Evaluation of Alternative Catch Limits for Illex in 2022

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

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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:

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

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 $\mathbf{B_t}$

$$B_t = B_0 \; e^{-Z\,t} \qquad (3)$$

Where $\mathbf{B_t}$ is defined by Eq. 2.

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

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

Substitution of Eq. 3 into 4 and rearranging results in

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

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.

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

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

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

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.

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

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

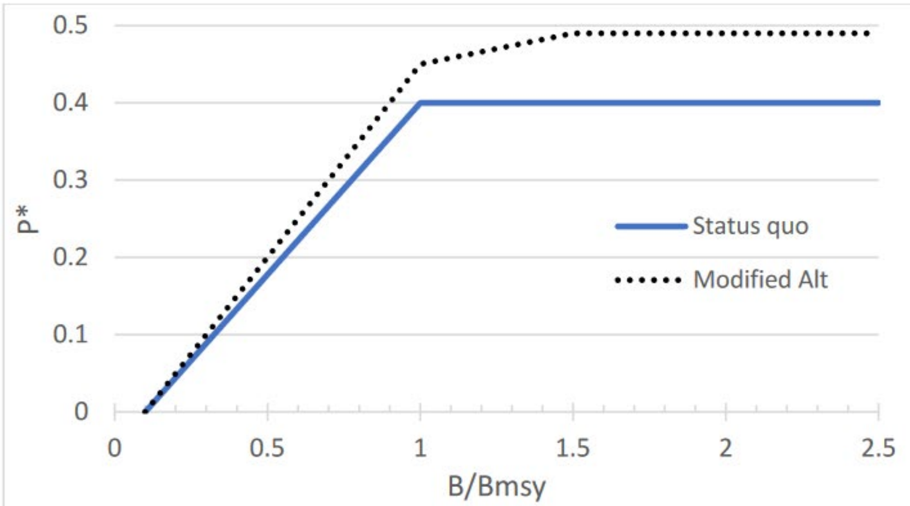
The lower bound of assumed weekly natural mortality rates (=0.01) was based on lowest assumed value in Hendrickson and Hart (2006). The upper bound of 0.13 week^{-1} was obtained from the predictive equation of Hewitt and Hoenig (2005) given a maximum age of 221 days in 2019-2020 samples.

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

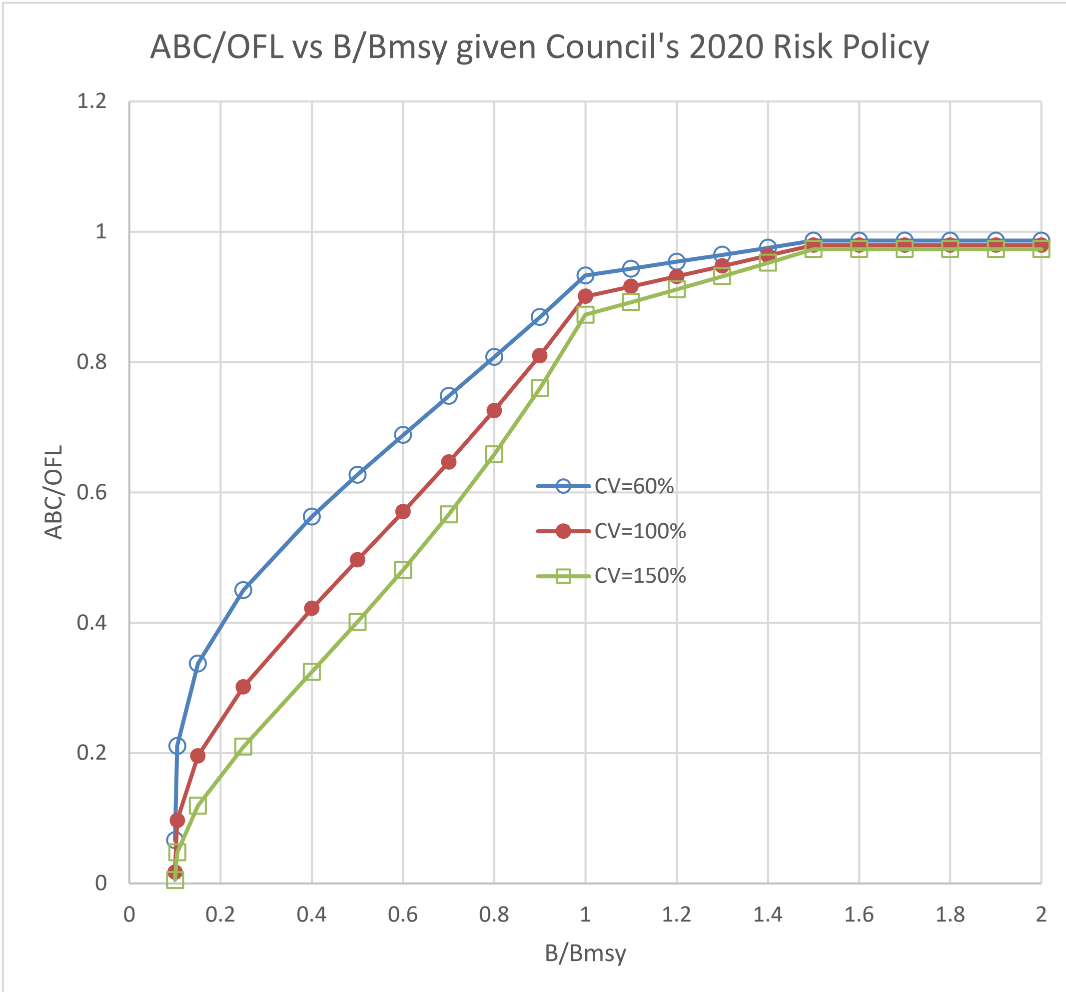
Risk Analyses

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≤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.



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.

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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

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 Quota (mt)	F/M Threshold 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

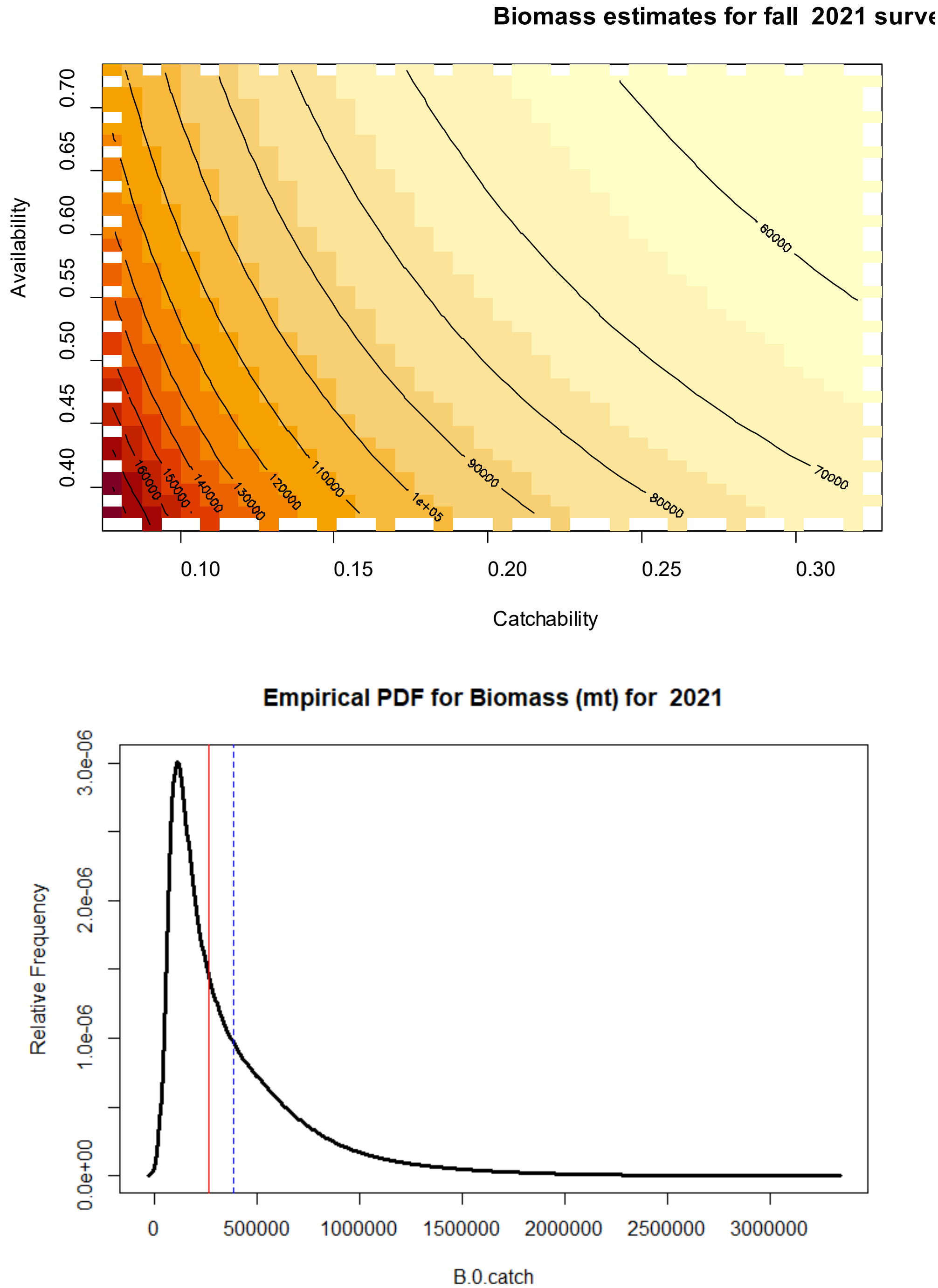
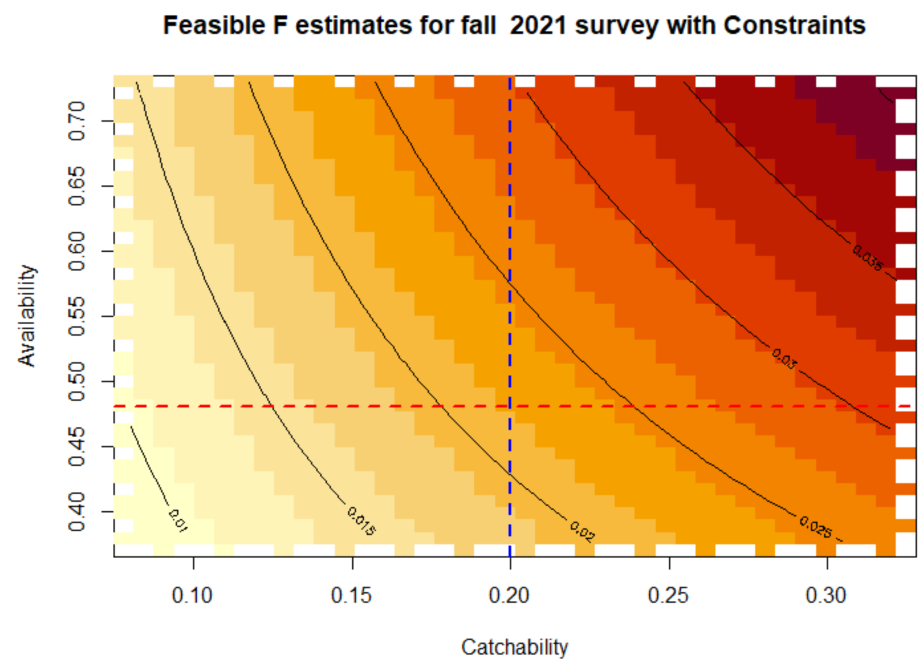


Figure 1. Isopleths of Illex biomass (mt) estimates for combinations of q and v for 2021 (top) and marginal distribution of biomass estimates over all combinations of q, v, and M (bottom). Solid red line is median; dashed blue line is mean.



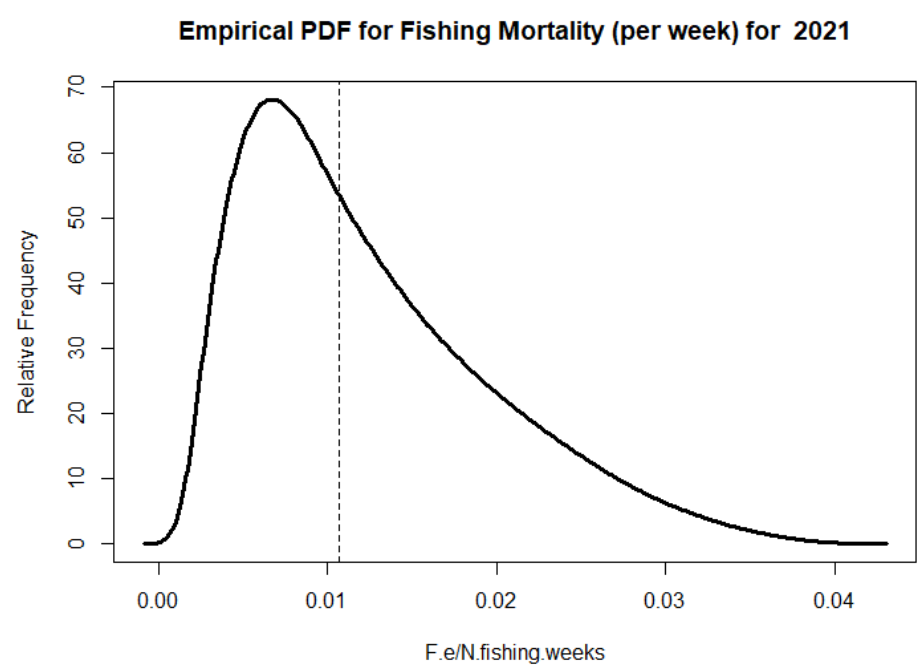
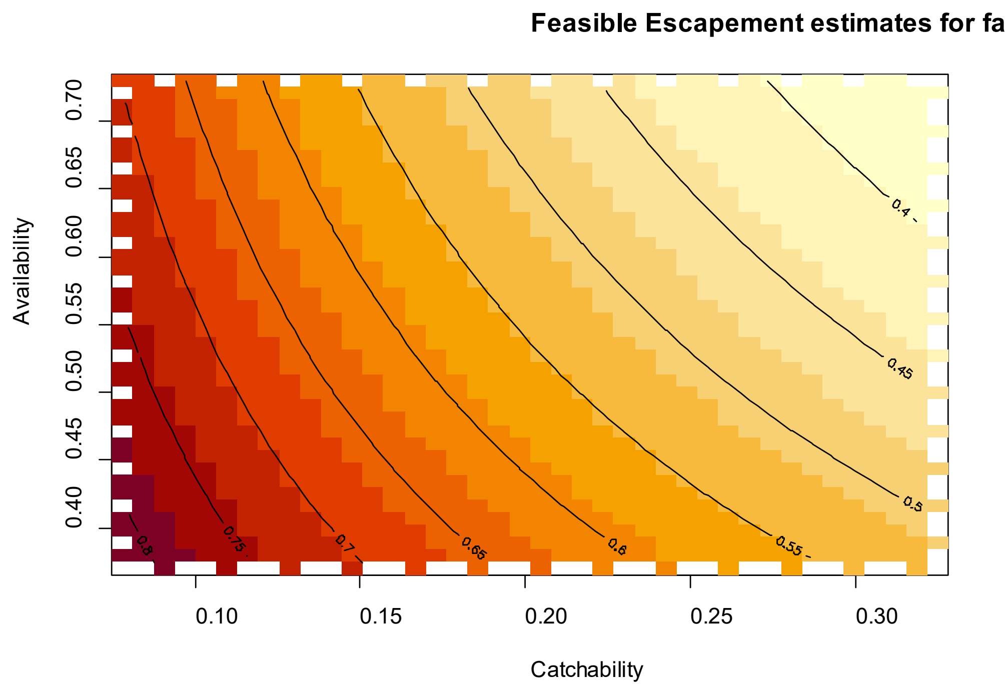


Figure 2. Isopleths of Illex fishing mortality estimates (per week) for various combinations of q and v for 2021 (top) and derived distribution of fishing mortality rates (per week) for 2021. The dashed black line represents the median value.



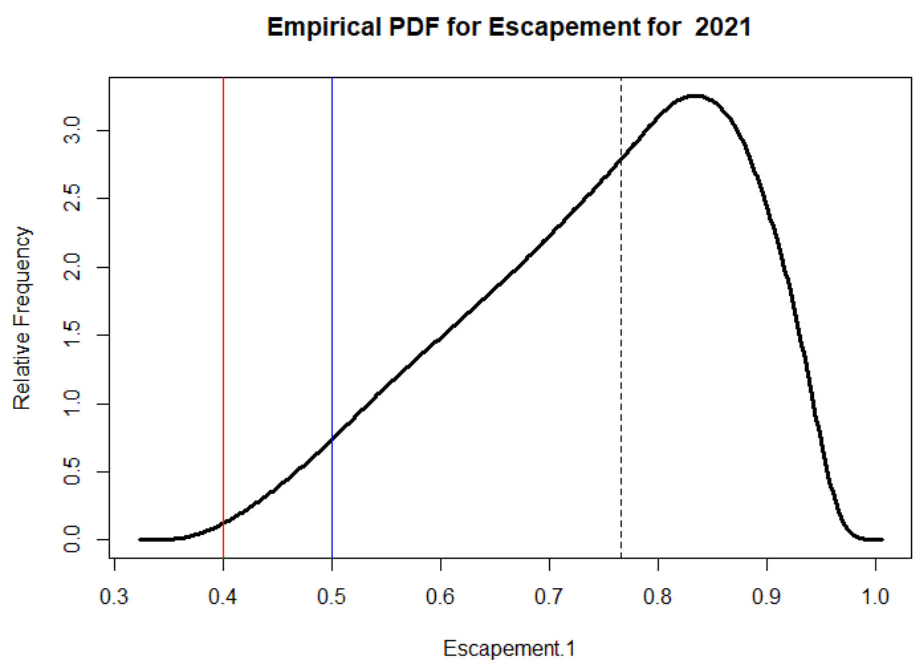


Figure 3. Isopleths of escapement as a function of cathability and availability (top) and empirical distribution of Escapement based on observed landings in 2021 and observed NEFSC fall bottom trawl indices (bottom). The dashed black line=median. Red and blue vertical lines represent escapement levels of 40 and 50%, respectively.

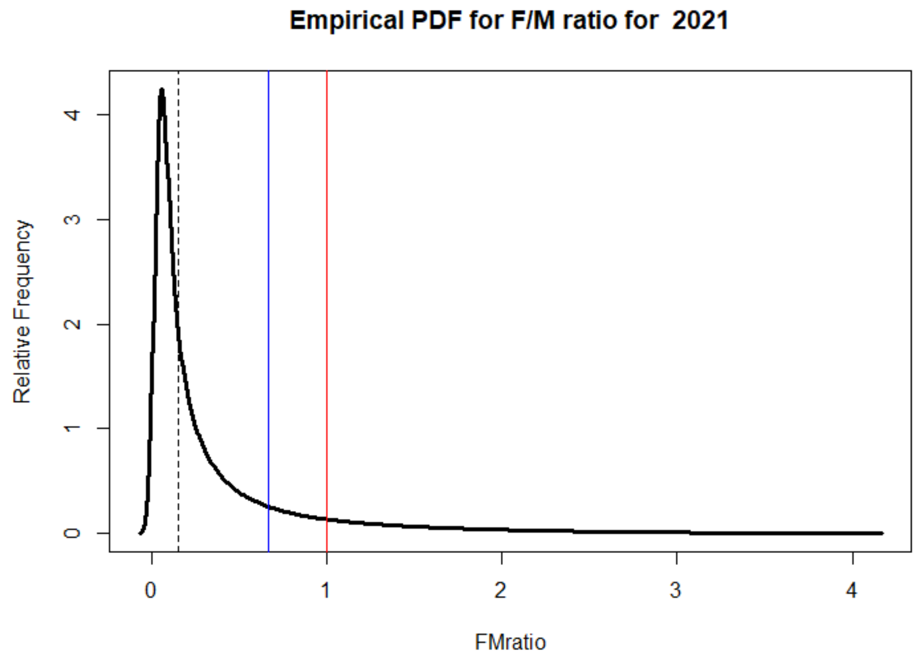


Figure 4. Empirical distribution of F/M ratio for 2021. Dashed line = median. Blue and red lines are for F= 2/3 M and F=M, respectively.

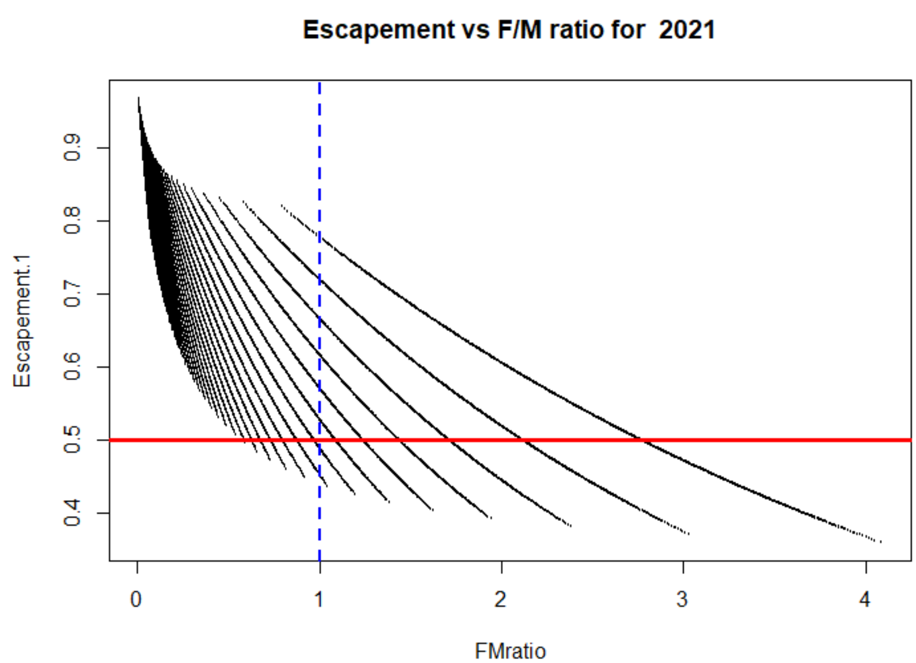


Figure 5. Relationship between Escapememt and estimated fishing mortality/assumed M over all 64,000 combinations of q, v, and M for 2021. The bands represent isopleths for assumed levels M. Low M (0.01 week^{-1}) on right and high M (0.13 week^{-1}) on left. .

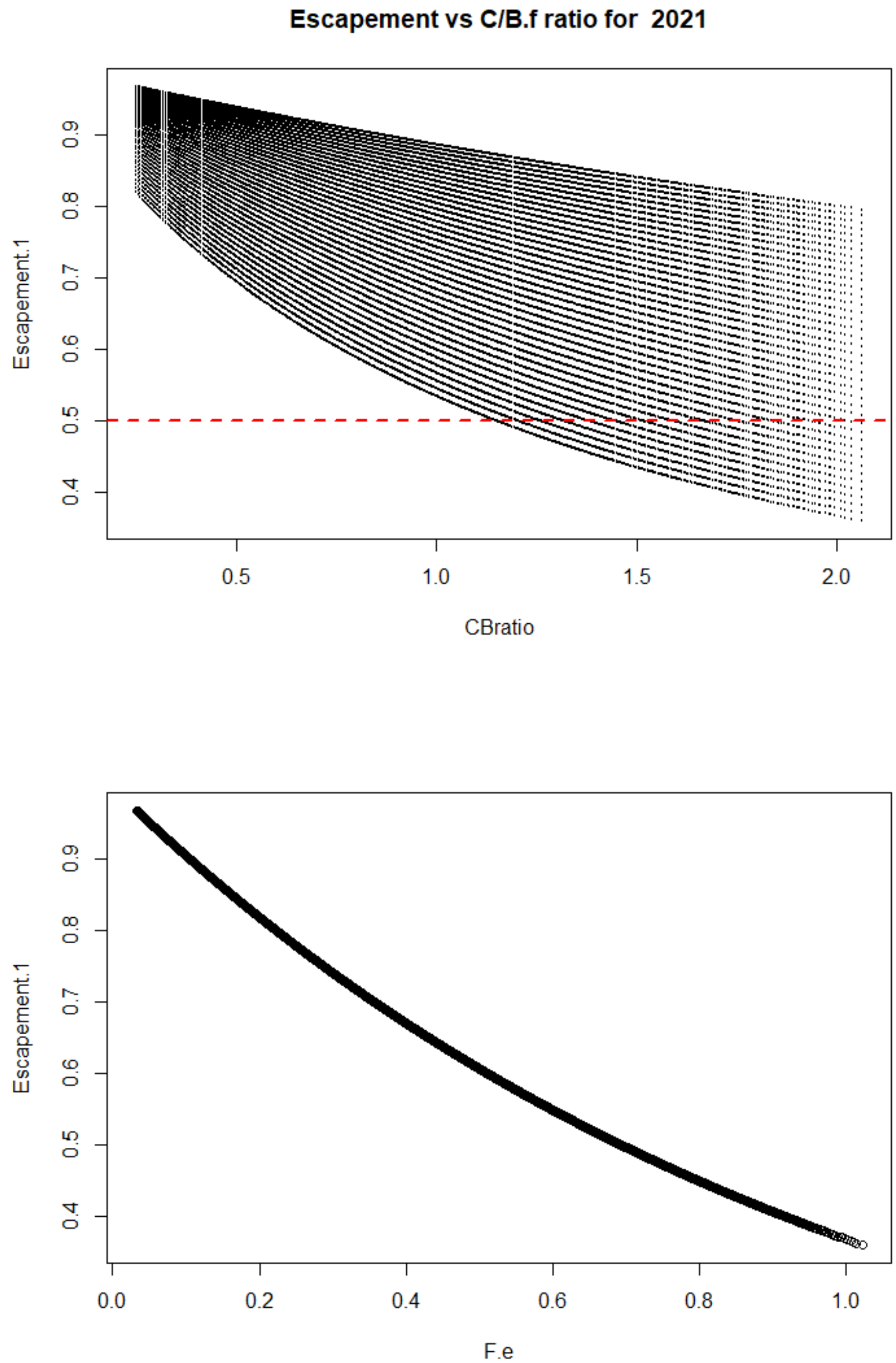


Figure 6. Relationship between Escapement and measures of exploitation for 2021. Catch divided by end of year biomass (i.e.. Fall survey) [top] . The trajectories correspond to assumed levels of M. Bottom panel depicts relationship between escapement and fishing mortality (see Eq. 9).

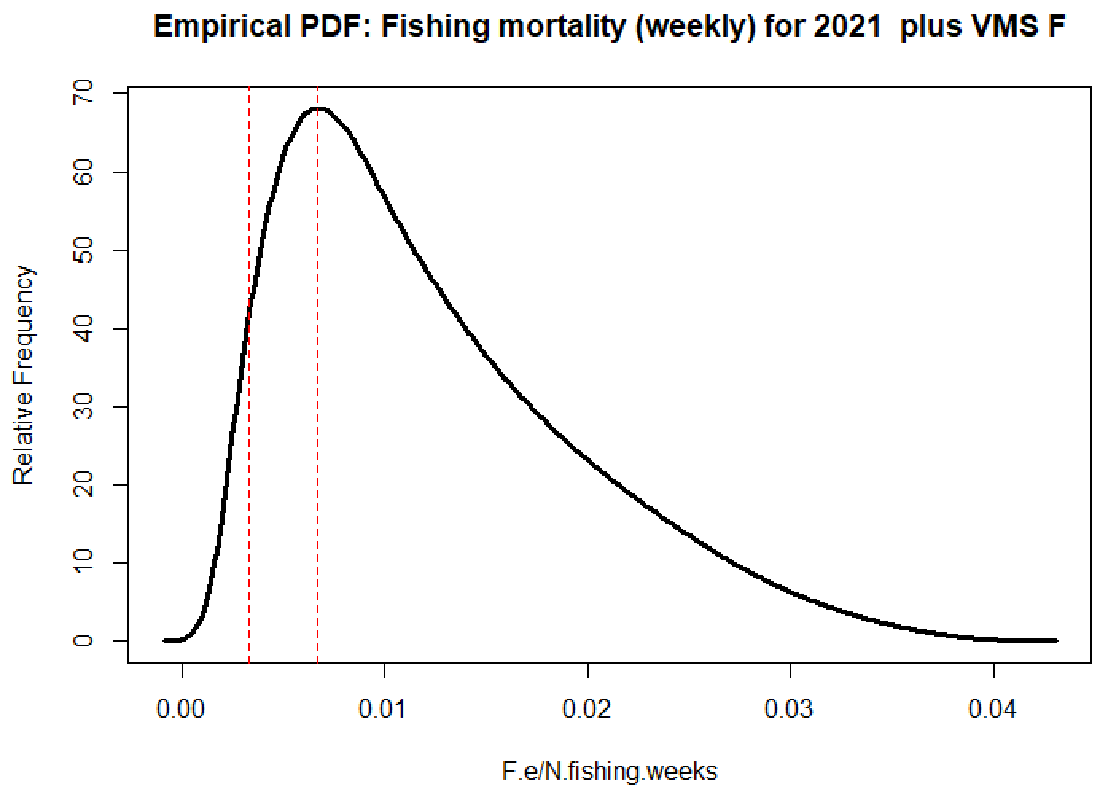
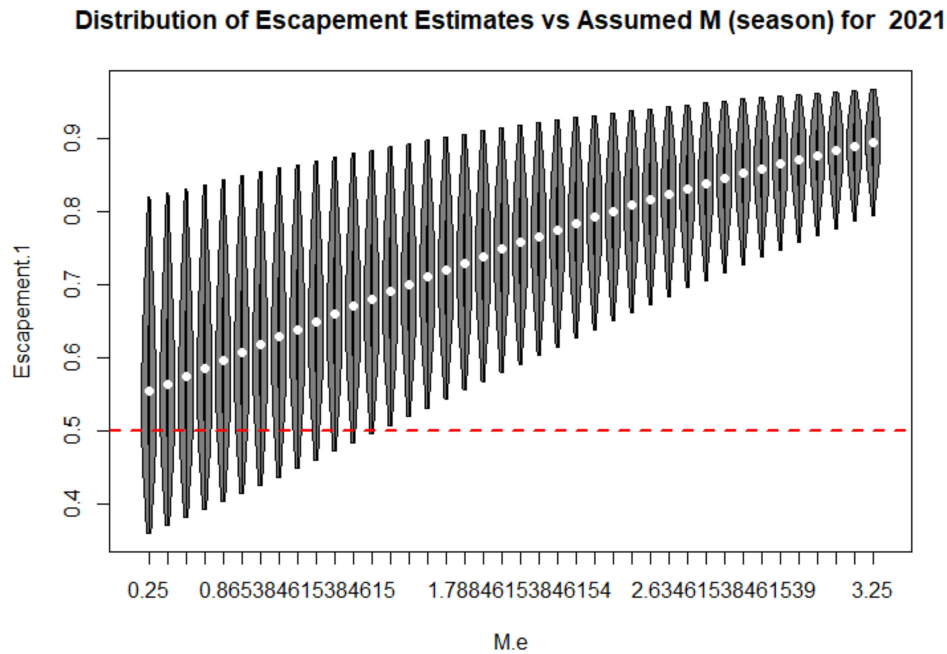


Figure 7. Empirical probability density function for F (week^{-1}) estimates based on assumed ranges of q, v and M for 2021. Red vertical lines depict range of F derived from VMS analyses for 2019. Weekly F range =[0.082/25, 0.167/25]



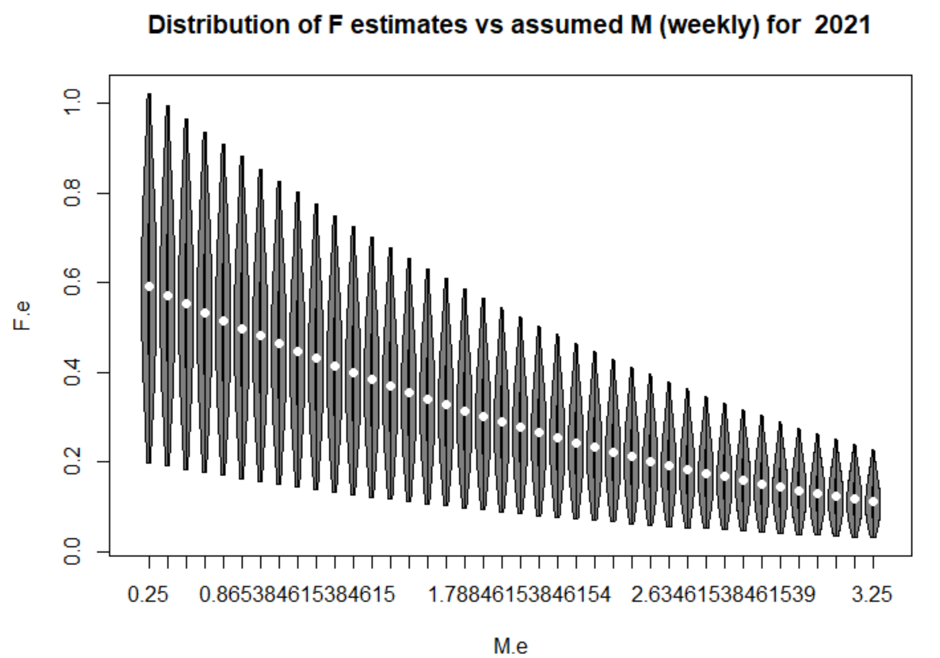


Figure 8. Relationship between estimated escapement and assumed M (per 25 week season) for 2021 [top]. Relationship between estimated F and assumed M (per season of 25 weeks) [bottom]. Variation in F.e is induced by range of q and v estimates.

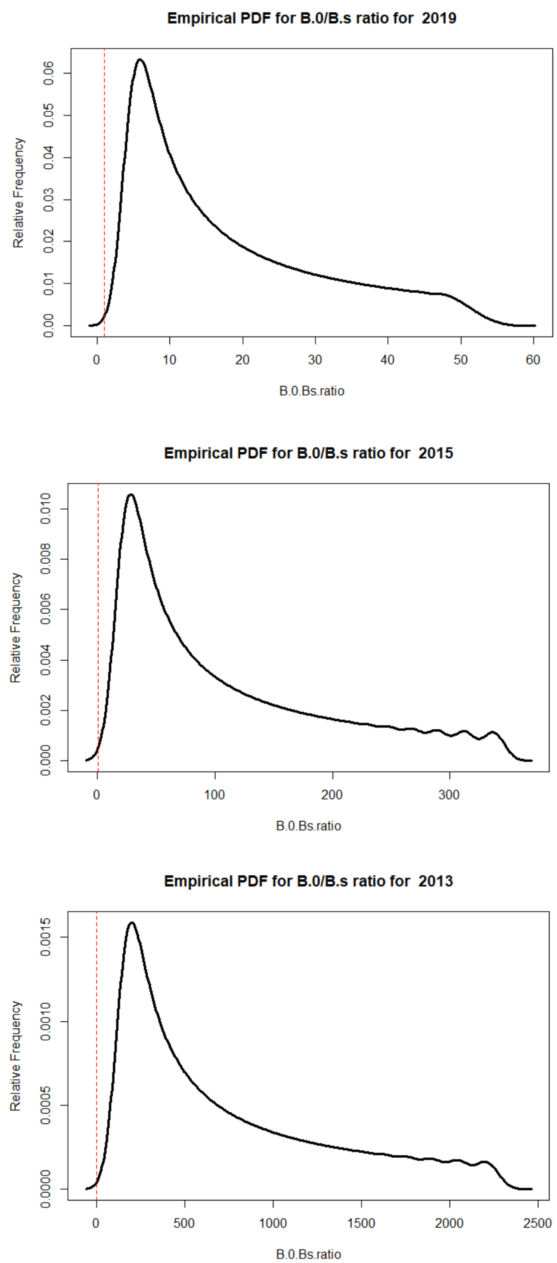


Figure 9. Distribution of ratio of estimated biomass necessary to support the observed landings in the fishery (B.0) to the initial biomass defined by the spring survey (B.s). Three examples (2019, 2015, 2013) illustrate the orders of magnitude range of differences among years.

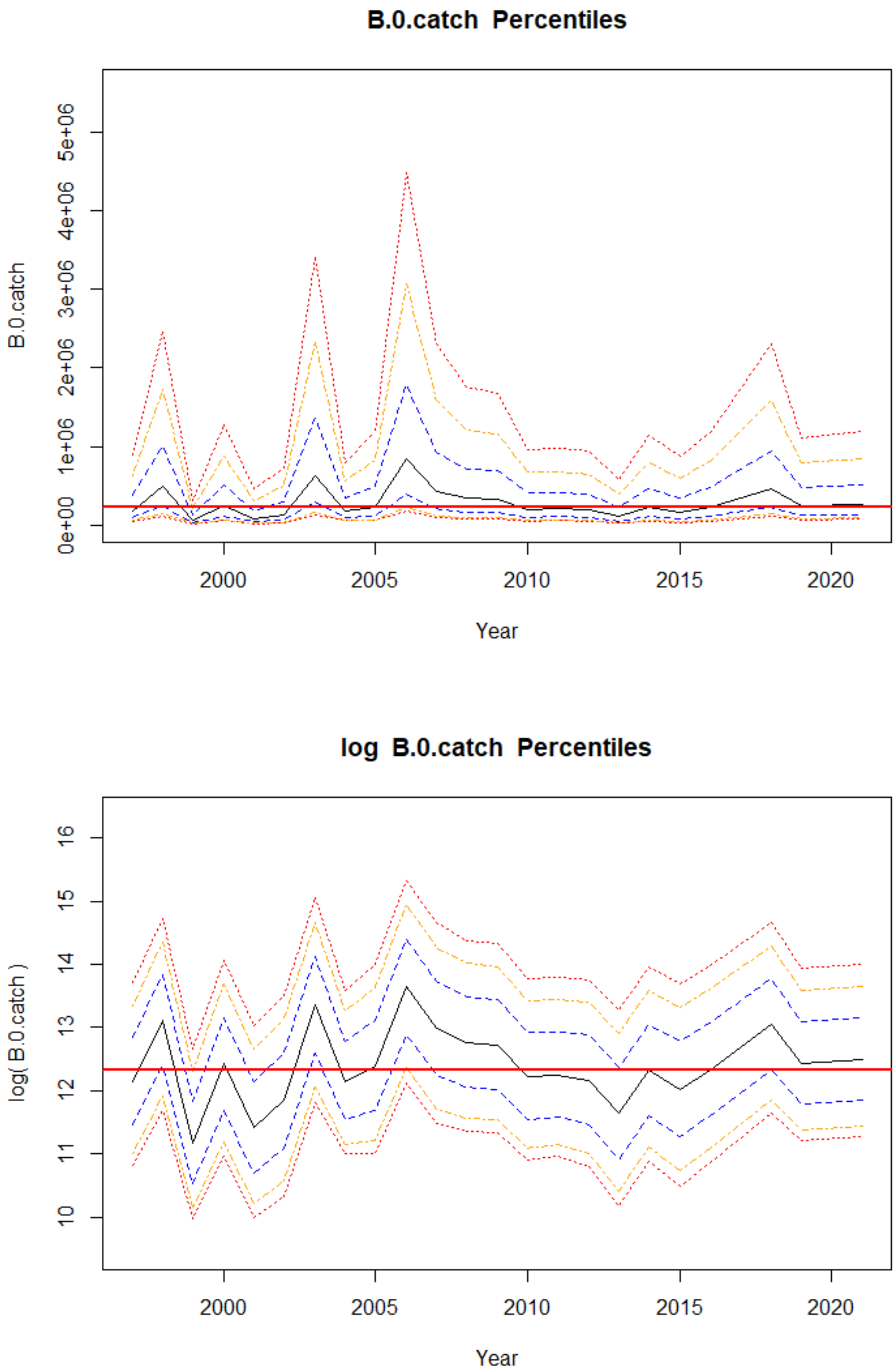
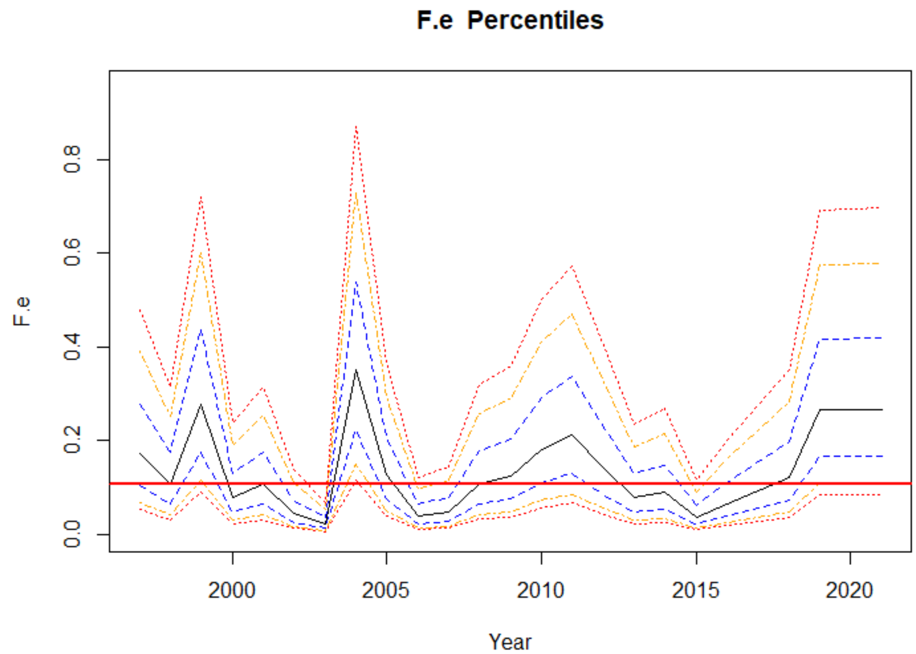


Figure 10. Estimated biomass levels in mt (1997-2021) based on 64,000 combinations of q, v, and M for each year [top]. Estimated percentiles for log biomass [bottom] Surveys were missing for 2017 and 2020. The black line represents the median. The blue lines represent the interquartile range. The orange 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.



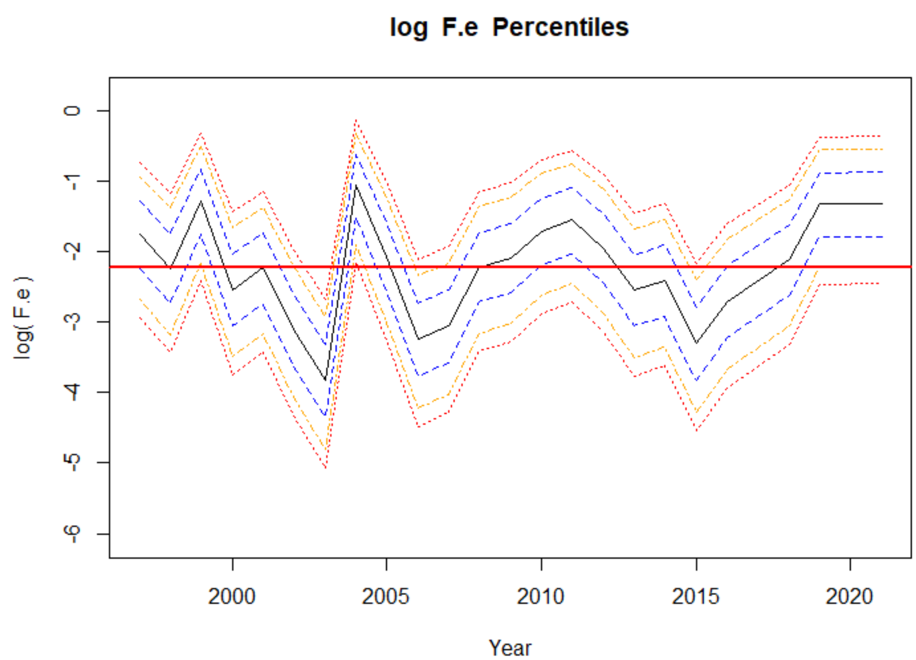
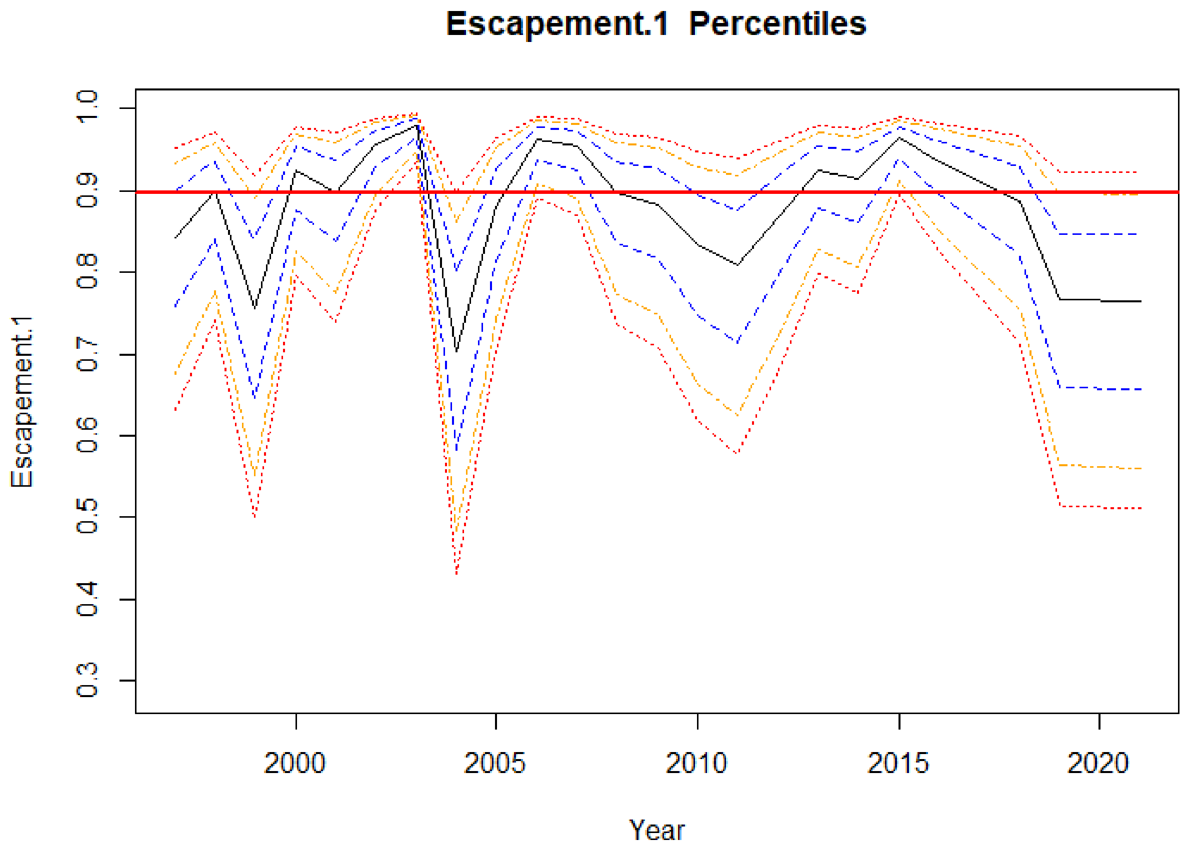


Figure 11. Estimated fishing mortality rates (season) (1997-2021) based on based on 64,000 combinations of q, v, and M for each year [top]. Log seasonal fishing mortality rates [bottom]. Surveys were missing for 2017 and 2020. The black line represents the median. The blue lines represent the interquartile 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.


Escapement.1 Percentiles
Escapement.1
Year
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
2000
2005
2010
2015
2020

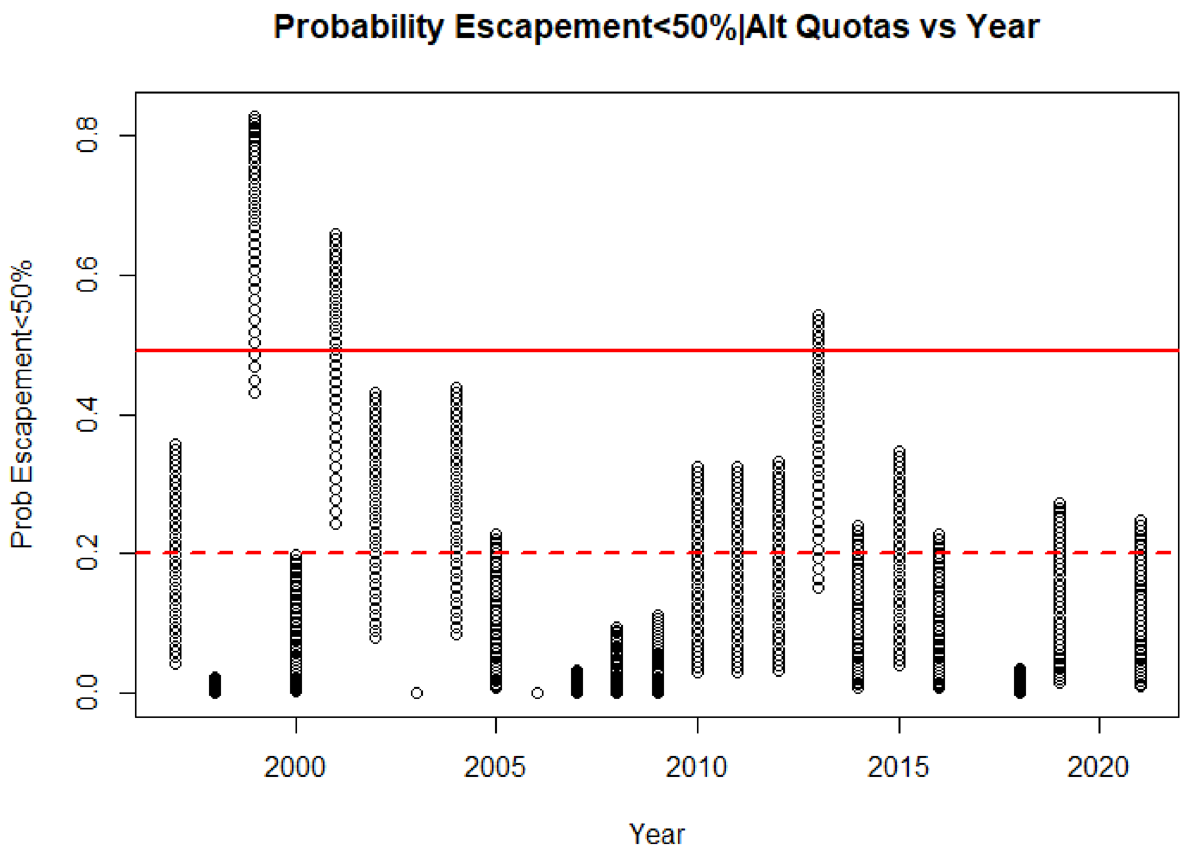
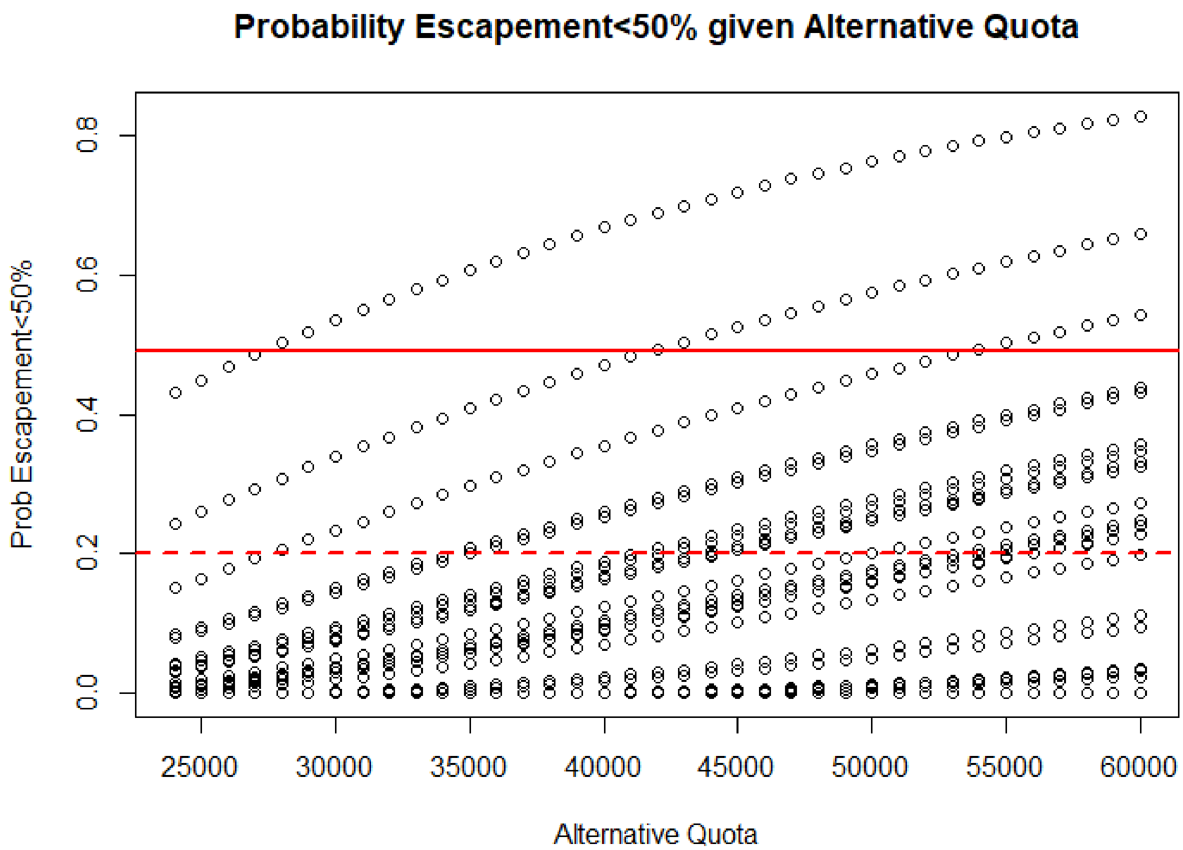


Figure 13. Estimated probability of escapement less than **50%** given alternative catch limits for each year ranging from 24,000 to 60,000. Each dot represents an alternative quota with lowest quotas at bottom and highest at top for each year. The initial population size in each year is based on the 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
Prob Escapement<50%
0.0
0.2
0.4
0.6
0.8
25000
30000
35000
40000
45000
50000
55000
60000
Alternative Quota

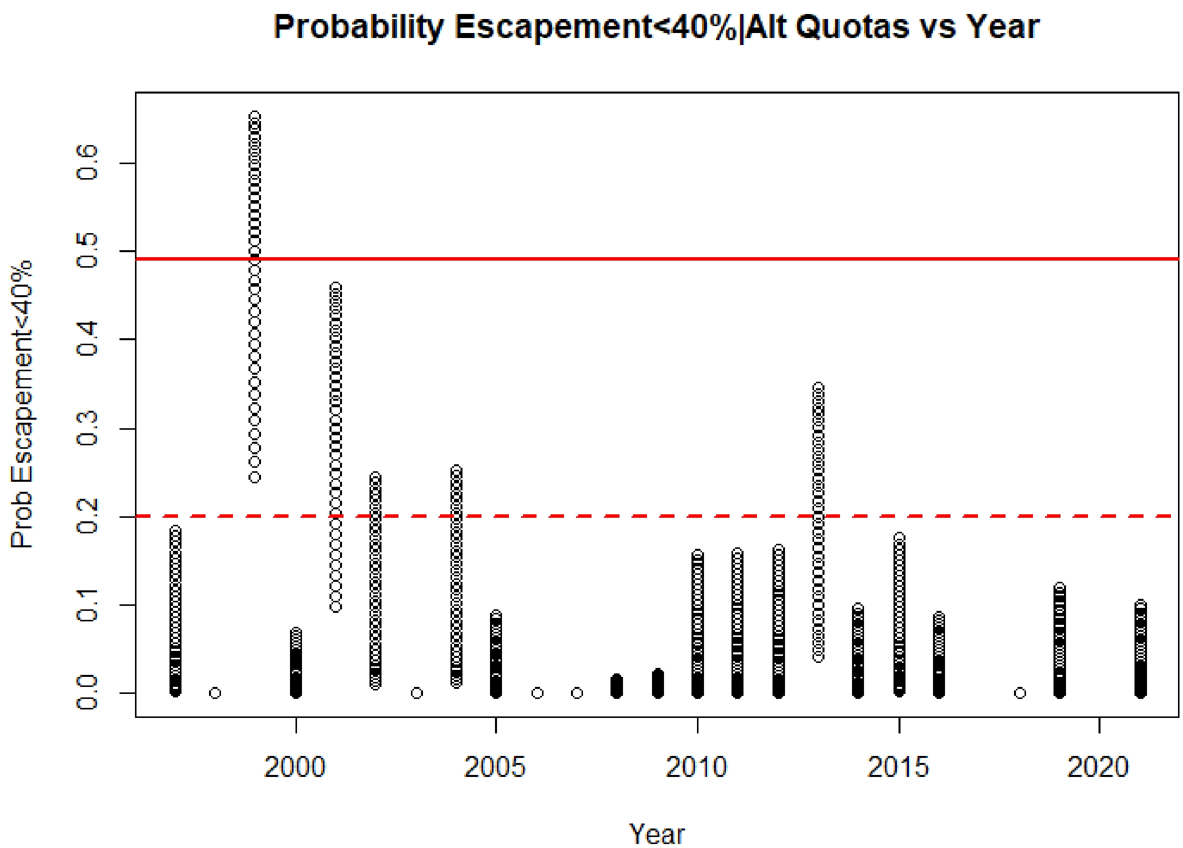


Figure 15. Estimated probability of escapement less than **40%** given alternative catch limits for each year ranging from 24,000 to 60,000. Each dot represents an alternative quota with lowest quotas at bottom and highest at top for each year. The initial population size in each year is based on the 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))
```