMratio	14358	Obs	0.95
300	96%2	1.317085	1997	FMratio	14358	Obs	0.96
301	97%2	1.507404	1997	FMratio	14358	Obs	0.97
302	98%2	1.769805	1997	FMratio	14358	Obs	0.98
303	99%2	2.153066	1997	FMratio	14358	Obs	0.99
304	100%2	3.467614	1997	FMratio	14358	Obs	1
305	0%3	0.420251	1997	Escapement.1	14358	Obs	0
306	1%3	0.545034	1997	Escapement.1	14358	Obs	0.01
307	2%3	0.572835	1997	Escapement.1	14358	Obs	0.02
308	3%3	0.592316	1997	Escapement.1	14358	Obs	0.03
309	4%3	0.607723	1997	Escapement.1	14358	Obs	0.04

• • •

505	99%4	0.946542	1997	Escapement.alt	24000	AltQuota	0.99
506	100%4	0.973574	1997	Escapement.alt	24000	AltQuota	1
507	0%5	0.295367	1997	Escapement.alt	25000	AltQuota	0
508	1%5	0.409849	1997	Escapement.alt	25000	AltQuota	0.01
509	2%5	0.437594	1997	Escapement.alt	25000	AltQuota	0.02
510	3%5	0.457445	1997	Escapement.alt	25000	AltQuota	0.03
511	4%5	0.473492	1997	Escapement.alt	25000	AltQuota	0.04

• • •

	A	B	C	D	E	F	G
189069	96%1871	3.049976	2022	FMratio.al	60000	AltQuota	0.96
189070	97%1871	3.480637	2022	FMratio.al	60000	AltQuota	0.97
189071	98%1871	4.069522	2022	FMratio.al	60000	AltQuota	0.98
189072	99%1871	4.744481	2022	FMratio.al	60000	AltQuota	0.99
189073	100%1871	6.737348	2022	FMratio.al	60000	AltQuota	1
189074							
189075							

7.2 Escapement_FMratio_probabilities_1997-2022.csv

This file summarizes the probabilities of **falling below** the escapement thresholds of 0.35, 0.4, 0.5, 0.6 and 0.75. These computations are done for both the observed catches AND the hypothetical alternative quotas. Similarly this contains the probabilities of exceeding F/M ratios of 0.33, 0.5, 0.66, 1.0 and 1.5. Finally, the joint probability of falling below the escapement threshold and exceeding the F/M ratios are computed for each realization of the n.sim estimates from the model.

The naming conventions for this file are similar in that **vname** defines the variable under consideration, **catchtype** defines whether the catch level is that observed in a given year or a hypothetical quota evaluated with respect to the biomass estimated in that year. Thus each year has risk estimates for escapement, F/M, and joint(escapement, F/M) for the actual catch and the alternative quotas for five escapement levels, and five F/M ratios. The risk value is in the column labeled **h**; its meaning varies depending upon whether it is evaluating Escapapement.1, FMratio, or Prob.overfishing.joint as shown in the column **vname**.

	A	B	C	D	E	F	G	H
1		h	year	catchlevel	catchtype	vname	percentile	
2	1	0	1997	14358	Obs	Escapement.1	0.35	
3	2	0	1997	14358	Obs	Escapement.1	0.4	
4	3	0.002136	1997	14358	Obs	Escapement.1	0.5	
5	4	0.034764	1997	14358	Obs	Escapement.1	0.6	
6	5	0.239608	1997	14358	Obs	Escapement.1	0.75	
7	6	0.224364	1997	14358	Obs	FMratio	0.33	
8	7	0.152888	1997	14358	Obs	FMratio	0.5	
9	8	0.111856	1997	14358	Obs	FMratio	0.666	
10	9	0.064576	1997	14358	Obs	FMratio	1	
11	10	0.030388	1997	14358	Obs	FMratio	1.5	
12	11	0	1997	14358	Obs	Prob.overfishing.joint	0.35	
13	12	0	1997	14358	Obs	Prob.overfishing.joint	0.4	
14	13	0.00212	1997	14358	Obs	Prob.overfishing.joint	0.5	
15	14	0.024596	1997	14358	Obs	Prob.overfishing.joint	0.6	
16	15	0.060632	1997	14358	Obs	Prob.overfishing.joint	0.75	
17	16	0.000548	1997	24000	AltQuota	Escapement.1	0.35	
18	17	0.005448	1997	24000	AltQuota	Escapement.1	0.4	
19	18	0.052088	1997	24000	AltQuota	Escapement.1	0.5	
20	19	0.166024	1997	24000	AltQuota	Escapement.1	0.6	
21	20	0.46632	1997	24000	AltQuota	Escapement.1	0.75	

• • •

13675	13674	0.18496	2022	60000	AltQuota	FMratio	1	
13676	13675	0.119932	2022	60000	AltQuota	FMratio	1.5	
13677	13676	0.055596	2022	60000	AltQuota	Prob.overfishing.joint	0.35	
13678	13677	0.096616	2022	60000	AltQuota	Prob.overfishing.joint	0.4	
13679	13678	0.154732	2022	60000	AltQuota	Prob.overfishing.joint	0.5	
13680	13679	0.178892	2022	60000	AltQuota	Prob.overfishing.joint	0.6	
13681	13680	0.18496	2022	60000	AltQuota	Prob.overfishing.joint	0.75	

Escapement_FMratio_probabilitie ⊕

8.0 Post Processing of csy files for tables

To create the report files, the .csv output files are loaded into a worksheet within an Excel spreadsheet. The spreadsheet file has multiple pivot tables that are automatically updated to create tables ready for insertion into the assessment report. There are two spreadsheet .xlsx files that are associated with the two csv output files. Logically the pairings are as follows

RiskAnalysis_stats_1997-2022.csv➔Tables for RiskAnalysis_stats_1997-2022.xlsx

And

Escapement_FMratio_probabilities_1997-2022.csv➔

           Tables for Escapement_FMratio_probabilities_1997-2022.xlsx

The ➔ symbol denotes a copy and paste operation. For each file, it is necessary to copy the .csv file to the appropriately named worksheet in the .xlsx file. This worksheet tab has a red colored background with white letters. Cell A1 in each worksheet needs to be named **index**. Do this after the data have been copied over. After this is done, the pivot tables will automatically be updated and tables suitable for inclusion in the assessment report will be prepared. In Excel it is always important to ensure that the table values are referring to the recently update data. To ensure this, I always "Refresh" the pivot tables (right click, select refresh). Some users turn off the automatic updating of pivot tables to reduce computation time until necessary.

The following table indicates the name of the worksheet containing the output tables an their captions.

Excel File Name	Worksheet Name <color>	Table Caption
Tables for Escapement _FMratio_probabilities _1997-2022.xlsx	Escapement_FMratio_probabilitie <red>	Contains the data used for all pivot tables
	Pivot AltQutoa by Yr	
	Esc stats by Q and Esc Thresh <yellow>	Table 10. Estimated probabilities of falling below Escapement thresholds based on alternative Quota values. Probabilities are averaged across all years
	Joint Prob by Q and Esc Thresh <yellow>	Table 12. Estimated JOINT probabilities of falling below Escapement Thresholds AND F/M>0.66 based on alternative Quota values. Probabilities are averaged across all years.
	FM ratios by Q and Esc Thresh <yellow>	Table 11. Estimated probabilities of exceeding F/M ratio thresholds based on alternative Quota values. Probabilities are averaged across all years
	Observed Catch stats <yellow>	Table cc. Estimated joint probabilities of falling below Escapement thresholds AND

		exceeding F/M=0.666 based on Observed catches.
	Tables for Report <gray>	This is a scratch worksheet that I use to store the updated files and to split the very wide tables which compute estimates for each alternative quota (rows) and year (column). Do not compute values here; just store tables. Otherwise, delete this worksheet.
Tables for RiskAnalysis_stats_1997-2022.xlsx	RiskAnalysis_stats <red>	Contains the data used for all pivot tables
	Escapement vs Quota by Yr Stats <yellow>	Table xx. Estimated escapement for the 50th percentile for alternative quotas (rows) by year based on assumed ranges of catchability, availability and natural mortality.
	FM ratio vs Quota by Year stats <yellow>	Table xx. Estimated F/M ratios for the 50th percentile for alternative quotas (rows) by year based on assumed ranges of catchability, avavailability and natural mortality.
	Biomass Stats by Year <yellow>	Table xx. Estimated percentiles for initial biomass (mt) by year given observed catch and fall survey biomass
	F.e Stats by Year <yellow>	Table xx. Estimated percentiles for seasonal F by year given observed catch and fall survey biomass
	FM ratio Stats by Year <yellow>	Table xx. Estimated percentiles for F/M ratio by year given observed catch and fall survey biomass
	Escapement Stats by Year <yellow>	Table xx. Estimated percentiles for Escapement by year given observed catch and fall survey biomass
	tables for report <gray>	This is a scratch worksheet that I use to store the updated

		files and to split the very wide tables which compute estimates for each alternative quota (rows) and year (column). Do not compute values here; just store tables. Otherwise, delete this worksheet.

9.0 Post Processing of pdf file for figures

A large number of output files are created. Not all of them are needed for the report. However these files can be helpful for improving one's understanding of the model and the variations in biomass, F, and escapement among years. It is particularly important to examine the results for the terminal year since other results will have been previously examined.

Adobe can be used to extract the plot files as necessary for embedding in the assessment report.

The pdf plot file is named= RiskAnalysis_plots_1997-2022.pdf and is located in the working directory for the R project in RStudio. The following tables provide an overview of the different groups of plots and suggested captions.

The largest block of plots is the set of isopleth and probability density functions for each year. For each year the following 7 graphs are produced. These are replicated for each of the n years in the simulation.

Figure	*Caption*
$1 + n$	Isopleths of Illex fishing mortality estimates (per week) vs catchability (x-axis) and availability (y-axis) for all combinations of q, v, M, and 80% CI for survey estimates for year=y.
$2 + n$	Empirical probability density function of fishing mortality rate (per week) based on ranges of q, v, M, and 80% CI for survey estimates for year=y The dashed red lines represents the range of F estimates derived from VMS analyses for 2019. Weekly F range=[0.082/25, 0.167/25].
$3 + n$	Isopleths of Illex biomass (mt) estimates catchability (x-axis) and availability (y-axis) for all combinations of q, v, M, and 80% CI for survey estimates for year=y
$4 + n$	Empirical probability density function of biomass estimates over all combinations of q, v, and M and 80% CI for Survey estimate for year = y. Solid red line is median; dashed blue line is mean.
$5 + n$	Isopleths of escapement as a function of catchability (x-axis) and availability (y-axis) for all combinations of q, v, M, and 80% CI for survey estimates for year=y.
$6 + n$	Empirical probability density function of Escapement based on observed landings and observed NEFSC fall bottom trawl indices in year = y. The dashed black line=median. Red and blue vertical lines represent escapement levels of 40 and 50%, respectively.

7 + n	Empirical distribution of F/M ratio for all combinations of q, v, M, and 80% CI for survey estimates for year=y. Dashed line = median. Blue and red lines are for F= 2/3 M and F=M, respectively.
	n=0, 7,14, 21, …,161 for each of the 24 years in the data set

The graphs are numbered sequentially for the period 1997 to 2022. Survey data are missing for 2017 and 2020. There are 24 years in which statistics can be computed. Thus there are 168 graphs in the file = RiskAnalysis_plots_1997-2022.pdf for the yearly plots.

Plots 169 to 171 are simple x-y plots of the catch and survey data.

Plots 172-183 are time series plots with empirical percentile intervals for biomass, F, escapement and F/M ratios.

Figure	Caption
172	Estimated percentiles of biomass in mt (1997-2022 based on 250,000 combinations of q, v, M and 80% CI for survey estimates each year. Surveys were missing for 2017 and 2020. The black line represents the median. The blue lines represent the interquartile range. The orange lines represent the 80% confidence bounds. The dotted red lines represent the 90% confidence interval. The solid red line is the median of the annual medians.
173	Estimated fishing mortality rates (season) (1997-2022) based on based on 250,000 combinations of q, v, M, and 80% CI for survey estimates for each year. Surveys were missing for 2017 and 2020. The black line represents the median. The blue lines represent the interquartile range. The orange lines represent the 80% confidence bounds. The dotted red lines represent the 90% confidence interval. The solid red line is the median of the annual medians. The average weekly rate is obtained by dividing the total by 25 weeks.
174	Estimated F/M ratios (1997-2022) based on based on 250,000 combinations of q, v, M, and 80% CI for survey estimates for each year. Surveys were missing for 2017 and 2020. The black line represents the median. The blue lines represent the interquartile range. The orange lines represent the 80% confidence bounds. The dotted red lines represent the 90% confidence interval. The solid red line is the median of the annual medians.
175	Estimated escapement ratios for 1997-2021 based on 250,000 combinations of q, v, and M, and 80% CI for survey estimates for each year. Fall surveys were missing for 2017 and 2020. The black line represents the median. The blue lines represent the interquartile range. The orange lines represent the 80% confidence bounds. The dotted red lines represent the 90% confidence interval. The solid red line is the median of the annual medians. Note that the lowest dashed line is the 5th percentile of the escapement fraction.
176	Estimated percentiles of log (biomass in mt) (1997-2022 based on 250,000 combinations of q, v, M and 80% CI for survey estimates each year. Surveys were missing for 2017 and 2020. The black line represents the median. The blue lines represent the interquartile range. The orange lines represent the 80% confidence

	bounds. The dotted red lines represent the 90% confidence interval. The solid red line is the median of the annual medians.
177	Estimated percentiles of log (fishing mortality rates (season)) (1997-2022) based on based on 250,000 combinations of q, v, M, and 80% CI for survey estimates for each year. Surveys were missing for 2017 and 2020. The black line represents the median. The blue lines represent the interquartile range. The orange lines represent the 80% confidence bounds. The dotted red lines represent the 90% confidence interval. The solid red line is the median of the annual medians. The average weekly rate is obtained by dividing the total by 25 weeks.
178	Estimated log(F/M ratios) (1997-2022) based on based on 250,000 combinations of q, v, M, and 80% CI for survey estimates for each year. Surveys were missing for 2017 and 2020. The black line represents the median. The blue lines represent the interquartile range. The orange lines represent the 80% confidence bounds. The dotted red lines represent the 90% confidence interval. The solid red line is the median of the annual medians.
179	Estimated log(escapement ratios) for 1997-2021 based on 250,000 combinations of q, v, and M, and 80% CI for survey estimates for each year. Fall surveys were missing for 2017 and 2020. The black line represents the median. The blue lines represent the interquartile range. The orange lines represent the 80% confidence bounds. The dotted red lines represent the 90% confidence interval. The solid red line is the median of the annual medians. Note that the lowest dashed line is the 5th percentile of the escapement fraction.

Plots 180-183 illustrate the effects of alternative quotas over time for 50%, 40% and 35% escapement threshold levels. Plots 184-190 illustrate the risks associated with various quotas, integrated over all years.

Figure	Caption
180	Estimated probability of Escapement less than 50%, 1997-2022 given the actual observed landings in each year. Probabilities are based on 250,000 combinations of q, v, M, and 80% CI for survey estimates for each year.
181	Estimated probability of escapement less than **50%** given alternative catch limits for each year ranging from 24,000 to 60,000. Each dot represents an alternative quota with lowest quotas at bottom and highest at top for each year. The initial population size in each year is based on the observed catch and the range of assumed q, v, and M, and 80% CI for survey estimates. The solid red line corresponds to the MAFMC's P*risk policy when B/Bmsy> 1.5. The dashed red line is the P* value corresponding to B/Bmsy=0.5.
182	Estimated probability of escapement less than **40%** given alternative catch limits for each year ranging from 24,000 to 60,000. Each dot represents an alternative quota with lowest quotas at bottom and highest at top for each year. The initial population size in each year is based on the observed catch and the range of assumed q, v, and M, and 80% CI for survey estimates. The solid red line corresponds to the MAFMC's P*risk policy when B/Bmsy> 1.5. The dashed red line is the P* value corresponding to B/Bmsy=0.5.

183	Estimated probability of escapement less than **35%** given alternative catch limits for each year ranging from 24,000 to 60,000. Each dot represents an alternative quota with lowest quotas at bottom and highest at top for each year. The initial population size in each year is based on the observed catch and the range of assumed q, v, and M, and 80% CI for survey estimates. The solid red line corresponds to the MAFMC's P*risk policy when B/Bmsy> 1.5. The dashed red line is the P* value corresponding to B/Bmsy=0.5.
184	Estimated probability of escapement being less than **50%** given alternative catch limits from 24,000 to 60,000 mt. Each line is the trajectory of a given year reflecting the effect of different B.0 by year. The top line is 1999 which had the lowest B.0 starting value. The initial population size in each year is based on the observed catch and the range of assumed q, v, and M, , and 80% CI for survey estimates.
185	Estimated probability of escapement being less than **40%** given alternative catch limits from 24,000 to 60,000 mt. Each line is the trajectory of a given year reflecting the effect of different B.0 by year. The top line is 1999 which had the lowest B.0 starting value. The initial population size in each year is based on the observed catch and the range of assumed q, v, and M, , and 80% CI for survey estimates.
186	Estimated probability of escapement being less than **35%** given alternative catch limits from 24,000 to 60,000 mt. Each line is the trajectory of a given year reflecting the effect of different B.0 by year. The top line is 1999 which had the lowest B.0 starting value. The initial population size in each year is based on the observed catch and the range of assumed q, v, and M, , and 80% CI for survey estimates.
187	Estimated probability of escapement being less than **75%** given alternative catch limits from 24,000 to 60,000 mt. Each line is the trajectory of a given year reflecting the effect of different B.0 by year. The top line is 1999 which had the lowest B.0 starting value. The initial population size in each year is based on the observed catch and the range of assumed q, v, and M, , and 80% CI for survey estimates.
188	Mean probability of Escapement less than 50% averaged over all years vs assumed quotas from 24,000 to 60,000 mt.
189	Median probability of Escapement less than 50% averaged over all years vs assumed quotas from 24,000 to 60,000 mt.
190	Median probability of Escapement less than 50% AND F/M greater than 0.666 averaged over all years vs assumed quotas from 24,000 to 60,000 mt.

Plots 191-202 provide additional insights into the terminal year estimates B.0, F, Escapement, and F/M ratio.

Figure	Caption
191	Bag plots of F estimates vs Assumed M (weekly) for 2022. Distributions are derived from the 250,000 estimates defined by the observed catch and fall survey

	biomass estimate in 2022 with assumed ranges of q, v, M, and 80% CI for survey values.
192	Bag plots of Escapement estimates vs Assumed M (weekly) for 2022. Distributions are derived from the 250,000 estimates defined by the observed catch and fall survey biomass estimate in 2022 with assumed ranges of q, v, M, and 80% CI for survey values.
193	Relationship between Escapement and measures of exploitation for 2021. Catch divided by end of year biomass (i.e.. Fall survey) . The trajectories correspond to assumed levels of M. Note how catch over end of season biomass is a poor predictor of true escapement over all ratios but particularly as C/Bt increases.
194	Relationship between Escapememt and estimated fishing mortality/assumed M over all 250,000 combinations of q, v, and M, and 80% CI for survey values for 2022. The bands represent isopleths for assumed levels M. Low M (0.01 week^{-1}) on right and high M (0.13 week^{-1}) on left. .
195	Closeup value of Fig 194 for the **low M** trajectory. Relationship between Escapememt and estimated fishing mortality/assumed M. Note differences in scale!
196	Closeup value of Fig 194 for the **high M** trajectory. Relationship between Escapememt and estimated fishing mortality/assumed M. Note differences in scale!
197-202	Probability density functions for F by week, F for entire 25 week season, log Biomass, Biomass, Escapement, and F/M. See captions for 1 Figures 162-168 for additional details.

10.0 Report Writing

As described above, the model generates tables and plots that can be incorporated into the report directly as long as it is possible to edit pdf files directly using Adobe. Otherwise, it will be necessary to create individually numbered .png or .wmf files for inclusion in a Word file.

The model theory is described in section 3.0

The report itself should be relatively stable with respect to the addition of new data. The biggest potential change will arise when high catches are coupled with very low fall survey biomass indices. This occurred in 1999 and in 2001. In these instances, the hypothetical alternative quotas would have caused escapement to fall below 50%.

Terminal year estimates should be examined in detail, particularly with respect to the capacity of the estimated biomass to support quotas in the range of 24,000 to 60,000 mt.

Appendix 1. Full source code for model in R, including plots, tables and database outputs.

```
## Revised code Jan 2023 to eliminate hardwired parameters, create a general output file for
# graphs and tables.
#  Ideally, add code to consider uncertainty in survey point estimates.

# This code is designed to characterize the potential implications of alternative
# quotas on escapement given uncertainty in catchability, availability, and natural mortality.
# The code is more generalized than that used to evaluate alternative quotas in March 2022.
# New features include:
#                1. Model parameters for ranges are from a csv input file rather than hardwired in the code
#                2. Graphs are output a pdf file rather than saved individually via the R-Studio graph box
#                3. potentially.  Tables for inclusion in the report are generated from the databases created
#                        by code.  Currently the output database of model runs is passed to Excel which
processes the
#                        data via Pivot tables.
#                4. (potentially) Uncertainty in the biomass estimate from the survey is explicitly considered

# This code extends the mass balance methods to consider escapement probabilities
# for alternative quota levels requested by the MAFMC for consideration in
# March 2022 at the SSC meeting
# The following code is based on a stochastic evaluation of the escapement risk
#  using the Baranov equation rather than Pope's approximation.
# The spring survey data will not be used for this analysis.

# An evaluation of the effects of uncertainty in the swept area biomass may be
# included if the run times are not excessive.
# An evaluation of 40 probability levels for the fall index would increase the
#  run times by 40 fold.

# Risk is evaluated for each proposed alternative catch level ranging from 24,000
#  to 60,000 mt.  This will further increase the run time by a factor of 37.

# load libraries

library(mgcv)
library(Hmisc)
library(contourPlot)
library(vioplot)
library(plyr)
library(sm)
#install.packages('EnvStats')
library(EnvStats)
library(MASS)
#install.packages('akima')
library(akima)
#install.packages('Polychrome')
library(Polychrome)
```

```
#install.packages("Rtools")
#library(Rtools)

# load functions
#F.fun<-function(F)(F/(F+M[k])*(1-exp(-(F+M[k]))))-Catch/(B.f[ijk]*exp(M[k])+Catch*exp(M[k]/2))  #
Pope's approx
Fb.fun<-function(F)(F/(F+M[k])*(exp(F+M[k])-1)*B.f[ijkl]-Catch)  # Baranov Eqn

#### Start the clock!
start_time=Sys.time()

# load data for observed catches and survey indices
MB.df<-read.csv(paste0(getwd(),"/catch_survey_data.csv"))   # read in the mass balance data frame

# load data for Alternative Quotas to be analyzed
AQ.df<-read.csv(paste0(getwd(),"/AlternativeQuotas.csv"))  # read in the AlternativeQuotas data frame
N.Quota=length(AQ.df$AltQuota)

# load the model parameter ranges for q, v, M and observation error.

# Read in the parameter ranges

input.par= read.csv(paste0(getwd(),"/inputtests.csv"))   # read in the scenario control parameter ranges
parspec.db= input.par
#read.csv(input.test)
parspec.db

q.min=parspec.db$Min[parspec.db$Par.Name=="q"]
q.max=parspec.db$Max[parspec.db$Par.Name=="q"]
N.q=parspec.db$N[parspec.db$Par.Name=="q"]
q<-rep(0,N.q)  # define the array
q<-seq(from = q.min, to = q.max, by= (q.max - q.min)/(N.q - 1))

v.min=parspec.db$Min[parspec.db$Par.Name=="v"]
v.max=parspec.db$Max[parspec.db$Par.Name=="v"]
N.v=parspec.db$N[parspec.db$Par.Name=="v"]
v<-rep(0,N.v)  # define the array
v<-seq(from = v.min, to = v.max, by= (v.max - v.min)/(N.v - 1))

M.min=parspec.db$Min[parspec.db$Par.Name=="M"]
M.max=parspec.db$Max[parspec.db$Par.Name=="M"]
N.M=parspec.db$N[parspec.db$Par.Name=="M"]
M<-rep(0,N.M)  # define the array
M.weekly<-seq(from = M.min, to = M.max, by= (M.max - M.min)/(N.M - 1))

# uncertainty in survey estimate
# inverse normal testing for 80% CI
 I.f.alpha.lo=parspec.db$Min[parspec.db$Par.Name=="I.f.alpha"]
 I.f.alpha.hi=parspec.db$Max[parspec.db$Par.Name=="I.f.alpha"]
 N.I=parspec.db$N[parspec.db$Par.Name=="I.f.alpha"]
 prob.val=rep(0,N.I)
```

```r
   prob.val=seq(from=I.f.alpha.lo,to= I.f.alpha.hi,by=((I.f.alpha.hi-I.f.alpha.lo)/(N.I-1)))

# feasibility bounds for estimated F
 F.min=parspec.db$Min[parspec.db$Par.Name=="F.range"]
 F.max=parspec.db$Max[parspec.db$Par.Name=="F.range"]

N.fishing.weeks<-25   # Convert M to full season estimates based on total weeks in fishery

#               Start of main loop for parametric simulations
yr.min<-min(MB.df$Year)
yr.max<-max(MB.df$Year)

#CREATE OUTPUT PLOTS AND SEND TO PDF FILE
#############################################
plotoutputfile=paste0(getwd(),"/RiskAnalysis_plots_1997-2022.pdf")   #specify plot output file
pdf(file=plotoutputfile,height=9.4545, width=5.5) #Open pdf file and specify plot area in inches(default)

par(mfrow=c(2,1),cex.main=0.7) # put 2 plots per page and use reduced font for titles.
ipl=0

### Add block of code here to summarize model parameterization of
### upper and lower bounds
###############################################################


for (iy in yr.min:yr.max){                 # Start: Main loop over years

# Test values for a given year

I.f=MB.df$I.f.t[MB.df$Year==iy]  # fall survey mean
I.f.sd=MB.df$cv.f.t[MB.df$Year==iy]/100*I.f
I.s=MB.df$I.s.t[MB.df$Year==iy]  # spring survey mean
Catch=MB.df$Catch.t[MB.df$Year==iy]

if (is.na(I.f)==FALSE){      # compute stats only for years with fall survey present

# Create the values of survey biomass, assuming normal distribution of mean. Each value has an equal
probability, hence the intervals vary between points
 I.f.int=rep(0,N.I)
  for (i in 1:N.I){
I.f.int[i]=qnorm(prob.val[i],mean=I.f, sd=I.f.sd)
}

# Initialize vectors
n.sim<-N.q*N.v*N.M*N.I   # This defines the number of iterations for each year and alterative quota
B.f<-rep(0,n.sim)
B.s<-rep(0,n.sim)
B.0.catch<-rep(0,n.sim)
F.e<-rep(0,n.sim)
M.e<-rep(0,n.sim)
```

```
q.e<-rep(0,n.sim)
v.e<-rep(0,n.sim)

FMratio<-rep(0,n.sim)
CBratio<-rep(0,n.sim)
B.0.Bs.ratio<-rep(0,n.sim)
Escapement.1<-rep(0,n.sim)
Catch.type<-rep(0,n.sim)

FMratio.mat<-matrix(0, nrow=n.sim, ncol=N.Quota)
Escapement.mat<-matrix(0, nrow=n.sim, ncol=N.Quota)

ijkl<-0    #Initialize the counter for the arrays within year.

i.infeasible=0
for (i in 1:N.q) {                #Start of main loop over q range
 for (j in 1:N.v){                                           #Start of main loop over v range
  for (k in 1:N.M){                                          #Start of main loop over M range
          for(l in 1:N.I){                    # start main loop over variation of Survey estimate
    ijkl<-ijkl+1
    I.f=I.f.int[l]       # assign index interval over 80% CI range
    B.f[ijkl]<-I.f/(q[i]*v[j])
    B.s[ijkl]<-NA
    if(is.na(I.s)==FALSE) {B.s[ijkl]<-I.s/(q[i]*v[j])}  # ignore the spring index for now
    M[k]<-M.weekly[k]*N.fishing.weeks  # adjust rates based on total fishing season
    M.e[ijkl]<-M[k]
    q.e[ijkl]<-q[i]
    v.e[ijkl]<-v[j]

    Catch=MB.df$Catch.t[MB.df$Year==iy]
    #             Check for feasibility of F estimate
    F.e[ijkl]<-NA

     if(is.na(B.f[ijkl])==FALSE){
       F.est<-uniroot(Fb.fun, lower=F.min,upper=F.max,extendInt = "yes",maxiter=20)  # Solve catch equation
using root finder.
       F.e[ijkl]=F.est$root    # this is total F overall fishing weeks.
         }
    if(F.e[ijkl]>=F.max){
     F.e[ijkl]<-NA
     i.infeasible=i.infeasible+1}      # exclude estimates greater than or equal to upper bound =F.max
    B.0.catch[ijkl]=B.f[ijkl]*exp(F.e[ijkl]+M[k])   # this formulation is equivalent algebraically to the following
line when F has been estimated using uniroot()
   # B.0.catch[ijk]=Catch/(F.e[ijk]/(F.e[ijk]+M[k])*(1-exp(-(F.e[ijk]+M[k]))))  #biomass based on catch with
estimated F (Baranov equation)
    Escapement.1[ijkl]=B.f[ijkl]/(B.0.catch[ijkl]*exp(-M[k])) # method based on Baranov catch equation
         # ratio of F/M
    FMratio[ijkl]<-F.e[ijkl]/M.e[ijkl]
    CBratio[ijkl]=Catch/B.f[ijkl]    # Utility of Catch over terminal biomass--compare with escapement
    #if(is.na(B.s[ijk]==FALSE)){B.0.Bs.ratio[ijk]=B.0.catch[ijk]/B.s[ijk]}
   if(is.na(I.s)==FALSE){ B.0.Bs.ratio[ijkl]=B.0.catch[ijkl]/B.s[ijkl]}
```

```
        Catch.type[ijkl]="Obs"

  # loop over all alternative quota levels here to obtain F/M ratios and Escapement levels.
  #  Compute new B.f.hyp given estimated B.0.catch and hypothetical alternative quota.

  #loop over alternative quotas
  for (iQ in 1:N.Quota){
  # find F necessary to catch alternative quota level
   Catch=AQ.df$AltQuota[iQ]
   F.est<-uniroot(Fb.fun,lower=F.min,upper=F.max, extendInt = "yes",maxiter=20)  # Solve catch equation
using root finder.
          F.alt=F.est$root    # this is total F overall fishing weeks.
                  B.f.alt=B.0.catch[ijkl]*exp(-(F.alt+M[k]))

                  Escapement.alt<-B.f.alt/(B.0.catch[ijkl]*exp(-M[k]))  # this is the estimate of escapement
based on alternative quota values
   FMratio.alt<-F.alt/M.e[ijkl]
          Catch.type[ijkl]="AltQuota"
          # load matrix for each alternative quota
          FMratio.mat[ijkl,iQ]<- FMratio.alt
          Escapement.mat[ijkl,iQ]<-Escapement.alt

     }  # end of loop over alternative quotas
            }    # End of loop over alternative estimates of Survey biomass index
     }    # end of loop over alternative M range
 }                  # end of loop over availability v range
}                              # end of loop over q range
 print(paste("end of loop for year = ",iy))


 # Summary stats and plots

  #  save the quantiles by year for summary plots   NOTE--101 intervals
 var.cut.points=seq(1, from=0.0, by=0.01)
 Catch=MB.df$Catch.t[MB.df$Year==iy]   #catch levels here are for the observed values

 x<-quantile(B.0.catch[is.na(F.e)==FALSE], var.cut.points,na.rm=TRUE) # criteria for feasible estimates.
 print(paste("Quantiles of B.0.catch", tail(x), " for year = ", iy))
 y<-as.data.frame(x)
 y$year<-iy
 y$vname<-"B.0.catch"
 y$catchlevel=Catch
 y$catchtype="Obs"  ###
# y$catchtype="AltQuota"
 y$percentile<- var.cut.points
 if (iy==yr.min){yyy<-y}
 if(iy!=yr.min){yyy<-rbind(yyy,y)}

 x<-quantile(F.e[is.na(B.0.catch)==FALSE],var.cut.points,na.rm=TRUE)
 y<-as.data.frame(x)
```

```
y$year<-iy
y$vname<-"F.e"
y$catchlevel=Catch
y$catchtype="Obs"  ###
#g$catchtype="AltQuota"
y$percentile<-var.cut.points
yyy<-rbind(yyy,y)

x<-quantile(FMratio[is.na(B.0.catch)==FALSE],var.cut.points,na.rm=TRUE)
y<-as.data.frame(x)
y$year<-iy
y$vname<-"FMratio"
y$catchlevel=Catch
y$catchtype="Obs"  ###
# y$catchtype="AltQuota"
y$percentile<-var.cut.points
yyy<-rbind(yyy,y)

x<-quantile(Escapement.1[is.na(B.0.catch)==FALSE],var.cut.points,na.rm=TRUE)
y<-as.data.frame(x)
y$year<-iy
y$vname<-"Escapement.1"
y$catchlevel=Catch
y$catchtype="Obs"  ###
# y$catchtype="AltQuota"
y$percentile<-var.cut.points
yyy<-rbind(yyy,y)

#        loop over quotas for each realization ijk to compute percentiles of FM ratio and Escapements
for (iQ in 1:N.Quota){
  x<-quantile(Escapement.mat[,iQ],var.cut.points,na.rm=TRUE)
  y<-as.data.frame(x)
  y$year<-iy
  y$vname<-"Escapement.alt"

  y$catchlevel=AQ.df$AltQuota[iQ]
        y$catchtype="AltQuota"
        y$percentile<-var.cut.points
        yyy<-rbind(yyy,y)
        }

for (iQ in 1:N.Quota){
 x<-quantile(FMratio.mat[,iQ],var.cut.points,na.rm=TRUE)
  y<-as.data.frame(x)
  y$year<-iy
  y$vname<-"FMratio.alt"
  y$catchlevel=AQ.df$AltQuota[iQ]
        y$catchtype="AltQuota"
        y$percentile<-var.cut.points
        yyy<-rbind(yyy,y)
        }
```

```
# Compute additional statistics for escapement, F/M ratio
Escapement.cutpoints=c(0.35,0.4,0.5,0.60, 0.75)
FMratio.cutpoints=c(0.33,0.5,0.666, 1.0,1.5)
Escapement.proportion<-c(0,0,0,0,0)
FMratio.proportion<-c(0,0,0,0,0)
Prob.overfishing.joint<-c(0,0,0,0,0)

# Compute fraction of valid observations above cut points for Escapement.1
#  This is for the base year and Observed Catch
for (ic in 1:5){
Escapement.proportion[ic]<-sum(Escapement.1[is.na(B.0.catch)==FALSE]<Escapement.cutpoints[ic])/
  length(Escapement.1[is.na(B.0.catch)==FALSE])
}

h<-Escapement.proportion
g<-as.data.frame(h)
g$year<-iy
g$catchlevel=Catch
g$catchtype="Obs"
##g$catchtype="AltQuota"
g$vname<-"Escapement.1"
g$percentile<-Escapement.cutpoints
if (iy==yr.min){ggg<-g}
if(iy!=yr.min){ggg<-rbind(ggg,g)}
#ggg<-rbind(ggg,g)


          # Compute fraction of valid observations above cut points for FMratio.  This is for the base year and
Observed catch.
for (ic in 1:5){
 FMratio.proportion[ic]<-sum(FMratio[is.na(B.0.catch)==FALSE]>FMratio.cutpoints[ic])/
   length(FMratio[is.na(B.0.catch)==FALSE])
}

h<-FMratio.proportion
g<-as.data.frame(h)
g$year<-iy
g$catchlevel=Catch
g$catchtype="Obs" ###
## g$catchtype="AltQuota"
g$vname<-"FMratio"
g$percentile<-FMratio.cutpoints
ggg<-rbind(ggg,g)

########################
# Compute fraction of valid observations below cut points for Escapement.1 and FMratio greater than 1.0
# This is for the base year and Observed Catch

for (ic in 1:5){
 Prob.overfishing.joint[ic]<-sum(Escapement.1<Escapement.cutpoints[ic] & FMratio>1)/
   length(Escapement.1)
```

```
    }

    h<- Prob.overfishing.joint
    g<-as.data.frame(h)
    g$year<-iy
    g$catchlevel=Catch
    g$catchtype="Obs"
    ##g$catchtype="AltQuota"
    g$vname<-"Prob.overfishing.joint"
    g$percentile<-Escapement.cutpoints
    #if (iy==yr.min){ggg<-g}
    #if(iy!=yr.min){ggg<-rbind(ggg,g)}
    ggg<-rbind(ggg,g)


#############################################################################
###
    ###### proportions for the alternative quotas.
      Escapement.proportion<-c(0,0,0,0,0)
      FMratio.proportion<-c(0,0,0,0,0)
#############################################################################
#####################################
# Loop over all the alternative quotas and count the proportions for the escapement and FM ratio outputs.
    for (iQ in 1:N.Quota) {
      for (ic in 1:5){
    Escapement.proportion[ic]<-sum(Escapement.mat[is.na(B.0.catch)==FALSE,
iQ]<Escapement.cutpoints[ic])/
      length(Escapement.mat[is.na(B.0.catch)==FALSE,iQ])
    }

    h<-Escapement.proportion
    g<-as.data.frame(h)
    g$year<-iy
    g$catchlevel=AQ.df$AltQuota[iQ]
  # g$catchtype="Obs"
    g$catchtype="AltQuota"
    g$vname<-"Escapement.1"
    g$percentile<-Escapement.cutpoints
  # if (iy==yr.min){ggg<-g}
  # if(iy!=yr.min){ggg<-rbind(ggg,g)}
    ggg<-rbind(ggg,g)

    # Compute fraction of valid observations above cut points for FMratio.  This is for the base year and
Observed catch.
    for (ic in 1:5){
      FMratio.proportion[ic]<-sum(FMratio.mat[is.na(B.0.catch)==FALSE,iQ]>FMratio.cutpoints[ic])/
        length(FMratio.mat[is.na(B.0.catch)==FALSE,iQ])
    }

    h<-FMratio.proportion
    g<-as.data.frame(h)
```

```
 g$year<-iy
 g$catchlevel=AQ.df$AltQuota[iQ]
## g$catchtype="Obs" ###
 g$catchtype="AltQuota"
 g$vname<-"FMratio"
 g$percentile<-FMratio.cutpoints
 ggg<-rbind(ggg,g)


 ##########################################################
 # compute the joint probability of Escapement<0.5 and F/M>0.666 for the alternative quotas


 # Compute fraction of valid observations below cut points for Escapement.1 and FMratio greater than 0.666
 # This is for the base year and Observed Catch

 for (ic in 1:5){
  Prob.overfishing.joint[ic]<-sum(Escapement.1<Escapement.cutpoints[ic] & FMratio>0.666)/
    length(Escapement.1)
  Prob.overfishing.joint[ic]<-sum(Escapement.mat[,iQ]<Escapement.cutpoints[ic]
                &FMratio.mat[,iQ]>1)/length(Escapement.mat[,iQ])
 }

 h<-Prob.overfishing.joint
 g<-as.data.frame(h)
 g$year<-iy
 g$catchlevel=AQ.df$AltQuota[iQ]
  # g$catchtype="Obs"
 g$catchtype="AltQuota"
 g$vname<-"Prob.overfishing.joint"
 g$percentile<-Escapement.cutpoints
#if (iy==yr.min){ggg<-g}
#if(iy!=yr.min){ggg<-rbind(ggg,g)}
 ggg<-rbind(ggg,g)



##############################################################################
##

  }  # end of loop over quotas


#}  # end of control on missing values for surveys.  Fall survey is required


##############################################################################
###
########## START OF CODE FOR VARIOUS 3D PLOTS ETC FOR EACH YEAR   ##########
##############################################################################
###

 # Plot #1 Feasible F
 yy<-interp(q.e[is.na(B.0.catch)==FALSE],v.e[is.na(B.0.catch)==FALSE],
```

```
        (F.e[is.na(B.0.catch)==FALSE])/N.fishing.weeks,
        linear=FALSE, extrap=FALSE,duplicate="strip", jitter=10^-12)
 ipl=ipl+1
 image(yy,main=paste("Fig",ipl,". Feasible F estimates for fall ",iy,"survey with Constraints"),
     xlab="Catchability",ylab="Availability")
  N.qq<-10
  contour(yy, add=TRUE, nlevels=N.qq)


 ipl=ipl+1
 epdfPlot(F.e/N.fishing.weeks, main=paste("Fig",ipl,". Empirical PDF: Fishing mortality (weekly) for",iy,"
plus VMS F"))
 abline(v=c(0.082/N.fishing.weeks,0.167/N.fishing.weeks),col="red",lty=2)



##############################################################################
###############################
 # 3-D plots for biomass, F, and escapement by year  # these could be looped into above plots by year.
 #Plot #2 Biomass

 yy<-interp(q.e[is.na(B.0.catch)==FALSE],v.e[is.na(B.0.catch)==FALSE],
        (B.0.catch[is.na(B.0.catch)==FALSE]),
        linear=FALSE, extrap=FALSE,duplicate="strip", jitter=10^-12)
 ipl=ipl+1
 image(yy,main=paste("Fig", ipl, ". Biomass estimates for fall ",iy,"survey"),
     xlab="Catchability",ylab="Availability")
 N.qq<-10
 contour(yy,add=TRUE,nlevels=N.qq)


 ipl=ipl+1
 epdfPlot(B.0.catch, main=paste("Fig", ipl," Empirical PDF for Biomass (mt) for ",iy))



 ###Plot #3 Biomass feasible escapement estimates
 yy<-interp(q.e[is.na(B.0.catch)==FALSE],v.e[is.na(B.0.catch)==FALSE],
        (Escapement.1[is.na(B.0.catch)==FALSE]),
        linear=FALSE, extrap=FALSE,duplicate="strip", jitter=10^-12)
 ipl=ipl+1
 image(yy,main=paste("Fig",ipl, ". Feasible Escapement estimates for fall ",iy,"survey"),
     xlab="Catchability",ylab="Availability")
 N.qq<-10
 contour(yy,add=TRUE,nlevels=N.qq)

 ipl=ipl+1
 epdfPlot(Escapement.1,main=paste("Fig", ipl," Empirical PDF for Escapement for ",iy))

### insert contour plot for F/M here####???
 ipl=ipl+1
 epdfPlot(FMratio,main=paste("Fig", ipl," Empirical PDF for F/M ratio for ",iy))
```

```
###############################################################################
###
########## END OF CODE FOR VARIOUS 3D PLOTS ETC FOR EACH YEAR   ##########
###############################################################################
###
  }  # end of control on missing values for surveys.  Fall survey is required

  }  # end of year loop


#PART 2.  EXPORT CSV FILES FOR SIMULATION RESULTS
###############################################################################
###  create output files analyses
# pause()
 # write out the summary files to the working directory
write.csv(yyy,paste0(getwd(),"/RiskAnalysis_stats_1997-2022.csv"))
write.csv(ggg,paste0(getwd(),"/Escapement_FMratio_probabilities_1997-2022.csv"))
###############################################################################
##############################
#
#PART 3.  CREATE OUTPUT PLOTS AND SEND TO PDF FILE
##################################################


###############################################################################
#########################
 #### EACH PLOT HAS A UNIQUE ID GIVEN BY THE VARIABLE ipl                    ##########
 #### The variable ipl is updated for each graph and embedded in the title as "Fig. ipl"   ##########

###############################################################################
#########################

 ## Part 3.1 Time series of catch and survey biomass indices

###plot the input data for catch and surveys
   ipl=ipl+1
         plot(MB.df$Year,MB.df$Catch.t, main=paste("Fig. ",ipl,". Observed Catch (mt)"), lty=1, col="black",
type="b")
                  abline(h=median(MB.df$Catch.t, na.rm=TRUE),col="red")
                  ipl=ipl+1
         plot(MB.df$Year,MB.df$I.f.t, main=paste("Fig. ", ipl, ". Fall Survey Swept Area Biomass (mt)"),lty=1,
col="black", type="b")
                  abline(h=median(MB.df$I.f.t,na.rm=TRUE),col="red")
                  ipl=ipl+1
         plot(MB.df$Year,MB.df$I.s.t, main=paste("Fig. ", ipl, ". Spring Survey Swept Area Biomass (mt)"),
lty=1, col="blue",type="b")
                  abline(h=median(MB.df$I.s.t, na.rm=TRUE), col="red")


 # Part 3.2  Summary plots for Mass Balance Approaches
```

```
linetypes=c(3,4,2,1,2,4,3)
colorlines<-c("red","orange", "blue", "black", "blue","orange","red")
lineweights<-c(0.5,0.75,1,1.9,1,0.75,0.5)
percentile.levels<-c(0.05,0.1,0.25,0.50,0.75,0.90,0.95)
vname.list=unique(yyy$vname)
n.baseplots=length(vname.list)-2   # exclude observations for alternative quotas: Escapement.alt, FMratio.alt
#ipl=99  # test index
for (ip in 1:n.baseplots) {
  ipl=ipl+1
# Examine time series plots on arithmetic scale
 xp<-yyy$year[yyy$vname==vname.list[ip] & yyy$percentile==percentile.levels[1] & yyy$catchtype=="Obs"]
 yp1<-yyy$x[yyy$vname==vname.list[ip] & yyy$percentile==percentile.levels[1] & yyy$catchtype=="Obs"]
 y.min=min(yyy$x[yyy$vname==vname.list[ip] & yyy$catchtype=="Obs"])
 y.max=max(yyy$x[yyy$vname==vname.list[ip] & yyy$catchtype=="Obs" & yyy$percentile==0.98]) # the
0.98 is just for presentation to reduce influence of extreme values

 plot(xp,yp1, main=paste("Fig ",ipl, ". ",vname.list[ip]," Percentiles"),
   ylim=c(y.min,y.max), xlab="Year",ylab=vname.list[ip],cex=.2,type="l",
   lwd=lineweights[1], col=colorlines[1], lty=linetypes[1])
   lenlinetype=length(linetypes)#  # add lines to each plot for 0.05 to 0.95 percentiles.
 for (iline in 2:lenlinetype){
  yp2=yyy$x[yyy$vname==vname.list[ip] & yyy$percentile==percentile.levels[iline]&
       yyy$catchtype=="Obs"]
  if(length(yp2)>0){
  lines(xp, yp2,lwd=lineweights[iline], col=colorlines[iline],lty=linetypes[iline])}
 }
 abline(h=median(yyy$x[yyy$vname==vname.list[ip] & yyy$percentile==percentile.levels[4]
          & yyy$catchtype=="Obs"]),col="red",lwd=2.2)
}

# Examine time series plots on log scale
for (ip in 1:n.baseplots) {
 xp<-yyy$year[yyy$vname==vname.list[ip] & yyy$percentile==percentile.levels[1]]
 yp1<-log(yyy$x[yyy$vname==vname.list[ip] & yyy$percentile==percentile.levels[1]])
 y.min=min(log(yyy$x[yyy$vname==vname.list[ip]&yyy$catchtype=="Obs"]))
 y.max=max(log(yyy$x[yyy$vname==vname.list[ip]&yyy$catchtype=="Obs"]))
 ipl=ipl+1
 plot(xp,yp1, main=paste("Fig.",ipl, ". log(",vname.list[ip],") Percentiles"),
   ylim=c(y.min,y.max), xlab="Year",ylab=paste("log(",vname.list[ip],")"),cex=.2,type="l",
   lwd=lineweights[1],col=colorlines[1],lty=linetypes[1])
 for (iline in 2:lenlinetype){

  yp2=log(yyy$x[yyy$vname==vname.list[ip] & yyy$percentile==percentile.levels[iline]])
  if(length(yp2)>0){
  lines(xp, yp2,
    lwd=lineweights[iline], col=colorlines[iline], lty=linetypes[iline])}
 }

 abline(h=median(log(yyy$x[yyy$vname==vname.list[ip] & yyy$percentile==percentile.levels[4]])),
col="red",lwd=2.2)
}#   end of loop over n.baseplots
```

Part 3.3 Escapement probabilities for exceeding alternative thresholds for observed and alternative catches
plot summaries escapement fractions by year using dataframe ggg
this contains summary stats for each quota level.

```
xp=ggg$year[ggg$catchtype=="Obs"&ggg$percentile==0.5 & ggg$vname=="Escapement.1"]
yp=ggg$h[ggg$catchtype=="Obs"& ggg$percentile==0.5&ggg$vname=="Escapement.1"]
ipl=ipl+1
plot(xp,yp, main=paste("Fig.", ipl,". Probability Escapement<50%| Obs Landings vs Year"), ylab="Prob
Escapement<50%",xlab="Year")

xp=ggg$year[ggg$catchtype=="AltQuota"& ggg$percentile==0.5 & ggg$vname=="Escapement.1"]
yp=ggg$h[ggg$catchtype=="AltQuota"& ggg$percentile==0.5 & ggg$vname=="Escapement.1"]
ipl=ipl+1
plot(xp,yp, main=paste("Fig. ", ipl, ". Probability Escapement<50%|Alt Quotas vs Year"), ylab="Prob
Escapement<50%",xlab="Year")
abline(h=c(0.49,0.2),col=c("red","red"),lwd=c(2,2),lty=c(1,2))

xp=ggg$year[ggg$catchtype=="AltQuota"& ggg$percentile==0.4 & ggg$vname=="Escapement.1"]
yp=ggg$h[ggg$catchtype=="AltQuota"& ggg$percentile==0.4 & ggg$vname=="Escapement.1"]
ipl=ipl+1
plot(xp,yp, main=paste("Fig.",ipl, ". Probability Escapement<40%|Alt Quotas vs Year"), ylab="Prob
Escapement<40%",xlab="Year")
abline(h=c(0.49,0.2),col=c("red","red"),lwd=c(2,2),lty=c(1,2))

xp=ggg$year[ggg$catchtype=="AltQuota"& ggg$percentile==0.35 & ggg$vname=="Escapement.1"]
yp=ggg$h[ggg$catchtype=="AltQuota"& ggg$percentile==0.35&ggg$vname=="Escapement.1"]
ipl=ipl+1
plot(xp,yp, main=paste("Fig.", ipl, ". Probability Escapement<35%|Alt Quotas vs Year"), ylab="Prob
Escapement<35%",xlab="Year")
abline(h=c(0.49,0.2),col=c("red","red"),lwd=c(2,2),lty=c(1,2))

xp=ggg$catchlevel[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" &ggg$percentile==0.5]
yp=ggg$h[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" & ggg$percentile==0.5]
ipl=ipl+1
plot(xp,yp,main=paste("Fig.",ipl,". Probability Escapement<50% given Alternative Quota"),
xlab="Alternative Quota", ylab="Prob Escapement<50%")
#abline(h=0.5, col="red")
abline(h=c(0.49,0.2),col=c("red","red"),lwd=c(2,2),lty=c(1,2))

xp=ggg$catchlevel[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" &ggg$percentile==0.40]
yp=ggg$h[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" & ggg$percentile==0.40]
ipl=ipl+1
plot(xp,yp, main=paste("Fig.",ipl,". Probability Escapement<40% given Alternative Quota"),
xlab="Alternative Quota", ylab="Prob Escapement<40%")
#abline(h=0.5, col="red")
abline(h=c(0.49,0.2),col=c("red","red"),lwd=c(2,2),lty=c(1,2))
```

```
xp=ggg$catchlevel[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" &ggg$percentile==0.35]
yp=ggg$h[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" & ggg$percentile==0.35]
ipl=ipl+1
plot(xp,yp, main=paste("Fig ",ipl," Probability Escapement<35% given Alternative Quota"),xlab="Alternative
Quota", ylab="Prob Escapement<35%")
abline(h=c(0.49,0.2),col=c("red","red"),lwd=c(2,2), lty=c(1,2))

xp=ggg$catchlevel[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" &ggg$percentile==0.75]
yp=ggg$h[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" & ggg$percentile==0.75]
ipl=ipl+1
plot(xp,yp,main=paste("Fig ", ipl, " Probability Escapement<75% given Alternative Quota"),
    xlab="Alternative Quota", ylab="Prob Escapement<75%")
abline(h=c(0.49,0.2),col=c("red","red"),lwd=c(2,2), lty=c(1,2))


##################################################################################
###############
# Compute summary statistics for simulations
##################################################################################
##############

# compute fraction of observations less than cut points for each %MSP and assumed catch level

#  mean probability over all years of  falling below 50% escapement as a function of alternative quotas
tapply(ggg$h[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" & ggg$percentile==0.5],
    ggg$catchlevel[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" & ggg$percentile==0.5],
mean)
ipl=ipl+1
plot(AQ.df$AltQuota,tapply(ggg$h[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" &
ggg$percentile==0.5],
    ggg$catchlevel[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" & ggg$percentile==0.5],
mean),
    xlab="Assumed Quota (mt)",
    ylab="Probability of Escapement < 0.5", main=paste("Fig. ",ipl, ". Mean Probability of Escapement <0.5 over
all yrs vs Quota"))


#  median probability over all years of  falling below 50% escapement as a function of alternative quotas
tapply(ggg$h[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" & ggg$percentile==0.5],
    ggg$catchlevel[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" & ggg$percentile==0.5],
quantile, probs=0.5)
ipl=ipl+1
plot(AQ.df$AltQuota,tapply(ggg$h[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" &
ggg$percentile==0.5],
    ggg$catchlevel[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" & ggg$percentile==0.5],
quantile, probs=0.5),
    xlab="Assumed Quota (mt)",
    ylab="Probability of Escapement < 0.5", main=paste("Fig ",ipl," Median Probability of Escapement <0.5
over all yrs vs Quota"))

#  mean probability over all years of  falling below 40% escapement as a function of alternative quotas
```

```
tapply(ggg$h[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" & ggg$percentile==0.4],
    ggg$catchlevel[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" & ggg$percentile==0.4],
mean)

# mean probability over all years of falling below 75% escapement as a function of alternative quotas
tapply(ggg$h[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" & ggg$percentile==0.75],
    ggg$catchlevel[ggg$catchtype=="AltQuota" & ggg$vname=="Escapement.1" & ggg$percentile==0.75],
mean)

#compute similar statistics for FMratio as function of assumed quota.

# mean probability over all years of exceeding F/M ratio=1.0 as function of quota
tapply(ggg$h[ggg$catchtype=="AltQuota" & ggg$vname=="FMratio" & ggg$percentile==1.0],
    ggg$catchlevel[ggg$catchtype=="AltQuota" & ggg$vname=="FMratio" & ggg$percentile==1.0], mean)

# mean probability over all years of exceeding F/M ratio=0.666 as function of quota
tapply(ggg$h[ggg$catchtype=="AltQuota" & ggg$vname=="FMratio" & ggg$percentile==0.666],
    ggg$catchlevel[ggg$catchtype=="AltQuota" & ggg$vname=="FMratio" & ggg$percentile==0.666], mean)

# mean probability over all years of exceeding F/M ratio=0.5 as function of quota
tapply(ggg$h[ggg$catchtype=="AltQuota" & ggg$vname=="FMratio" & ggg$percentile==0.5],
    ggg$catchlevel[ggg$catchtype=="AltQuota" & ggg$vname=="FMratio" & ggg$percentile==0.5], mean)

# use tapply function to get sum of probabilities above threshold
# compute the overall ratio of joint overfishing for each escapement threshold and FMratio>1

tapply(ggg$h[ggg$catchtype=="AltQuota" & ggg$vname=="Prob.overfishing.joint" & ggg$percentile==0.5],
    ggg$catchlevel[ggg$catchtype=="AltQuota" & ggg$vname=="Prob.overfishing.joint" &
ggg$percentile==0.5], mean)
ipl=ipl+1
plot(AQ.df$AltQuota,tapply(ggg$h[ggg$catchtype=="AltQuota" & ggg$vname=="Prob.overfishing.joint" &
ggg$percentile==0.5],
    ggg$catchlevel[ggg$catchtype=="AltQuota" & ggg$vname=="Prob.overfishing.joint" &
ggg$percentile==0.5], mean),
    xlab="Assumed Quota (mt)",
    ylab="JOINT Prob Escapement < 0.5 and F/M>1.0", main=paste("Fig ",ipl," Median Prob of Escapement
<0.5 AND F/M>0.666 over all yrs vs Quota"))

tapply(ggg$h[ggg$catchtype=="AltQuota" & ggg$vname=="Prob.overfishing.joint" & ggg$percentile==0.75],
    ggg$catchlevel[ggg$catchtype=="AltQuota" & ggg$vname=="Prob.overfishing.joint" &
ggg$percentile==0.75], mean)


##############################################################################
#########################
# Illustrate the impacts of reduced parameter space by constricting range of q and v.
# plots for illustration of principles of integration

ipl=ipl+1
vioplot(F.e~M.e)
title(paste("Fig ",ipl,". Distribution of F estimates vs assumed M (weekly) for ", iy))
```

```
ipl=ipl+1
vioplot(Escapement.1~M.e)
abline(h=0.5, col="red",lty=2,lwd=2)
title(paste("Fig", ipl, ". Distribution of Escapement Estimates vs Assumed M (season) for ", iy))

#plot(F.e,Escapement.1)
ipl=ipl+1
plot(CBratio,Escapement.1,main=paste("Fig",ipl, ". Escapement vs C/B.f ratio for ", iy),cex=0.2)
abline(h=0.5, col="red", lty=2,lwd=2)

ipl=ipl+1
plot(FMratio,Escapement.1,cex=.2, main=paste("Fig ",ipl, " Escapement vs F/M ratio for ", iy))
abline(h=0.5, v=1, col=c("red","blue"),lty=c(1,2), lwd=c(3,2))

ipl=ipl+1
plot(FMratio[M.e==0.25],Escapement.1[M.e==0.25],cex=.2,main=paste("Fig ", ipl," Escapement vs F/M ratio
(low M) for ", iy))
abline(h=0.5, v=1, col=c("red","blue"),lty=c(1,2), lwd=c(3,2))

ipl=ipl+1
plot(FMratio[M.e==3.25],Escapement.1[M.e==3.25],cex=.2,main=paste("Fig ", ipl, " Escapement vs F/M ratio
(high M) for ", iy))
abline(h=0.5, v=1, col=c("red","blue"),lty=c(1,2), lwd=c(3,2))

# misc plots for report to SSC.  These are for the terminal year.
ipl=ipl+1
epdfPlot(F.e/N.fishing.weeks, main=paste("Fig ", ipl," Empirical PDF for Fishing Mortality (per week) for ",iy))
abline(v=median(F.e/N.fishing.weeks), col="black",lty=2)

ipl=ipl+1
epdfPlot(F.e, main=paste("Fig ", ipl," Empirical PDF for Fishing Mortality (per 25 week season) for ",iy))
abline(v=median(F.e),col="black",lty=2)

ipl=ipl+1
epdfPlot(log(B.0.catch),main=paste("Fig ", ipl," Empirical PDF for log(Biomass) for ",iy))
abline(v=c(median(log(B.0.catch)), mean(log(B.0.catch))), col=c("red", "blue"),lty=c(1,2))

ipl=ipl+1
epdfPlot(B.0.catch,main=paste("Fig ", ipl," Empirical PDF for Biomass (mt) for ",iy))
abline(v=c(median(B.0.catch),mean(B.0.catch)),col=c("red","blue"), lty=c(1,2))

ipl=ipl+1
epdfPlot(Escapement.1, main=paste("Fig ", ipl," Empirical PDF for Escapement for ",iy))
abline(v=c(0.4,0.5),col=c("red","blue"))
abline(v=median(Escapement.1),col="black",lty=2)

ipl=ipl+1
epdfPlot(FMratio, main=paste("Fig ", ipl," Empirical PDF for F/M ratio for ",iy))
abline(v=c(1.0,0.666),col=c("red", "blue"))
abline(v=median(FMratio),col="black",lty=2)
```

```
#}   # end of year loop for 3D plots, prob density function, and violin plots

end_time=Sys.time()
TotalRunTime=end_time-start_time
Timeper100000Simulations=TotalRunTime/n.sim*100000
print(paste("Total Elapsed Time for simulation = ",TotalRunTime))
print(paste("Time per 100,000 simulations = ",Timeper100000Simulations))
###############################################End of simulations

dev.off()    # close the pdf plot output file

#### the following plots have been transferred to beginning.  Plot to screen.
plot(MB.df$Year,MB.df$Catch.t, main="Observed Catch (mt)", lty=1, col="black", type="b")
abline(h=median(MB.df$Catch.t, na.rm=TRUE),col="red")
plot(MB.df$Year,MB.df$I.f.t, main="Fall Survey Swept Area Biomass (mt)", lty=1, col="black", type="b")
abline(h=median(MB.df$I.f.t, na.rm=TRUE),col="red")
plot(MB.df$Year,MB.df$I.s.t, main="Spring Survey Swept Area Biomass (mt)",lty=1, col="blue", type="b")
abline(h=median(MB.df$I.s.t, na.rm=TRUE), col="red")




#############################################################################################
#################  END OF MODEL CODE #######################################################
#############################################################################################
```

Appendix 2. Report to SSC in 2022.

Evaluation of Alternative Catch Limits for Illex in 2022

Report to Mid-Atlantic Fishery Management Council Scientific and Statistical Committee

Paul Rago

March 8, 2022

OVERVIEW

Illex squid is a difficult species to assess. Illex grow rapidly, live less than a year, and die shortly after spawning. They exhibit strong diel vertical migrations and an unknown fraction of the population lives outside the survey sampling domain. Migrations from the offshore region to inshore survey and fishing areas vary within and among years. Recent oceanographic studies (Salois et al. 2021) suggest promising insights into the causal mechanisms but predictive models are not yet available.

The assessment of Illex is further complicated by the period of the fishery and it's minimal temporal overlap with the NEFSC bottom trawl surveys. The NEFSC conducts research bottom trawl surveys in the Northeast U.S. The spring survey typically begins about March 1 and continues for 8 to 10 weeks with 4 separate cruises with sampling progressing from south to north. The fall survey is similarly executed but begins in first week of September. In terms of *Illex* migrations, the spring survey ends well before the bulk of the offshore population arrives in the sampling domain. The fall survey begins after much of the catch has been taken and *Illex* are thought to be moving out of the survey domain. The commercial fishery is prosecuted primarily between May and September in most years, although catches can occur well into fall in some years. Owing to the short lifespan, there is intervals between annual survey (ie. fall to fall) span lifetimes and carryover of individuals alive in the spring survey to the fall survey is low.

These migration and timing considerations suggest that the fall survey should be useful as a post fishery measure of abundance. The spring survey will be less useful if migrations during the season occur after the spring survey supply most of the squid landed during the fishery. This aspect will be examined later in this working paper. Collectively, these considerations suggest that a form of virtual population analysis can be useful for estimating the population size necessary to support the observed landings. In this paper initial population size is denoted as B.0. Given B.0 and assumptions that will be described later, the population that would have survived in the absence of the fishery can be compared to the observed abundance. The ratio of observed abundance to this forward projection of stock size is defined as a measure of escapement.

The estimate of B.0 can also be used to evaluate the effects of hypothetical removals on potential escapements. If the hypothesized quotas are greater than the observed catches that defined B.0, then escapement estimates will be lower, and vice versa. The projected escapement conditional

on the assumed quota can be compared to some threshold of acceptable escapement. There are no accepted biological reference points for *Illex illecebrosis*, but other squid stocks have been managed with percent escapement targets (see Arkhipken et al. 2015, 2020) for reviews. An escapement target of 50% seems to be one of the most commonly used, but it does not appear to be the product of a stock recruitment analysis. Instead it is often justified by an appeal to life history considerations (e.g., short life span, multiple within year cohorts etc.).

The simple methodology for estimating virtual population biomass and escapement is extended to consider the uncertainty in catchability, availability and natural mortality. These analyses allow estimation of relative risks of overfishing (defined as falling below an escapement threshold).

METHODS

Data

Landings information for 1997 to 2019 was provided by Lisa Hendrickson (NEFCSC) and by Jason Didden (MAFMC) for 2021. The 2021 estimate is considered preliminary. Survey based estimates of minimum swept area biomass were provided by Lisa Hendrickson. The computations in Table 1 represent the expansion of the observed mean weight per tow to total biomass over the entire survey area. Catchability (or equivalently in this case, efficiency) is assumed to be 1.0 and all of the population is assumed to be in the survey area (i.e., availability =1.0).

Model

Estimation of Initial Biomass, Fishing Mortality and Escapement

Let I_t represent observed index of biomass at time t and C_t represent the catch at time t. The estimated swept area total biomass consistent with the index is

$$B_t = \frac{I_t}{q}\frac{A}{a} \qquad (1)$$

where the catchability or efficiency **q**, is an assumed value. The average area swept per tow is **a** and the total area of the survey is **A**. To account for the fact that a sizable fraction of the Illex population lies outside of the survey area, an additional parameter **v** is introduced which represents the fraction of the resource measured by the survey. If the population is closed **v** is set to one and all of the population is assumed to be in the survey areas. Eq. 1 can be modified to account for this by dividing the right hand side by **v** such that:

$$B_t = \frac{I_t}{q}\frac{A}{a}\frac{1}{v} = \frac{A I_t}{qav} \qquad (2)$$

The NEFSC fall bottom trawl survey occurs after most of the fishery occurs and therefore can be considered a measure of post-fishery abundance. In order to account for the potential swept area biomass that existed at the start of the season, it is necessary to add the total landings removed from the fishery. Thus, the estimate of abundance at the start of fishing season is what was left

plus what was extracted. Since the removals take place over a period of time and the squid are subject to natural mortality during that period, it is further necessary to inflate those removals.

To "back up" the abundance estimate to what it would have been at the start of the season, one needs to adjust the actual catch for natural mortality and add it back into B_t

$$B_t = B_0 \ e^{-Zt} \qquad (3)$$

Where B_t is defined by Eq. 2.

The initial biomass consistent with observed catch can be obtained by rearranging the Baranov catch equation as

$$B_0 = \frac{C_t}{\frac{F}{F+M}(1-e^{-(F+M)})} \qquad (4)$$

Substitution of Eq. 3 into 4 and rearranging results in

$$B_t e^{(F+M)} = \frac{C_t}{\frac{F}{F+M}(1-e^{-(F+M)})} \qquad (5)$$

Further substitution of Eq 2 into 5 expresses B_t and B_0 as functions of observations of survey indices I_t and landings C_t and assumed values for q, v and M.

$$\frac{AI_t}{qav} e^{(F+M)} = \frac{C_t}{\frac{F}{F+M}(1-e^{-(F+M)})} \qquad (6)$$

Fishing mortality F can now be computed directly by numerical methods (see function uniroot in R). Direct estimation of F was used in this analysis rather than Pope's approximation in view of the potential consequences of violating the parameter range over which the Pope's method is appropriate. Direct estimation of F also simplifies consideration of escapement under alternative assumed quotas.

For the purposes of this work, escapement is defined as the ratio of the observed end of fishing season population B_t to that expected if no fishing mortality occurred. The projected population if no fishing occurred can be obtained by projecting B0 in Equation 10 by the fraction surviving natural mortality:

$$B_{t,without\ fishery} = B_0 e^{-Mt} \qquad (7)$$

The "escapement" is now computed as the ratio of the estimated Bt based on the survey divided by the projected biomass that would have occurred in the absence of the fishery.

$$Escapement = \frac{B_t}{B_{t,without\ fishery}} \qquad (8)$$

Further substitution of Eq. 3 and 7 into Eq. 8 results in

$$Escapement = \frac{B_t}{B_{t,without\ fishery}} = \frac{B_0\,e^{-(F+M)}}{B_0\,e^{-M}} = e^{-F} \qquad (9)$$

Estimates of B_0 can also be used to evaluate the effects of alternative catch levels on escapement. Let C_H equal a hypothesized catch to be obtained from the estimated B_0. Substitution of C_H into Eq. 6 allows for estimation of the F necessary to obtain C_H, denoted as F_H.

$$B_0 = \frac{C_H}{\frac{F_H}{F_H+M}\left(1-e^{-(F_H+M)}\right)} \qquad (10)$$

Thus, escapement given C_H is now defined as $\exp(-F_H)$. To investigate the implications of alternative higher catches Equation 10 was applied to each year, 1997-2021 using hypothetical quotas of 24,000 to 60,000 mt in steps of 1,000 mt.

Stochastic Methods for Biomass, Fishing Mortality and Escapement

For a given set of assumed parameters {q,v,M} and fixed inputs for survey estimates and catch {$I_{f,t}$, $I_{s,t}$, C_t} it is possible to estimate $B_{0,t}$, F_t, $Escapement_t$ F/M and other outputs of possible utility for the assessment. The ranges of these quantities can be established by examining a range of values. By assuming that each of the parameters is drawn from an underlying distribution of values, it is possible to compute the resulting distribution of $B_{0,t}$, F_t, $Escapement_t$ etc. One way of efficiently sampling over the entire range of values is known as Latin hypercube sampling. In simple terms, one assigns an equal probability to each value drawn from the underlying distribution by dividing the range of the parameter into equal probability intervals. The area under the curve (ie. the integral) for a probability density function over a define range e.g., (q_1, q_2) is the same for all intervals. Thus each observation, defined as the midpoint of (q_1, q_2) now has the same probability. For a uniform distribution this just means dividing the domain of the distribution (p_{min}, p_{max}) into equally spaced intervals.

This same principle can be applied to any hypothetical parameter, say r, (r_{min}, r_{max}) to obtain equal probability observations. By looping over the full range of r for every value of p you obtain a measure of the expected value of some function Y for p over every value of r. If there are N_q intervals for parameter q, N_v for v and N_M for M, then the joint probability for any combination {q_i, v_j, M_k} is $(1/N_q)(1/N_v)(1/N_M)$. Looping over all possible combinations yields a probability density function for any function of q, v and M. In this case, N was set to 40 for each parameter so each plot constitutes 64,000 evaluations of the function. The models were implemented in R and the core code is listed in Appendix 1.

Probability levels for candidate thresholds can be computed by counting the proportion of realizations that fall above for below a criteria. For example, the average probability that a given alternative quota induces escapement below 50% can be found by estimating the proportion of

cases that fall below 0.5 and averaging the probabilities over all years. This was done for each candidate quota level between 24,000 and 60,000 mt.

Constraints on parameters.

Catchability

Bigelow to Albatross is 1/1.4093 implies max q Albatross is 0.71 if Bigelow q=1 (Miller et al 2010). In addition, catch rates of Illex are higher during the day than at night. Diurnal differences in catch rates are known for many squid. For longfin squid Jacobson et al. (2015, cf Table 3, p. 1334) found a nearly two-fold difference between a composite median abundance and an estimate based on daytime tows only (0.74 B vs 1.5 B). A model adjusted estimate of median abundance was 2.0B. Together these estimates suggest an upper bound in the range of q to be 0.37 to 0.493 for longfin squid.

In another study, Benoit and Swain (2003) compared day vs night catches from the Canadian research vessels Alfred Needler and Lady Hammand, both of which used the Yankee 36 net or the period 1971 to 2001. Using estimated the log catch ratios of night to day tows for the research vessels) were -1.224 and -1.376 respectively (P<0.001; see their Table A1, p 1317). These imply day to night ratios of catch rates of 3.401 and 3.959. If roughly half the tows during the day, then the expected catch expressed in daytime equivalents would by 2.2 to 2.5 times higher. Using a model statistical method comparable to the "statististical control" model of Benoit and Swain (2003), Sagarese et al. (2016) computed an overall day night coefficient of 1.2 (log scale) for Illex in the Northeast US Continental Shelf Large Marine Ecosystem (P<0.005). The arithmetic day to night ratios is exp(1.2) = 3.32, similar to that found by Benoit and Swain (2003).

As noted in Hendrickson and Showell (2019) the Benoit and Swain (2003) did not find significant differences for Illex in pairwise comparison tests, but this may have been a function of sample size (about 67 stations each in 1988 and 1992). Brodziak and Hendrickson (1997) reported catch rates for pre-recruit (<10 cm mantle length) Illex illecebrosus to be 1.6 to 2.4 times higher in the day than during dusk and night, respectively (P<0.001). The same ratios for Illex recruits (>10 cm) had a significance value of 0.106 and was not reported.

Collectively, these studies suggest that night time catches are low by a factor of at least two. Combining this with the known information from the Bigelow to Albatross calibration coefficient (1/1.4093) results in reasonable upper bound of 0.5/1.4093=0.355. This compares favorably to the 95% upper bound (=0.325) proposed by Manderson et al for commercial vessels.

The likely lower bound on catchability has important implications for estimating the likely range of biomass bounds. Assuming very low values of q imply very high values of biomass. Manderson et al. (2021) reported a potential lower bound of 2% for q based expert opinion. While efficiencies may be this low for specific tows, it is unlikely to be the case over an entire survey within a year. The average estimate from the experts for commercial gear was 7.8%. Assuming that this is based on daytime tows, it would be reasonable to assume that research vessel tows, which are collected both day and night, the lower bound on research vessel tows

should be less than 7.8%. It is not possible to determine if the differences in diel catch rates factored into the average defined by the expert panel.

Availability

Spatial analyses methods were used by Lowman et al. (2021) and Manderson et al. (2022) were used to compute estimates of likely availability of Illex to the US survey strata. Depending on the method used for the sensitivity-specificity threshold, availability estimates ranged from 34.5 to 46% with one method to 31-73% with another. The wider range (31-73%) was used in this report for setting bounds.

Natural Mortality

The lower bound of assumed weekly natural mortality rates (=0.01) was based on lowest assumed value in Hendrickson and Hart (2006). The upper bound of 0.13 week^{-1} was obtained from the predictive equation of Hewitt and Hoenig (2005) given a maximum age of 221 days in 2019-2020 samples.

Candidate Thresholds for Escapement and F/M

Escapement levels of 50%, 40% and 35% from literature and assessment reports
F/M ratio for forage species. F/M =1, 2/3

Risk Analyses

Decisions by the MAFMC regarding catch levels are governed by its Risk Policy that attempts to avoid overfishing over all levels of stock biomass. The risk of overfishing is defined as the probability of exceeding the overfishing limit and is denoted as P* as depicted below.

Comparison of the current risk policy (status quo) and the modified alternative. The modified alternative depicted is now the MAFMC's policy. Source= https://static1.squarespace.com/static/511cdc7fe4b00307a2628ac6/t/5e56e0ccb8195137f6d160d7/1582751948674/1_Risk+Policy+memo+to+SSC.pdf Under the new risk policy, the probability of overfishing can reach 0.49 when the ratio of current to MSY stock levels exceeds 1.5. Below 1.5 the acceptable risk of overfishing declines to zero when B/Bmsy$\leq$0.1.

The Scientific and Statistical Committee of the MAFMC is responsible for recommending Acceptable Biological Catches (ABC) given an estimate of the Over Fishing Level (OFL) from a stock assessment. This is usually obtained by estimated as the total catch if the population were fished at its Fmsy proxy. The probability of overfishing is further defined by the uncertainty of the OFL. In most instances, the stock assessment is unlikely to fully characterize the uncertainty of the OFL because it is based on a single model and does not integrate overall possible states of nature. To overcome this philosophically unknowable cul de sac, the SSC has developed a rubric that derives an uncertainty level based on meta-analysis of multiple model outcomes for simulated assessments. Three levels of uncertainty 60, 100 and 150% CV have been identified as representative. The reduction in OFLs, consistent with the Council's Risk Policy is expressed as the ratio of ABC to OFL as shown below.

The risk of overfishing for Illex can be expressed as the probability of escapement falling below a specific threshold level (say 35%, 40%, 50%) or the probability of exceeding F/M =2/3, 1 or other values that attempt to preserve forage for available predators.   Finally, one can estimate the joint probability of exceeding F/M threshold and falling below an escapement threshold. The *only* other requirement to apply the risk policy it to guesstimate the likely current state of the resource (i.e., Bt/Bmsy).

RESULTS

The stochastic escapement model was applied to each available year between 1997-2021. Fall bottom trawl surveys were not available in 2017 and 2020 (Table 1).   Figure 1 to 9 illustrate the behavior of the escapement model as a function the assumed ranges of catchability q=[0.078,0.325, availability v=[0.37,0.73], and natural mortality (per week) M=[0.01,0.13], given observed survey and catches in 2021. Estimates of initial biomass B.0 decrease inversely with the product of q*v (Fig. 1 top). The empirical distribution of B.0 given the joint distribution of q, v, and M is strongly skewed (Fig. 1 bottom) with the mean exceeding the median. As expected the distribution of F is inversely related to the product of qv (Fig. 2 top). Estimated F is less strongly skewed (Fig. 2 bottom).   Equation 9 predicts escapement will be inversely related

to fishing mortality as shown in Fig. 3 (top). The distribution of escapement values is nearly the mirror image of the F (Fig. 3 bottom).

F/M has been proposed as a "rule of thumb" reference points for forage species (Fig. 4) and Patterson (1992) has proposed F=2/3 M as a candidate reference point.

Escapement declines as F/M increases but the rate of decline depends on the assume M. When M is low, the rate of decline is very slow; in contrast escapement declines rapidly with F/M when the assumed M is high (Fig. 5). Catch over fall swept area biomass levels has been used as a measure of exploitation in some assessments. Since the fall survey is essentially a post fishery survey, this ratio depends on the assumed M estimate (Fig. 6 top). In contrast, escapement is directly related to F (Fig. 6, bottom, and Eq. 9). Catch over estimated B.0 is a preferred metric of exploitation.

The distribution of 2021 weekly F estimates correspond well with independent estimates of weekly F derived by VMS analyses (Rago 2021) (Fig. 7). The effect of assumed M levels is shown in Fig. 8. The escapement increases as assumed M increases but the range of escapements decreases with M (Fig. 8 top). Estimated F declines with M but the range also decreases (Fig. 8 bottom).

Estimates of $B.0_t$ illustrate the magnitude of biomass necessary to support the observed landings and the estimated biomass as the end of the season. Theoretically, in a closed population the estimated biomass would be close to the beginning of the season biomass approximated by the spring survey. However, the ratio of B.0 to spring survey biomass (B.s) ranges widely from 5 to 2500 (Fig. 9). This disparity is important because it highlights the likely magnitude of other processes necessary to support the observed catch. The initial biomass B.0 is based on the observed landings and fall survey given assumptions about catchability q, availability v, and natural mortality M. The spring survey biomass, for any realization, is based on the same q and v parameters. Ratios greater than one illustrate the amount of immigration , in-season recruitment and/or growth in weight necessary to support the fishery.

Changes in growth alone are insufficient to explain the large ratios. Even a 10-fold increase in average weight between the spring survey and midpoint of the fishery would have little impact on the distribution of B.0/B.s values. Collectively, the evidence suggests that the summertime fishery is supported by intermittent fluxes of recruits from offshore populations or recruitment of individuals from within the survey area.

The time series of biomass, fishing mortality, F/M and escapements for 1997-2021 are shown in Fig. 10-12. Corresponding values for each plot are given in Table 2-4. Apart from the wide confidence intervals, a notable feature of these estimates is a general absence of significant trend. Runs of observations above and below the median suggest a slight degree of autocorrelation. The 90% confidence interval for B.0 has about a 14 to 25-fold range (Table 2). Wide ranges in the lower and upper bounds in B.0 do not translate to comparable ranges of escapement (Table 3). The median escapement level across all years exceeded 0.7. Even the 5%-ile of escapement was above 50% escapement in all years (Table 3). These estimates suggest that the historical

range of catches were unlikely to have resulted in escapements below 50%. The F/M ratio infrequently exceeded 1 (Table 4).

These results beg the question about how the population might have responded to higher levels of historical catches. The effects of hypothetical quotas over the entire range of years is summarized in Table 5 for median escapement rates and Table 6 for median F/M.

Graphs of these probabilities are shown in Fig. 13 to 15. Even the highest quota levels (60,000 mt) do not induce probabilities of overfishing (i.e., escapement below 50%) in most years. In fact, the problematic years are 1999, 2001 and 2013. If the escapement threshold is lowered to 40%, then the overfishing criteria would only be triggered in 1999 (Fig. 15).

Risk Analyses

The historical probabilities of overfishing having occurred were computed by estimating the proportion of simulated escapements that fell below escapement thresholds of 0.35, 0.4, 0.5, 0.6 and 0.75 (Table 7) for each year. A similar analysis was done for F/M exceeding 0.33, 0.5, 0.666, 1, and 1.5 for each year (Table 8). Finally, the joint probability F/M exceeding 0.666 and escapement of falling below thresholds of 0.35, 0.4, 0.5, 0.6, and 0.75 was computed for each year (Table 9). Across Tables 7-9 there was no evidence of historical catches inducing overfishing probabilities above 0.5. In fact, most of the table entries are less than 0.1.

The consequences of alternative quotas from 24 kt to 60kt on overfishing probabilities can also be estimated by averaging over all years (Table 10-12). As an illustration, if 50% escapement defines the overfishing threshold, then the maximum average risk of overfishing is 0.2739 when the quota is 60,000 mt (Table 10). Similarly, if 0.666 defines the overfishing limit for F/M then a 60,000 mt quota results in an overfishing probability of 0.2589 (Table 11). The joint probability of overfishing with escapement <0.5 and F/M>0.666 is 0.1468 when the quota is 60,000 mt (Table 12).

Needless to say, none of the above thresholds for overfishing have been defined for Illex, but many of these thresholds are used for management of other squid stocks around the world.

The other aspect of risk evaluation is the current status of the stock. If one assumes that the overall biomass is stable without significant trend (e.g., Fig. 10, Table 2) the next question becomes "Is this stock oscillating about a stable point near Bmsy or some fraction of it?". If the stock is near Bmsy, then the risk policy would suggest an overfishing risk of 0.45 is appropriate. If the stock is oscillating about an equilibrium of 0.5 Bmsy then the overfishing risk should not exceed 0.2. If the first scenario is true (i.e., B/Bmsy~1) then quotas up to 60,000 mt would be acceptable. If the second scenario is true (i.e, B/Bmsy~0.5) then quotas should not exceed 47,000 mt (Table 10) or 40,000 mt if F/M=2/3 criterion is applied.

DISCUSSION

The methods used in this report build on the approaches considered by the SSC in 2021. At the time only two alternative quotas were considered and the risk of overfishing was defined by

examining a range of extreme values in the parameter space for {q, v, M}. The approach is improved in following ways:

1. The ranges of catchability, availability and M are informed by work conducted by the Research Track Assessment for Illex.
2. Pope's approximation of the VPA is replaced with a more accurate numerical solution of the catch equation for F.
3. The effects of uncertainty in the {q,v,M} parameters on biomass, F, and escapement estimation, are examined by integrating over the full range of the distributions of each parameter.
4. The risk of overfishing is compared with a wide array of candidate biological reference points for Escapement and F/M.
5. A wide range of alternative quotas (24,000 mt to 60,000 mt) are evaluated.
6. The implications of the Councils risk policy are considered.
7. The ratio of B.0 based on the fall survey to the estimated biomass in the spring survey in the same year indicates that current quotas are largely supported by immigration of recruits to the fishing areas rather than growth of the existing stock at the end of the spring survey.
8. Comparisons between independent VMS-based estimates of fishing mortality compare favorably with the derived F based on the parametric model.
9. Landings and survey data for 2021 were added.
10. The model was implemented in R. Core code is in Appendix 1. Full code will be distributed to SSC.

The perception of risk is governed by many factors. Arkhipkin et al. (2020) review many considerations that affect risk in cephalopod management. In this working paper I have examined the implications of many factors related to a closed population (v), sampling efficiency (q) and uncertainty in natural mortality (M). These factors are assumed to be independent of each other such that the integration of some function of these random variables provides some meaningful insights about the function. The use of uniform distributions for these parameters is consistent with what we think we know, and the model can easily be re-parameterized as new information becomes available. The uniform distribution is useful in that it is parameterized only by the upper and lower bounds. The Beta distribution can also be defined on the [a,b] interval but its parameterization depends on two additional parameters to define its shape. In the absence of additional information, such an extension seems speculative.

Low q, low v and high M drive the high stock biomasses in Table 2. The extreme values, above 1 M mt seem highly unlikely, but the distribution of median values across years reasonable (70-845 k mt). Perhaps more importantly, the range of values across years is consistent with the wide ranges of fluctuations in catch levels experienced in other squid fisheries. Median biomass estimates over the past 10 years have ranged from 112 to 461 k mt (Table 2) and median escapement percentiles have exceeded 0.765 for this same period (Table 3).

Escapement based management procedures are widely applied (Macewicz et al., 2004; Maxwell et al., 2005; Dorval et al., 2013) but the theoretical justification for the choice of 50% or 40% is often governed by general notions of sustainability and life history characteristics (e.g. Rago 2022) rather than actual stock recruitment relationships.

The analyses herein provide general support for the notion that exploitation rates are generally low. One has to posit much higher average availability and catchability rates than used herein to significantly reduce median stock size or escapement. For reasons noted in Manderson et al. (2021) and Lowman et al. 2021) the availability estimates are probably high, particularly since stock sizes outside the survey areas is not considered. One of the more useful deductions from these analyses is the reliance of the fishery on processes that occur after the spring survey (Fig. 9). The flux of squid into the fishing areas is a primary support the fishery. Changes in average weight during the season are important but unlikely to be sufficient to support the observed removals.

The range of natural mortality rates in this analysis is consistent with non-spawner natural mortality rates used in Hendrickson and Hart (2006). Their analyses supported much higher rates of mortality on spawning squid albeit for a short period of time after maturation. Analyses of average sizes during the fishery reveal a general absence of larger squid (Rago 2021 WP). This may be due to spawning mortality or migration out of the fishing areas. Hendrickson and Hart (2006, p. 10-11) suggested that the "low number of older females in the survey [i.e., the 2000 cooperative survey] samples was due to spawning mortality rather than a lack of selectivity to the gear." Increasing M in the current model would increase the biomass estimates in Table 2.

The probability of overfishing (i.e., falling below a threshold escapement level) is computed for each of the 23 years (1997-2021, with 2017 and 2020 excluded). The average probability thus depends on all of the realized estimates for this period. Moreover it is assumed that all are equally probable. Recent high success rates in the fishery are not explicitly considered. Inclusion of an autocorrelative model for might be useful but perhaps not warranted until the parameterizations of the model are further refined.

References

Agnew D. J., R. Baranowski, J.R. Beddington, S. des Clers, and C.P. Nolan. 1998. Approaches to assessing stocks of *Loligo gahi* around the Falkland Islands. Fisheries Research 35:155–169.

Arkhipkin, A. I., Paul G. K. Rodhouse, Graham J. Pierce, Warwick Sauer, Mitsuo Sakai, Louise Allcock, Juan Arguelles, John R. Bower, Gladis Castillo, Luca Ceriola, Chih-Shin Chen, Xinjun Chen, Mariana Diaz-Santana, Nicola Downey, Angel F. González, Jasmin Granados Amores, Corey P. Green, Angel Guerra, Lisa C. Hendrickson, Christian Ibáñez, Kingo Ito, Patrizia Jereb, Yoshiki Kato, Oleg N. Katugin, Mitsuhisa Kawano, Hideaki Kidokoro, Vladimir V. Kulik, Vladimir V. Laptikhovsky, Marek R. Lipinski, Bilin Liu, Luis Mariátegui, Wilbert Marin, Ana Medina, Katsuhiro Miki, Kazutaka Miyahara, Natalie Moltschaniwskyj, Hassan Moustahfid, Jaruwat Nabhitabhata, Nobuaki Nanjo, Chingis M. Nigmatullin, Tetsuya Ohtani, Gretta Pecl, J. Angel A. Perez, Uwe Piatkowski, Pirochana Saikliang, Cesar A. Salinas-Zavala, Michael Steer, Yongjun Tian, Yukio Ueta, Dharmamony Vijai, Toshie Wakabayashi, Tadanori Yamaguchi, Carmen Yamashiro, Norio Yamashita & Louis D. Zeidberg. 2015. World Squid Fisheries, Reviews in Fisheries Science & Aquaculture, 23:2, 92-252, DOI:

10.1080/23308249.2015.1026226

Arkhipkin, A. I., Hendrickson, L. C., Paya´, I., Pierce, G. J., Roa-Ureta, R. H., Robin, J.-P., and Winter, A. 2020. Stock Assessment and management of cephalopods: advances and challenges for short-lived fishery resources. ICES Journal of Marine Science 78: 714–730.

Barton, J. 2002. Fisheries and fisheries management in Falkland Islands Conservation Zones. Aquatic Conservation: Marine and Freshwater Ecosystems, 12: 127–135.

Benoit, H. P., and Swain, D. P. 2003. Accounting for length- and depth-dependent diel variation in catchability of fish and invertebrates in an annual bottom-trawl survey. ICES Journal of Marine Science, 60: 1298–1317.

Caddy, J. F. 1983. The cephalopods: factors relevant to their population dynamics and to the assessment and management of stocks. In Advances in Assessment of World Cephalopod Resources, pp. 416–457. FAO Fisheries Technical Papers, 231, FAO Publications, Rome.

Dorval, E., Crone, P.R., McDaniel, J.D., 2013. Variability of egg escapement, fishing mortality and spawning population in the market squid fishery in the California Current Ecosystem. Mar. Freshw. Res. 64, 80–90.

Hendrickson, L. C., and D. R. Hart. 2006. An age-based cohort model for estimating the spawning mortality of semelparous cephalopods with an application to per-recruit calculations for the northern shortfin squid, Illex illecebrosus. Fish. Res., 78: 4–13.

Hendrickson L.C. and M. A. Showell. 2019. 2019 Assessment of Northern Shortfin Squid (*Illex illecebrosus*) in Subareas 3+4. NAFO SCR Doc 19/042, Serial No. N6973. 38 p.

Hewitt, D.A. and J. M Hoenig. 2005. Comparison of two approaches for estimating natural mortality based on longevity. Fish. Bull. 103:433–437.

Lowman, B. A., A.W. Jones, J.P. Pessutti, A.M. Mercer, J.P. Manderson, and B. Galuardi. 2021. Northern shortfin squid (Illex illecebrosus) fishery footprint on the Northeast US continental shelf. Frontiers in Marine Science 8:85

Macewicz, B.J., Hunter, J.R., Lo, N.C.H., LaCasella, E.L., 2004. Fecundity, egg deposition, and mortality of market squid (Loligo opalescens). Fish. Bull. 102, 306–327.

Manderson, J.P., B. Lowman, B. Galuardi, and A. Mercer. 2021. Plausible bounds for availability of and net efficiency for northern shortfin squid in the US fishery and Northeast Fisheries Science Center bottom trawl survey. Illex RTA working paper.

Maxwell, M.R., Jacobson, L.D., Conser, R.J., 2005. Eggs-per-recruit model for management of the California market squid (Loligo opalescens) fishery. Can. J. Fish. Aquat. Sci. 62, 1640–1650.

Miller, T. J., C. Das, P. J. Politis, A. S. Miller, S. M. Lucey, C. M. Legault, R. W. Brown, and P. J. Rago. 2010. Estimation of Albatross IV to Henry B. Bigelow calibration factors. National Marine Fisheries Service, Northeast Fisheries Science Center Reference Document 10-05, Woods Hole, Massachusetts. or online at http://www.nefsc. noaa.gov/nefsc/publications/

Patterson, K. (1992). Fisheries for small pelagic species: an empirical approach to management targets. *Rev. Fish Biol. Fish.* 2, 321–338. doi: 10.1007/bf00043521

Rago, P.J. 2021. Indirect Methods for Bounding Biomass and Fishing Mortality for Illex Squid and Implications of an Alternative Quota in 2022. Report to the Scientific and Statistical Committee. MidAtlantic Fishery Management Council. May 11, 2021.

Rago, P.J. 2021. Analyses of Illex weight frequencies for evidence of cohorts: 1. Percentile tracking of cohorts based on weight and estimated ages, 2. Birth week frequencies by year. Working Paper for Illex Research Track Assessment. Nov. 21, 2021

Rago, P.J. , 2022. Biological reference points for Illex squid: Extensions of the Hendrickson and Hart Approach. Working Paper for Illex Research Track Assessment. Jan. 21, 2022.

Ralston, S., E. Dorval, L. Ryley, K. M. Sakuma, J. C. Field. 2018. Predicting market squid (Doryteuthis opalescens) landings from pre-recruit Abundance. Fisheries Research 199:12–18

Sagarese, S.R., M. G. Frisk, R. M. Cerrato, K.A. Sosebee, J. A. Musick, and P.J. Rago. 2016. Diel Variations in Survey Catch Rates and Survey Catchability of Spiny Dogfish and their Pelagic Prey in the Northeast U.S. Continental Shelf Large Marine Ecosystem. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 8(8) : 244-262

Sissenwine, M. P., and Bowman, E. W. 1978. An analysis of some factors affecting the catchability of fish by bottom trawls. International Commission for the Northwest Atlantic Fisheries Research Bulletin, 13: 81–87.

Table 1. Summary of swept area biomass estimates Illex in NEFSC spring and fall bottom trawl surveys, and USA landings, 1997-2021.

Year	Landings (mt)	Spring Survey (mt)	Fall Survey (mt)
1997	14,358	511	2,730
1998	24,154	226	7,725
1999	8,482	149	929
2000	9,117	35	3,999
2001	4,475	110	1,422
2002	2,907	68	2,322
2003	6,557	23	10,913
2004	27,499	139	2,279
2005	13,861	14	3,696
2006	15,500	121	14,220
2007	9,661	147	7,311
2008	17,429	54	5,462
2009	19,090	404	5,170
2010	16,394	101	2,941
2011	19,487	294	2,937
2012	12,211	1,099	2,895
2013	4,107	22	1,827
2014	9,342	NA	3,592
2015	2,873	217	2,795
2016	7,004	2,641	3,711
2017	23,371	314	NA
2018	25,524	382	7,146
2019	28,495	1,901	3,310
2020	not used	NA	NA
2021	30,714	NA	3,531

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Table 2.

Table xx	Estimated percentiles for initial biomass (mt) by year given observed catch and fall survey biomass								
	Entries are based on 64,000 combinations of catchability, availability and natural mortality rates.								
			Percentile						
Year	**1%**	**5%**	**50%**	**95%**	**99%**				
1997	38,717	49,453	185,723	827,290	1,302,851				
1998	90,447	119,492	491,716	2,291,773	3,634,128				
1999	17,286	21,200	70,404	292,095	454,671				
2000	42,897	57,597	247,572	1,176,229	1,870,164				
2001	16,683	22,036	90,570	421,949	669,056				
2002	22,069	30,436	138,670	675,594	1,078,045				
2003	95,429	133,978	636,952	3,153,136	5,043,164				
2004	49,962	60,024	185,940	736,078	1,136,097				
2005	45,982	60,047	240,044	1,103,850	1,746,282				
2006	132,472	183,477	844,856	4,129,800	6,594,388				
2007	70,075	96,451	437,739	2,128,825	3,395,985				
2008	64,367	84,952	348,369	1,621,446	2,570,678				
2009	63,968	83,639	335,164	1,543,213	2,441,738				
2010	42,783	54,403	201,850	894,134	1,406,623				
2011	46,323	58,125	207,939	902,171	1,414,560				
2012	37,589	48,682	190,867	868,604	1,372,251				
2013	19,531	26,243	112,984	537,195	854,219				
2014	39,853	53,183	224,777	1,060,072	1,683,614				
2015	25,836	35,840	165,692	811,169	1,295,581				
2016	38,055	51,597	226,736	1,087,174	1,730,689				
2018	87,405	114,530	461,505	2,130,361	3,372,161				
2019	59,635	73,425	247,376	1,035,568	1,614,499				
2021	63,971	78,711	264,534	1,105,657	1,723,324				

Table 3.

Table xx	Estimated percentiles for Escapement by year given observed catch and fall survey biomass								
	Entries are based on 64,000 combinations of catchability, availability and natural mortality rates.								
		Percentile							
Year	*1%*	*5%*	*50%*	*95%*	*99%*				
1997	0.562	0.631	0.842	0.948	0.965				
1998	0.682	0.741	0.899	0.968	0.979				
1999	0.427	0.499	0.757	0.914	0.941				
2000	0.745	0.796	0.924	0.977	0.985				
2001	0.680	0.739	0.898	0.968	0.979				
2002	0.841	0.876	0.956	0.987	0.991				
2003	0.917	0.936	0.979	0.994	0.996				
2004	0.362	0.432	0.704	0.890	0.924				
2005	0.641	0.705	0.881	0.962	0.975				
2006	0.859	0.890	0.962	0.989	0.993				
2007	0.834	0.870	0.954	0.986	0.991				
2008	0.677	0.737	0.897	0.968	0.979				
2009	0.645	0.708	0.883	0.963	0.975				
2010	0.548	0.618	0.834	0.945	0.963				
2011	0.505	0.577	0.809	0.935	0.957				
2012	0.614	0.680	0.869	0.958	0.972				
2013	0.748	0.798	0.925	0.977	0.985				
2014	0.720	0.774	0.914	0.973	0.982				
2015	0.866	0.896	0.964	0.989	0.993				
2016	0.779	0.825	0.936	0.981	0.987				
2018	0.653	0.715	0.886	0.964	0.976				
2019	0.441	0.514	0.767	0.918	0.944				
2021	0.439	0.511	0.765	0.917	0.944				

Table 4.

Table xx	Estimated percentiles for F/M ratio by year given observed catch and fall survey biomass								
	Entries are based on 64,000 combinations of catchability, availability and natural mortality rates.								
			Percentile						
Year	1%	5%	50%	95%	99%				
1997	0.012	0.019	0.101	1.035	1.854				
1998	0.007	0.011	0.063	0.668	1.217				
1999	0.020	0.032	0.163	1.584	2.778				
2000	0.005	0.008	0.047	0.506	0.927				
2001	0.007	0.011	0.063	0.672	1.223				
2002	0.003	0.005	0.026	0.291	0.540				
2003	0.001	0.002	0.013	0.145	0.270				
2004	0.026	0.041	0.205	1.932	3.345				
2005	0.008	0.013	0.074	0.782	1.417				
2006	0.002	0.004	0.023	0.256	0.475				
2007	0.003	0.005	0.028	0.306	0.567				
2008	0.007	0.012	0.064	0.680	1.238				
2009	0.008	0.013	0.073	0.771	1.398				
2010	0.012	0.020	0.106	1.085	1.939				
2011	0.015	0.023	0.124	1.244	2.208				
2012	0.009	0.015	0.083	0.863	1.557				
2013	0.005	0.008	0.046	0.499	0.915				
2014	0.006	0.009	0.053	0.569	1.039				
2015	0.002	0.004	0.022	0.242	0.450				
2016	0.004	0.007	0.039	0.426	0.783				
2018	0.008	0.013	0.071	0.750	1.360				
2019	0.019	0.030	0.155	1.516	2.666				
2021	0.019	0.030	0.157	1.528	2.685				

Table 5.

Table xx.	Estimated Escapement rates for the 50th percentile for alternative quotas (rows) by year based on assumed ranges of catchability, availability, and natural mortality. Table entries repesent percentiles for 64,000 realizations of the estimated escapement.											
Alternative Quota (mt)	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*
24,000	0.763	0.899	0.535	0.824	0.633	0.734	0.926	0.730	0.812	0.942	0.894	0.864
25,000	0.756	0.896	0.525	0.818	0.624	0.726	0.923	0.723	0.806	0.940	0.890	0.859
26,000	0.749	0.892	0.516	0.812	0.615	0.719	0.921	0.715	0.800	0.938	0.887	0.854
27,000	0.742	0.888	0.507	0.807	0.606	0.711	0.918	0.707	0.794	0.936	0.883	0.850
28,000	0.735	0.885	0.498	0.801	0.598	0.704	0.915	0.700	0.788	0.933	0.879	0.845
29,000	0.729	0.881	0.490	0.795	0.590	0.697	0.912	0.693	0.783	0.931	0.875	0.841
30,000	0.722	0.878	0.482	0.790	0.582	0.690	0.910	0.686	0.777	0.929	0.872	0.836
31,000	0.716	0.874	0.475	0.785	0.574	0.683	0.907	0.679	0.772	0.927	0.868	0.832
32,000	0.710	0.871	0.467	0.779	0.567	0.676	0.904	0.672	0.766	0.925	0.864	0.827
33,000	0.703	0.867	0.460	0.774	0.560	0.670	0.902	0.666	0.761	0.923	0.861	0.823
34,000	0.697	0.864	0.453	0.769	0.553	0.664	0.899	0.660	0.755	0.920	0.857	0.819
35,000	0.691	0.860	0.446	0.764	0.546	0.657	0.896	0.653	0.750	0.918	0.854	0.814
36,000	0.686	0.857	0.440	0.759	0.539	0.651	0.894	0.647	0.745	0.916	0.850	0.810
37,000	0.680	0.854	0.434	0.754	0.533	0.645	0.891	0.641	0.740	0.914	0.847	0.806
38,000	0.674	0.850	0.427	0.749	0.527	0.639	0.889	0.635	0.735	0.912	0.843	0.802
39,000	0.669	0.847	0.422	0.745	0.521	0.634	0.886	0.630	0.730	0.910	0.840	0.798
40,000	0.663	0.844	0.416	0.740	0.515	0.628	0.884	0.624	0.725	0.908	0.837	0.794
41,000	0.658	0.841	0.410	0.735	0.509	0.623	0.881	0.618	0.720	0.906	0.833	0.790
42,000	0.653	0.838	0.405	0.731	0.503	0.617	0.879	0.613	0.716	0.904	0.830	0.786
43,000	0.648	0.834	0.399	0.726	0.498	0.612	0.876	0.608	0.711	0.902	0.827	0.782
44,000	0.643	0.831	0.394	0.722	0.492	0.607	0.874	0.602	0.706	0.900	0.823	0.778
45,000	0.638	0.828	0.389	0.718	0.487	0.602	0.871	0.597	0.702	0.898	0.820	0.775
46,000	0.633	0.825	0.385	0.713	0.482	0.597	0.869	0.592	0.697	0.896	0.817	0.771
47,000	0.628	0.822	0.380	0.709	0.477	0.592	0.866	0.587	0.693	0.894	0.814	0.767
48,000	0.624	0.819	0.375	0.705	0.472	0.587	0.864	0.582	0.689	0.892	0.811	0.763
49,000	0.619	0.816	0.371	0.701	0.467	0.582	0.861	0.578	0.685	0.890	0.808	0.760
50,000	0.614	0.813	0.366	0.697	0.462	0.577	0.859	0.573	0.680	0.888	0.805	0.756
51,000	0.610	0.810	0.362	0.693	0.458	0.573	0.857	0.568	0.676	0.886	0.802	0.753
52,000	0.606	0.807	0.358	0.689	0.453	0.568	0.854	0.564	0.672	0.884	0.799	0.749
53,000	0.601	0.804	0.354	0.685	0.449	0.564	0.852	0.559	0.668	0.882	0.796	0.746
54,000	0.597	0.801	0.350	0.681	0.445	0.559	0.850	0.555	0.664	0.880	0.793	0.742
55,000	0.593	0.798	0.346	0.677	0.440	0.555	0.847	0.551	0.660	0.878	0.790	0.739
56,000	0.589	0.796	0.342	0.673	0.436	0.551	0.845	0.547	0.656	0.876	0.787	0.735
57,000	0.584	0.793	0.339	0.669	0.432	0.547	0.843	0.542	0.652	0.874	0.784	0.732
58,000	0.580	0.790	0.335	0.666	0.428	0.543	0.841	0.538	0.649	0.872	0.781	0.729
59,000	0.576	0.787	0.331	0.662	0.424	0.539	0.838	0.534	0.645	0.870	0.778	0.725
60,000	0.573	0.784	0.328	0.658	0.420	0.535	0.836	0.530	0.641	0.869	0.775	0.722

Table 5 (cont.)

Table xx. (cont)	Estimated Escapement rates for the 50th percentile for alternative quotas (rows) by year based on assumed ranges of catchability availability, and natural mortality. Table entries repesent percentiles for 64,000 realizations of the estimated escapement.

Alternative Quota (mt)	2009	2010	2011	2012	2013	2014	2015	2016	2018	2019	2021	Average
24,000	0.858	0.776	0.776	0.774	0.686	0.808	0.767	0.813	0.892	0.795	0.806	0.796
25,000	0.853	0.769	0.769	0.766	0.678	0.802	0.760	0.807	0.888	0.789	0.799	0.790
26,000	0.848	0.762	0.762	0.760	0.670	0.796	0.753	0.801	0.884	0.783	0.793	0.784
27,000	0.843	0.756	0.755	0.753	0.662	0.790	0.746	0.795	0.880	0.776	0.787	0.778
28,000	0.838	0.749	0.749	0.746	0.654	0.784	0.740	0.789	0.877	0.770	0.781	0.772
29,000	0.833	0.743	0.742	0.740	0.646	0.778	0.733	0.783	0.873	0.764	0.775	0.766
30,000	0.829	0.736	0.736	0.733	0.639	0.772	0.727	0.778	0.869	0.758	0.769	0.761
31,000	0.824	0.730	0.730	0.727	0.631	0.767	0.720	0.772	0.865	0.752	0.764	0.755
32,000	0.819	0.724	0.724	0.721	0.624	0.761	0.714	0.767	0.862	0.746	0.758	0.750
33,000	0.815	0.718	0.718	0.715	0.618	0.756	0.708	0.761	0.858	0.741	0.752	0.745
34,000	0.811	0.712	0.712	0.709	0.611	0.750	0.702	0.756	0.855	0.735	0.747	0.740
35,000	0.806	0.707	0.706	0.703	0.604	0.745	0.696	0.751	0.851	0.730	0.742	0.734
36,000	0.802	0.701	0.701	0.698	0.598	0.740	0.690	0.746	0.847	0.724	0.737	0.729
37,000	0.798	0.695	0.695	0.692	0.592	0.735	0.685	0.741	0.844	0.719	0.731	0.725
38,000	0.793	0.690	0.690	0.687	0.585	0.729	0.679	0.736	0.840	0.714	0.726	0.720
39,000	0.789	0.684	0.684	0.681	0.579	0.725	0.674	0.731	0.837	0.708	0.721	0.715
40,000	0.785	0.679	0.679	0.676	0.573	0.720	0.668	0.726	0.834	0.703	0.716	0.710
41,000	0.781	0.674	0.674	0.671	0.568	0.715	0.663	0.721	0.830	0.698	0.711	0.706
42,000	0.777	0.669	0.669	0.666	0.562	0.710	0.658	0.716	0.827	0.694	0.707	0.701
43,000	0.773	0.664	0.664	0.661	0.557	0.705	0.653	0.712	0.824	0.689	0.702	0.697
44,000	0.769	0.659	0.659	0.656	0.551	0.701	0.648	0.707	0.820	0.684	0.697	0.692
45,000	0.765	0.654	0.654	0.651	0.546	0.696	0.643	0.703	0.817	0.679	0.693	0.688
46,000	0.761	0.649	0.649	0.646	0.541	0.692	0.638	0.698	0.814	0.675	0.688	0.684
47,000	0.757	0.645	0.644	0.641	0.536	0.687	0.633	0.694	0.811	0.670	0.684	0.680
48,000	0.754	0.640	0.640	0.637	0.531	0.683	0.629	0.690	0.807	0.666	0.679	0.676
49,000	0.750	0.636	0.635	0.632	0.526	0.679	0.624	0.685	0.804	0.661	0.675	0.671
50,000	0.746	0.631	0.631	0.628	0.521	0.674	0.620	0.681	0.801	0.657	0.671	0.667
51,000	0.743	0.627	0.626	0.623	0.517	0.670	0.615	0.677	0.798	0.653	0.667	0.664
52,000	0.739	0.622	0.622	0.619	0.512	0.666	0.611	0.673	0.795	0.648	0.662	0.660
53,000	0.735	0.618	0.618	0.614	0.507	0.662	0.607	0.669	0.792	0.644	0.658	0.656
54,000	0.732	0.614	0.613	0.610	0.503	0.658	0.602	0.665	0.789	0.640	0.654	0.652
55,000	0.728	0.610	0.609	0.606	0.499	0.654	0.598	0.661	0.786	0.636	0.650	0.648
56,000	0.725	0.606	0.605	0.602	0.495	0.650	0.594	0.657	0.783	0.632	0.646	0.645
57,000	0.722	0.602	0.601	0.598	0.490	0.646	0.590	0.653	0.780	0.628	0.642	0.641
58,000	0.718	0.598	0.597	0.594	0.486	0.642	0.586	0.650	0.777	0.624	0.639	0.637
59,000	0.715	0.594	0.593	0.590	0.482	0.639	0.582	0.646	0.774	0.621	0.635	0.634
60,000	0.711	0.590	0.589	0.586	0.478	0.635	0.578	0.642	0.771	0.617	0.631	0.631

Table 6.

Table yy.	Estimated F/M ratios for the 50th percentile for alternative quotas (rows) by year based on assumed ranges of catchability, availablity and natural mortality. Table entries repesent percentiles for 64,000 realizations of the estimated F/M ratio.											
Alternative Quota (mt)	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
24,000	0.158	0.062	0.363	0.114	0.267	0.181	0.045	0.184	0.122	0.035	0.066	0.086
25,000	0.164	0.065	0.374	0.118	0.275	0.187	0.047	0.190	0.126	0.036	0.068	0.089
26,000	0.169	0.067	0.384	0.122	0.283	0.193	0.049	0.196	0.131	0.038	0.071	0.092
27,000	0.174	0.070	0.394	0.126	0.291	0.199	0.050	0.202	0.135	0.039	0.073	0.096
28,000	0.180	0.072	0.404	0.130	0.299	0.205	0.052	0.208	0.139	0.041	0.076	0.099
29,000	0.185	0.074	0.413	0.134	0.307	0.211	0.054	0.214	0.143	0.042	0.078	0.102
30,000	0.190	0.077	0.423	0.138	0.315	0.217	0.056	0.220	0.148	0.043	0.081	0.105
31,000	0.195	0.079	0.432	0.142	0.322	0.222	0.057	0.226	0.152	0.045	0.083	0.108
32,000	0.200	0.081	0.441	0.146	0.330	0.228	0.059	0.231	0.156	0.046	0.086	0.111
33,000	0.205	0.084	0.450	0.150	0.337	0.234	0.061	0.237	0.160	0.047	0.088	0.114
34,000	0.210	0.086	0.459	0.154	0.344	0.239	0.063	0.242	0.164	0.049	0.090	0.117
35,000	0.215	0.088	0.467	0.157	0.351	0.244	0.064	0.248	0.168	0.050	0.093	0.120
36,000	0.220	0.091	0.475	0.161	0.358	0.250	0.066	0.253	0.172	0.052	0.095	0.123
37,000	0.225	0.093	0.484	0.165	0.365	0.255	0.068	0.259	0.176	0.053	0.098	0.126
38,000	0.230	0.095	0.492	0.169	0.372	0.260	0.069	0.264	0.180	0.054	0.100	0.129
39,000	0.235	0.097	0.500	0.172	0.379	0.266	0.071	0.270	0.184	0.056	0.102	0.132
40,000	0.239	0.100	0.508	0.176	0.385	0.271	0.073	0.275	0.188	0.057	0.105	0.135
41,000	0.244	0.102	0.515	0.180	0.392	0.276	0.074	0.280	0.192	0.058	0.107	0.138
42,000	0.248	0.104	0.523	0.183	0.398	0.281	0.076	0.285	0.195	0.060	0.109	0.141
43,000	0.253	0.106	0.530	0.187	0.405	0.286	0.078	0.290	0.199	0.061	0.112	0.144
44,000	0.257	0.108	0.538	0.190	0.411	0.291	0.079	0.295	0.203	0.062	0.114	0.147
45,000	0.262	0.111	0.545	0.194	0.417	0.296	0.081	0.300	0.207	0.064	0.116	0.150
46,000	0.266	0.113	0.552	0.197	0.423	0.301	0.083	0.305	0.210	0.065	0.118	0.152
47,000	0.271	0.115	0.559	0.201	0.429	0.305	0.084	0.310	0.214	0.066	0.121	0.155
48,000	0.275	0.117	0.566	0.204	0.435	0.310	0.086	0.314	0.218	0.067	0.123	0.158
49,000	0.279	0.119	0.573	0.208	0.441	0.315	0.088	0.319	0.221	0.069	0.125	0.161
50,000	0.284	0.121	0.580	0.211	0.447	0.319	0.089	0.324	0.225	0.070	0.127	0.164
51,000	0.288	0.124	0.587	0.214	0.453	0.324	0.091	0.328	0.228	0.071	0.130	0.166
52,000	0.292	0.126	0.593	0.218	0.458	0.329	0.092	0.333	0.232	0.073	0.132	0.169
53,000	0.296	0.128	0.600	0.221	0.464	0.333	0.094	0.337	0.235	0.074	0.134	0.172
54,000	0.300	0.130	0.606	0.224	0.469	0.337	0.096	0.342	0.239	0.075	0.136	0.174
55,000	0.304	0.132	0.612	0.228	0.475	0.342	0.097	0.347	0.242	0.076	0.138	0.177
56,000	0.308	0.134	0.619	0.231	0.480	0.346	0.099	0.351	0.245	0.078	0.140	0.180
57,000	0.312	0.136	0.625	0.234	0.486	0.351	0.100	0.355	0.249	0.079	0.143	0.182
58,000	0.316	0.138	0.631	0.237	0.491	0.355	0.102	0.360	0.252	0.080	0.145	0.185
59,000	0.320	0.140	0.637	0.240	0.496	0.359	0.104	0.364	0.256	0.082	0.147	0.188
60,000	0.324	0.142	0.643	0.244	0.502	0.363	0.105	0.368	0.259	0.083	0.149	0.190

Table 6 (cont.)

| Table yy. (cont.) Estimated F/M ratios for the 50th percentile for alternative quotas (rows) by year based on assumed ranges of catchability, availablity and natural mortality. Table entries repesent percentiles for 64,000 realizations of the estimated F/M ratio. |

Alternative Quota (mt)	2009	2010	2011	2012	2013	2014	2015	2016	2018	2019	2021	Average
24,000	0.090	0.148	0.148	0.150	0.220	0.125	0.155	0.121	0.067	0.134	0.127	0.138
25,000	0.094	0.154	0.154	0.156	0.227	0.129	0.160	0.126	0.070	0.139	0.131	0.143
26,000	0.097	0.159	0.159	0.161	0.234	0.134	0.166	0.130	0.072	0.144	0.136	0.147
27,000	0.100	0.164	0.164	0.166	0.241	0.138	0.171	0.134	0.075	0.148	0.140	0.152
28,000	0.104	0.169	0.169	0.171	0.248	0.143	0.176	0.139	0.077	0.153	0.145	0.156
29,000	0.107	0.174	0.174	0.176	0.254	0.147	0.181	0.143	0.080	0.158	0.149	0.161
30,000	0.110	0.179	0.179	0.181	0.261	0.151	0.187	0.147	0.082	0.162	0.153	0.165
31,000	0.114	0.184	0.184	0.186	0.268	0.156	0.192	0.151	0.085	0.167	0.158	0.170
32,000	0.117	0.189	0.189	0.191	0.274	0.160	0.197	0.155	0.087	0.171	0.162	0.174
33,000	0.120	0.193	0.194	0.196	0.281	0.164	0.202	0.160	0.090	0.176	0.166	0.179
34,000	0.123	0.198	0.198	0.201	0.287	0.168	0.206	0.164	0.092	0.180	0.171	0.183
35,000	0.126	0.203	0.203	0.205	0.293	0.172	0.211	0.168	0.095	0.184	0.175	0.187
36,000	0.129	0.207	0.208	0.210	0.299	0.176	0.216	0.172	0.097	0.189	0.179	0.191
37,000	0.133	0.212	0.212	0.215	0.306	0.180	0.221	0.176	0.100	0.193	0.183	0.195
38,000	0.136	0.217	0.217	0.219	0.312	0.184	0.226	0.179	0.102	0.197	0.187	0.200
39,000	0.139	0.221	0.221	0.224	0.317	0.188	0.230	0.183	0.104	0.201	0.191	0.204
40,000	0.142	0.226	0.226	0.229	0.323	0.192	0.235	0.187	0.107	0.205	0.195	0.208
41,000	0.145	0.230	0.230	0.233	0.329	0.196	0.239	0.191	0.109	0.209	0.199	0.212
42,000	0.148	0.234	0.235	0.237	0.335	0.200	0.244	0.195	0.112	0.214	0.203	0.216
43,000	0.151	0.239	0.239	0.242	0.340	0.204	0.248	0.199	0.114	0.218	0.207	0.220
44,000	0.154	0.243	0.243	0.246	0.346	0.208	0.253	0.202	0.116	0.222	0.210	0.223
45,000	0.157	0.247	0.248	0.250	0.351	0.211	0.257	0.206	0.119	0.226	0.214	0.227
46,000	0.160	0.252	0.252	0.255	0.357	0.215	0.262	0.210	0.121	0.230	0.218	0.231
47,000	0.163	0.256	0.256	0.259	0.362	0.219	0.266	0.213	0.123	0.233	0.222	0.235
48,000	0.165	0.260	0.260	0.263	0.368	0.223	0.270	0.217	0.125	0.237	0.226	0.239
49,000	0.168	0.264	0.264	0.267	0.373	0.226	0.274	0.220	0.128	0.241	0.229	0.242
50,000	0.171	0.268	0.268	0.271	0.378	0.230	0.279	0.224	0.130	0.245	0.233	0.246
51,000	0.174	0.272	0.272	0.275	0.383	0.233	0.283	0.228	0.132	0.249	0.237	0.250
52,000	0.177	0.276	0.276	0.280	0.388	0.237	0.287	0.231	0.134	0.252	0.240	0.253
53,000	0.180	0.280	0.280	0.284	0.393	0.240	0.291	0.235	0.137	0.256	0.244	0.257
54,000	0.182	0.284	0.284	0.287	0.398	0.244	0.295	0.238	0.139	0.260	0.247	0.260
55,000	0.185	0.288	0.288	0.291	0.403	0.247	0.299	0.241	0.141	0.264	0.251	0.264
56,000	0.188	0.292	0.292	0.295	0.408	0.251	0.303	0.245	0.143	0.267	0.254	0.267
57,000	0.191	0.296	0.296	0.299	0.413	0.254	0.307	0.248	0.145	0.271	0.258	0.271
58,000	0.193	0.300	0.300	0.303	0.418	0.258	0.311	0.251	0.148	0.274	0.261	0.274
59,000	0.196	0.303	0.304	0.307	0.423	0.261	0.315	0.255	0.150	0.278	0.265	0.278
60,000	0.199	0.307	0.308	0.311	0.427	0.265	0.319	0.258	0.152	0.281	0.268	0.281

Table 7.

Table bb.	Estimated probabilities of falling below Escapement thresholds based on observed catches.								
		Escapement Threshold							
Year	*0.35*	*0.4*	*0.5*	*0.6*	*0.75*				
1997	0.000	0.000	0.000	0.027	0.231				
1998	0.000	0.000	0.000	0.000	0.061				
1999	0.000	0.004	0.051	0.170	0.482				
2000	0.000	0.000	0.000	0.000	0.012				
2001	0.000	0.000	0.000	0.000	0.063				
2002	0.000	0.000	0.000	0.000	0.000				
2003	0.000	0.000	0.000	0.000	0.000				
2004	0.007	0.028	0.123	0.280	0.617				
2005	0.000	0.000	0.000	0.002	0.110				
2006	0.000	0.000	0.000	0.000	0.000				
2007	0.000	0.000	0.000	0.000	0.000				
2008	0.000	0.000	0.000	0.000	0.066				
2009	0.000	0.000	0.000	0.001	0.105				
2010	0.000	0.000	0.001	0.036	0.255				
2011	0.000	0.000	0.009	0.072	0.332				
2012	0.000	0.000	0.000	0.006	0.148				
2013	0.000	0.000	0.000	0.000	0.011				
2014	0.000	0.000	0.000	0.000	0.027				
2015	0.000	0.000	0.000	0.000	0.000				
2016	0.000	0.000	0.000	0.000	0.002				
2018	0.000	0.000	0.000	0.001	0.095				
2019	0.000	0.002	0.040	0.149	0.454				
2021	0.000	0.002	0.041	0.153	0.459				

Table 8.

Table aa.	Estimated probabilities of exceeding F/M thresholds based on observed catches.								
			F/M Threshold						
Year	**0.33**	**0.5**	**0.666**	**1**	**1.5**				
1997	0.216	0.143	0.101	0.053	0.021				
1998	0.138	0.081	0.050	0.020	0.003				
1999	0.314	0.223	0.168	0.105	0.056				
2000	0.097	0.051	0.028	0.007	0.000				
2001	0.139	0.081	0.051	0.020	0.004				
2002	0.039	0.013	0.004	0.000	0.000				
2003	0.004	0.000	0.000	0.000	0.000				
2004	0.369	0.268	0.207	0.135	0.078				
2005	0.163	0.101	0.066	0.030	0.008				
2006	0.030	0.008	0.002	0.000	0.000				
2007	0.043	0.016	0.005	0.000	0.000				
2008	0.141	0.083	0.052	0.021	0.004				
2009	0.161	0.099	0.065	0.029	0.007				
2010	0.226	0.150	0.107	0.058	0.024				
2011	0.256	0.175	0.128	0.073	0.034				
2012	0.181	0.115	0.078	0.037	0.012				
2013	0.096	0.050	0.027	0.007	0.000				
2014	0.113	0.063	0.036	0.012	0.001				
2015	0.026	0.006	0.001	0.000	0.000				
2016	0.077	0.036	0.018	0.003	0.000				
2018	0.156	0.095	0.062	0.027	0.006				
2019	0.303	0.213	0.161	0.099	0.051				
2021	0.305	0.215	0.162	0.100	0.052				

Table 9.

Table cc.	Estimated joint probabilities of falling below Escapement thresholds AND						
	and exceeding F/M=0.666 based on Observed catches.						
	Escapement Threshold						
Year	0.35	0.4	0.5	0.6	0.75		
1997	0.000	0.000	0.000	0.020	0.051		
1998	0.000	0.000	0.000	0.000	0.016		
1999	0.000	0.004	0.043	0.084	0.104		
2000	0.000	0.000	0.000	0.000	0.004		
2001	0.000	0.000	0.000	0.000	0.017		
2002	0.000	0.000	0.000	0.000	0.000		
2003	0.000	0.000	0.000	0.000	0.000		
2004	0.007	0.027	0.088	0.122	0.135		
2005	0.000	0.000	0.000	0.002	0.027		
2006	0.000	0.000	0.000	0.000	0.000		
2007	0.000	0.000	0.000	0.000	0.000		
2008	0.000	0.000	0.000	0.000	0.017		
2009	0.000	0.000	0.000	0.001	0.026		
2010	0.000	0.000	0.001	0.025	0.056		
2011	0.000	0.000	0.009	0.044	0.072		
2012	0.000	0.000	0.000	0.006	0.035		
2013	0.000	0.000	0.000	0.000	0.004		
2014	0.000	0.000	0.000	0.000	0.008		
2015	0.000	0.000	0.000	0.000	0.000		
2016	0.000	0.000	0.000	0.000	0.001		
2018	0.000	0.000	0.000	0.001	0.024		
2019	0.000	0.002	0.035	0.076	0.098		
2021	0.000	0.002	0.036	0.078	0.099		

Table 10.

Table pp.	Estimated probabilities of falling below Escapement thresholds based on							
	alternative Quota values. Probabilities are averaged across all years							
Alternative Quota	Escapement Threshold							
	0.35	0.4	0.5	0.6	0.75			
24000	0.0097	0.0180	0.0530	0.1295	0.3551			
25000	0.0109	0.0201	0.0585	0.1394	0.3707			
26000	0.0122	0.0223	0.0641	0.1493	0.3858			
27000	0.0136	0.0246	0.0699	0.1591	0.4005			
28000	0.0150	0.0271	0.0758	0.1690	0.4148			
29000	0.0165	0.0297	0.0818	0.1787	0.4287			
30000	0.0181	0.0324	0.0880	0.1884	0.4422			
31000	0.0197	0.0353	0.0942	0.1980	0.4552			
32000	0.0215	0.0382	0.1005	0.2076	0.4680			
33000	0.0233	0.0413	0.1068	0.2170	0.4803			
34000	0.0252	0.0446	0.1132	0.2263	0.4923			
35000	0.0272	0.0479	0.1197	0.2356	0.5040			
36000	0.0293	0.0513	0.1261	0.2447	0.5153			
37000	0.0314	0.0547	0.1326	0.2537	0.5263			
38000	0.0337	0.0583	0.1390	0.2627	0.5370			
39000	0.0360	0.0620	0.1455	0.2715	0.5474			
40000	0.0384	0.0657	0.1519	0.2802	0.5575			
41000	0.0409	0.0695	0.1583	0.2888	0.5674			
42000	0.0434	0.0733	0.1648	0.2972	0.5769			
43000	0.0460	0.0772	0.1711	0.3056	0.5862			
44000	0.0487	0.0812	0.1775	0.3138	0.5952			
45000	0.0514	0.0852	0.1838	0.3220	0.6040			
46000	0.0542	0.0892	0.1901	0.3300	0.6125			
47000	0.0571	0.0932	0.1963	0.3379	0.6208			
48000	0.0600	0.0973	0.2026	0.3457	0.6289			
49000	0.0629	0.1014	0.2088	0.3534	0.6367			
50000	0.0659	0.1056	0.2149	0.3610	0.6444			
51000	0.0689	0.1097	0.2210	0.3684	0.6518			
52000	0.0720	0.1139	0.2271	0.3758	0.6590			
53000	0.0750	0.1181	0.2331	0.3832	0.6659			
54000	0.0781	0.1223	0.2391	0.3903	0.6728			
55000	0.0813	0.1264	0.2450	0.3974	0.6794			
56000	0.0845	0.1306	0.2508	0.4043	0.6858			
57000	0.0877	0.1348	0.2567	0.4112	0.6922			
58000	0.0909	0.1390	0.2625	0.4180	0.6983			
59000	0.0942	0.1432	0.2682	0.4246	0.7042			
60000	0.0974	0.1474	0.2739	0.4313	0.7100			

Table 11

Table rr.	Estimated probabilities of exceeding F/M ratio thresholds						
	based on alternative Quota values. Probabilities are averaged across all year						
Alternative	**F/M Threshold**						
Quota (mt)	**0.33**	**0.5**	**0.666**	**1**	**1.5**		
24000	0.2620	0.1814	0.1346	0.0810	0.0420		
25000	0.2690	0.1871	0.1394	0.0845	0.0444		
26000	0.2759	0.1927	0.1441	0.0880	0.0467		
27000	0.2825	0.1981	0.1487	0.0914	0.0491		
28000	0.2890	0.2034	0.1532	0.0948	0.0513		
29000	0.2953	0.2086	0.1576	0.0980	0.0536		
30000	0.3014	0.2136	0.1618	0.1013	0.0558		
31000	0.3074	0.2186	0.1660	0.1044	0.0580		
32000	0.3133	0.2233	0.1701	0.1075	0.0602		
33000	0.3190	0.2280	0.1741	0.1106	0.0624		
34000	0.3245	0.2326	0.1780	0.1136	0.0645		
35000	0.3300	0.2371	0.1819	0.1165	0.0666		
36000	0.3353	0.2415	0.1856	0.1194	0.0687		
37000	0.3405	0.2459	0.1893	0.1222	0.0707		
38000	0.3456	0.2501	0.1930	0.1250	0.0727		
39000	0.3506	0.2542	0.1965	0.1278	0.0747		
40000	0.3555	0.2583	0.2000	0.1305	0.0766		
41000	0.3602	0.2623	0.2034	0.1331	0.0786		
42000	0.3649	0.2662	0.2068	0.1357	0.0805		
43000	0.3695	0.2700	0.2101	0.1383	0.0823		
44000	0.3740	0.2738	0.2133	0.1408	0.0842		
45000	0.3785	0.2775	0.2165	0.1433	0.0860		
46000	0.3828	0.2811	0.2197	0.1458	0.0878		
47000	0.3871	0.2847	0.2227	0.1482	0.0896		
48000	0.3913	0.2882	0.2258	0.1506	0.0913		
49000	0.3954	0.2917	0.2288	0.1529	0.0931		
50000	0.3995	0.2951	0.2317	0.1552	0.0948		
51000	0.4034	0.2985	0.2347	0.1575	0.0965		
52000	0.4074	0.3018	0.2375	0.1597	0.0982		
53000	0.4112	0.3050	0.2403	0.1619	0.0998		
54000	0.4150	0.3082	0.2431	0.1641	0.1014		
55000	0.4188	0.3114	0.2458	0.1663	0.1030		
56000	0.4224	0.3145	0.2485	0.1684	0.1046		
57000	0.4261	0.3175	0.2512	0.1705	0.1062		
58000	0.4296	0.3205	0.2538	0.1726	0.1078		
59000	0.4332	0.3235	0.2564	0.1746	0.1093		
60000	0.4366	0.3265	0.2589	0.1766	0.1108		

Table 12

Table qq.	Estimated JOINT probabilities of falling below Escapement thresholds AND F/M>0.666							
	based on alternative Quota values. Probabilities are averaged across all years							
Alternative	*Escapement Threshold*							
Quota (mt)	*0.35*	*0.4*	*0.5*	*0.6*	*0.75*			
24000	0.0089	0.0147	0.0350	0.0601	0.0796			
25000	0.0099	0.0163	0.0384	0.0640	0.0832			
26000	0.0110	0.0180	0.0419	0.0678	0.0867			
27000	0.0121	0.0198	0.0454	0.0716	0.0902			
28000	0.0133	0.0217	0.0490	0.0753	0.0936			
29000	0.0145	0.0237	0.0525	0.0790	0.0970			
30000	0.0158	0.0258	0.0561	0.0826	0.1002			
31000	0.0172	0.0281	0.0596	0.0861	0.1034			
32000	0.0186	0.0304	0.0632	0.0896	0.1066			
33000	0.0201	0.0327	0.0667	0.0930	0.1097			
34000	0.0217	0.0352	0.0701	0.0964	0.1127			
35000	0.0234	0.0378	0.0736	0.0997	0.1157			
36000	0.0251	0.0404	0.0770	0.1030	0.1186			
37000	0.0268	0.0430	0.0804	0.1062	0.1214			
38000	0.0287	0.0457	0.0837	0.1093	0.1243			
39000	0.0306	0.0485	0.0869	0.1124	0.1270			
40000	0.0326	0.0513	0.0902	0.1155	0.1298			
41000	0.0346	0.0541	0.0934	0.1185	0.1324			
42000	0.0367	0.0569	0.0965	0.1214	0.1351			
43000	0.0388	0.0598	0.0996	0.1244	0.1377			
44000	0.0410	0.0626	0.1027	0.1272	0.1402			
45000	0.0433	0.0655	0.1058	0.1301	0.1428			
46000	0.0456	0.0684	0.1088	0.1328	0.1452			
47000	0.0479	0.0712	0.1117	0.1355	0.1477			
48000	0.0502	0.0741	0.1146	0.1383	0.1500			
49000	0.0526	0.0770	0.1175	0.1409	0.1524			
50000	0.0550	0.0798	0.1203	0.1435	0.1547			
51000	0.0574	0.0827	0.1232	0.1461	0.1570			
52000	0.0599	0.0855	0.1259	0.1486	0.1593			
53000	0.0623	0.0883	0.1286	0.1511	0.1615			
54000	0.0648	0.0911	0.1314	0.1535	0.1637			
55000	0.0673	0.0938	0.1340	0.1560	0.1659			
56000	0.0698	0.0966	0.1366	0.1584	0.1680			
57000	0.0723	0.0993	0.1392	0.1607	0.1701			
58000	0.0748	0.1020	0.1418	0.1630	0.1722			
59000	0.0773	0.1046	0.1443	0.1653	0.1743			
60000	0.0798	0.1073	0.1468	0.1675	0.1763			

Biomass estimates for fall 2021 surve

Empirical PDF for Biomass (mt) for 2021
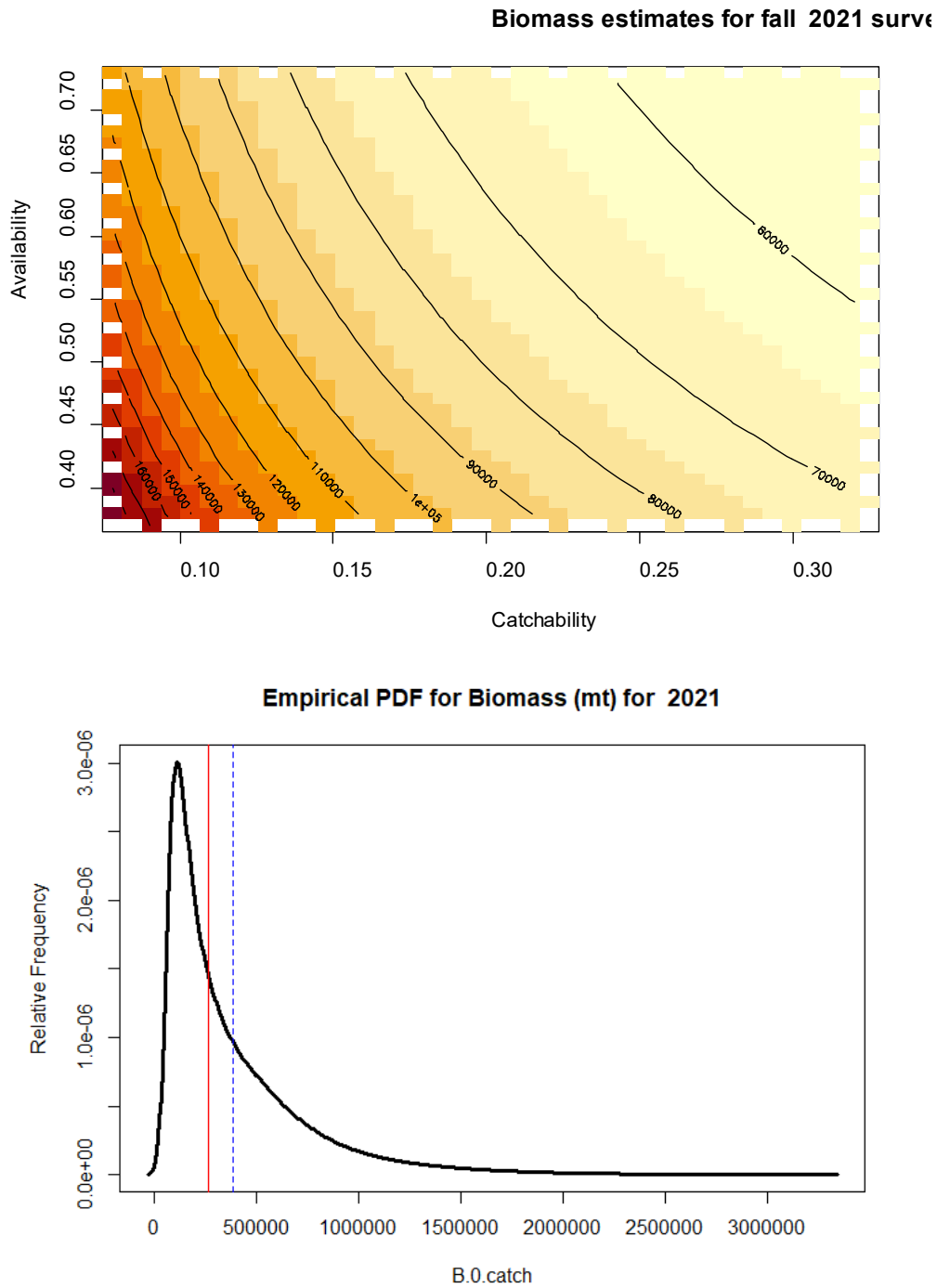
Figure 1. Isopleths of Illex biomass (mt) estimates for combinations of q and v for 2021 (top) and marginal distribution of biomass estimates over all combinations of q, v, and M (bottom). Solid red line is median; dashed blue line is mean.

Feasible F estimates for fall 2021 survey with Constraints

Empirical PDF for Fishing Mortality (per week) for 2021
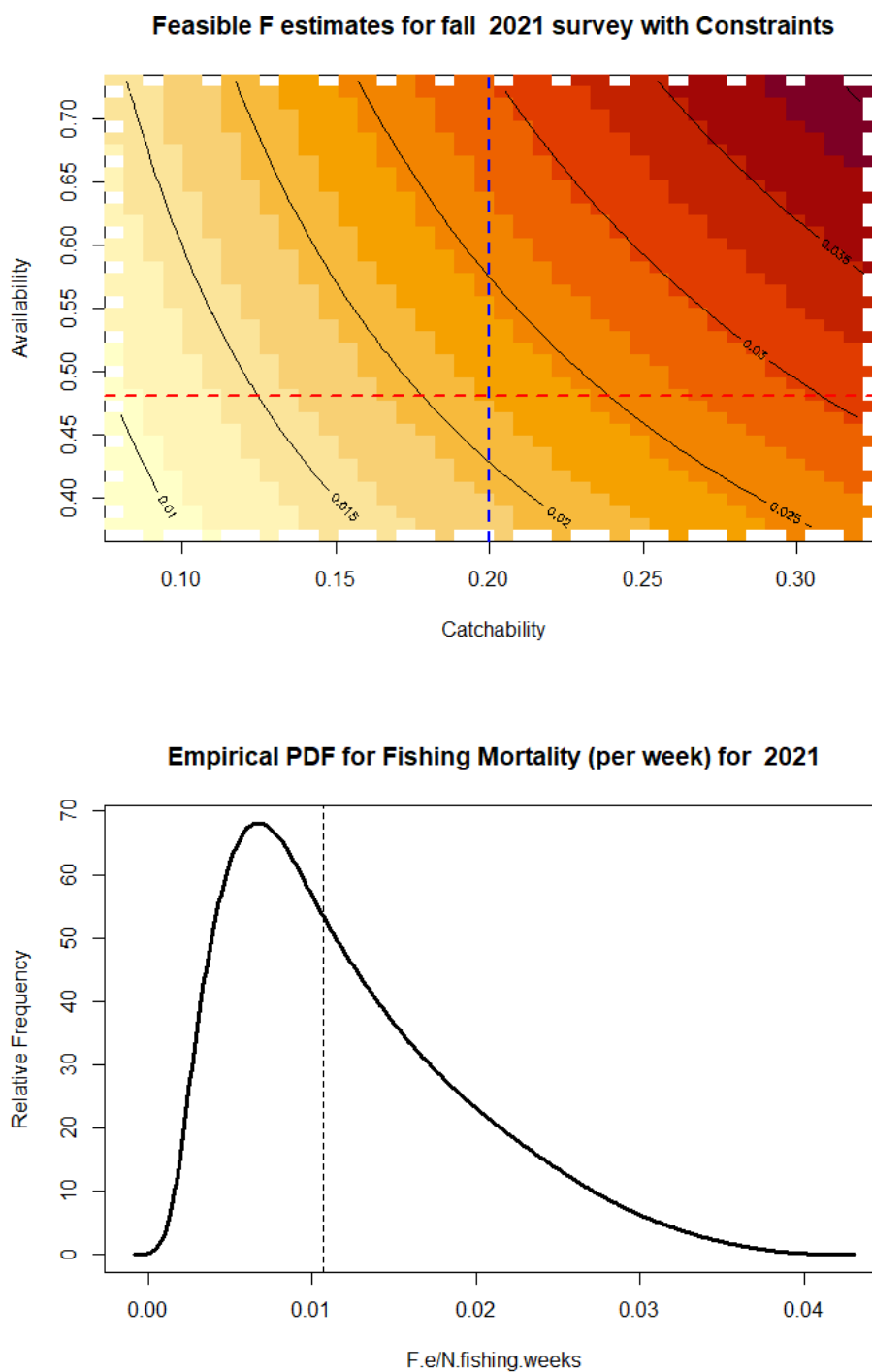
Figure 2. Isopleths of Illex fishing mortality estimates (per week) for various combinations of q and v for 2021 (top) and derived distribution of fishing mortality rates (per week) for 2021. The dashed black line represents the median value.

Feasible Escapement estimates for fa

Empirical PDF for Escapement for 2021
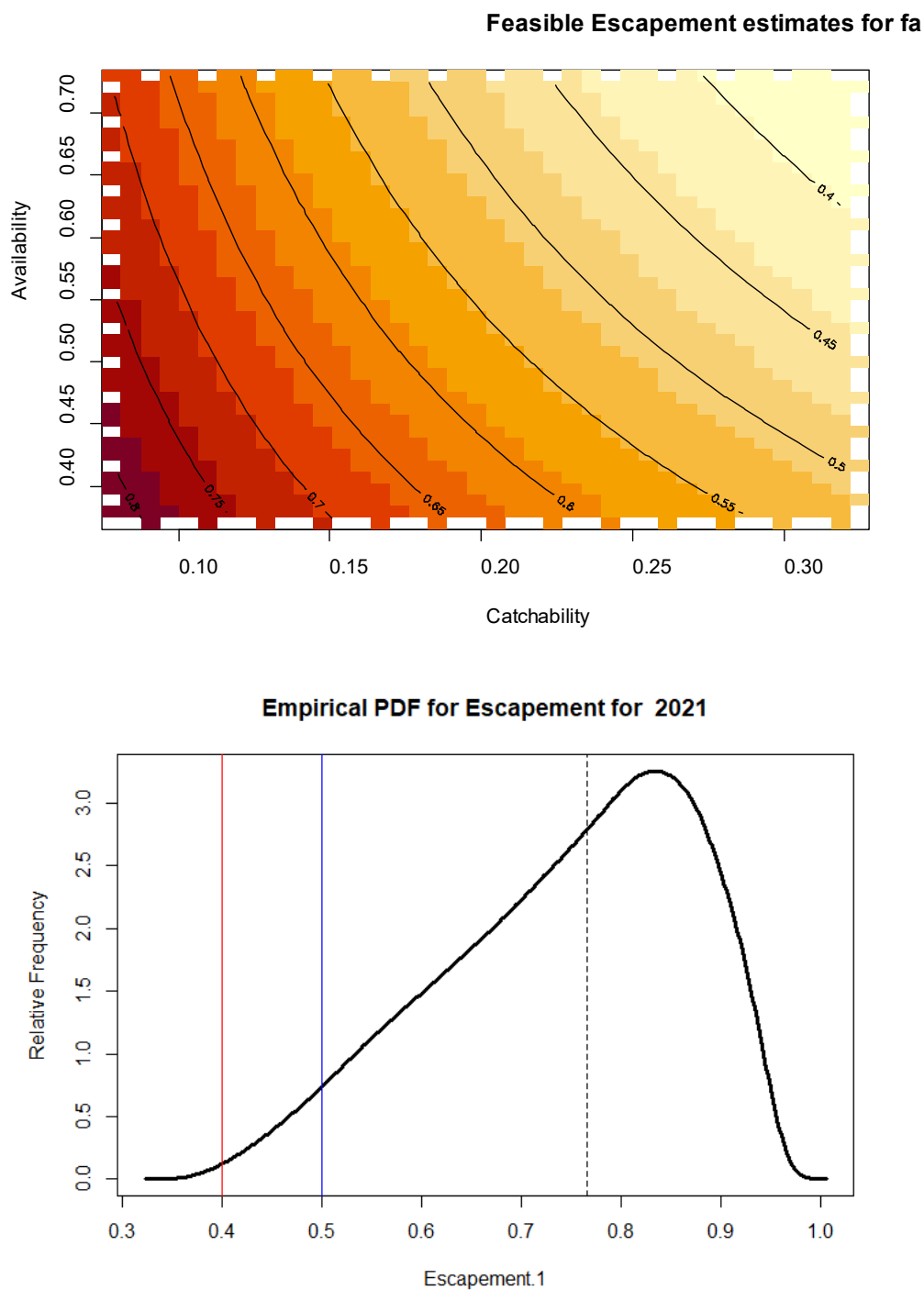
Figure 3. Isopleths of escapement as a function of cathability and availability (top) and empirical distribution of Escapement based on observed landings in 2021 and observed NEFSC fall bottom trawl indices (bottom). The dashed black line=median. Red and blue vertical lines represent escapement levels of 40 and 50%, respectively.
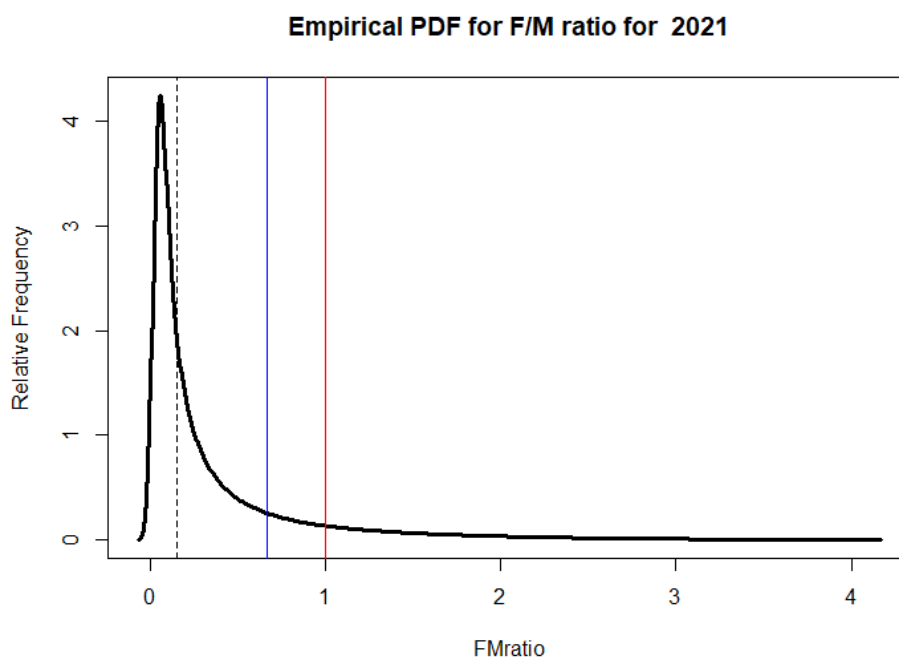
Figure 4. Empirical distribution of F/M ratio for 2021. Dashed line = median. Blue and red lines are for F= 2/3 M and F=M, respectively.
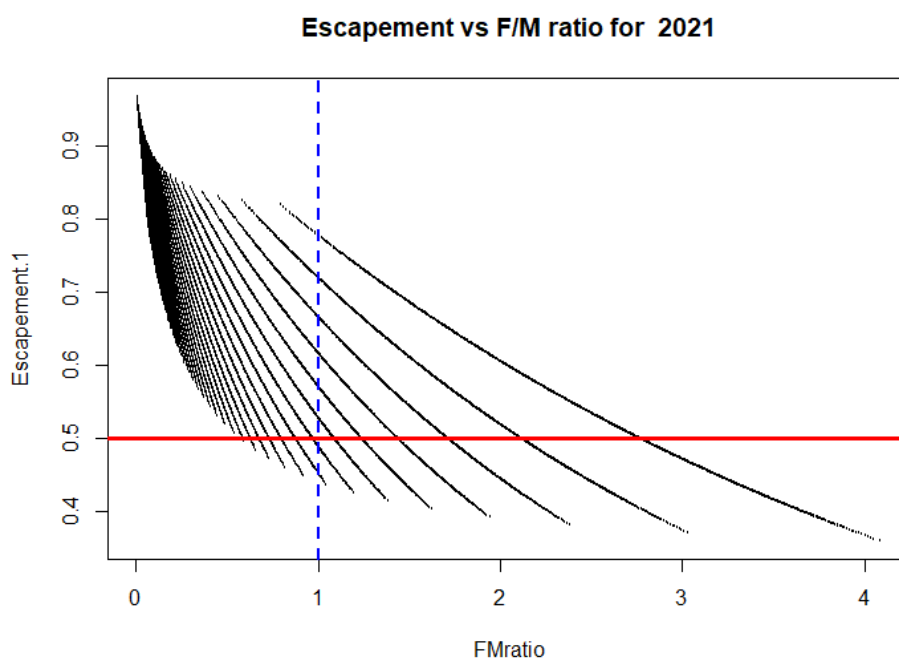
Figure 5. Relationship between Escapememt and estimated fishing mortality/assumed M over all 64,000 combinations of q, v, and M for 2021. The bands represent isopleths for assumed levels M. Low M (0.01 week^{-1}) on right and high M (0.13 week^{-1}) on left. .
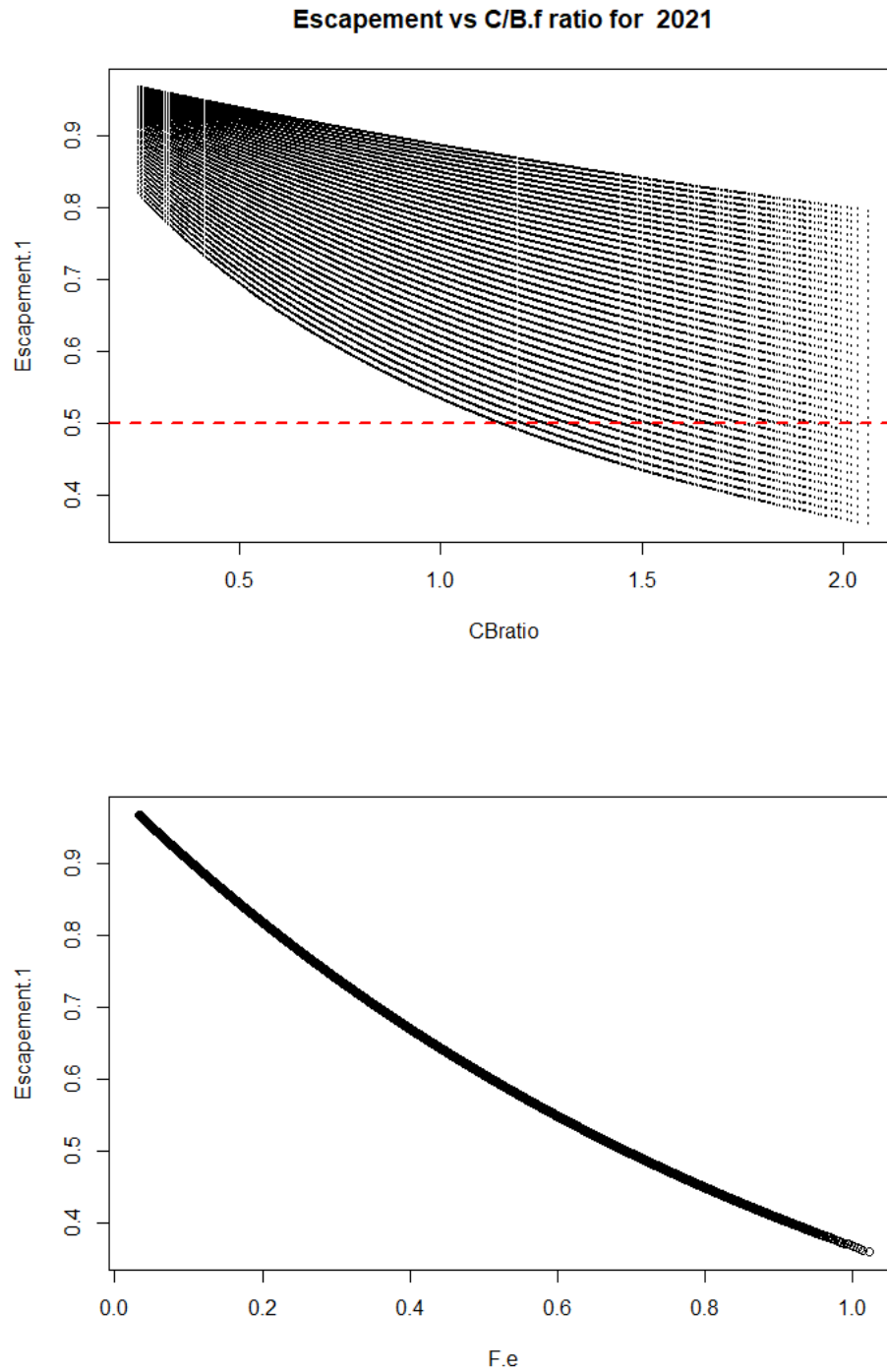
Figure 6. Relationship between Escapement and measures of exploitation for 2021. Catch divided by end of year biomass (i.e.. Fall survey) [top] . The trajectories correspond to assumed levels of M. Bottom panel depicts relationship between escapement and fishing mortality (see Eq. 9).
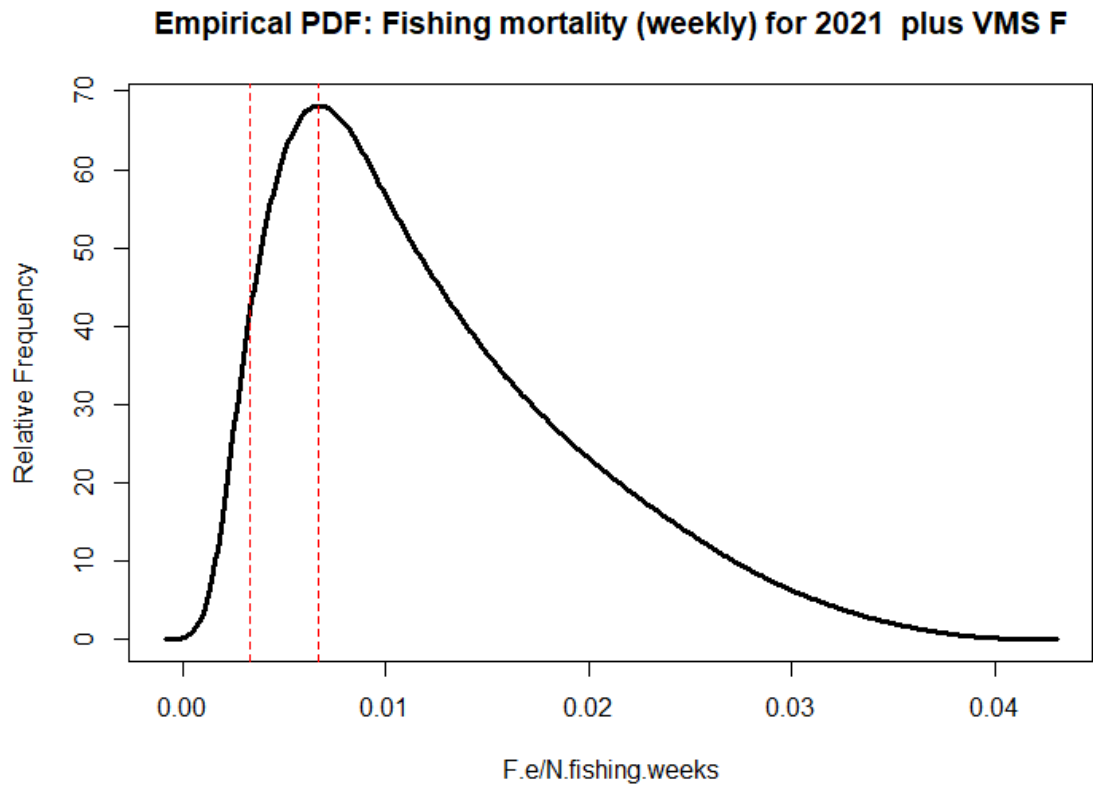
Figure 7. Empirical probability density function for F (week^{-1}) estimates based on assumed ranges of q, v and M for 2021. Red vertical lines depict range of F derived from VMS analyses for 2019. Weekly F range =[0.082/25, 0.167/25]
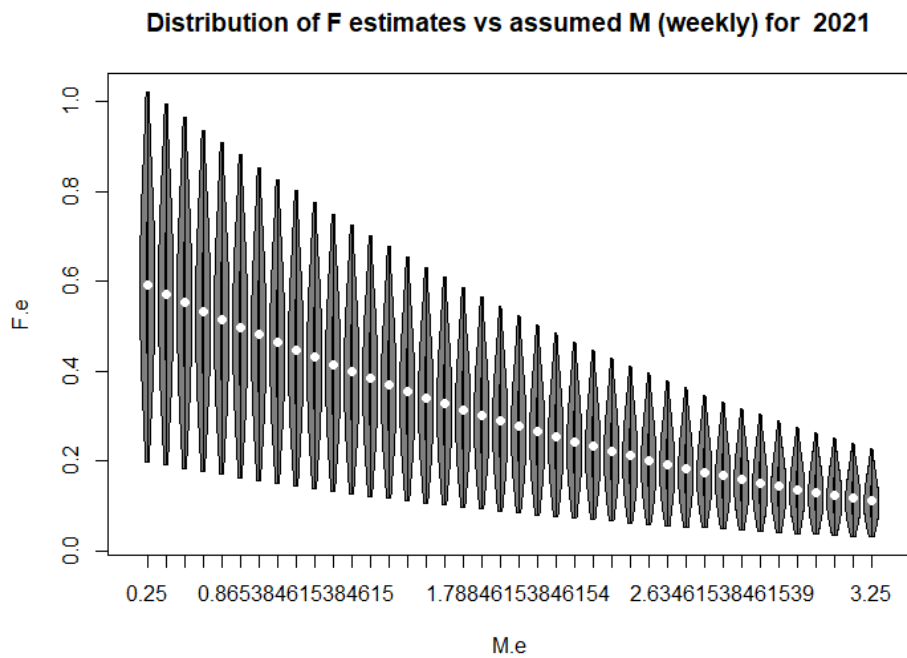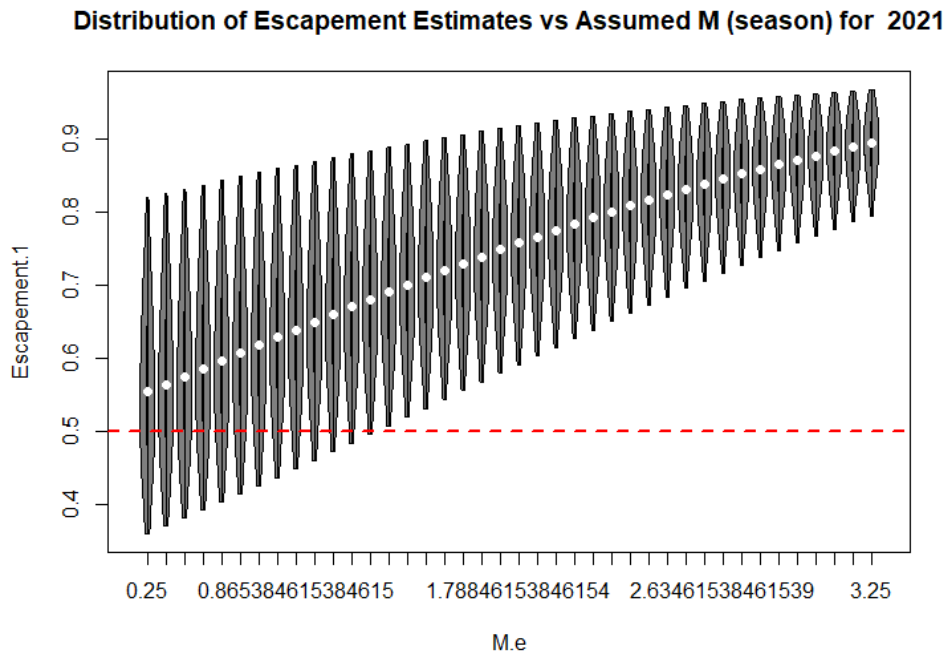
Figure 8. Relationship between estimated escapement and assumed M (per 25 week season) for 2021 [top]. Relationship between estimated F and assumed M (per season of 25 weeks) [bottom]. Variation in F.e is induced by range of q and v estimates.
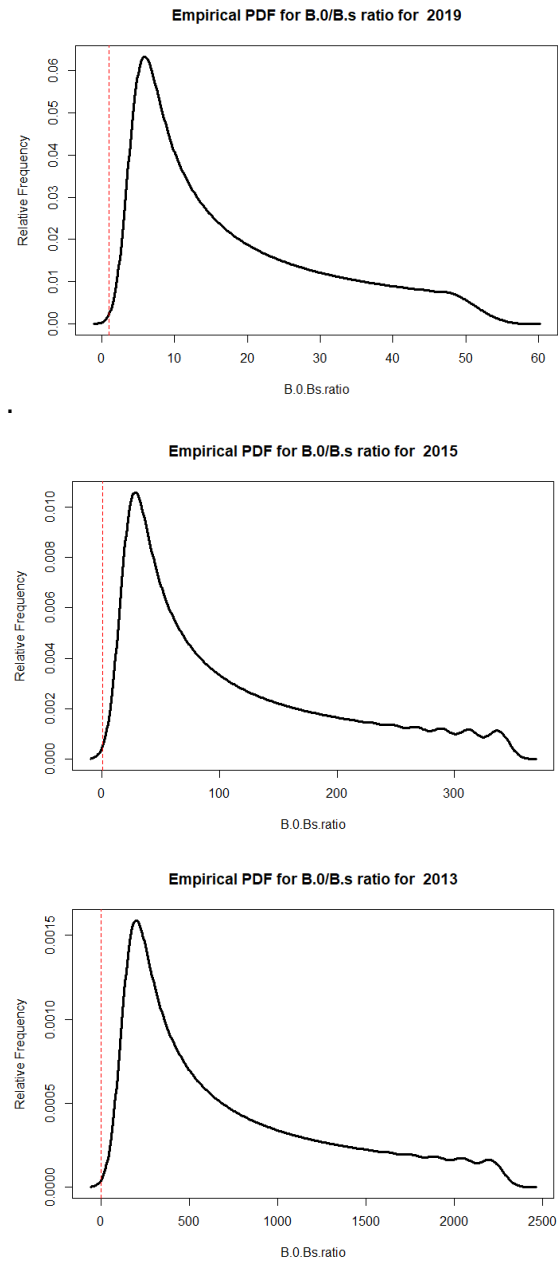
Figure 9. Distribution of ratio of estimated biomass necessary to support the observed landings in the fishery (B.0) to the initial biomass defined by the spring survey (B.s). Three examples (2019, 2015, 2013) illustrate the orders of magnitude range of differences among years.

B.0.catch Percentiles

log B.0.catch Percentiles
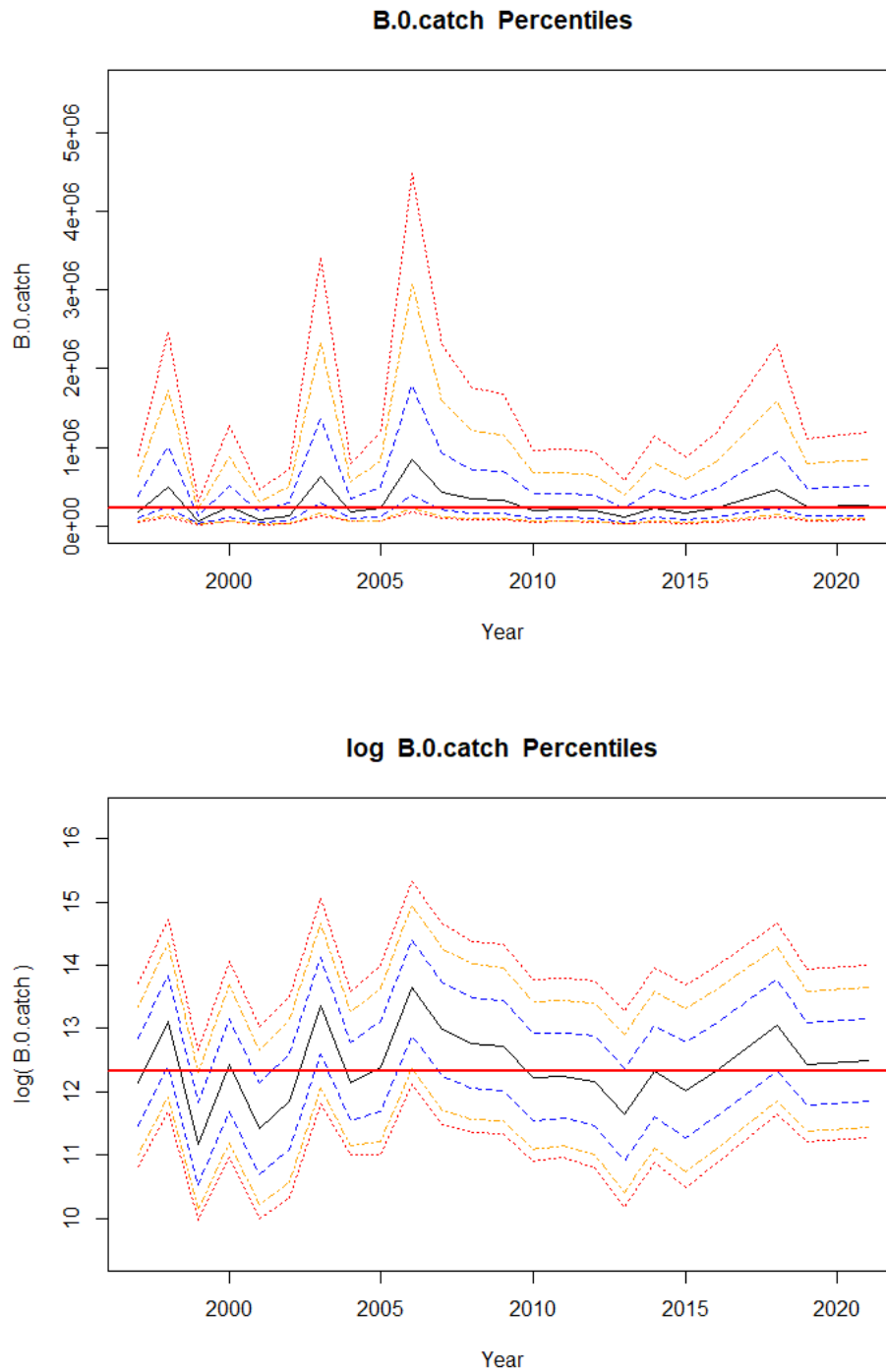
Figure 10. Estimated biomass levels in mt (1997-2021) based on 64,000 combinations of q, v, and M for each year [top]. Estimated percentiles for log biomass [bottom] Surveys were missing for 2017 and 2020. The black line represents the median. The blue lines represent the interquartile range. The orange lines represent the 80% confidence bounds. The dotted red lines represent the 90% confidence interval. The solid red line is the median of the annual medians.
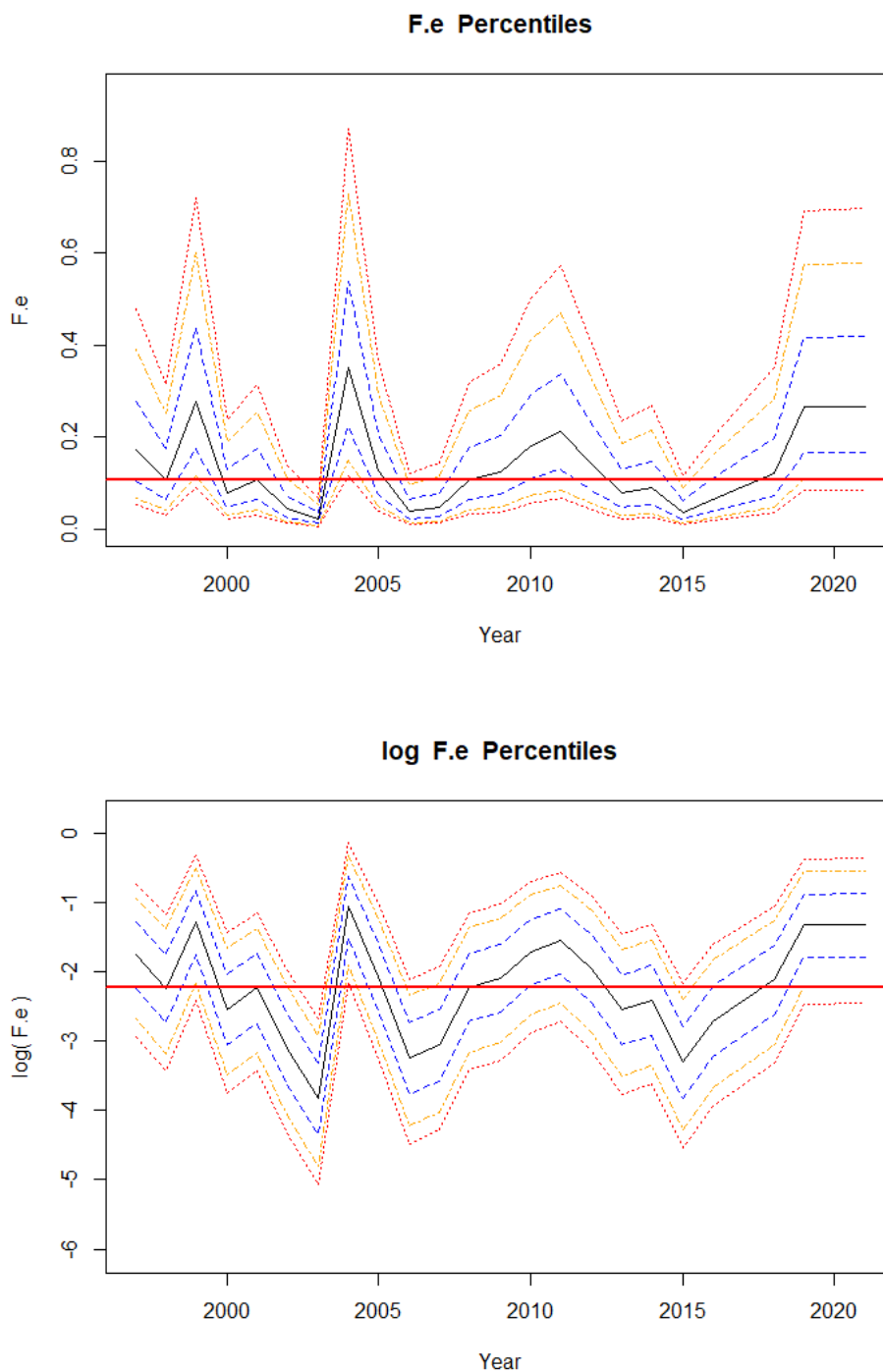
Figure 11. Estimated fishing mortality rates (season) (1997-2021) based on based on 64,000 combinations of q, v, and M for each year [top]. Log seasonal fishing mortality rates [bottom]. Surveys were missing for 2017 and 2020. The black line represents the median. The blue lines represent the interquartile range. The orange lines represent the 80% confidence bounds. The dotted red lines represent the 90% confidence interval. The solid red line is the median of the annual medians.   The average weekly rate is obtained by dividing the total by 25 weeks.

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Escapement.1 Percentiles
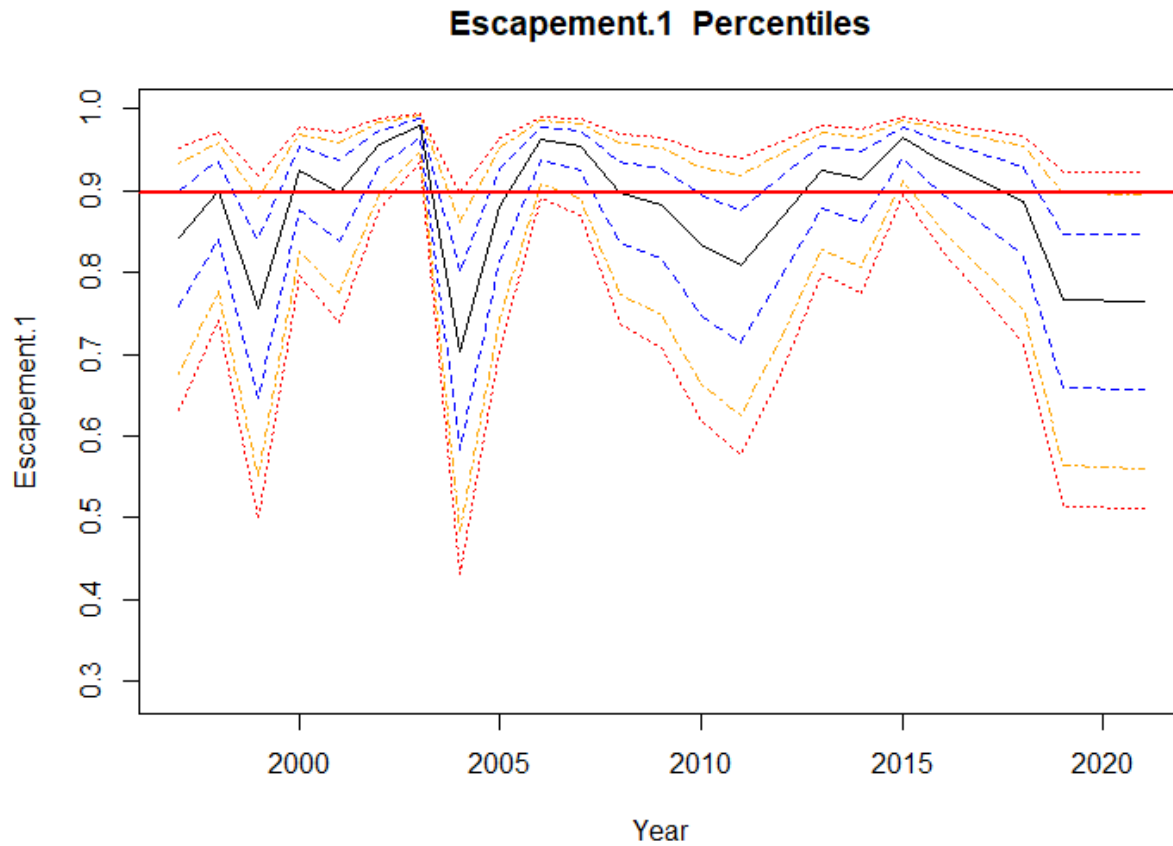
Figure 12. Estimated escapement ratios for 1997-2021 based on 64,000 combinations of q, v, and M for each year. Fall surveys were missing for 2017 and 2020. The black line represents the median. The blue lines represent the interquartile range. The orange lines represent the 80% confidence bounds. The dotted red lines represent the 90% confidence interval. The solid red line is the median of the annual medians. Note that the lowest dashed line is the 5th percentile of the escapement fraction.
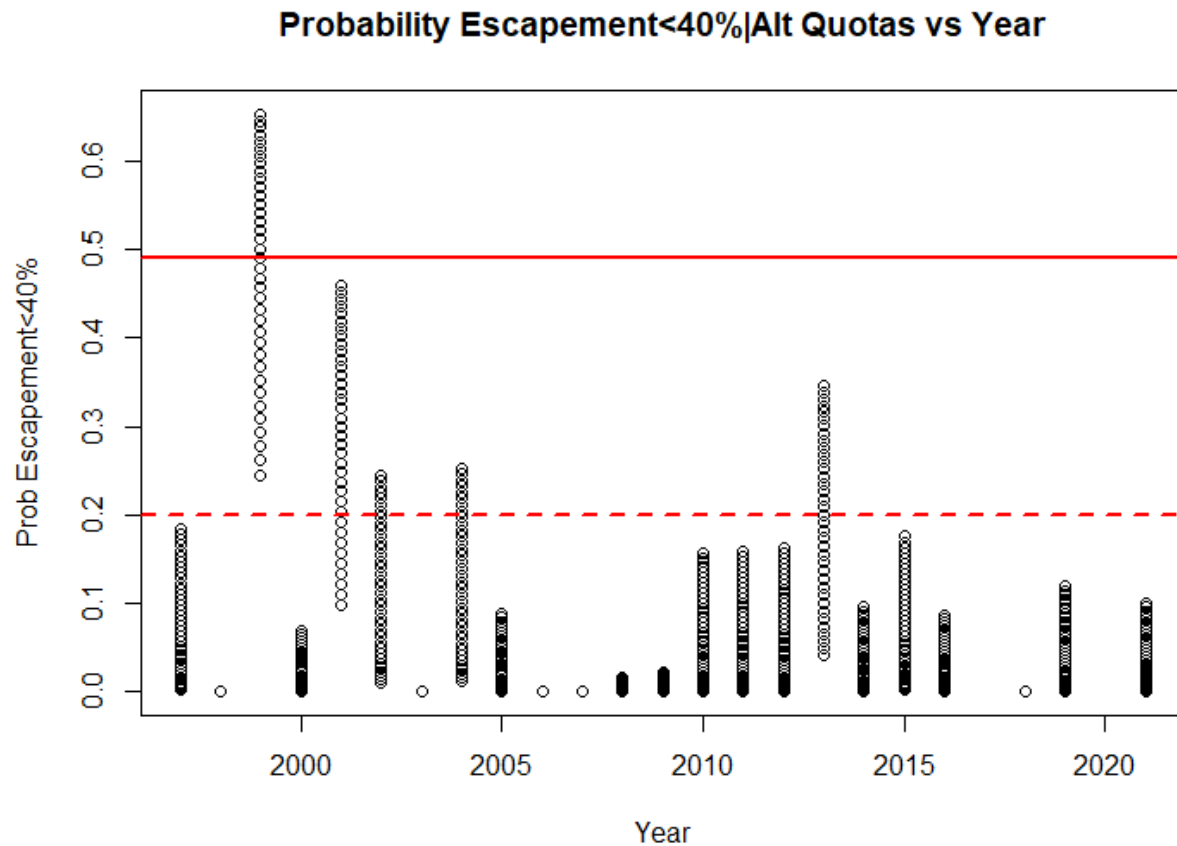
Probability Escapement<50%|Alt Quotas vs Year
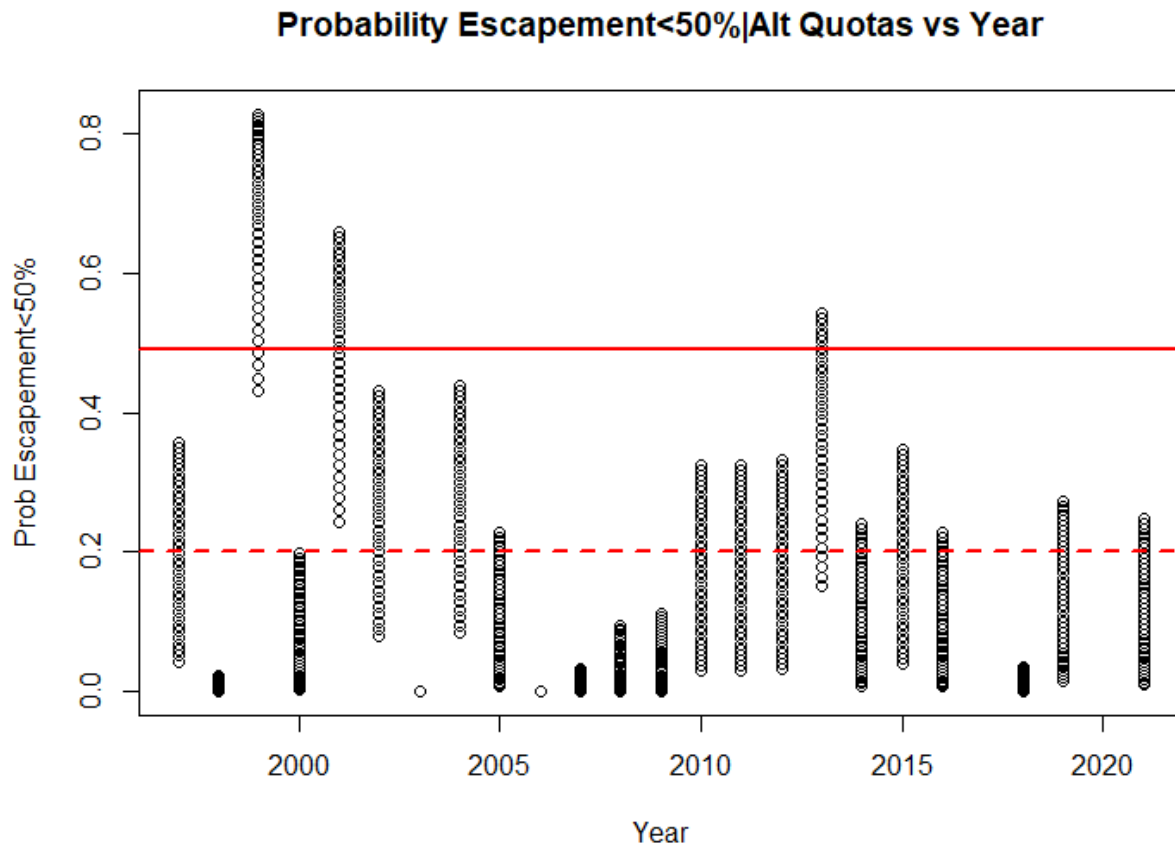
Figure 13. Estimated probability of escapement less than **50%** given alternative catch limits for each year ranging from 24,000 to 60,000. Each dot represents an alternative quota with lowest quotas at bottom and highest at top for each year. The initial population size in each year is based on the observed catch and the range of assumed q, v, and M values. The solid red line corresponds to the MAFMC's P*risk policy when B/Bmsy> 1.5. The dashed red line is the P* value corresponding to B/Bmsy=0.5.

Probability Escapement<50% given Alternative Quota
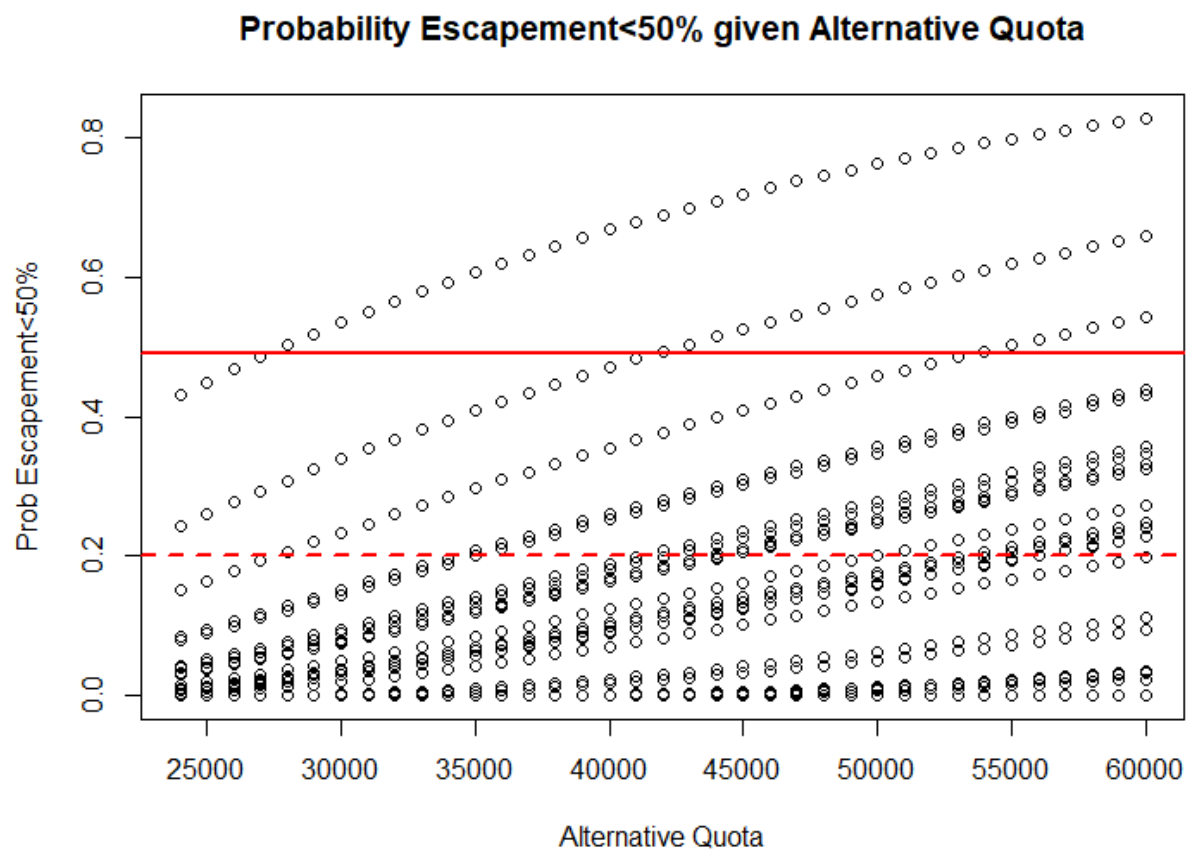
Figure 14. Estimated probability of escapement being less than **50%** given alternative catch limits from 24,000 to 60,000 mt. Each line is the trajectory of a given year reflecting the effect of different B.0 by year. The top line is 1999 which had the lowest B.o starting value. The initial population size in each year is based on the observed catch and the range of assumed q, v, and M values.

Figure 15. Estimated probability of escapement less than **40%** given alternative catch limits for each year ranging from 24,000 to 60,000. Each dot represents an alternative quota with lowest quotas at bottom and highest at top for each year. The initial population size in each year is based on the observed catch and the range of assumed q, v, and M values. The solid red line corresponds to the MAFMC's P*risk policy when B/Bmsy> 1.5. The dashed red line is the P* value corresponding to B/Bmsy=0.5.

APPENDIX 1.   Partial R Code for Estimation of Biomass, Fishing Mortality, and Escapement

The following represents the core code used to generate the distributions of biomass, fishing mortality and escapement, given survey and catch observations and assumed ranges of catchability, availability and natural mortality . Code for plotting routines, data handling, table generation and so forth is excluded.   Full copy of program is available upon request.

```
# load functions
Fb.fun<-function(F)(F/(F+M[k])*(exp(F+M[k])-1)*B.f[ijk]-Catch)  # Baranov Eqn

# load data for observed catches and survey indices
MB.df<-read.csv(paste0(getwd(),"/catch_survey_data.csv"))  # read in the mass balance data frame

# load data for Alternative Quotas to be analyzed
AQ.df<-read.csv(paste0(getwd(),"/AlternativeQuotas.csv"))  # read in the AlternativeQuotas data frame
N.Quota=length(AQ.df$AltQuota)

# Set up parameter ranges
q.min=0.078#  0.078=mean via experts for NEFSC trawl. Manderson et al 2021.
q.max= 0.325  # upper 95% CI bound on q for fishing vessels per Manderson et al. WP
N.q= 40    # number of probability intervals for uniform distribution of catchability
q<-seq(from = q.min, to = q.max, by= (q.max - q.min)/(N.q - 1))

v.min=0.37  #0.01  based on Lowman et al paper
v.max=0.73  #0.8   based on Lowman et al paper
N.v=40  # number of probability intervals for uniform distribution of availability
v<-seq(from = v.min, to = v.max, by= (v.max - v.min)/(N.v - 1))

#              Range of M estimates by week
M.min=0.01    # lowest value used in Hendrickson and Hart 2006
M.max=0.13    # based on Hewitt Hoenig 2005 estimator using max age=221 d in 2020 samples
N.M=40  # number of probability intervals for uniform distribution of natural mortality
M<-rep(0,N.M)  # define the array,
M.weekly<-seq(from = M.min, to = M.max, by= (M.max - M.min)/(N.M - 1))

F.min=0.000001
F.max=5   # this allows for 99% reduction within year as upper maximum bound

N.fishing.weeks<-25   # Convert M to full season estimates based on total weeks in fishery

#              Start of main loop for parametric simulations
yr.min<-min(MB.df$Year)
yr.max<-max(MB.df$Year)

for (iy in yr.min:yr.max){
# Test values for a given year

I.f=MB.df$I.f.t[MB.df$Year==iy]  # fall survey
```

```
I.s=MB.df$I.s.t[MB.df$Year==iy]  # spring survey
Catch=MB.df$Catch.t[MB.df$Year==iy]

if (is.na(I.f)==FALSE){     # compute stats only for years with fall survey present

# Initialize vectors
n.sim<-N.q*N.v*N.M
B.f<-rep(0,n.sim)
B.s<-rep(0,n.sim)
B.0.catch<-rep(0,n.sim)
F.e<-rep(0,n.sim)
M.e<-rep(0,n.sim)
q.e<-rep(0,n.sim)
v.e<-rep(0,n.sim)
FMratio<-rep(0,n.sim)
CBratio<-rep(0,n.sim)
B.0.Bs.ratio<-rep(0,n.sim)
Escapement.1<-rep(0,n.sim)
Catch.type<-rep(0,n.sim)

FMratio.mat<-matrix(0, nrow=n.sim, ncol=N.Quota)
Escapement.mat<-matrix(0, nrow=n.sim, ncol=N.Quota)

ijk<-0
i.infeasible=0
for (i in 1:N.q){
 for (j in 1:N.v){
  for (k in 1:N.M){
   ijk<-ijk+1

   B.f[ijk]<-I.f/(q[i]*v[j])
   B.s[ijk]<-NA
   if(is.na(I.s)==FALSE){B.s[ijk]<-I.s/(q[i]*v[j])}
   M[k]<-M.weekly[k]*N.fishing.weeks  # adjust rates based on total fishing season
   M.e[ijk]<-M[k]
   q.e[ijk]<-q[i]
   v.e[ijk]<-v[j]

   Catch=MB.df$Catch.t[MB.df$Year==iy]
   #              Check for feasibility of F estimate
   F.e[ijk]<-NA
   if(is.na(B.f[ijk])==FALSE){
      F.est<-uniroot(Fb.fun, lower=F.min,upper=F.max, extendInt= "yes",maxiter=20)  # Solve catch
equation using root finder.
      F.e[ijk]=F.est$root    # this is total F overall fishing weeks.
         }
   if(F.e[ijk]>=F.max){
     F.e[ijk]<-NA
     i.infeasible=i.infeasible+1}     # exclude estimates greater than or equal to upper bound
=F.max
```

```
    B.0.catch[ijk]=B.f[ijk]*exp(F.e[ijk]+M[k])
    Escapement.1[ijk]=B.f[ijk]/(B.0.catch[ijk]*exp(-M[k])) # method based on Baranov catch
equation
    FMratio[ijk]<-F.e[ijk]/M.e[ijk]  # ratio of F/M
    CBratio[ijk]=Catch/B.f[ijk]   # Utility of Catch over terminal biomass--compare with escapement
   if(is.na(I.s)==FALSE){B.0.Bs.ratio[ijk]=B.0.catch[ijk]/B.s[ijk]}
    Catch.type[ijk]="Obs"


  # loop over all alternative quota levels here to obtain F/M ratios and Escapement levels.
  #  Compute new B.f.hyp given estimated B.0.catch and hypothetical alternative quota.


  #loop over alternative quotas
  for (iQ in 1:N.Quota){
  # find F necessary to catch alternative quota level
  Catch=AQ.df$AltQuota[iQ]
  F.est<-uniroot(Fb.fun, lower=F.min,upper=F.max,extendInt= "yes",maxiter=20) # Solve catch
equation using root finder.
    F.alt=F.est$root    # this is total F overall fishing weeks.
    B.f.alt=B.0.catch[ijk]*exp(-(F.alt+M[k]))
  Escapement.alt<-B.f.alt/(B.0.catch[ijk]*exp(-M[k]))  # this is the estimate of escapement based on
alternative quota values
    FMratio.alt<-F.alt/M.e[k]
                            Catch.type[ijk]="AltQuota"
                            # load matrix  for each alternative quota
                            FMratio.mat[ijk,iQ]<- FMratio.alt
                            Escapement.mat[ijk,iQ]<-Escapement.alt


    }
    }
 }
}
 print(paste("end of loop for year = ",iy))
```