Effects of Survey Uncertainty on Risk of Violating Escapement and F/M Thresholds for Illex Squid: 1997-2021

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1.0 Executive Summary

This report describes a recommended enhancement of the methodology used by the SSC in March 2022 to set ABCs for Illex squid for 2022 and 2023. The 2022 methodology explicitly considered the uncertainty induced by variation in catchability, availability, and natural mortality. The recommended enhancement considers the additional uncertainty of the biomass estimate from NEFSC fall trawl survey on the distribution of initial biomass and fishing mortality and the risks of violating thresholds related to escapement and F/M ratios.

Inclusion of uncertainty increases the variance of the derived quantities: initial biomass, fishing mortality, escapement, and F/M ratio. In turn, the wider range of possible values increases the fraction of simulated values that fall below candidate escapement thresholds and that fall above F/M thresholds. Over the entire period, these changes have relatively modest impacts on the overall risk. For example, the risk of falling below a 50% escapement threshold for a quota of 40,000 mt was 0.1519 when variability in survey biomass was excluded (i.e., at the 2022 SSC meeting). When variability in survey biomass is included, the average probability of falling below 50% escapement increases to 0.1620, or about a 6.6% increase (Table 6). Similarly, the probability of F/M exceeding 0.66 increases about 5.2% to 0.2104 (Table 7). The effects of including variability in survey biomass are not uniform across all years. Years with high coefficients of variation will have a greater fraction of realizations that violate candidate biological thresholds.

With respect to the Mid Atlantic Council's Risk Policy, all of the quotas from 24,000 to 60,000 mt result in overfishing probabilities less than 0.45 for escapement thresholds up to 60% when the stock is assumed to be at or above Bmsy. If the stock is, at say 50% of Bmsy, then the overfishing risk of 20% at an Escapement threshold of 0.5 would result in a quota of 46,000 mt (versus 47,000 mt in the 2022 report). Applying the most restrictive overfishing definition of having escapement exceed 50% and F/M <0.66 leads to a quota of 37,000 mt. It should be noted that this type of joint threshold model has not been applied in any fishery of which I am aware.

2.0 Background

In May 2021 the SSC first considered methods to estimate the likely ranges of initial biomass B.0 and escapement (Esc) as a function of uncertainty in catchability (q), availability of Illex to the survey area (v), and natural mortality (M) (Rago 2021). The ranges of q, v, and M were drawn from the literature and used to bound feasible ranges of Biomass and Escapement. Only two alternative quotas were considered, and Pope's approximation was used to develop escapement estimates.

In March 2022 (Rago 2022), the methodology for estimating escapement was enhanced in several ways:

- Baranov's catch equation, rather than Pope's approximation was used to estimate initial population size
- Solution of catch equation provided a direct estimate of the seasonal fishing mortality and the virtual population that would be necessary to support the observed catch.
- The probability density functions (pdf) of q, v, and M were assumed to be uniform, with upper and lower bounds based on a variety of analyses conducted as part of the Research Track Assessment for Illex squid.
- The sampling distributions of initial biomass B.0, fishing mortality (F), escapement (Esc), and the ratio of fishing to natural mortality (F/M) were approximated by numerically integrating over the three parameter pdfs.
- The numerical integration evaluated each function using 40 equal probability intervals. The sampling distributions were based on $40^3 = 64,000$ estimates.
- A range of alternative quotas from 24,000 to 60,000 mt were considered. The effects of the alternative quotas were evaluated for each the 64,000 realizations of B.0 with respect to the F necessary to support the alternative quota, the escapement implied by the alternative quota, and the ratio of F/M.
- Escapement and F/M have been considered as reference points for other squid stocks and forage fish species. There are no agreed upon biological reference points for US *Illex* squid.
- The probability of falling below escapement rates of 35,40,50, 60, and 75% was computed for each alternative quota.
- The probability of exceeding F/M ratios of 0.33, 0.50, 0.66, 1.00 and 1.5 was computed for each alternative quota.
- Finally, the joint probability of falling below escapement rates of 35, 40, 50, 60, and 75% AND exceeding F/M=0.66 was computed for each alternative quota.

In the absence of defined biological reference points, the SSC considered the overall risk levels to be acceptable over a broad range of candidate reference points.

The SSC met July 25-26, 2022 to review the results of the NRCC Research Track Assessment for Illex squid. As part of the RTA a number of indirect assessment methods were developed to address the uncertainty in our understanding of Illex stock dynamics.

One of the indirect methods addressed potential escapement rates of Illex as a measure of fishery impact on spawning potential. Escapement is defined as the ratio of population size in presence of the fishery compared to population size with natural mortality only. This methodology evaluates the uncertainty in catchability, availability of Illex to the survey area, and natural mortality. The model considered in March 2022 did not consider the uncertainty due to the sampling variability of the fall survey biomass estimate. The SSC's Report to MAFMC, August 4, 2022 for the July 25-26, 2022 meeting noted that

> "Further work could include consideration of uncertainty in the survey indices. This would be expected to increase the range of likely outcomes for key decision variables, such as escapement."

The SSC also made the following recommendations to improve the improve the "indirect method analysis":

- **Consider effects of point estimates of uncertainty in estimates of abundance on overall risk profiles.**
- Undertake a “first principles” consideration of the sign and potential magnitude of covariation among q, v, and M.
- Conduct exploratory analyses over whether the model effort results are sensitive to levels of covariation among q, v, and M. If these exploratory analyses indicate that covariation is important, additional analyses should be conducted to inform the scale of the anticipated covariation.
- **Consider development of an “indirect method” analysis package that facilitates the transfer of the approach to the Center.**

This report summarizes the methodology used to consider the uncertainty in the estimates of abundance on the risk profiles. Comparisons of the revised model are made with the estimates used in March 2022. No progress was made on the potential effects of covariation among q, v, and M. Progress was made, however, on the analysis package to estimate risks of alternative quotas. A user’s manual and all software was delivered to the NEFSC on February 1, 2023 (Rago 2023).

3.0 Revision to Methods

3.1 Review of Model Theory

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.

With a little algebra and the catch equation, the following implicit function of F can be derived:

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

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.

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:

$$B_{t,without\ fishery} = B_0 e^{-Mt} \qquad (5)$$

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.

$$Escapement = \frac{B_t}{B_{t,without\ fishery}} \qquad (6)$$

Further substitution of Eq. 3 and 5 into Eq. 6 results in

$$Escapement = \frac{B_t}{B_{t,without\ fishery}} = \frac{B_0 e^{-(F+M)}}{B_0 e^{-M}} = e^{-F} \qquad (7)$$

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.

$$B_0 = \frac{C_H}{\frac{F_H}{F_H+M}\left(1-e^{-(F_H+M)}\right)} \qquad (8)$$

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. The input data for the period 1997-2021 is summarized in Table 1A.

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 the revised 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. 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 4, i.e., **{q,v,M}** are described in Rago(2022) and are based on the results of the Research Track Assessment for Illex squid.

One way of efficiently sampling over the entire range of values is known as Latin hypercube sampling (Figure 1). 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 (Table 1B). 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 Rago (2023).

Probability levels for candidate thresholds can be computed by counting the proportion of realizations that fall above for below a criterion. 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.

4.0 Results

The effects of including uncertainty in the fall survey index were evaluated in two ways. First, the estimates of B.0, F, Escapement and F/M are compared with the results of the model without uncertainty in the survey index. Comparisons are expressed as the percentage change in the percentiles for each output variable for each year (Tables 2-5). Second, the effects of increased uncertainty on the risk of overfishing (ie falling below a candidate escapement threshold, or exceeding a candidate F/M threshold) are computed for each alternative quota. Probabilities are based on a summation of all simulated estimates across all years that fall above or below a threshold for each of the 37 catch levels (24,000 to 60,000 mt). The ratio of the revised probabilities to the original probabilities is a measure of the increased risks of violating a threshold Results are summarized in Tables 6 to 8.

4.1 Effects on Individual Years

The percentage changes in the 1^{st} ,5^{th} , 50^{th}, 95^{th}, and 99^{th} percentiles for Initial Biomass (B.0), total season fishing mortality (F), Escapement (Esc) and F/M are summarized for each year in Tables 2-6. The net effect of the uncertainty in survey biomass is to broaden the distributions of the B.0, F, Esc and

F/M. The percentage changes are greatest in the tails of the distributions. The differences in percentiles, averaged over all years are summarized in Figure 2. For example, the 5th percentile of initial biomass was 6.6% lower when uncertainty in survey biomass was considered; the 95th percentile was 5.5% higher (Figure 2A). The effects of survey uncertainty were less symmetrical for F, Esc and F/M. This is expected since these quantities involve logarithmic transformations. Season-long fishing mortalities increase at the higher percentiles because a higher rate of fishing is required to support the same catch taken from the lower biomass levels (Fig. 2B). The F/M plot shows the same pattern as F (Figure 2D). Percentage reductions in Esc are greatest as the lower percentiles (Figure 2C) since escapement is defined as e^{-F}.

Figure 2 summarizes the average effect over all years. The magnitude of the differences between the original and revised methods increases with the relative precision (i.e., coefficient of variation CV) of the fall survey index (Table 1A). Increases in CV "flatten" the distributions of B.0, F, Esc and F/M, thereby increasing the width of the confidence intervals. The percentage change in the revised confidence interval width to the original confidence interval is depicted in Figure 3 for B.0 and Figure 4 for Esc. Each point represents a single year. CVs above 40% result in a sharp increase in CI width for both variables.

4.2 Risk of Alternative Quotas Over All Years

The overall effect of increased uncertainty in survey biomass is to increase the probabilities of falling below an escapement threshold or exceeding a F/M threshold. Tables 6 to 8 evaluate the changes for falling below escapement thresholds {0.35, 0.40, 0.50, 0.6, 0.75} (Table 6), exceeding F/M thresholds {0.33, 0.5, 0.66, 1.0, 1.5}(Table 7) and the joint probability of falling below each of the escapement thresholds AND exceeding F/M=0.66 (Table 8). In March and July, 2022 the SSC recommended an ABC of 40,000 mt for 2023. The probability of falling below Escapement thresholds (Table 6) were:

Escapement Threshold	0.35	0.40	0.5	0.6	0.75
Probability	0.0384	0.0657	0.1519	0.2802	0.5575

The inclusion of uncertainty in survey biomass increased these probabilities to:

Escapement Threshold	0.35	0.40	0.5	0.6	0.75
Probability	0.0437	0.0731	0.1620	0.2912	0.5641

The ratio of these probabilities is

Escapement Threshold	0.35	0.40	0.5	0.6	0.75
Probability	1.1392	1.1130	1.066	1.0392	1.0118

The percentage changes are greatest at the lowest threshold levels but the overall risk of overfishing is small.

Similar negligible changes in risks of overfishing can be seen for F/M (Table 7), and for the joint risk of violating escapement and F/M thresholds (Table 8).

In terms of the Mid Atlantic Council's Risk Policy, none of the quotas between 24,000 and 60,000 mt would violate the policy IF the stock was assumed to be at Bmsy or greater. The Rago (2022) report noted:

> *"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."*

Applying the same logic to the updated analyses herein, all of the quotas result in overfishing probabilities below 0.45 for escapement thresholds up to 60% when the stock is assumed to be near Bmsy. If the stock is, at say 50% of Bmsy, then the overfishing risk of 20% at an Escapement threshold of 0.5 would result in a quota of 46,000 mt (versus 47,000 mt in the 2022 report). Applying the most restrictive overfishing definition of having escapement exceed 50% and F/M <0.66 leads to a quota of 37,000 mt. It should be noted that type of joint threshold model has not been applied in any fishery of which I am aware.

5.0 References

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. 2022. Evaluation of Alternative Catch Limits for Illex in 2022. Report to Mid-Atlantic Fishery Management Council Scientific and Statistical Committee. . MidAtlantic Fishery Management Council. March 8, 2022.

Rago, P. J. 2023. 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. 87 pp. Report delivered to MAFMC and NEFSC, February 1, 2023.

Table 1. (A) Summary of swept area biomass estimates for Illex squid in NEFSC spring and fall bottom trawl surveys, and USA landings, 1997-2021. (B) Summary of parameter ranges for q, v, M, and probability levels used to evaluate uncertainty in estimates of Fall Survey biomass.

(A)

Year	*Landings (mt)*	*Spring Survey (mt)*	*Fall Survey (mt)*	*CV Fall Survey (%)*
1997	14,358	511	2,730	17
1998	24,154	226	7,725	51
1999	8,482	149	929	16
2000	9,117	35	3,999	22
2001	4,475	110	1,422	15
2002	2,907	68	2,322	20
2003	6,557	23	10,913	68
2004	27,499	139	2,279	12
2005	13,861	14	3,696	46
2006	15,500	121	14,220	34
2007	9,661	147	7,311	8
2008	17,429	54	5,462	18
2009	19,090	404	5,170	20
2010	16,394	101	2,941	22
2011	19,487	294	2,937	18
2012	12,211	1,099	2,895	12
2013	4,107	22	1,827	13
2014	9,342	NA	3,592	11
2015	2,873	217	2,795	14
2016	7,004	2,641	3,711	26
2017	23,371	314	NA	NA
2018	25,524	382	7,146	13
2019	28,495	1,901	3,310	14
2020	not used	NA	NA	NA
2021	30,714	NA	3,531	17

(B)

	A	B	C	D	E
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					

Table 2 Estimated percentiles for initial biomass (mt) by year given observed catch and Fall Bottom Trawl Survey Biomass. Confidence Inteval width is 90%

(A) Includes uncertainty in catchability, availability, and M only. (B) Includes uncertainty in catchability, availability, M and Fall Survey Index. (C) Percentage change in Percentiles from scenario (A) to (B)

	(A) Original Analyses {q,v,M}					
	Percentile					90%CI
Year	*1%*	*5%*	*50%*	*95%*	*99%*	width
1997	38,717	49,453	185,723	827,290	1,302,851	777,837
1998	90,447	119,492	491,716	2,291,773	3,634,128	2,172,282
1999	17,286	21,200	70,404	292,095	454,671	270,895
2000	42,897	57,597	247,572	1,176,229	1,870,164	1,118,633
2001	16,683	22,036	90,570	421,949	669,056	399,913
2002	22,069	30,436	138,670	675,594	1,078,045	645,158
2003	95,429	133,978	636,952	3,153,136	5,043,164	3,019,158
2004	49,962	60,024	185,940	736,078	1,136,097	676,054
2005	45,982	60,047	240,044	1,103,850	1,746,282	1,043,803
2006	132,472	183,477	844,856	4,129,800	6,594,388	3,946,324
2007	70,075	96,451	437,739	2,128,825	3,395,985	2,032,374
2008	64,367	84,952	348,369	1,621,446	2,570,678	1,536,494
2009	63,968	83,639	335,164	1,543,213	2,441,738	1,459,574
2010	42,783	54,403	201,850	894,134	1,406,623	839,731
2011	46,323	58,125	207,939	902,171	1,414,560	844,047
2012	37,589	48,682	190,867	868,604	1,372,251	819,922
2013	19,531	26,243	112,984	537,195	854,219	510,952
2014	39,853	53,183	224,777	1,060,072	1,683,614	1,006,889
2015	25,836	35,840	165,692	811,169	1,295,581	775,330
2016	38,055	51,597	226,736	1,087,174	1,730,689	1,035,577
2018	87,405	114,530	461,505	2,130,361	3,372,161	2,015,832
2019	59,635	73,425	247,376	1,035,568	1,614,499	962,143
2021	63,971	78,711	264,534	1,105,657	1,723,324	1,026,946
Average	52,667	69,457	285,130	1,327,539	2,104,555	1,258,081

	(B) Revised Analyses {q,v,M, CV(I_t)}					
	Percentile					90%CI
Year	*1%*	*5%*	*50%*	*95%*	*99%*	width
1997	36,936	47,606	185,199	865,375	1,391,943	817,769
1998	68,670	100,773	461,803	2,511,512	4,309,863	2,410,739
1999	16,659	20,539	70,284	305,065	484,055	284,527
2000	39,716	54,571	245,669	1,235,322	2,019,005	1,180,751
2001	15,880	21,181	90,438	441,055	712,910	419,874
2002	20,474	28,830	137,883	708,998	1,160,249	680,168
2003	38,093	81,196	555,374	3,620,695	6,441,818	3,539,499
2004	48,560	58,474	185,866	766,910	1,202,999	708,436
2005	37,365	52,649	228,845	1,195,665	2,031,464	1,143,016
2006	112,292	165,629	823,876	4,395,210	7,367,541	4,229,581
2007	67,191	93,137	438,818	2,220,827	3,594,807	2,127,690
2008	60,798	81,274	347,123	1,696,752	2,754,724	1,615,479
2009	60,209	79,882	333,176	1,616,953	2,624,473	1,537,070
2010	40,379	52,028	200,551	937,797	1,515,733	885,769
2011	44,257	56,041	207,244	943,577	1,513,930	887,536
2012	36,093	47,085	190,855	906,125	1,456,294	859,040
2013	18,594	25,256	112,956	561,099	908,174	535,843
2014	38,171	51,336	224,932	1,106,103	1,785,947	1,054,768
2015	24,409	34,331	165,564	848,404	1,381,160	814,073
2016	34,526	48,299	223,883	1,145,734	1,888,454	1,097,435
2018	83,637	110,417	461,407	2,224,021	3,582,213	2,113,603
2019	57,584	71,257	247,196	1,080,734	1,715,310	1,009,477
2021	61,539	76,167	263,892	1,155,825	1,838,988	1,079,657
Average	46,175	63,390	278,384	1,412,598	2,334,002	1,349,209

	(C) % Difference between Original and Revised						
	Percentile					% DIF CI	CV of
Year	*1%*	*5%*	*50%*	*95%*	*99%*	widths	Survey
1997	-4.6	-3.7	-0.3	4.6	6.8	5.1	17
1998	-24.1	-15.7	-6.1	9.6	18.6	11.0	51
1999	-3.6	-3.1	-0.2	4.4	6.5	5.0	16
2000	-7.4	-5.3	-0.8	5.0	8.0	5.6	22
2001	-4.8	-3.9	-0.1	4.5	6.6	5.0	15
2002	-7.2	-5.3	-0.6	4.9	7.6	5.4	20
2003	-60.1	-39.4	-12.8	14.8	27.7	17.2	68
2004	-2.8	-2.6	0.0	4.2	5.9	4.8	12
2005	-18.7	-12.3	-4.7	8.3	16.3	9.5	46
2006	-15.2	-9.7	-2.5	6.4	11.7	7.2	34
2007	-4.1	-3.4	0.2	4.3	5.9	4.7	8
2008	-5.5	-4.3	-0.4	4.6	7.2	5.1	18
2009	-5.9	-4.5	-0.6	4.8	7.5	5.3	20
2010	-5.6	-4.4	-0.6	4.9	7.8	5.5	22
2011	-4.5	-3.6	-0.3	4.6	7.0	5.2	18
2012	-4.0	-3.3	0.0	4.3	6.1	4.8	12
2013	-4.8	-3.8	0.0	4.4	6.3	4.9	13
2014	-4.2	-3.5	0.1	4.3	6.1	4.8	11
2015	-5.5	-4.2	-0.1	4.6	6.6	5.0	14
2016	-9.3	-6.4	-1.3	5.4	9.1	6.0	26
2018	-4.3	-3.6	0.0	4.4	6.2	4.9	13
2019	-3.4	-3.0	-0.1	4.4	6.2	4.9	14
2021	-3.8	-3.2	-0.2	4.5	6.7	5.1	17
Average	-9.3	-6.6	-1.4	5.5	8.9	6.2	

Table 3 Estimated percentiles for seasonal F by year given observed catch and Fall Bottom Trawl Survey Biomass. Confidence Inteval width is 90%

(A) Includes uncertainty in catchability, availability, and M only. (B) Includes uncertainty in catchability, availability, M and Fall Survey Index. (C) Percentage change in Percentiles from scenario (A) to

	(A) Original Analyses {q,v,M}					
	Percentile					*90% CI*
Year	*1%*	*5%*	*50%*	*95%*	*99%*	*width*
1997	0.035	0.053	0.172	0.460	0.577	0.407
1998	0.021	0.032	0.107	0.300	0.383	0.268
1999	0.060	0.090	0.279	0.695	0.851	0.604
2000	0.016	0.024	0.079	0.228	0.294	0.205
2001	0.021	0.032	0.107	0.302	0.385	0.270
2002	0.009	0.013	0.044	0.132	0.173	0.119
2003	0.004	0.006	0.022	0.066	0.087	0.060
2004	0.079	0.117	0.351	0.840	1.016	0.723
2005	0.025	0.038	0.126	0.350	0.444	0.311
2006	0.007	0.011	0.039	0.116	0.152	0.105
2007	0.009	0.014	0.047	0.139	0.181	0.125
2008	0.022	0.033	0.109	0.306	0.389	0.273
2009	0.025	0.038	0.125	0.345	0.439	0.308
2010	0.038	0.056	0.181	0.482	0.602	0.425
2011	0.044	0.067	0.212	0.550	0.684	0.484
2012	0.029	0.043	0.141	0.385	0.487	0.342
2013	0.015	0.023	0.078	0.225	0.290	0.202
2014	0.018	0.027	0.090	0.256	0.329	0.229
2015	0.007	0.011	0.037	0.110	0.144	0.099
2016	0.013	0.020	0.066	0.193	0.249	0.173
2018	0.024	0.037	0.121	0.336	0.427	0.299
2019	0.057	0.085	0.265	0.666	0.818	0.581
2021	0.058	0.086	0.268	0.671	0.824	0.585
Average	0.028	0.042	0.133	0.355	0.445	0.313

	(B) Revised Analyses {q,v,M, CV(I_t)}					
	Percentile					*90% CI*
Year	*1%*	*5%*	*50%*	*95%*	*99%*	*width*
1997	0.033	0.051	0.173	0.477	0.607	0.426
1998	0.018	0.029	0.113	0.383	0.571	0.354
1999	0.057	0.087	0.279	0.716	0.887	0.629
2000	0.014	0.023	0.080	0.241	0.320	0.218
2001	0.020	0.031	0.108	0.312	0.404	0.281
2002	0.008	0.013	0.045	0.139	0.187	0.127
2003	0.003	0.005	0.024	0.128	0.271	0.123
2004	0.075	0.113	0.351	0.859	1.047	0.746
2005	0.022	0.035	0.133	0.422	0.603	0.386
2006	0.007	0.011	0.040	0.131	0.185	0.120
2007	0.009	0.013	0.047	0.143	0.187	0.129
2008	0.020	0.032	0.109	0.318	0.414	0.287
2009	0.023	0.036	0.125	0.362	0.469	0.325
2010	0.035	0.054	0.183	0.505	0.647	0.451
2011	0.042	0.064	0.212	0.571	0.720	0.507
2012	0.027	0.042	0.141	0.396	0.505	0.355
2013	0.015	0.022	0.078	0.233	0.303	0.210
2014	0.017	0.026	0.090	0.263	0.341	0.237
2015	0.007	0.010	0.037	0.114	0.151	0.104
2016	0.012	0.019	0.067	0.207	0.279	0.188
2018	0.023	0.035	0.121	0.346	0.445	0.311
2019	0.054	0.082	0.265	0.685	0.849	0.602
2021	0.054	0.083	0.268	0.693	0.862	0.610
Average	0.026	0.040	0.134	0.376	0.489	0.336

	(C) % Difference between Original and Revised					
	Percentile					% DIF CI
Year	*1%*	*5%*	*50%*	*95%*	*99%*	widths
1997	-5.9	-3.9	0.3	3.6	5.2	4.6
1998	-16.4	-9.4	6.0	27.4	49.0	31.9
1999	-5.6	-3.7	0.2	3.0	4.3	4.0
2000	-7.1	-4.4	0.8	5.6	8.7	6.8
2001	-5.6	-3.7	0.1	3.5	5.1	4.3
2002	-6.5	-4.2	0.6	5.2	8.0	6.2
2003	-22.6	-14.1	11.0	94.5	212.4	106.0
2004	-4.9	-3.4	-0.1	2.2	3.0	3.1
2005	-14.6	-8.2	4.8	20.5	35.7	24.0
2006	-10.5	-6.0	2.5	12.2	21.6	14.2
2007	-4.7	-3.5	-0.3	2.4	3.2	3.1
2008	-6.1	-4.0	0.4	4.2	6.3	5.2
2009	-6.4	-4.1	0.6	4.7	7.0	5.8
2010	-6.9	-4.3	0.7	4.9	7.5	6.2
2011	-6.0	-3.9	0.3	3.7	5.3	4.8
2012	-5.1	-3.6	0.0	2.8	3.7	3.6
2013	-5.3	-3.7	0.0	3.1	4.5	3.9
2014	-5.0	-3.5	-0.1	2.7	3.8	3.5
2015	-5.4	-3.7	0.1	3.5	5.1	4.3
2016	-8.0	-4.8	1.3	7.2	12.0	8.6
2018	-5.2	-3.6	0.0	3.1	4.2	3.9
2019	-5.2	-3.5	0.0	2.7	3.7	3.7
2021	-5.7	-3.8	0.3	3.3	4.7	4.3
Average	-7.60	-4.82	1.28	9.84	18.43	11.56

Table 4. Estimated percentiles for Escapement by year given observed catch and Fall Bottom Trawl Survey Biomass. Confidence Inteval width is 90%

(A) Includes uncertainty in catchability, availability, and M only. (B) Includes uncertainty in catchability, availability, M and Fall Survey Index. (C) Percentage change in Percentiles from scenario (A) to (B)

(A) Original Analyses {q,v,M}

	Percentile					*90% CI*
Year	*1%*	*5%*	*50%*	*95%*	*99%*	*width*
1997	0.562	0.631	0.842	0.948	0.965	0.317
1998	0.682	0.741	0.899	0.968	0.979	0.228
1999	0.427	0.499	0.757	0.914	0.941	0.415
2000	0.745	0.796	0.924	0.977	0.985	0.181
2001	0.680	0.739	0.898	0.968	0.979	0.229
2002	0.841	0.876	0.956	0.987	0.991	0.111
2003	0.917	0.936	0.979	0.994	0.996	0.058
2004	0.362	0.432	0.704	0.890	0.924	0.458
2005	0.641	0.705	0.881	0.962	0.975	0.258
2006	0.859	0.890	0.962	0.989	0.993	0.098
2007	0.834	0.870	0.954	0.986	0.991	0.116
2008	0.677	0.737	0.897	0.968	0.979	0.231
2009	0.645	0.708	0.883	0.963	0.975	0.255
2010	0.548	0.618	0.834	0.945	0.963	0.327
2011	0.505	0.577	0.809	0.935	0.957	0.359
2012	0.614	0.680	0.869	0.958	0.972	0.278
2013	0.748	0.798	0.925	0.977	0.985	0.179
2014	0.720	0.774	0.914	0.973	0.982	0.200
2015	0.866	0.896	0.964	0.989	0.993	0.094
2016	0.779	0.825	0.936	0.981	0.987	0.156
2018	0.653	0.715	0.886	0.964	0.976	0.249
2019	0.441	0.514	0.767	0.918	0.944	0.405
2021	0.439	0.511	0.765	0.917	0.944	0.406
Average	0.660	0.716	0.878	0.960	0.973	0.244

(B) Revised Analyses {q,v,M, CV(I_t)}

	Percentile					*90% CI*
Year	*1%*	*5%*	*50%*	*95%*	*99%*	*width*
1997	0.545	0.621	0.841	0.950	0.967	0.329
1998	0.565	0.682	0.893	0.971	0.982	0.289
1999	0.412	0.489	0.756	0.917	0.945	0.428
2000	0.726	0.786	0.923	0.978	0.986	0.192
2001	0.667	0.732	0.898	0.969	0.980	0.238
2002	0.830	0.870	0.956	0.988	0.992	0.118
2003	0.762	0.880	0.976	0.995	0.997	0.115
2004	0.351	0.424	0.704	0.893	0.928	0.470
2005	0.547	0.656	0.876	0.965	0.978	0.309
2006	0.831	0.878	0.961	0.989	0.993	0.112
2007	0.829	0.867	0.954	0.987	0.991	0.120
2008	0.661	0.727	0.897	0.969	0.980	0.242
2009	0.625	0.697	0.882	0.964	0.977	0.268
2010	0.524	0.603	0.833	0.947	0.966	0.344
2011	0.487	0.565	0.809	0.938	0.959	0.373
2012	0.603	0.673	0.869	0.959	0.973	0.286
2013	0.738	0.793	0.925	0.978	0.986	0.185
2014	0.711	0.769	0.914	0.974	0.983	0.206
2015	0.860	0.892	0.964	0.990	0.993	0.097
2016	0.756	0.813	0.935	0.981	0.988	0.168
2018	0.641	0.707	0.886	0.965	0.977	0.258
2019	0.428	0.504	0.767	0.921	0.947	0.417
2021	0.422	0.500	0.765	0.920	0.947	0.420
Average	0.631	0.701	0.878	0.961	0.975	0.260

(C) % Difference between Original and Revised

	Percentile					%DIF CI
Year	*1%*	*5%*	*50%*	*95%*	*99%*	Width
1997	-3.0	-1.7	-0.1	0.2	0.2	3.9
1998	-17.1	-7.9	-0.6	0.3	0.3	27.0
1999	-3.6	-2.1	0.0	0.3	0.3	3.2
2000	-2.5	-1.3	-0.1	0.1	0.1	6.2
2001	-1.9	-1.0	0.0	0.1	0.1	3.9
2002	-1.4	-0.7	0.0	0.1	0.1	5.9
2003	-16.8	-6.0	-0.2	0.1	0.1	99.9
2004	-3.0	-1.9	0.0	0.4	0.4	2.5
2005	-14.7	-6.9	-0.6	0.3	0.4	20.1
2006	-3.2	-1.4	-0.1	0.1	0.1	13.4
2007	-0.6	-0.3	0.0	0.0	0.0	2.9
2008	-2.4	-1.3	0.0	0.1	0.1	4.6
2009	-3.0	-1.6	-0.1	0.2	0.2	5.0
2010	-4.4	-2.3	-0.1	0.2	0.3	5.1
2011	-3.6	-2.0	-0.1	0.3	0.3	4.0
2012	-1.8	-1.1	0.0	0.2	0.1	3.1
2013	-1.3	-0.7	0.0	0.1	0.1	3.6
2014	-1.2	-0.7	0.0	0.1	0.1	3.2
2015	-0.7	-0.4	0.0	0.0	0.0	4.1
2016	-2.9	-1.4	-0.1	0.1	0.1	7.9
2018	-1.8	-1.0	0.0	0.1	0.1	3.5
2019	-3.0	-1.8	0.0	0.3	0.3	3.0
2021	-3.8	-2.2	-0.1	0.3	0.3	3.5
Average	-4.25	-2.07	-0.10	0.18	0.18	10.42

Table 5 Estimated percentiles for F/M ratio by year given observed catch and Fall Bottom Trawl Survey Biomass. Confidence Inteval width is 90%

(A) Includes uncertainty in catchability, availability, and M only. (B) Includes uncertainty in catchability, availability, M and Fall Survey Index. (C) Percentage change in Percentiles from scenario (A) to (I

	(A) Original Analyses {q,v,M}					
	Percentile					***90% CI***
Year	***1%***	***5%***	***50%***	***95%***	***99%***	***width***
1997	0.012	0.019	0.101	1.035	1.854	1.017
1998	0.007	0.011	0.063	0.668	1.217	0.657
1999	0.020	0.032	0.163	1.584	2.778	1.553
2000	0.005	0.008	0.047	0.506	0.927	0.497
2001	0.007	0.011	0.063	0.672	1.223	0.660
2002	0.003	0.005	0.026	0.291	0.540	0.287
2003	0.001	0.002	0.013	0.145	0.270	0.142
2004	0.026	0.041	0.205	1.932	3.345	1.891
2005	0.008	0.013	0.074	0.782	1.417	0.768
2006	0.002	0.004	0.023	0.256	0.475	0.252
2007	0.003	0.005	0.028	0.306	0.567	0.301
2008	0.007	0.012	0.064	0.680	1.238	0.668
2009	0.008	0.013	0.073	0.771	1.398	0.758
2010	0.012	0.020	0.106	1.085	1.939	1.065
2011	0.015	0.023	0.124	1.244	2.208	1.221
2012	0.009	0.015	0.083	0.863	1.557	0.848
2013	0.005	0.008	0.046	0.499	0.915	0.491
2014	0.006	0.009	0.053	0.569	1.039	0.559
2015	0.002	0.004	0.022	0.242	0.450	0.238
2016	0.004	0.007	0.039	0.426	0.783	0.419
2018	0.008	0.013	0.071	0.750	1.360	0.737
2019	0.019	0.030	0.155	1.516	2.666	1.487
2021	0.019	0.030	0.157	1.528	2.685	1.498
Average	0.009	0.015	0.078	0.798	1.428	0.783

	(B) Revised Analyses {q,v,M, CV(I_t)}					
	Percentile					***90% CI***
Year	***1%***	***5%***	***50%***	***95%***	***99%***	***width***
1997	0.011	0.018	0.102	1.166	2.153	1.148
1998	0.006	0.010	0.068	0.836	1.664	0.826
1999	0.019	0.030	0.164	1.783	3.205	1.753
2000	0.005	0.008	0.047	0.576	1.093	0.568
2001	0.007	0.011	0.063	0.756	1.421	0.745
2002	0.003	0.004	0.026	0.331	0.636	0.327
2003	0.001	0.002	0.015	0.224	0.568	0.222
2004	0.024	0.039	0.205	2.169	3.835	2.129
2005	0.007	0.012	0.079	0.951	1.842	0.938
2006	0.002	0.004	0.024	0.301	0.590	0.298
2007	0.003	0.005	0.028	0.342	0.656	0.338
2008	0.007	0.011	0.064	0.769	1.444	0.758
2009	0.008	0.013	0.074	0.874	1.635	0.861
2010	0.011	0.019	0.107	1.231	2.270	1.212
2011	0.014	0.022	0.125	1.404	2.565	1.382
2012	0.009	0.014	0.083	0.967	1.800	0.952
2013	0.005	0.008	0.046	0.560	1.063	0.553
2014	0.006	0.009	0.053	0.637	1.203	0.628
2015	0.002	0.004	0.022	0.272	0.523	0.269
2016	0.004	0.007	0.040	0.490	0.937	0.483
2018	0.008	0.012	0.071	0.841	1.575	0.829
2019	0.018	0.029	0.156	1.704	3.071	1.676
2021	0.018	0.029	0.157	1.722	3.106	1.693
Average	0.008	0.014	0.079	0.909	1.689	0.895

	(C) % Difference between Original and Revised					
	Percentile					**% DIF CI**
Year	***1%***	***5%***	***50%***	***95%***	***99%***	**widths**
1997	-6.6	-4.6	0.5	12.6	16.1	12.9
1998	-15.8	-8.7	8.1	25.2	36.8	25.8
1999	-6.4	-4.5	0.3	12.5	15.4	12.9
2000	-7.5	-5.0	1.1	13.9	18.0	14.2
2001	-6.3	-4.5	0.3	12.6	16.2	12.9
2002	-7.1	-4.9	0.8	13.7	17.7	14.0
2003	-21.5	-12.7	19.2	54.6	110.3	55.7
2004	-5.8	-4.3	0.1	12.2	14.7	12.6
2005	-14.1	-7.8	6.2	21.6	30.0	22.2
2006	-10.5	-6.1	3.2	17.9	24.2	18.3
2007	-5.6	-4.4	-0.1	11.8	15.7	12.0
2008	-6.8	-4.7	0.6	13.1	16.7	13.4
2009	-7.1	-4.8	0.8	13.3	17.0	13.6
2010	-7.4	-4.9	0.9	13.5	17.1	13.8
2011	-6.7	-4.7	0.5	12.9	16.2	13.2
2012	-6.0	-4.4	0.1	12.0	15.6	12.3
2013	-6.0	-4.5	0.2	12.3	16.1	12.5
2014	-5.9	-4.4	0.0	12.0	15.8	12.2
2015	-6.2	-4.6	0.3	12.6	16.3	12.8
2016	-8.3	-5.3	1.6	14.9	19.6	15.3
2018	-6.0	-4.4	0.1	12.2	15.8	12.5
2019	-6.1	-4.4	0.2	12.4	15.2	12.7
2021	-6.6	-4.6	0.4	12.7	15.6	13.0
Average	-8.1	-5.4	2.0	15.8	22.3	16.1

Table 6 Estimated probabilities of falling below Escapement thresholds based on alternative quota values. Probabilities are averaged across all years (1997-2021, 2022 excluded).
(A) Includes uncertainty in catchability, availability and M only. (B) Includes uncertainty in catchability, availability, M, and Fall Survey Index. (C) Ratio of probabilities in scenario (A) to (B).

	Original Analyses {q,v,M}				
Alternative	*Escapement Threshold*				
Quota (mt)	***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
Average	0.0471	0.0765	0.1640	0.2911	0.5615

	Revised Analyes {q,v,M, CV(I_t)}				
Alternative	*Escapement Threshold*				
Quota (mt)	***0.35***	***0.4***	***0.5***	***0.6***	***0.75***
24000	0.0111	0.0206	0.0596	0.1391	0.3658
25000	0.0125	0.0230	0.0654	0.1492	0.3812
26000	0.0140	0.0255	0.0714	0.1593	0.3961
27000	0.0155	0.0282	0.0775	0.1693	0.4106
28000	0.0172	0.0310	0.0837	0.1793	0.4247
29000	0.0189	0.0340	0.0901	0.1892	0.4383
30000	0.0207	0.0371	0.0965	0.1990	0.4515
31000	0.0227	0.0403	0.1029	0.2087	0.4644
32000	0.0247	0.0435	0.1094	0.2183	0.4768
33000	0.0268	0.0470	0.1160	0.2278	0.4889
34000	0.0289	0.0504	0.1225	0.2372	0.5006
35000	0.0312	0.0541	0.1291	0.2465	0.5120
36000	0.0336	0.0577	0.1357	0.2557	0.5231
37000	0.0360	0.0615	0.1423	0.2647	0.5338
38000	0.0385	0.0653	0.1489	0.2737	0.5442
39000	0.0411	0.0692	0.1554	0.2825	0.5543
40000	0.0437	0.0731	0.1620	0.2912	0.5641
41000	0.0465	0.0771	0.1685	0.2997	0.5736
42000	0.0492	0.0812	0.1750	0.3082	0.5829
43000	0.0521	0.0853	0.1815	0.3165	0.5919
44000	0.0550	0.0894	0.1879	0.3247	0.6007
45000	0.0579	0.0935	0.1943	0.3328	0.6091
46000	0.0609	0.0977	0.2007	0.3408	0.6174
47000	0.0640	0.1019	0.2070	0.3486	0.6255
48000	0.0670	0.1062	0.2133	0.3564	0.6332
49000	0.0702	0.1104	0.2195	0.3640	0.6408
50000	0.0733	0.1146	0.2257	0.3715	0.6482
51000	0.0765	0.1189	0.2319	0.3789	0.6554
52000	0.0797	0.1232	0.2380	0.3862	0.6623
53000	0.0830	0.1275	0.2440	0.3934	0.6691
54000	0.0862	0.1318	0.2500	0.4005	0.6757
55000	0.0895	0.1360	0.2559	0.4074	0.6821
56000	0.0928	0.1403	0.2618	0.4143	0.6884
57000	0.0962	0.1446	0.2677	0.4211	0.6945
58000	0.0995	0.1489	0.2735	0.4277	0.7004
59000	0.1029	0.1531	0.2792	0.4343	0.7062
60000	0.1062	0.1574	0.2849	0.4408	0.7118
Average	0.0526	0.0838	0.1738	0.3016	0.5676

	Ratio of Revised to Original Probabilities				
Alternative	*Escapement Threshold*				
Quota (mt)	***0.35***	***0.4***	***0.5***	***0.6***	***0.75***
24000	1.1432	1.1462	1.1237	1.0746	1.0301
25000	1.1436	1.1470	1.1190	1.0705	1.0284
26000	1.1435	1.1472	1.1144	1.0671	1.0268
27000	1.1448	1.1472	1.1096	1.0644	1.0252
28000	1.1465	1.1462	1.1045	1.0611	1.0238
29000	1.1473	1.1457	1.1007	1.0586	1.0225
30000	1.1486	1.1438	1.0965	1.0560	1.0212
31000	1.1479	1.1416	1.0924	1.0539	1.0201
32000	1.1484	1.1388	1.0889	1.0517	1.0189
33000	1.1482	1.1359	1.0856	1.0499	1.0179
34000	1.1478	1.1322	1.0823	1.0482	1.0169
35000	1.1473	1.1295	1.0789	1.0463	1.0160
36000	1.1464	1.1258	1.0758	1.0446	1.0150
37000	1.1450	1.1229	1.0733	1.0432	1.0141
38000	1.1435	1.1194	1.0711	1.0418	1.0134
39000	1.1414	1.1162	1.0685	1.0404	1.0125
40000	1.1392	1.1130	1.0666	1.0392	1.0118
41000	1.1371	1.1099	1.0643	1.0380	1.0111
42000	1.1344	1.1068	1.0622	1.0369	1.0104
43000	1.1314	1.1038	1.0606	1.0357	1.0097
44000	1.1290	1.1011	1.0588	1.0347	1.0092
45000	1.1259	1.0983	1.0571	1.0337	1.0085
46000	1.1238	1.0955	1.0556	1.0327	1.0079
47000	1.1212	1.0933	1.0545	1.0319	1.0074
48000	1.1181	1.0906	1.0528	1.0310	1.0068
49000	1.1156	1.0883	1.0514	1.0301	1.0064
50000	1.1133	1.0861	1.0502	1.0292	1.0059
51000	1.1105	1.0835	1.0489	1.0285	1.0055
52000	1.1081	1.0815	1.0478	1.0276	1.0051
53000	1.1058	1.0796	1.0467	1.0267	1.0048
54000	1.1037	1.0777	1.0455	1.0262	1.0044
55000	1.1008	1.0760	1.0447	1.0254	1.0040
56000	1.0987	1.0741	1.0437	1.0248	1.0037
57000	1.0967	1.0725	1.0428	1.0240	1.0034
58000	1.0943	1.0709	1.0418	1.0233	1.0031
59000	1.0923	1.0695	1.0410	1.0227	1.0028
60000	1.0906	1.0679	1.0401	1.0221	1.0026
Average	1.1277	1.1088	1.0692	1.0404	1.0124

TABLE 7. Estimated probabilities of exceeding F/M ratio thresholds based on alternative quota values. Probabilities are averaged across all years (1997-2021, 2022 excluded).
(A) Includes uncertainty in catchability, availability and M only. (B) Includes uncertainty in catchability, availability, M, and Fall Survey Index. (C) Ratio of probabilities in scenario (A) to (B).

	(A) Original Analyses {q,v,M}				
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
Average	0.3596	0.2620	0.2033	0.1333	0.0790

	(B) Revised Analyes {q,v,M, CV(I_t)}				
Alternative	*F/M Threshold*				
Quota (mt)	***0.33***	***0.5***	***0.666***	***1***	***1.5***
24000	0.2715	0.1924	0.1461	0.0924	0.0520
25000	0.2785	0.1980	0.1509	0.0960	0.0545
26000	0.2852	0.2035	0.1555	0.0995	0.0570
27000	0.2917	0.2088	0.1601	0.1029	0.0595
28000	0.2980	0.2140	0.1645	0.1063	0.0620
29000	0.3042	0.2191	0.1688	0.1096	0.0644
30000	0.3102	0.2240	0.1730	0.1128	0.0667
31000	0.3160	0.2288	0.1771	0.1160	0.0690
32000	0.3217	0.2335	0.1811	0.1191	0.0713
33000	0.3273	0.2381	0.1851	0.1221	0.0735
34000	0.3327	0.2426	0.1889	0.1251	0.0757
35000	0.3380	0.2470	0.1927	0.1280	0.0778
36000	0.3432	0.2513	0.1964	0.1309	0.0799
37000	0.3483	0.2555	0.2000	0.1337	0.0820
38000	0.3533	0.2597	0.2035	0.1365	0.0840
39000	0.3582	0.2637	0.2070	0.1392	0.0861
40000	0.3629	0.2677	0.2104	0.1418	0.0880
41000	0.3676	0.2716	0.2138	0.1445	0.0900
42000	0.3722	0.2754	0.2171	0.1470	0.0919
43000	0.3766	0.2792	0.2203	0.1496	0.0938
44000	0.3810	0.2829	0.2235	0.1521	0.0956
45000	0.3854	0.2865	0.2266	0.1545	0.0975
46000	0.3896	0.2900	0.2297	0.1569	0.0993
47000	0.3938	0.2935	0.2327	0.1593	0.1011
48000	0.3979	0.2969	0.2357	0.1617	0.1029
49000	0.4019	0.3003	0.2386	0.1640	0.1046
50000	0.4059	0.3037	0.2415	0.1662	0.1063
51000	0.4098	0.3069	0.2444	0.1685	0.1080
52000	0.4136	0.3102	0.2471	0.1707	0.1096
53000	0.4173	0.3133	0.2499	0.1728	0.1113
54000	0.4210	0.3165	0.2526	0.1750	0.1129
55000	0.4247	0.3195	0.2553	0.1771	0.1145
56000	0.4283	0.3226	0.2579	0.1792	0.1161
57000	0.4318	0.3255	0.2605	0.1812	0.1177
58000	0.4353	0.3285	0.2631	0.1833	0.1192
59000	0.4387	0.3314	0.2656	0.1853	0.1207
60000	0.4421	0.3343	0.2681	0.1872	0.1222
Average	0.3669	0.2713	0.2137	0.1445	0.0902

	(C) Ratio of Revised to Original Probabilities				
Alternative	*F/M Threshold*				
Quota (mt)	***0.33***	***0.5***	***0.666***	***1***	***1.5***
24000	1.0366	1.0605	1.0855	1.1410	1.2377
25000	1.0351	1.0583	1.0821	1.1353	1.2290
26000	1.0337	1.0558	1.0789	1.1307	1.2208
27000	1.0325	1.0539	1.0762	1.1261	1.2135
28000	1.0311	1.0520	1.0736	1.1217	1.2070
29000	1.0300	1.0502	1.0711	1.1179	1.2010
30000	1.0290	1.0485	1.0688	1.1137	1.1943
31000	1.0279	1.0469	1.0668	1.1106	1.1887
32000	1.0270	1.0456	1.0647	1.1071	1.1832
33000	1.0260	1.0442	1.0628	1.1040	1.1780
34000	1.0253	1.0428	1.0611	1.1014	1.1732
35000	1.0244	1.0416	1.0594	1.0985	1.1684
36000	1.0237	1.0405	1.0578	1.0961	1.1641
37000	1.0229	1.0392	1.0564	1.0938	1.1600
38000	1.0222	1.0383	1.0549	1.0914	1.1561
39000	1.0216	1.0373	1.0535	1.0894	1.1523
40000	1.0210	1.0364	1.0523	1.0872	1.1488
41000	1.0204	1.0355	1.0510	1.0853	1.1453
42000	1.0198	1.0348	1.0499	1.0835	1.1420
43000	1.0192	1.0339	1.0489	1.0817	1.1389
44000	1.0188	1.0332	1.0479	1.0800	1.1363
45000	1.0183	1.0323	1.0468	1.0782	1.1335
46000	1.0178	1.0316	1.0458	1.0766	1.1310
47000	1.0173	1.0309	1.0449	1.0752	1.1282
48000	1.0169	1.0302	1.0439	1.0738	1.1260
49000	1.0165	1.0296	1.0430	1.0724	1.1233
50000	1.0160	1.0289	1.0421	1.0710	1.1213
51000	1.0156	1.0284	1.0413	1.0697	1.1191
52000	1.0152	1.0279	1.0406	1.0686	1.1170
53000	1.0149	1.0273	1.0398	1.0675	1.1151
54000	1.0144	1.0267	1.0391	1.0663	1.1130
55000	1.0141	1.0261	1.0383	1.0650	1.1115
56000	1.0139	1.0257	1.0377	1.0641	1.1097
57000	1.0135	1.0253	1.0371	1.0630	1.1079
58000	1.0132	1.0248	1.0365	1.0620	1.1061
59000	1.0128	1.0244	1.0359	1.0610	1.1047
60000	1.0125	1.0239	1.0354	1.0602	1.1031
Average	1.0214	1.0371	1.0533	1.0889	1.1516

Table 8. Estimated JOINT probability of falling below Escapement ***AND*** exceeding F/M=0.66 thresholds given alternative quota values. Probabilities are averaged across all years (1997-2021, 2022 excluded). (A) Includes uncertainty in catchability, availability and M only. (B) Includes uncertainty in catchability, availability, M, and Fall Survey Index. (C) Ratio of probabilities in scenario (A) to (B).

	Original Analyses {q,v,M}				
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
Average	0.0395	0.0582	0.0944	0.1188	0.1326

	Revised Analyes {q,v,M, CV(I_t)}				
Alternative	***Escapement Threshold***				
Quota (mt)	***0.35***	***0.4***	***0.5***	***0.6***	***0.75***
24000	0.0102	0.0172	0.0403	0.0668	0.0898
25000	0.0114	0.0191	0.0439	0.0709	0.0935
26000	0.0126	0.0211	0.0476	0.0749	0.0971
27000	0.0140	0.0232	0.0513	0.0789	0.1007
28000	0.0154	0.0254	0.0550	0.0828	0.1041
29000	0.0168	0.0277	0.0588	0.0866	0.1075
30000	0.0184	0.0301	0.0625	0.0904	0.1108
31000	0.0200	0.0326	0.0662	0.0941	0.1141
32000	0.0217	0.0352	0.0698	0.0977	0.1173
33000	0.0235	0.0378	0.0735	0.1012	0.1204
34000	0.0253	0.0405	0.0771	0.1047	0.1234
35000	0.0272	0.0433	0.0806	0.1081	0.1264
36000	0.0292	0.0461	0.0841	0.1115	0.1293
37000	0.0312	0.0490	0.0876	0.1148	0.1322
38000	0.0333	0.0519	0.0910	0.1181	0.1350
39000	0.0355	0.0548	0.0944	0.1213	0.1378
40000	0.0377	0.0577	0.0978	0.1244	0.1405
41000	0.0399	0.0606	0.1011	0.1275	0.1432
42000	0.0422	0.0636	0.1043	0.1305	0.1458
43000	0.0446	0.0666	0.1075	0.1335	0.1484
44000	0.0470	0.0695	0.1107	0.1364	0.1509
45000	0.0494	0.0725	0.1138	0.1393	0.1534
46000	0.0519	0.0755	0.1169	0.1421	0.1559
47000	0.0543	0.0784	0.1199	0.1448	0.1583
48000	0.0568	0.0814	0.1229	0.1476	0.1607
49000	0.0594	0.0843	0.1259	0.1502	0.1630
50000	0.0619	0.0872	0.1288	0.1529	0.1653
51000	0.0644	0.0901	0.1317	0.1554	0.1676
52000	0.0670	0.0929	0.1345	0.1580	0.1698
53000	0.0696	0.0958	0.1373	0.1605	0.1720
54000	0.0721	0.0987	0.1400	0.1629	0.1742
55000	0.0747	0.1015	0.1427	0.1653	0.1763
56000	0.0773	0.1043	0.1454	0.1677	0.1784
57000	0.0799	0.1070	0.1481	0.1701	0.1805
58000	0.0825	0.1098	0.1507	0.1724	0.1826
59000	0.0850	0.1125	0.1533	0.1746	0.1846
60000	0.0876	0.1152	0.1558	0.1769	0.1866
Average	0.0446	0.0643	0.1020	0.1274	0.1432

	Ratio of Revised to Original Probabilities				
Alternative	***Escapement Threshold***				
Quota (mt)	***0.35***	***0.4***	***0.5***	***0.6***	***0.75***
24000	1.1466	1.1638	1.1491	1.1106	1.1279
25000	1.1485	1.1665	1.1419	1.1066	1.1234
26000	1.1506	1.1688	1.1359	1.1042	1.1197
27000	1.1536	1.1687	1.1296	1.1016	1.1160
28000	1.1561	1.1680	1.1239	1.0989	1.1123
29000	1.1590	1.1673	1.1192	1.0969	1.1091
30000	1.1614	1.1656	1.1141	1.0939	1.1057
31000	1.1624	1.1631	1.1100	1.0923	1.1031
32000	1.1636	1.1591	1.1058	1.0901	1.1002
33000	1.1648	1.1557	1.1023	1.0882	1.0973
34000	1.1649	1.1509	1.0990	1.0863	1.0952
35000	1.1646	1.1467	1.0958	1.0848	1.0927
36000	1.1636	1.1422	1.0925	1.0832	1.0907
37000	1.1624	1.1381	1.0903	1.0818	1.0886
38000	1.1612	1.1338	1.0882	1.0800	1.0865
39000	1.1593	1.1298	1.0862	1.0787	1.0848
40000	1.1567	1.1252	1.0841	1.0772	1.0829
41000	1.1539	1.1212	1.0825	1.0760	1.0812
42000	1.1509	1.1173	1.0806	1.0746	1.0796
43000	1.1477	1.1135	1.0792	1.0734	1.0780
44000	1.1443	1.1100	1.0777	1.0721	1.0764
45000	1.1407	1.1063	1.0761	1.0707	1.0748
46000	1.1381	1.1032	1.0748	1.0695	1.0734
47000	1.1349	1.1006	1.0738	1.0685	1.0721
48000	1.1315	1.0974	1.0724	1.0673	1.0708
49000	1.1283	1.0946	1.0712	1.0663	1.0696
50000	1.1256	1.0922	1.0703	1.0654	1.0683
51000	1.1220	1.0894	1.0691	1.0640	1.0671
52000	1.1192	1.0870	1.0682	1.0630	1.0661
53000	1.1164	1.0849	1.0673	1.0621	1.0651
54000	1.1136	1.0832	1.0661	1.0611	1.0640
55000	1.1104	1.0814	1.0651	1.0599	1.0628
56000	1.1077	1.0794	1.0644	1.0592	1.0620
57000	1.1053	1.0777	1.0636	1.0582	1.0610
58000	1.1025	1.0764	1.0626	1.0574	1.0601
59000	1.1001	1.0751	1.0619	1.0566	1.0592
60000	1.0980	1.0731	1.0609	1.0557	1.0584
Average	1.1403	1.1210	1.0885	1.0772	1.0839

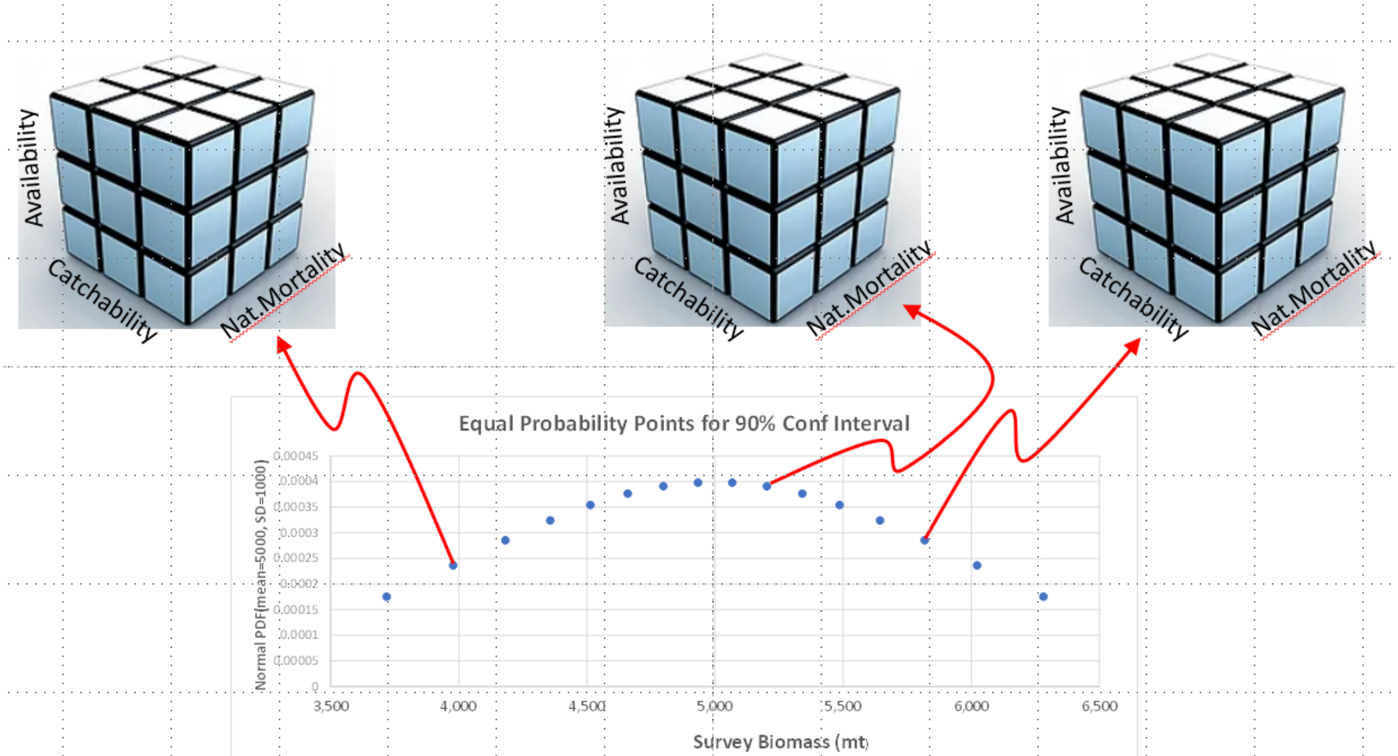

Figure 1. Schematic representation of the method used to estimate B.0, F, Escapement and F/M given uncertainty in the values of q, v, M, and Fall Survey Biomass. The parameters q, v, and M are assumed to be uniformly distributed. Mean Survey biomass is normally distributed and is evaluated at n values, each with equal probabilities over the 80% confidence interval.

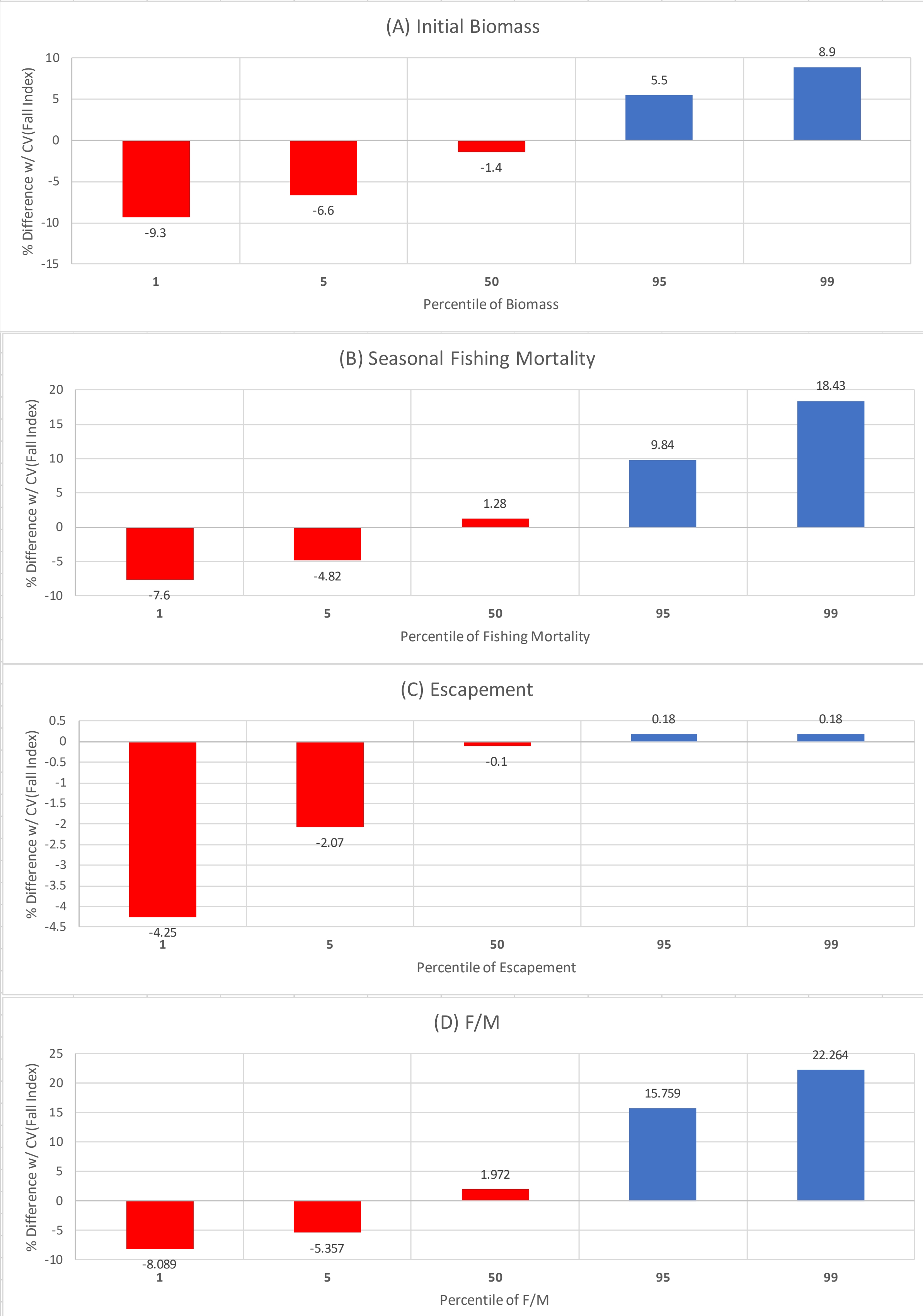

Figure 2. Summary of average percentage change in (A) Initial Biomass, (B) Fishing Mortality, (C) Escapement, and (D) F/M for selected percentiles of each variable. Averages are computed over the period 1997-2021.

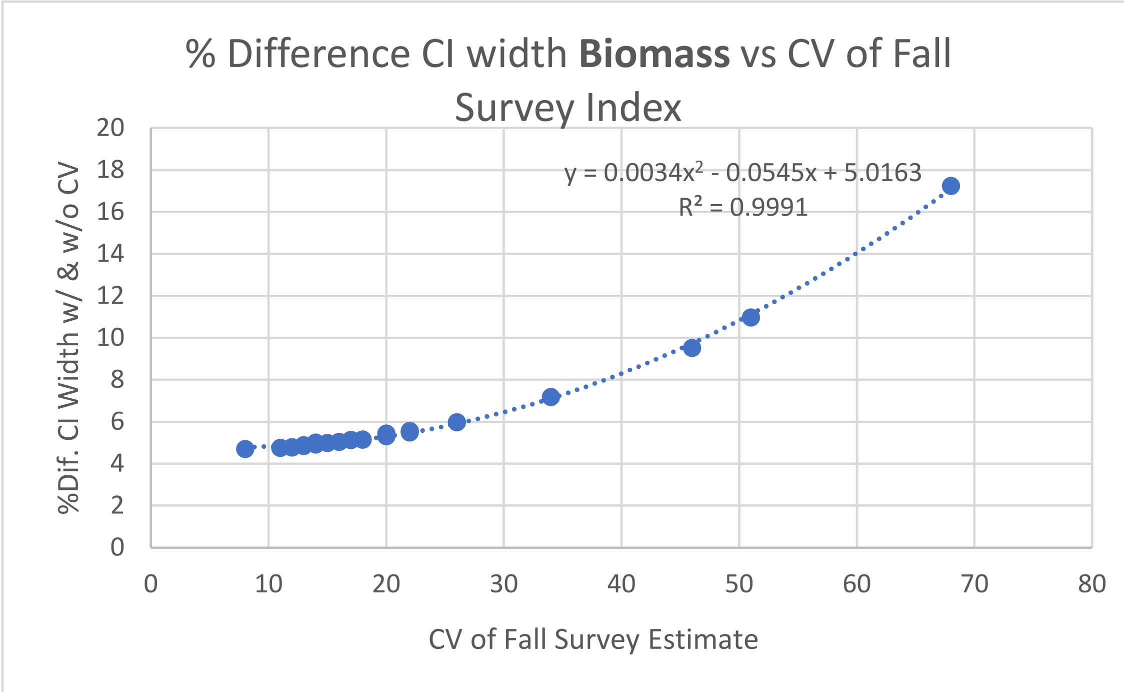

Figure 3. Empirical relationship between the percent difference in the confidence interval width of initial biomass (B.0) vs the Coefficient of Variation of fall bottom trawl survey. The y-axis is the percentage change in the ratio of the 90% confidence interval width when the Survey CV is included over the 90% CI width when the Survey CV is NOT included. Each point represents a given year. The polynomial fit is purely empirical. Deviations are based on the magnitude of the catch and the fall survey biomass.

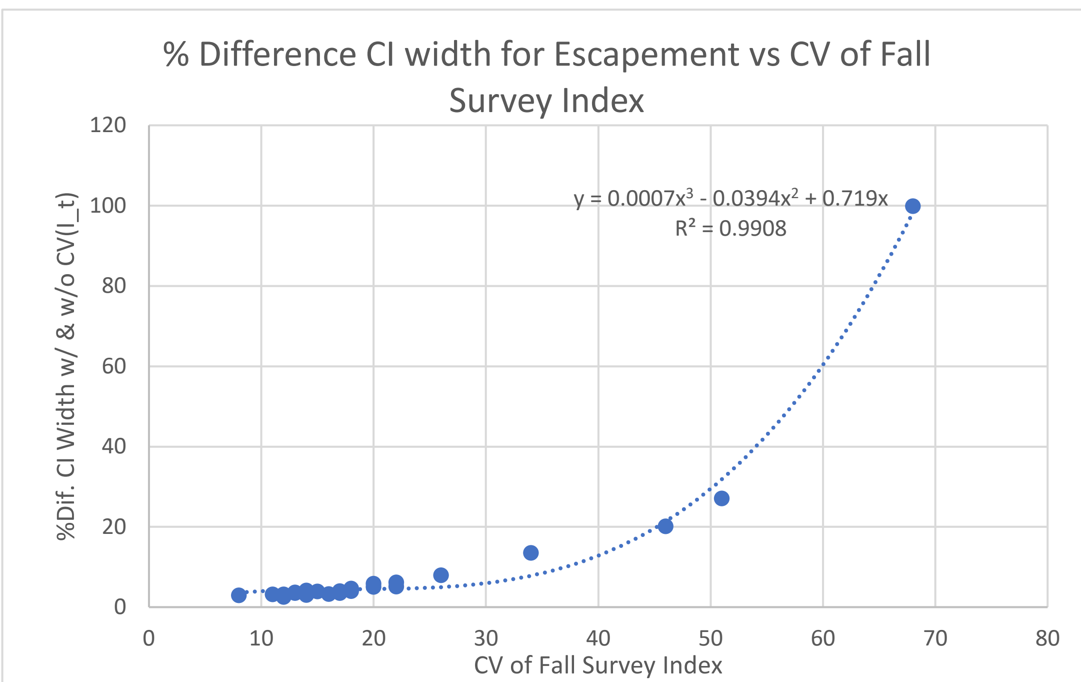

Figure 4. Empirical relationship between the percent difference in the confidence interval width of Escapement (Esc) vs the Coefficient of Variation of fall bottom trawl survey. The y-axis is the percentage change in the ratio of the 90% confidence interval width when the Survey CV is included over the 90% CI width when the Survey CV is NOT included. Each point represents a given year. The polynomial fit is purely empirical. Deviations are based on the magnitude of the catch and the fall survey biomass.