Comparison of RTA and SSC Methods for Illex 2022

Presentation to Mid-Atlantic Fishery Management Council
Scientific and Statistical Committee
Hybrid Meeting
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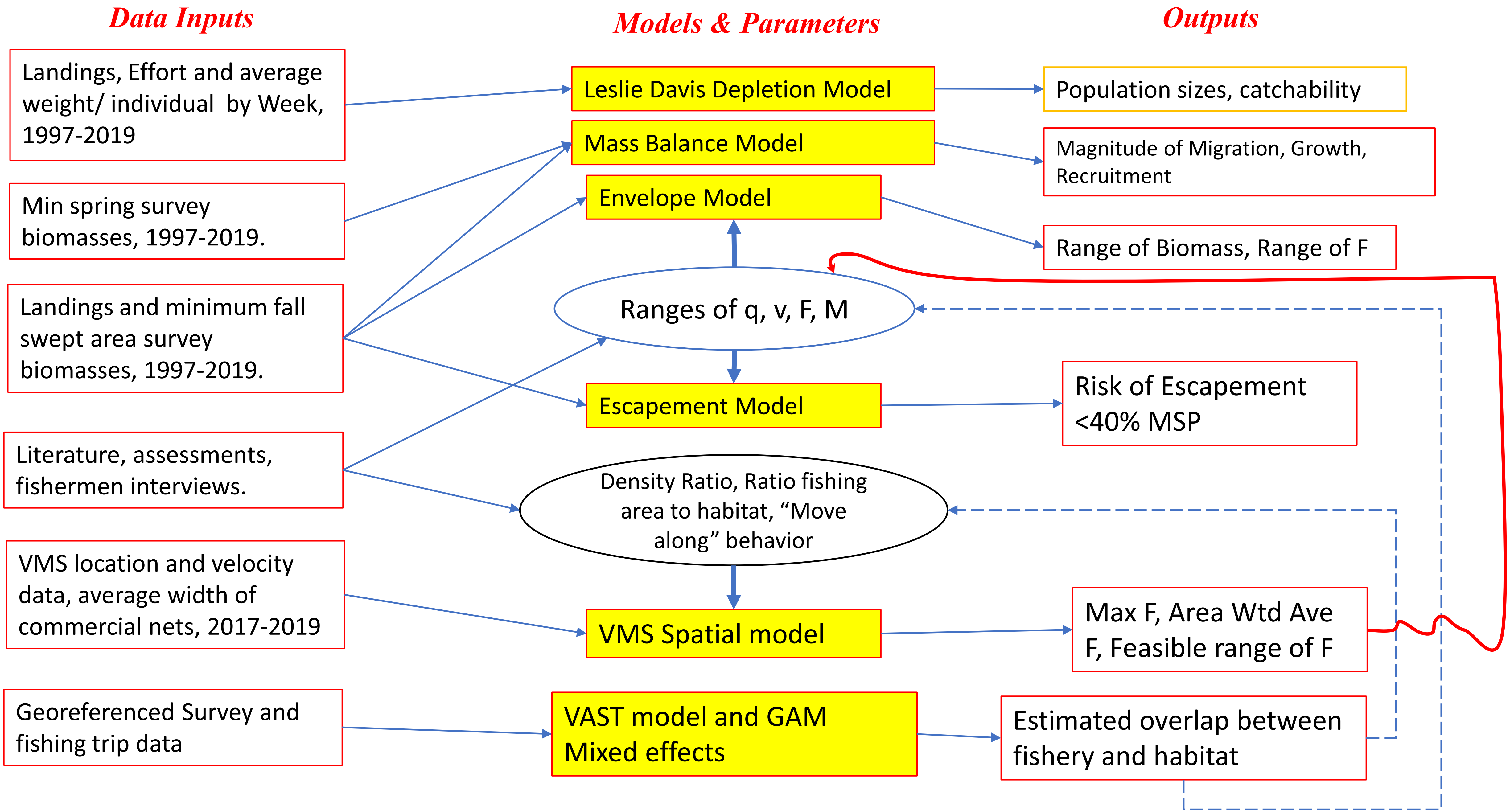
Research Track Assessment Approach

- Overview of multiple lines of evidence
- Approach to bounding feasible estimates of B, F, and Escapement.
- Illustrate potential magnitude of growth, natural mortality and unobserved migrations during fishery.
- Provide framework for inclusion of additional information from fishermen, biologists, oceanographers, and managers
- Suggest areas of research
- Set stage for more complicated in-season depletion models

The Big Picture

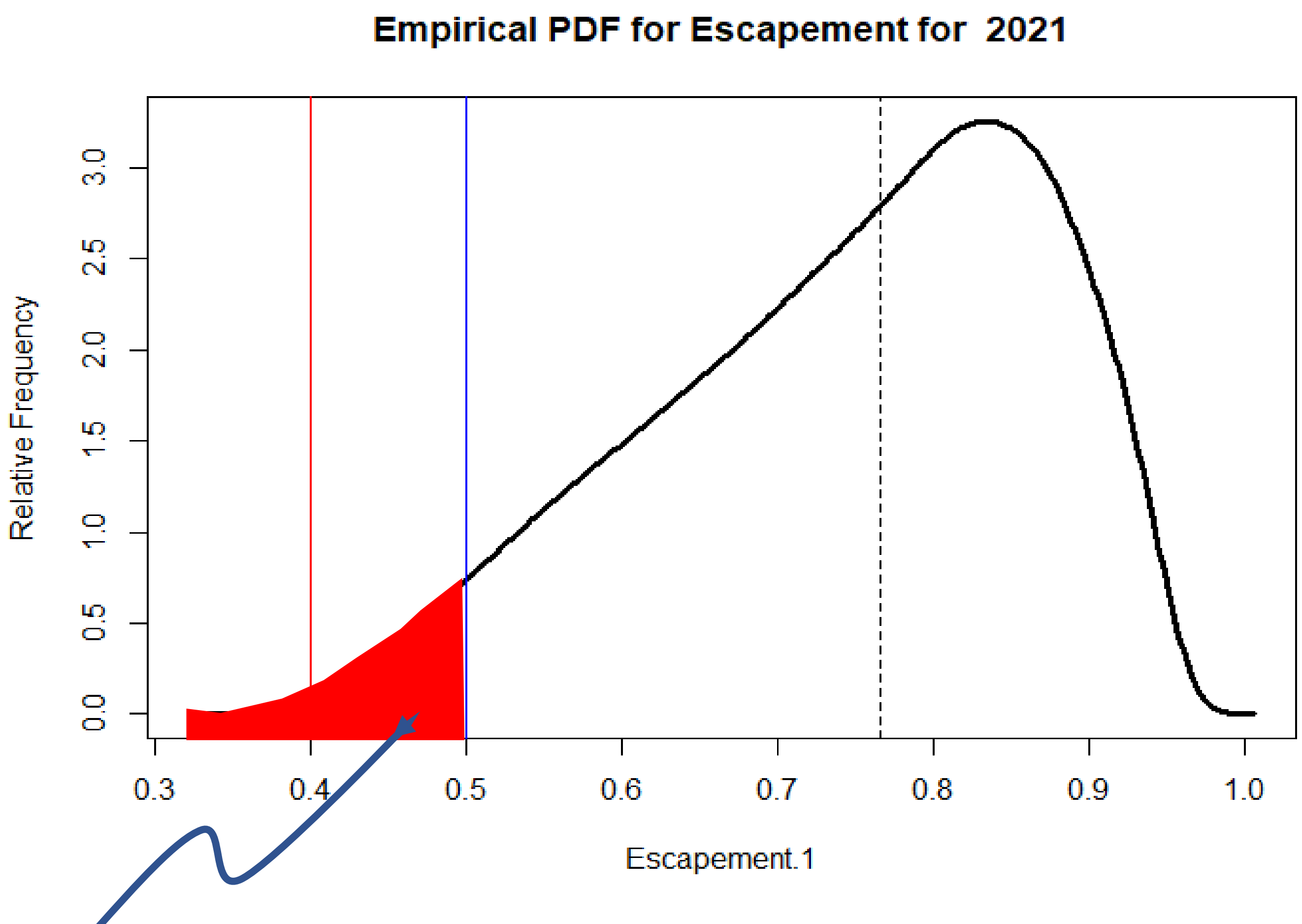


SSC Approach

- Data: 1997-2021
- Focus on Escapement Model (exclude Envelope, Leslie Davis, VMS, Mass Balance)
- Use Baranov catch equation instead of Pope's approximation
- Consider full range of uncertainty of parameters rather than just combinations of extreme values
- Updated ranges of parameters based on new research results from RTA
- Consider full range of alternative quota limits
- Compare with candidate BRPs used for other squid stocks
    - Escapement
    - F/M
- Compute average probability of overfishing over all years given each alternative quota for each candidate BRP
- Relate to Council Risk policy

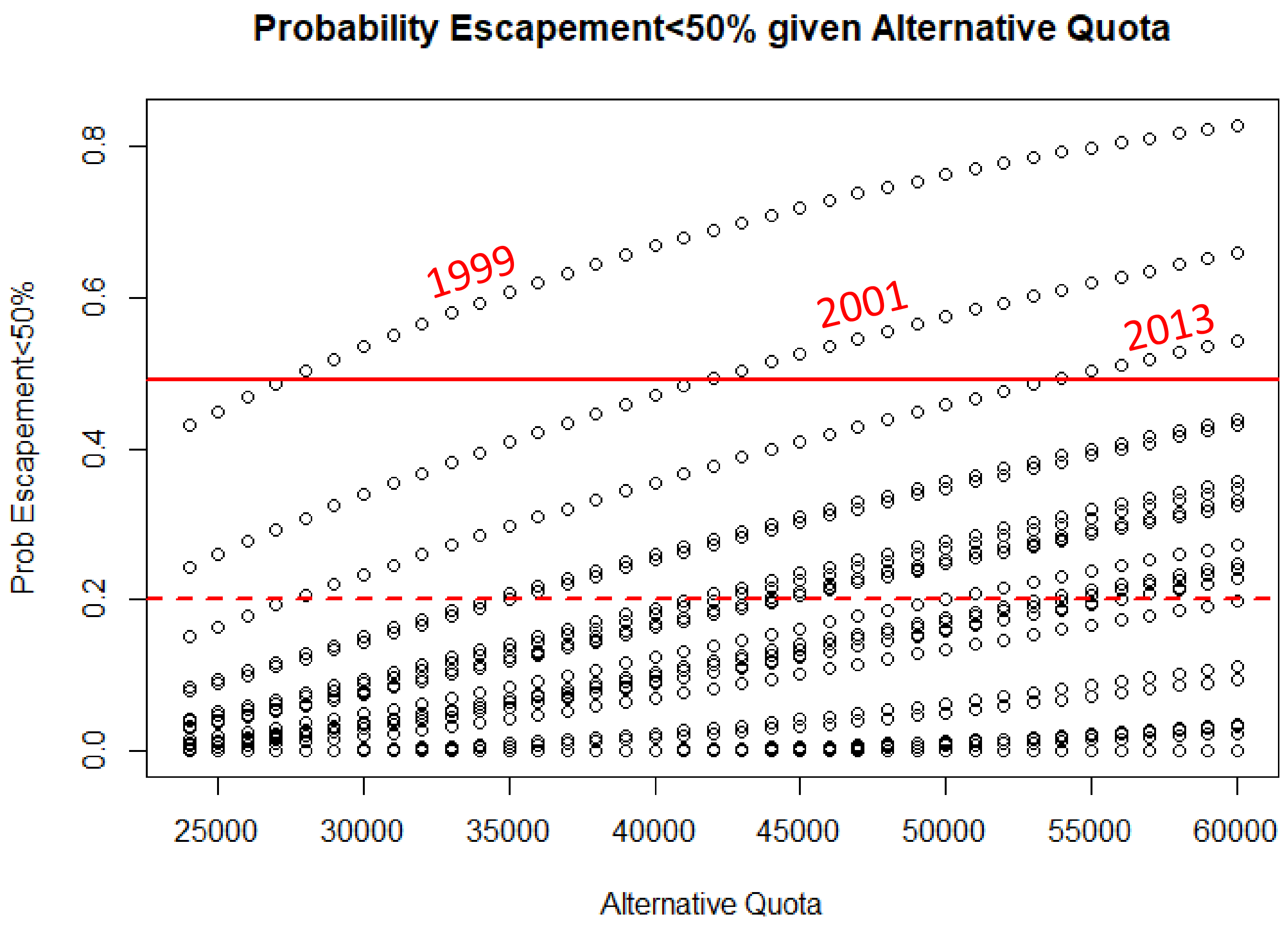
Average probability of falling below escapement threshold

- Compute probability of Escapement below threshold for each year.
- Compute average over all years
- This can be done for both the actual OBSERVED catches and the ALTERNATIVE hypothesized catches.

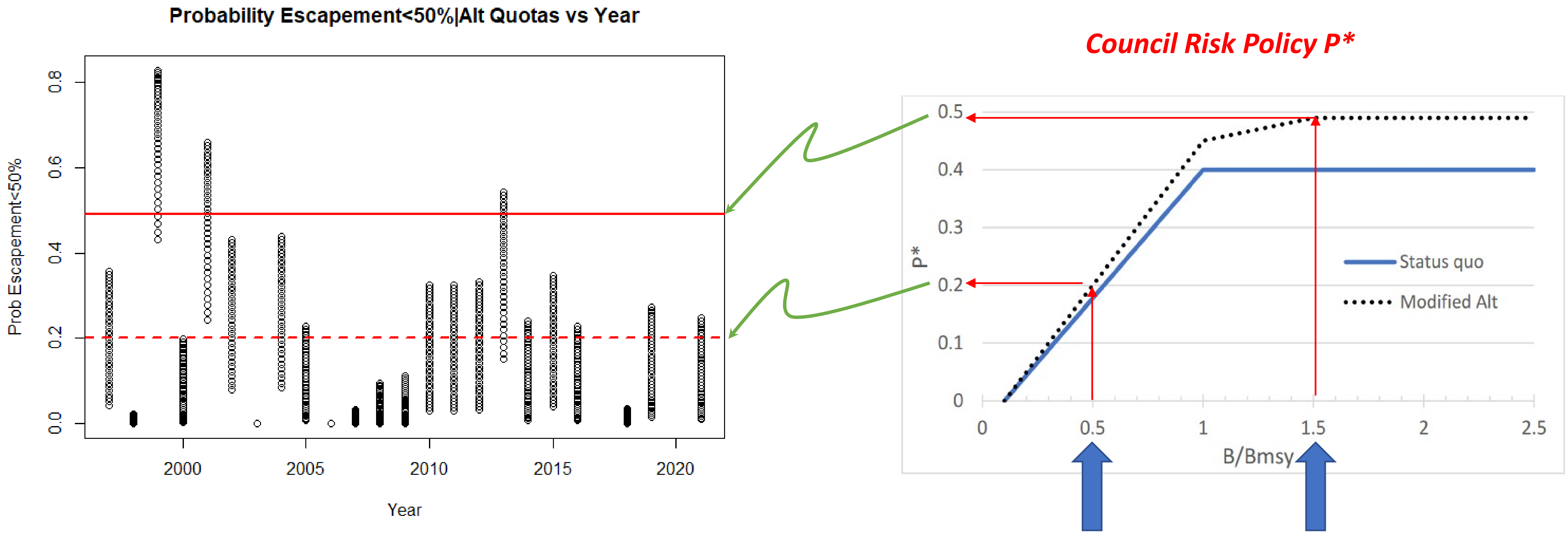


Probability of Escapement less than 50% for observed catch in 2021=4.1%

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

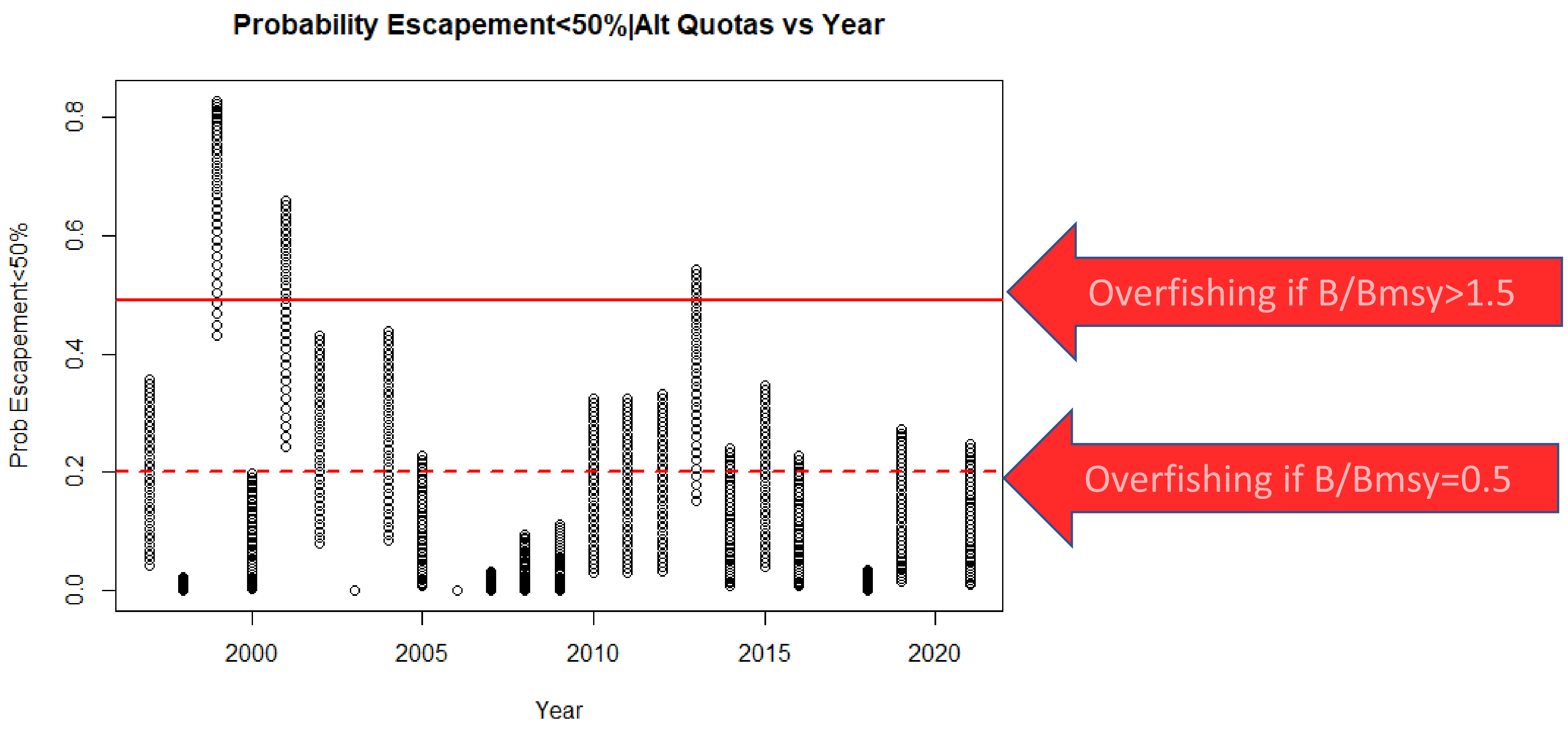


Estimated probability of escapement less than **50%** given alternative catch limits for each year ranging from 24,000 to 60,000. Each dot represents an alternative quota with lowest quotas at bottom and highest at top for each year. The initial population size in each year is based on the observed catch 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.



Assumed Status of Illex

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.



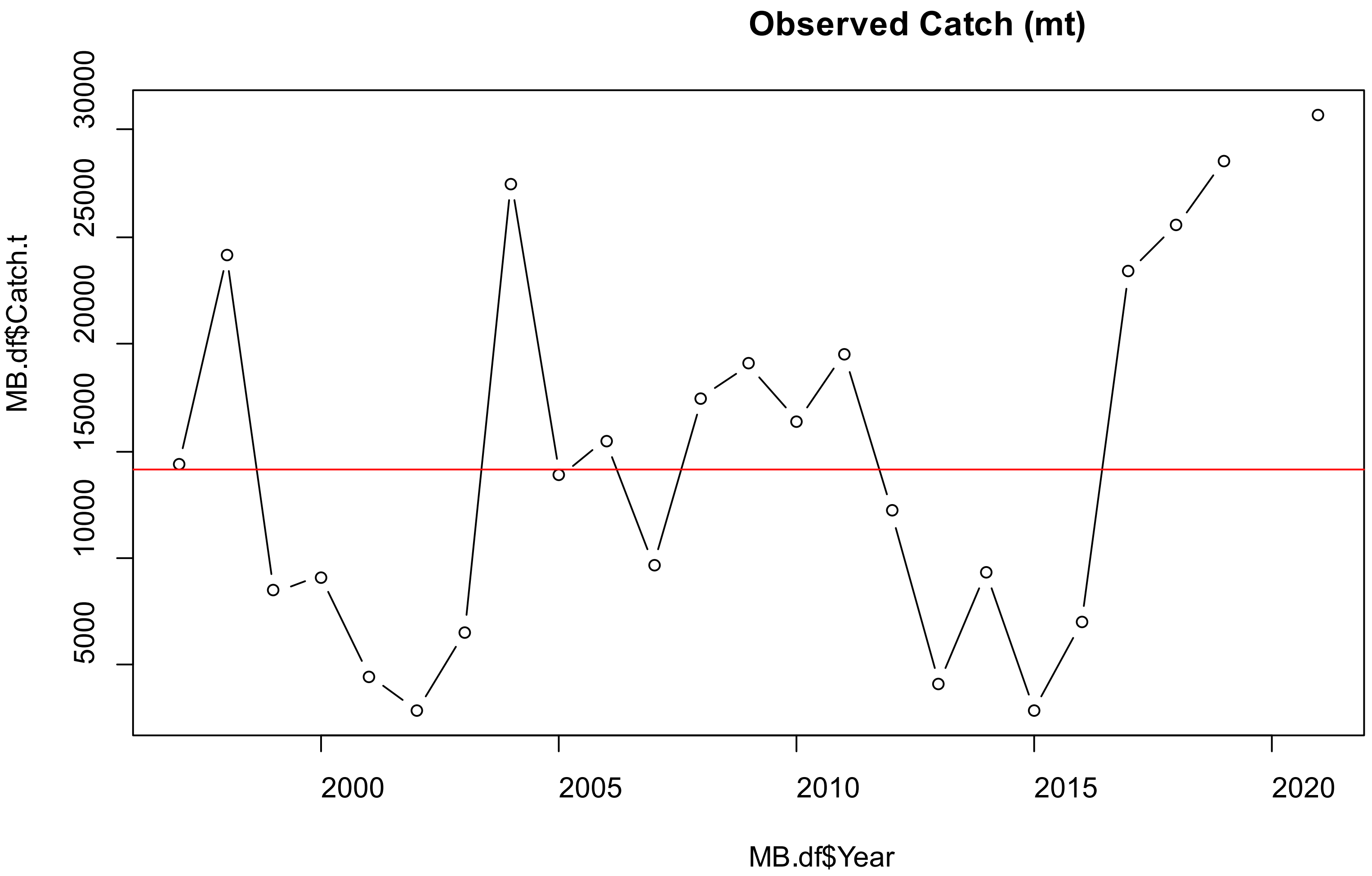
Potential Changes for 2023

- 2022 Fall Survey data
- Evaluate effects of uncertainty in abundance estimates (4 factors)
  - Range of M
  - Range of Efficiency
  - Range of Availability
  - Range of density estimation in each year (Normal, Lognormal)
- Risk analyses unlikely to change much since evaluation is based on many years of data (eg n vs n+1 estimates).
- Possible autoregressive model for time series of surveys
- MSE approach? Simple operating model could be developed and used to evaluate escapement risks under different policies.

Questions?

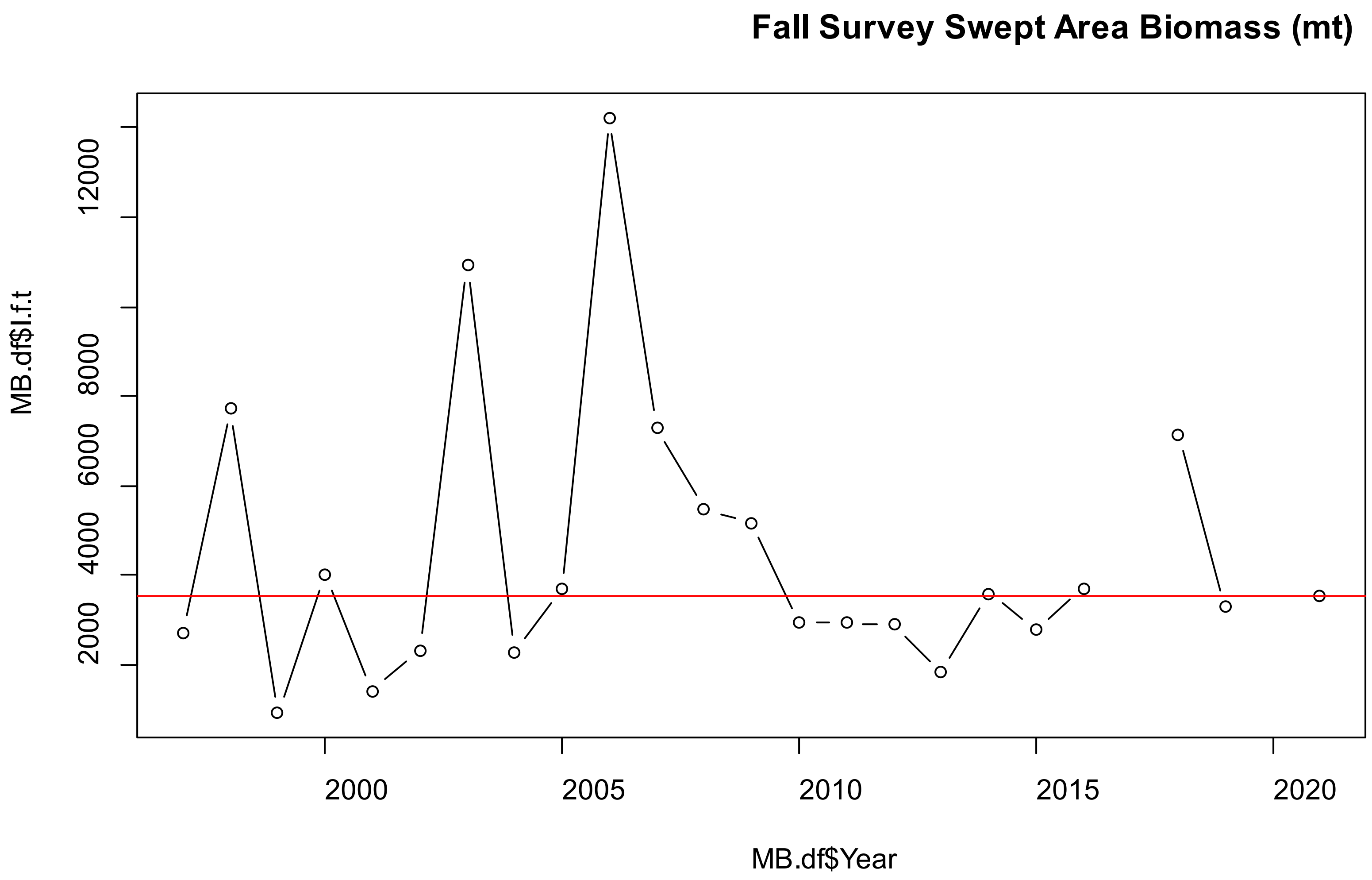
Rest easy--
Extra Backup Slides—not for presentation

Catch Data 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

Fall Survey Data 1997-2021



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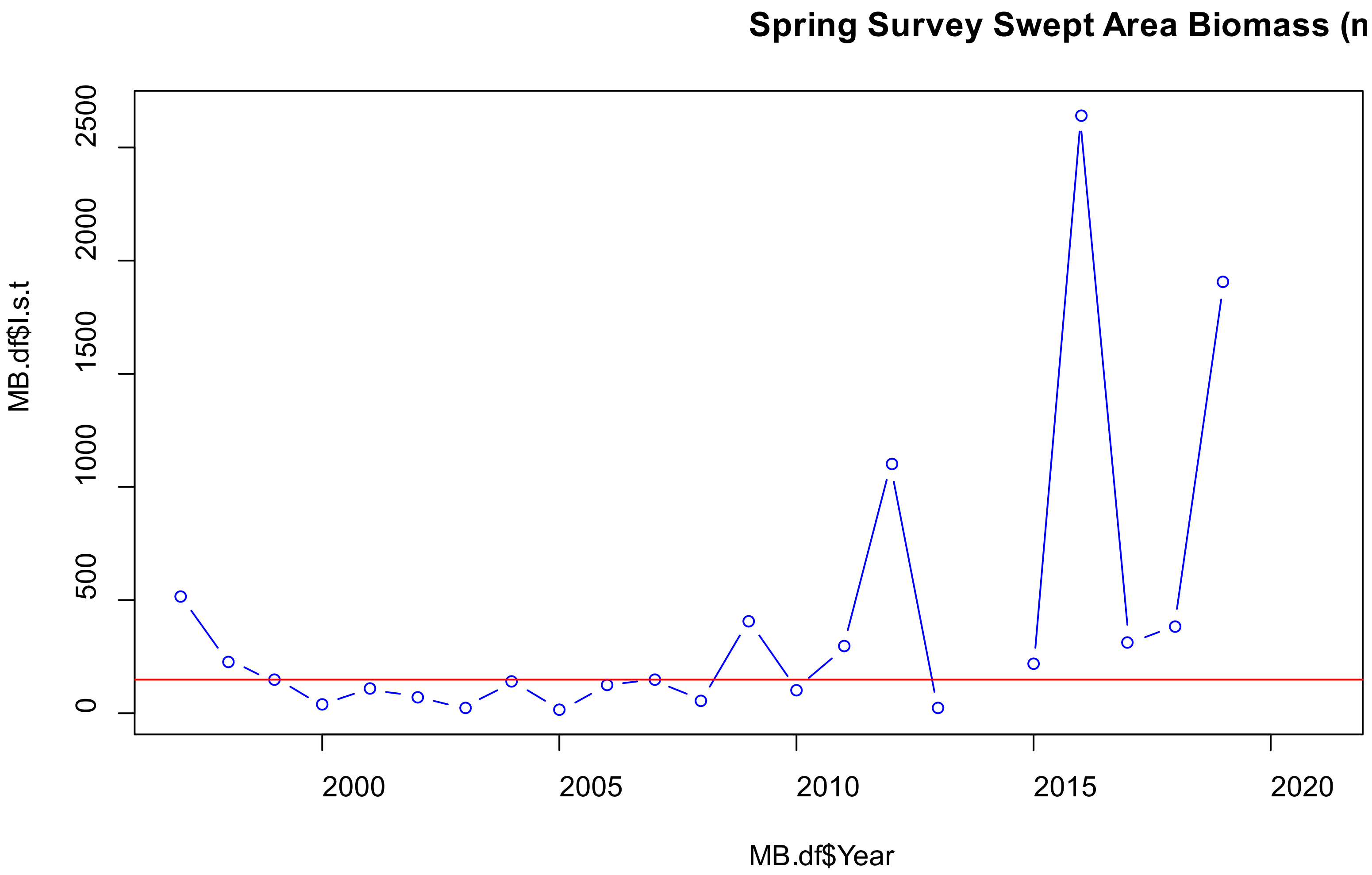

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Finding F

- 1. Expand Fall survey index to total assuming q and v

$$B_t = \frac{I_t}{q}\frac{A}{a}\frac{1}{v} = \frac{AI_t}{qav}$$

- 2. Write Bt as function of B.o and Z

$$B_t = B_0 \ e^{-Z\,t}$$

- 3. Baranov catch equation assuming M

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

- 4. Combine Eq. 2 and 3

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

- 5. Plug Eq. 1 into Eq. 4

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

- 6. Solve for F given assumed levels of q, v, M and observations of I_t and C_t in Eq. 5

Escapement Estimation for OBSERVED Catches

- Find B.0 and F for each year given C(t), I(t) and assumed q,v,M.
- Project terminal population without fishery

$$B_{t,without\ fishery} = B_0 e^{-Mt}$$

- Compute escapement as ratio of observed B(t) over B(t|F=0)

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

- Or equivalently

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

- This formulation is useful for evaluating alternative quotas

Escapement Estimation for ALTERNATIVE Catches

- Find B.0 and F for each year given observed C(t), I.f(t) and assumed q,v,M.
- Assume alternative catch C_H
- Find F_H associated with alternative catch C_H

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

- Compute escapement as ratio of observed B(t) over B(t|F=0)

$$Escapement(B_0, C_H) = \frac{B'_t}{B_{t,without\ fishery}} = \frac{B_0 e^{-(F_H+M)}}{B_0 e^{-M}} = e^{-F_H}$$

Stochastic methods (1)

- Assume distribution for parameters q, v, M
  - $q \sim Uniform(q_{min}, q_{max})$
  - $v \sim Uniform(v_{min}, v_{max})$
  - $M \sim Uniform(M_{min}, M_{max})$
- Compute distribution of functions of assumed parameters and observations over the entire range of possible values of q, v, and M using equal probability intervals.

Methods (2)

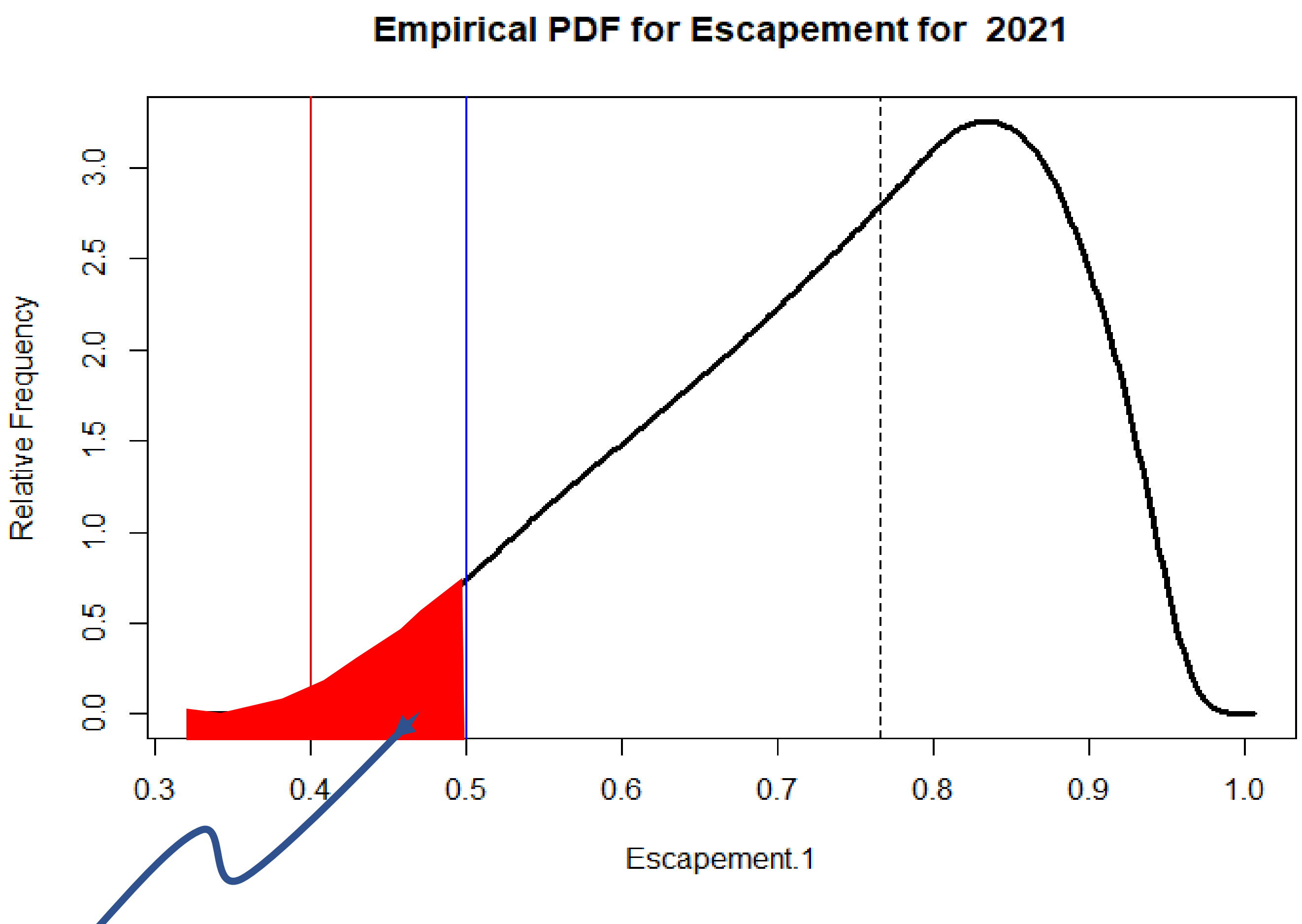
- Basic approach
  - Divide each distribution into N equal probability intervals.
  - Prob(x_i)=1/N for x_i =x_min+i*((max-min)/(N-1)), and i=1,2, …,N
  - Joint probability obtained by assuming independence of q, v, M such that
    - Prob(q_i)=1/N.q for $q_i = q_{min}$+i*((q_{max}-q_{min})/(N.q-1)), and i=1,2, …,N.q
    - Prob(v_j)=1/N.v for $v_j = v_{min}$+j*((v_{max}-v_{min})/(N.v-1)), and j=1,2, …,N.v
    - Prob(M_k)=1/N.q for $M_k = M_{min}$+k*((M_{max}-M_{min})/(N.M-1)), and k=1,2, …,N.M
  - Assumed N.q=N.v=N.M=40
  - Probability for each triple{q_i, v_j, M_k} is (1/N.q)*(1/N.v)*(1/N.M)
  - Sum of probabilities over all N.q*N.v*N.m combinations is equal to one
  - Can demonstrate that any function of weighted observations is also a pdf that sums to one. Thus f(q,v,M|I.s,I.f, C) is a pdf.

Percentiles and Probabilities of B, F, Escapement

- Compute naïve percentiles from the 64,000 realizations for each year y ($N.q*N.v*N.M=40^3$)
- Compare $Esc(y|C_H)$ to some threshold level T, e.g., 50% escapement
- Compute probability of overfishing (i.e., falling below escapement threshold) as sum of cases over all assumed {q,v,M} for all years y where $(Esc(y|C_H, \{q,v,M\}) < T)$
- Divide this sum by product of number of years times N.q * N.v* N.M
- Composite probability assumes all historical abundance estimates B.0(y) are equally likely. This could be refined to account for trend and/or autocorrelation.

Average probability of falling below escapement threshold

- Compute probability of Escapement below threshold for each year.
- Compute average over all years
- This can be done for both the actual OBSERVED catches and the ALTERNATIVE hypothesized catches.



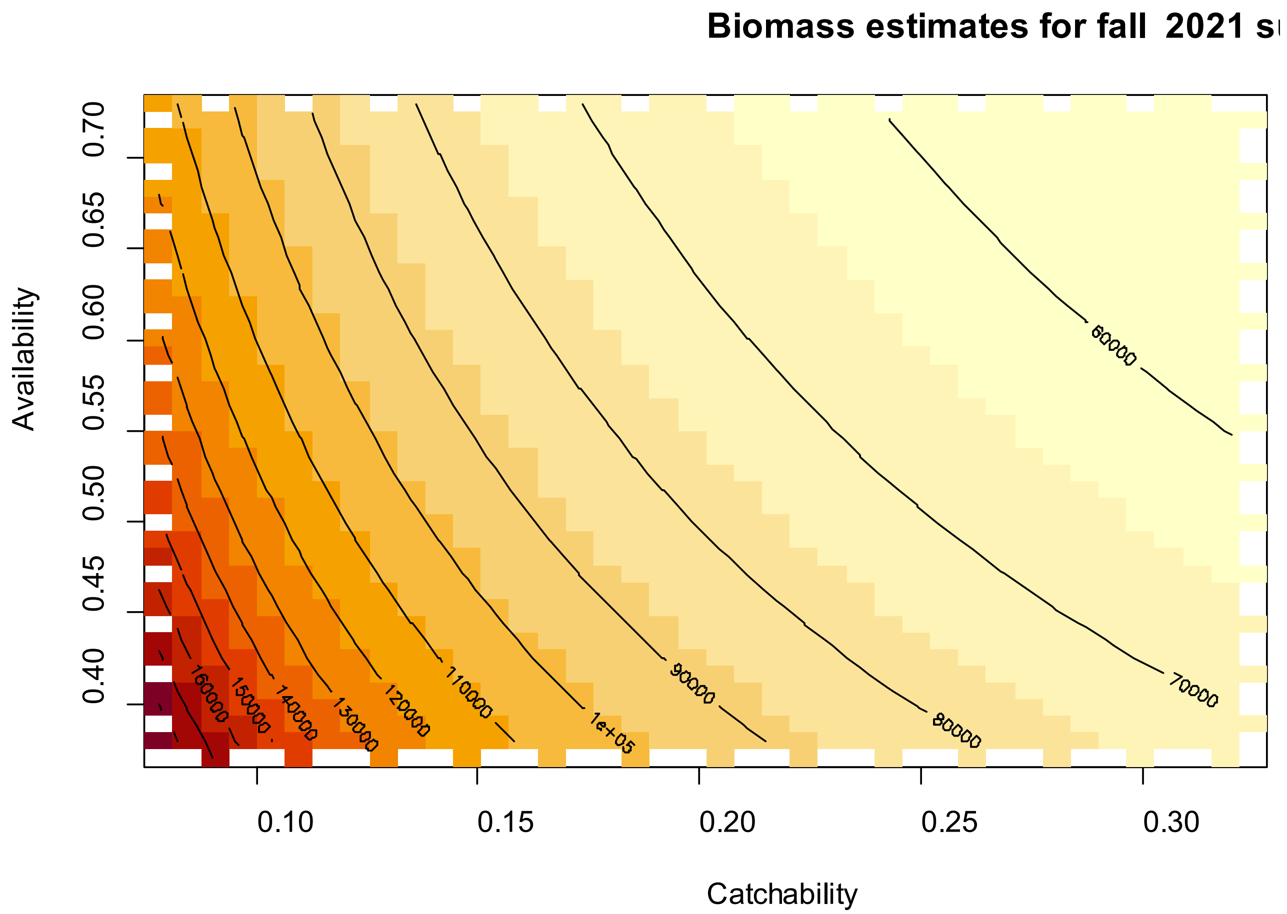
Probability of Escapement less than 50% for observed catch in 2021=4.1%

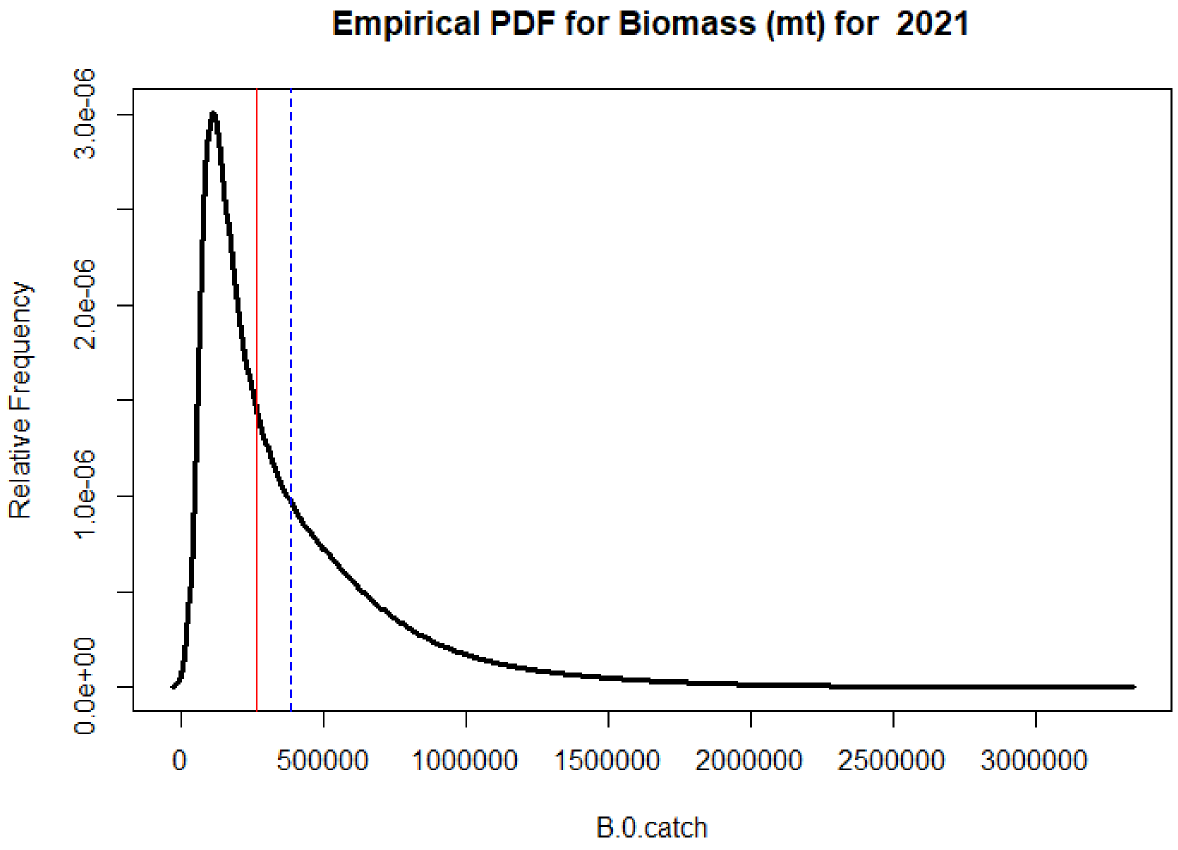
Parameterization—Bounds for {q,v,M}

- Catchability **q**
  - Min=0.078 --expert judgement, { key point: >>value used in 2021 (0.01)}
  - Max=0.325 --per analyses of Bigelow-Albatross & day-night differences
- Availability **v** per analyses of Manderson et al.'22, Lowman et al.'21
  - Min=0.37
  - Max=0.73
- Natural Mortality **M** (per week)
  - Min=0.01, per Hendrickson and Hart (lowest assumed value for non spawners)
  - Max= 0.13, per Hewitt and Hoenig, A_{max}=221 days per 2019-2020 samples

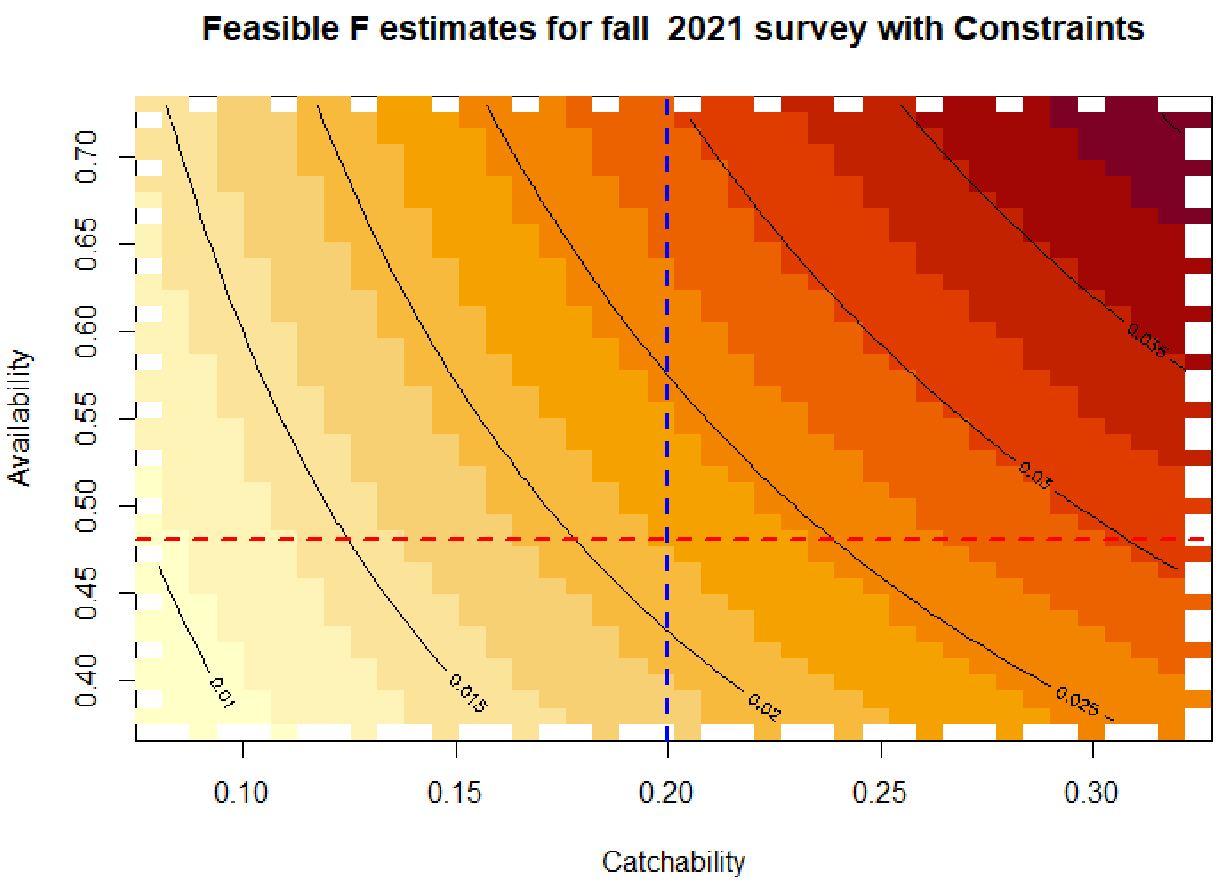
Examining the parameter space

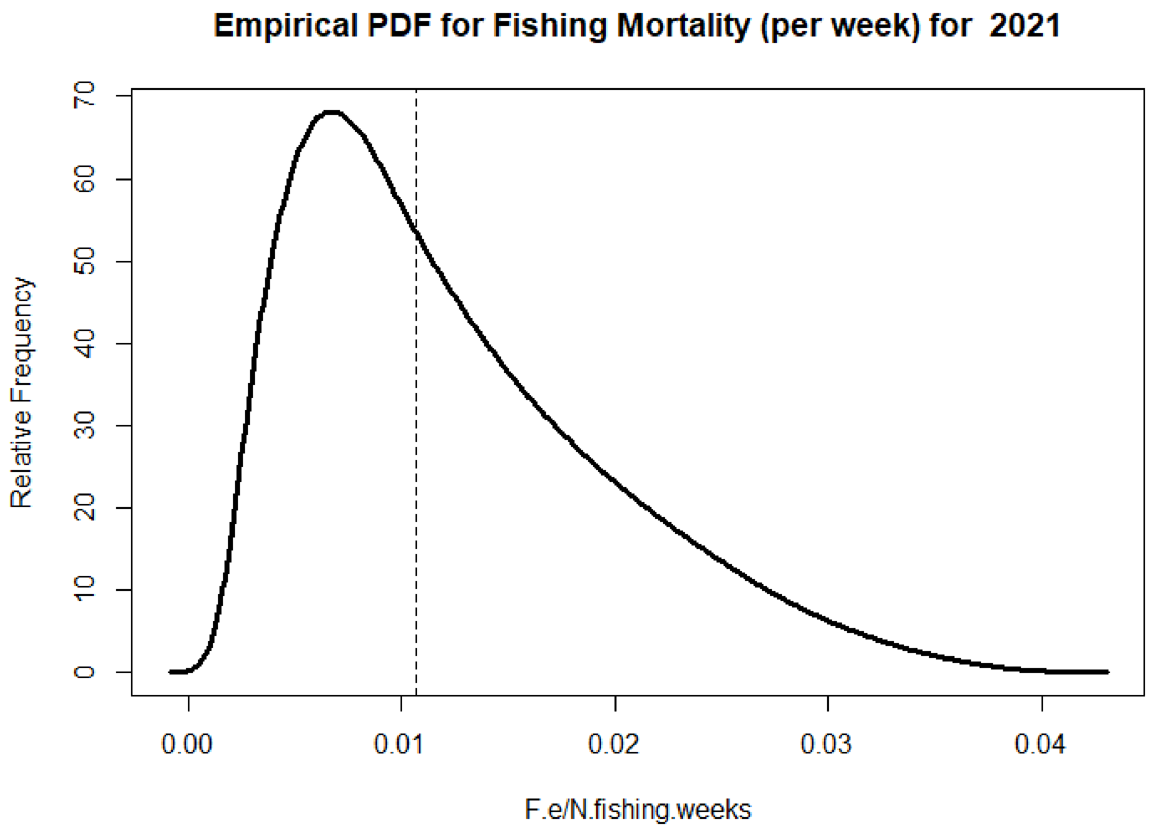
Isopleths of Illex biomass (mt) estimates for combinations of q and v for 2021 (left) and marginal distribution of biomass estimates over all combinations of q, v, and M (right). Solid red line is median; dashed blue line is mean.



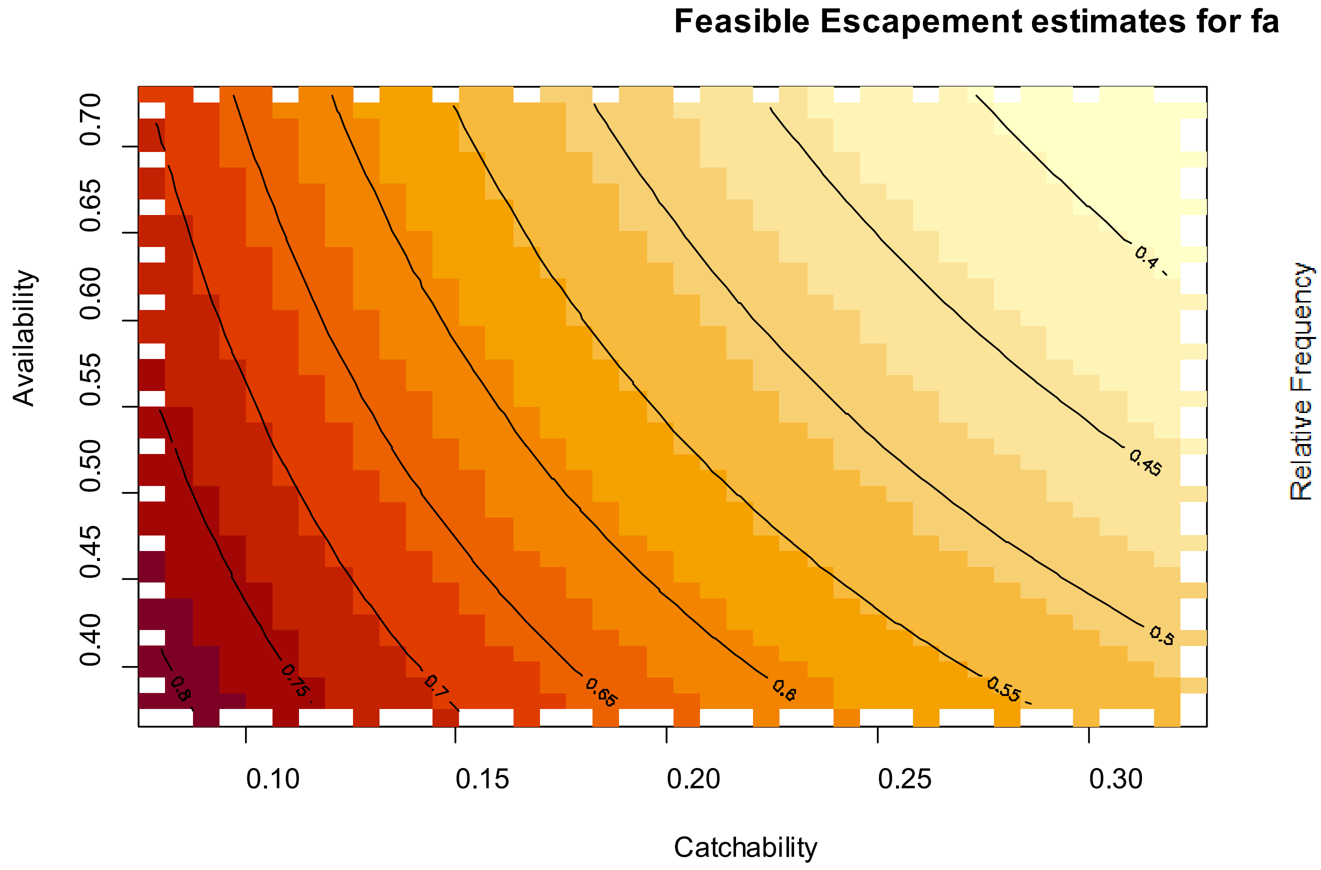


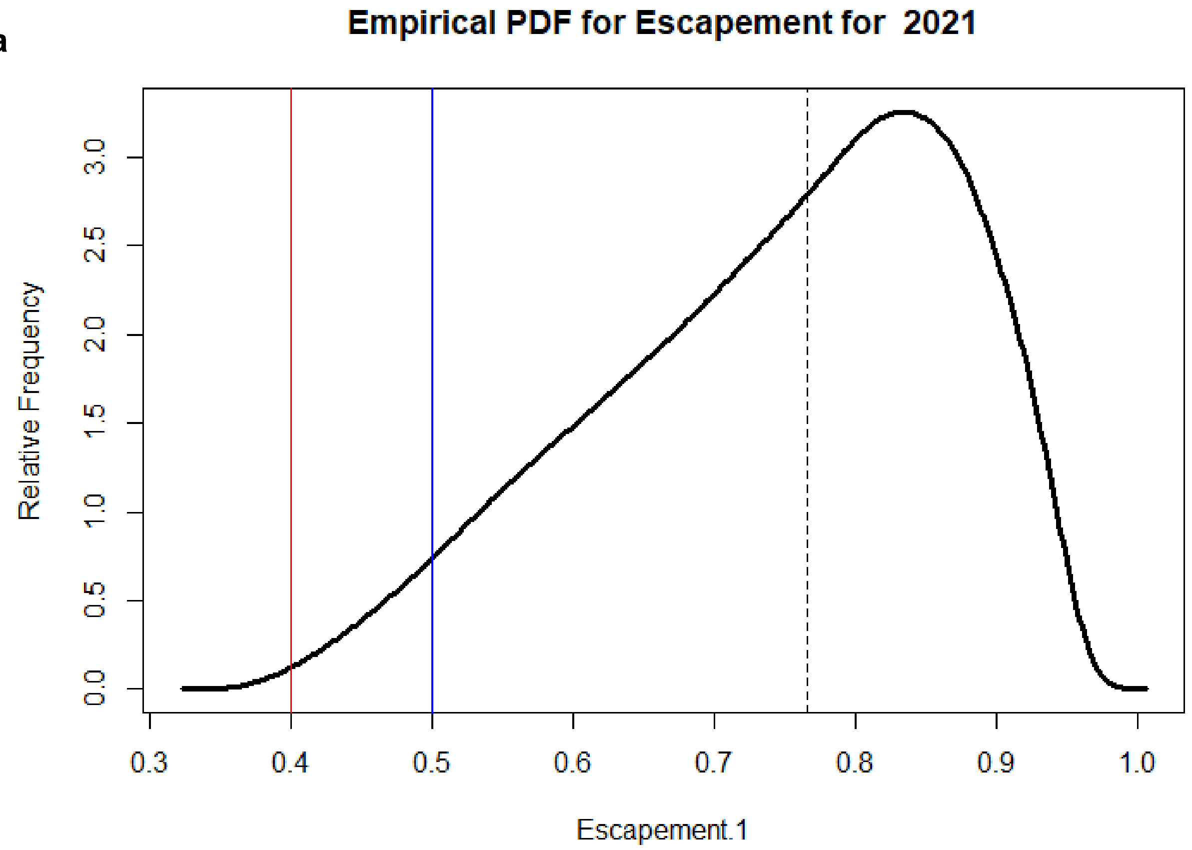
Isopleths of Illex fishing mortality estimates (per week) for various combinations of q and v for 2021 (top) and derived distribution of fishing mortality rates (per week) for 2021. The dashed black line represents the median value.



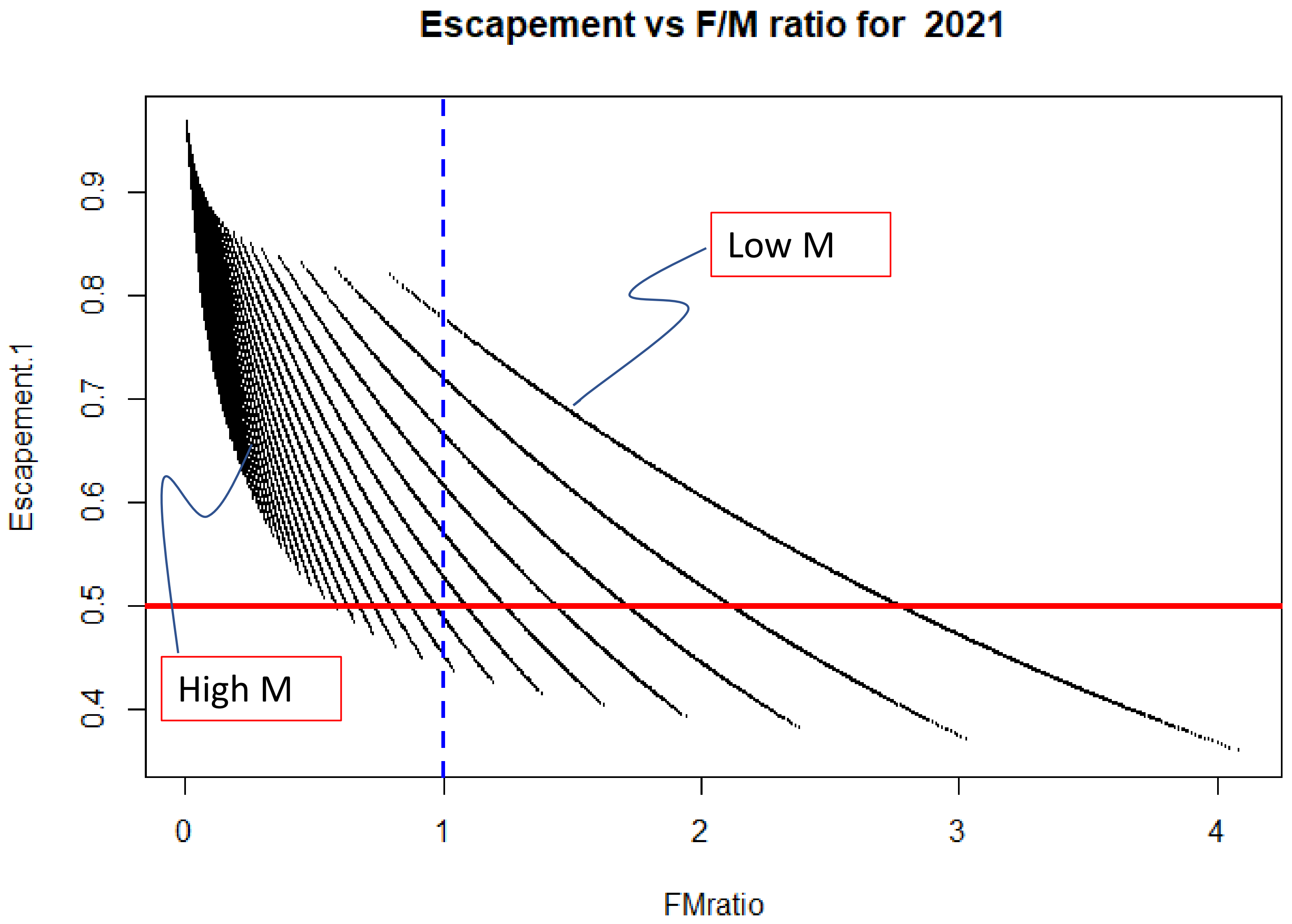


Isopleths of escapement as a function of catchability and availability (left) and empirical distribution of Escapement based on observed landings in 2021 and observed NEFSC fall bottom trawl indices (right). The dashed black line=median. Red and blue vertical lines represent escapement levels of 40 and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

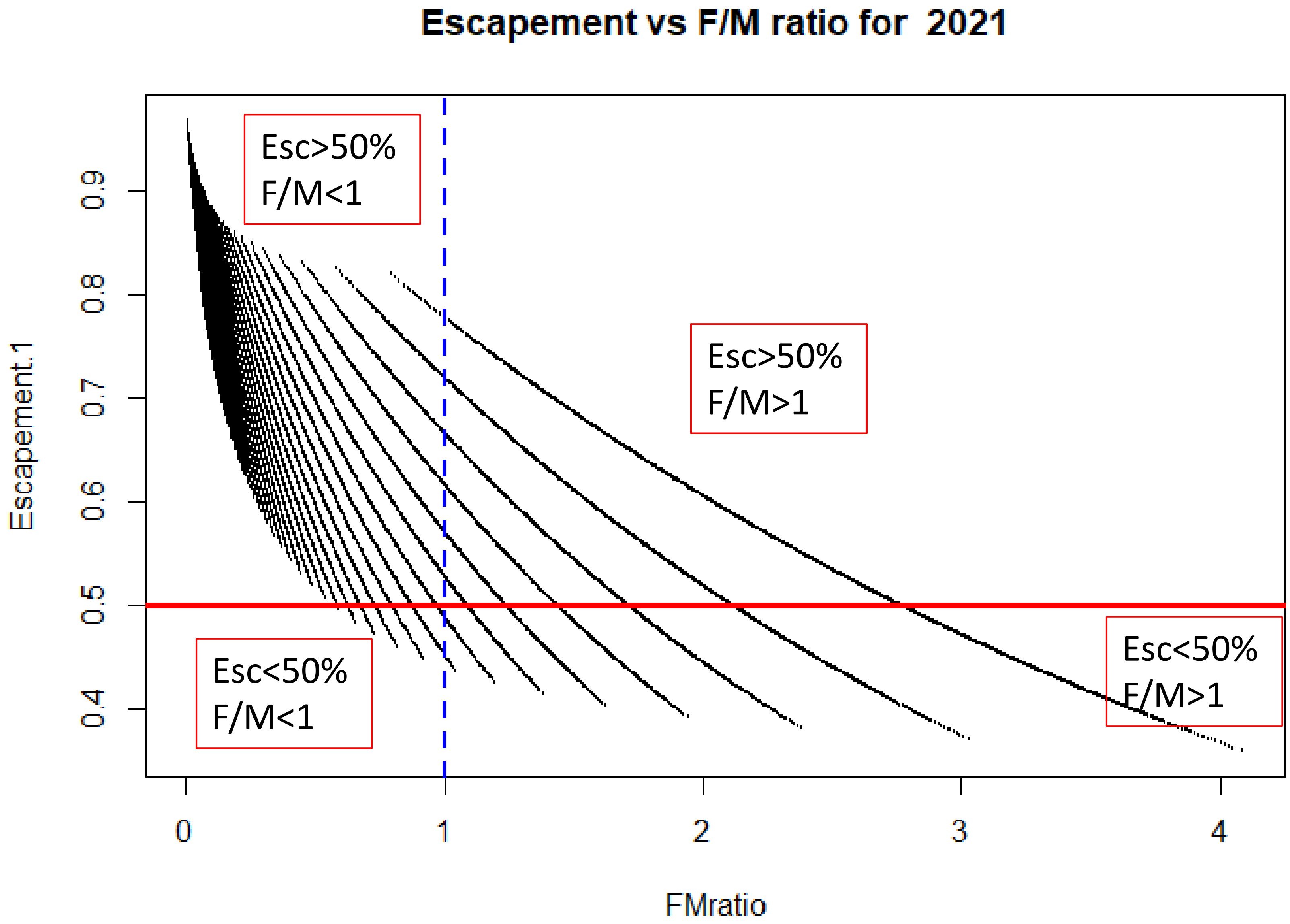




Escapement vs estimated fishing mortality/assumed M over all 64,000 combinations of q, v, and M for 2021. “Bands” are isopleths for assumed levels M. Highest Ms are on the left (0.13/wk); lowest Ms(0.01/wk) on the right.

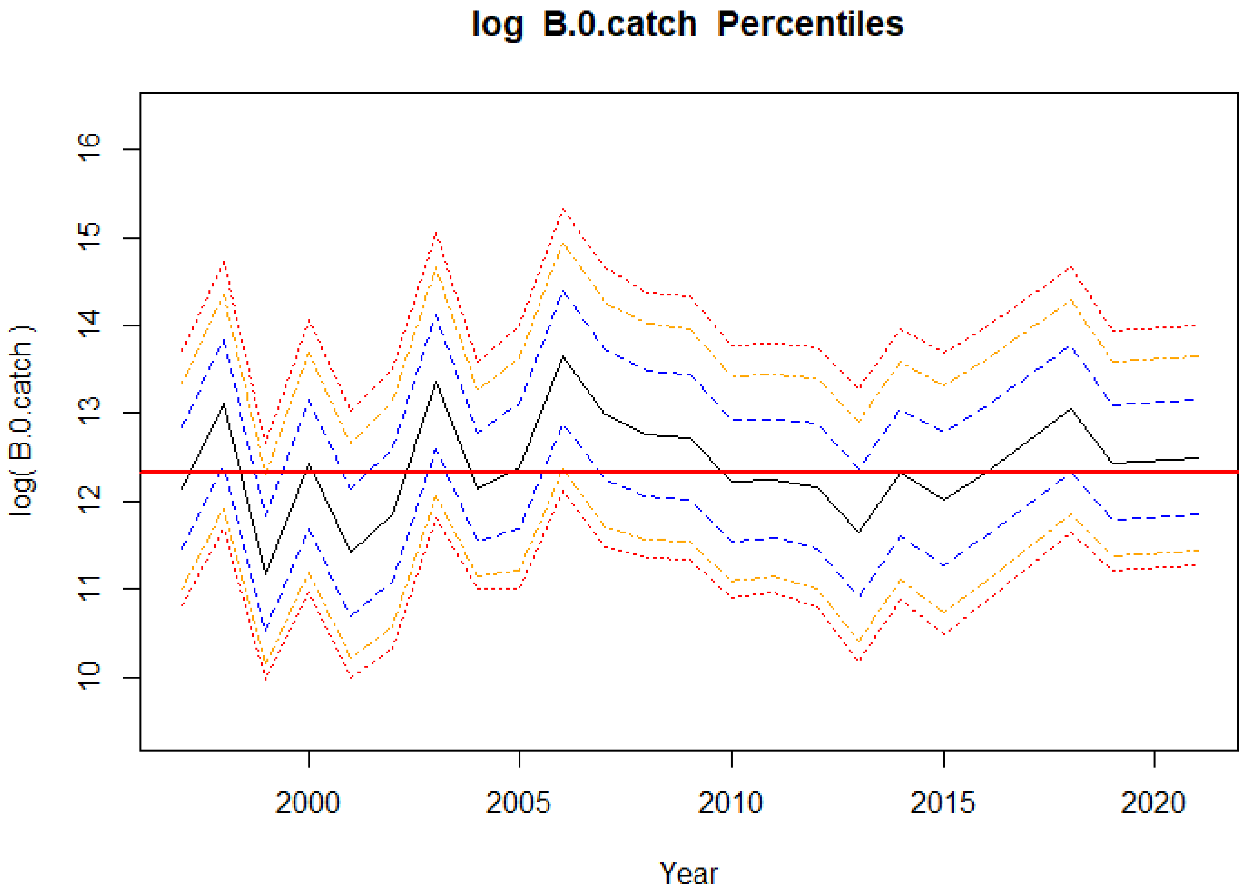


Escapement vs estimated fishing mortality/assumed M over all 64,000 combinations of q, v, and M for 2019. “Bands” are isopleths for assumed levels M. Highest Ms are on the left (0.13/wk); lowest Ms(0.01/wk) on the right.



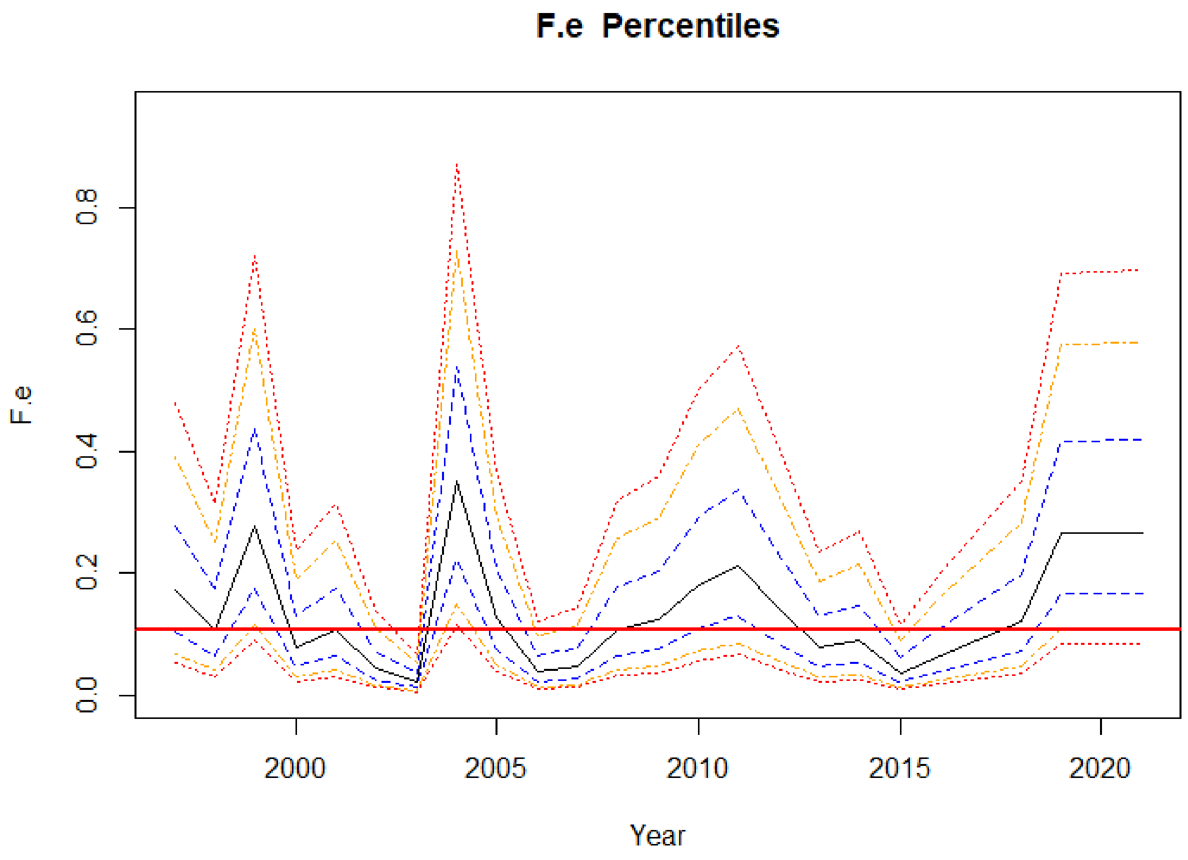
Percentiles of Biomass, F, and Escapement for each year

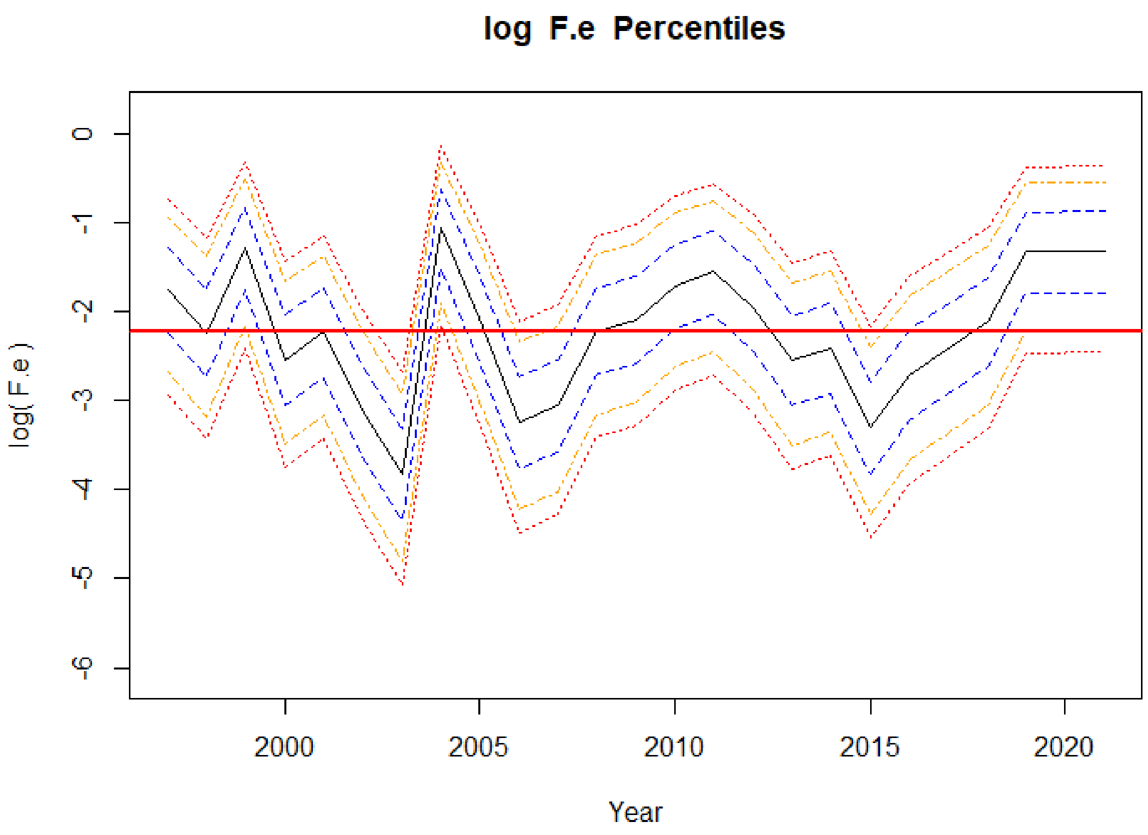
Percentiles of Initial Biomass, 1997-2021



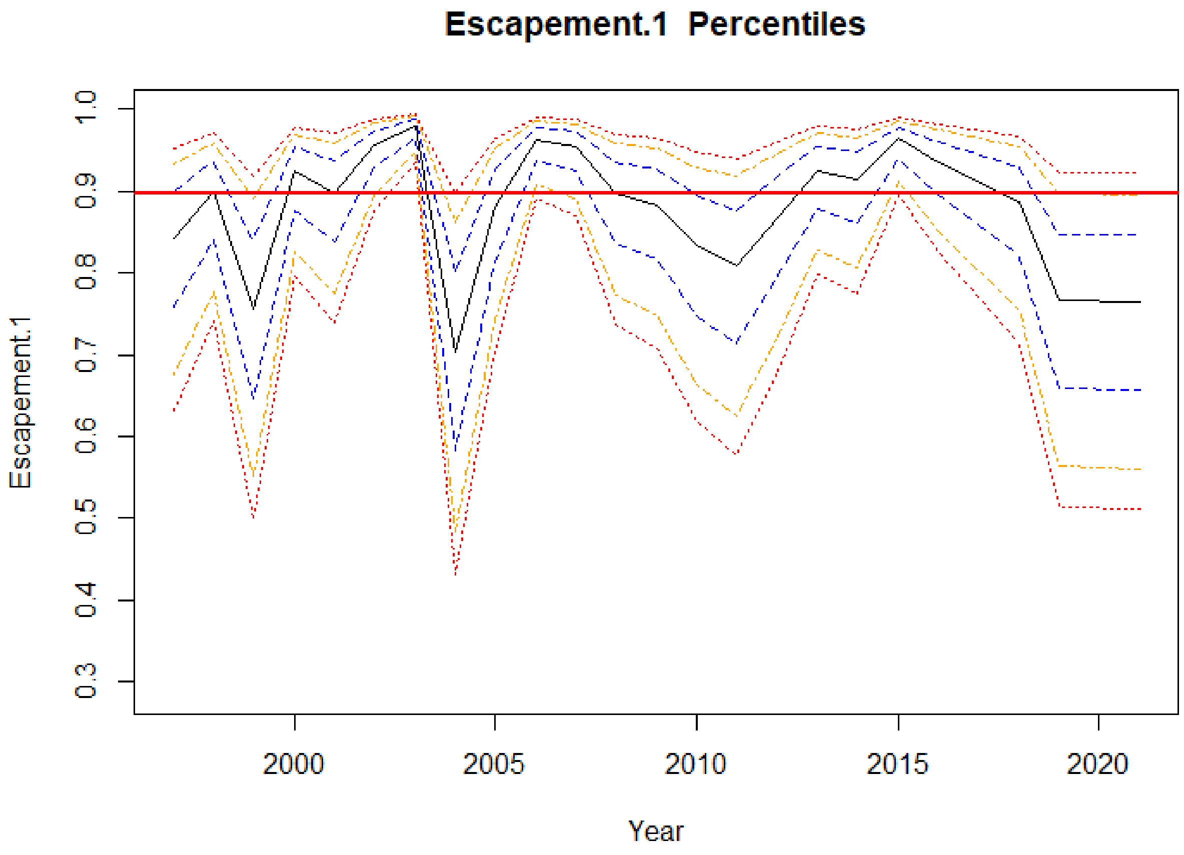
Year	Percentile 1%	5%	50%	95%	99%
1997	38,717	49,453	185,723	827,290	1,302,851
1998	90,447	119,492	491,716	2,291,773	3,634,128
1999	17,286	21,200	70,404	292,095	454,671
2000	42,897	57,597	247,572	1,176,229	1,870,164
2001	16,683	22,036	90,570	421,949	669,056
2002	22,069	30,436	138,670	675,594	1,078,045
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

Estimated fishing mortality rates (per season) (1997-2021) based on based on 64,000 combinations of q, v, and M for each year [left]. Log seasonal fishing mortality rates [right]. Black line=median. The blue lines = interquartile range. Solid red line is the median of the annual medians. The average weekly rate is obtained by dividing the total by 25 weeks.



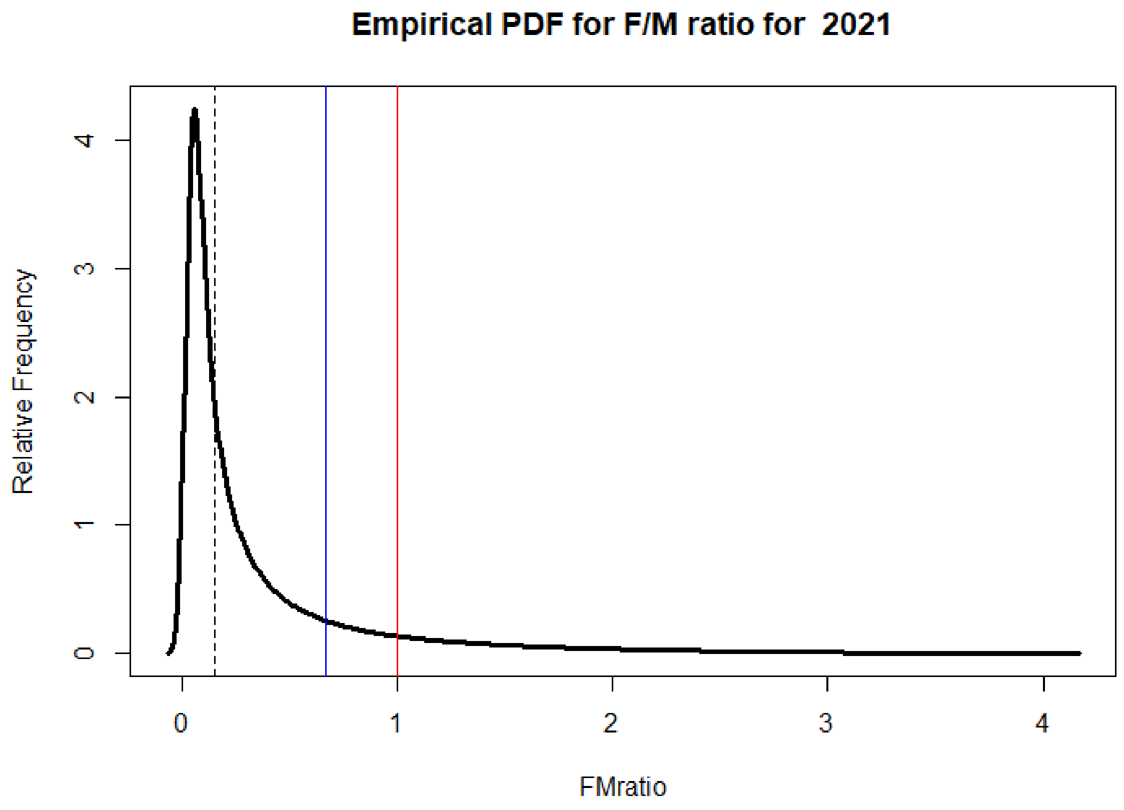


Percentiles of Escapement 1997-2021



	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

Percentiles of F/M, 1997-2021



	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

Probabilities of falling below Escapement thresholds or exceeding F/M thresholds

Estimated Probabilities of falling below various 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

Estimated Probabilities of Exceeding various F/M Thresholds based on OBSERVED catches

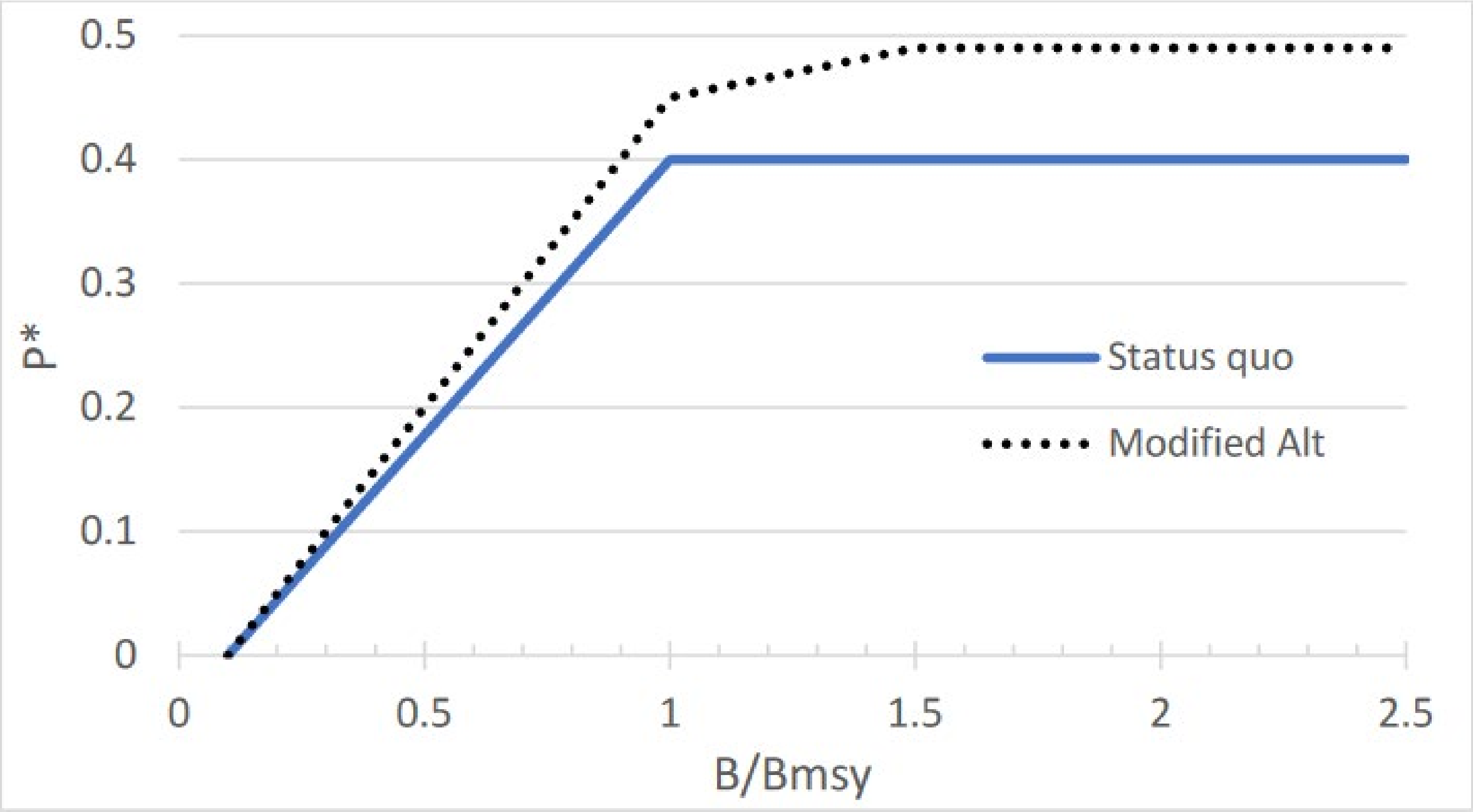
	F/M Threshold				
Year	**0.33**	**0.5**	**0.666**	**1**	**1.5**
1997	0.216	0.143	0.101	0.053	0.021
1998	0.138	0.081	0.050	0.020	0.003
1999	0.314	0.223	0.168	0.105	0.056
2000	0.097	0.051	0.028	0.007	0.000
2001	0.139	0.081	0.051	0.020	0.004
2002	0.039	0.013	0.004	0.000	0.000
2003	0.004	0.000	0.000	0.000	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

Joint probability of falling below various escapement threshold AND exceeding F/M=0.66 based on Observed Catches for 1997-2021

	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

Choosing a Quota Consistent with Council Risk Policy

- Risk of overfishing cannot exceed 0.49 irrespective of relative abundance
- Risk decreases slowly as stock size falls below 1.5 B/B_{msy}
- Risk decreases sharply when $B/B_{msy}<1$
- No fishing when $B/B_{msy}<0.1$



Candidate Reference Points

Although *L. gahi* stocks are nominally managed on an arbitrary target escapement of 40%, the fishery has never been closed early even when escapement has apparently declined below this level. (Agnew et al. 1998)

- There are no approved Biological Reference Points for Illex
- Percent Escapement levels have been used for other species, e.g.,
  - Illex argentinus and Doryteuthis gahi=40%
  - Dosidicus gigas =40% (in Mexico, not entire range)
  - Ommastrephes bartramii=40%
- The risk of overfishing for Illex can be expressed as the probability of escapement falling below a specific threshold level (say 35%, 40%, 50%) or the probability of exceeding F/M =2/3, 1 or other values that attempt to preserve forage for available predators. Finally, one can estimate the joint probability of exceeding F/M threshold and falling below an escapement threshold.
- The ***only*** other requirement to apply the risk policy is a guesstimate the likely current state of the resource (i.e., B_t/B_{msy}).
  - Is population trending OR randomly fluctuating about a mean?
  - Is that mean about B_{MSY} or 0.5 B_{MSY} or ??

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.

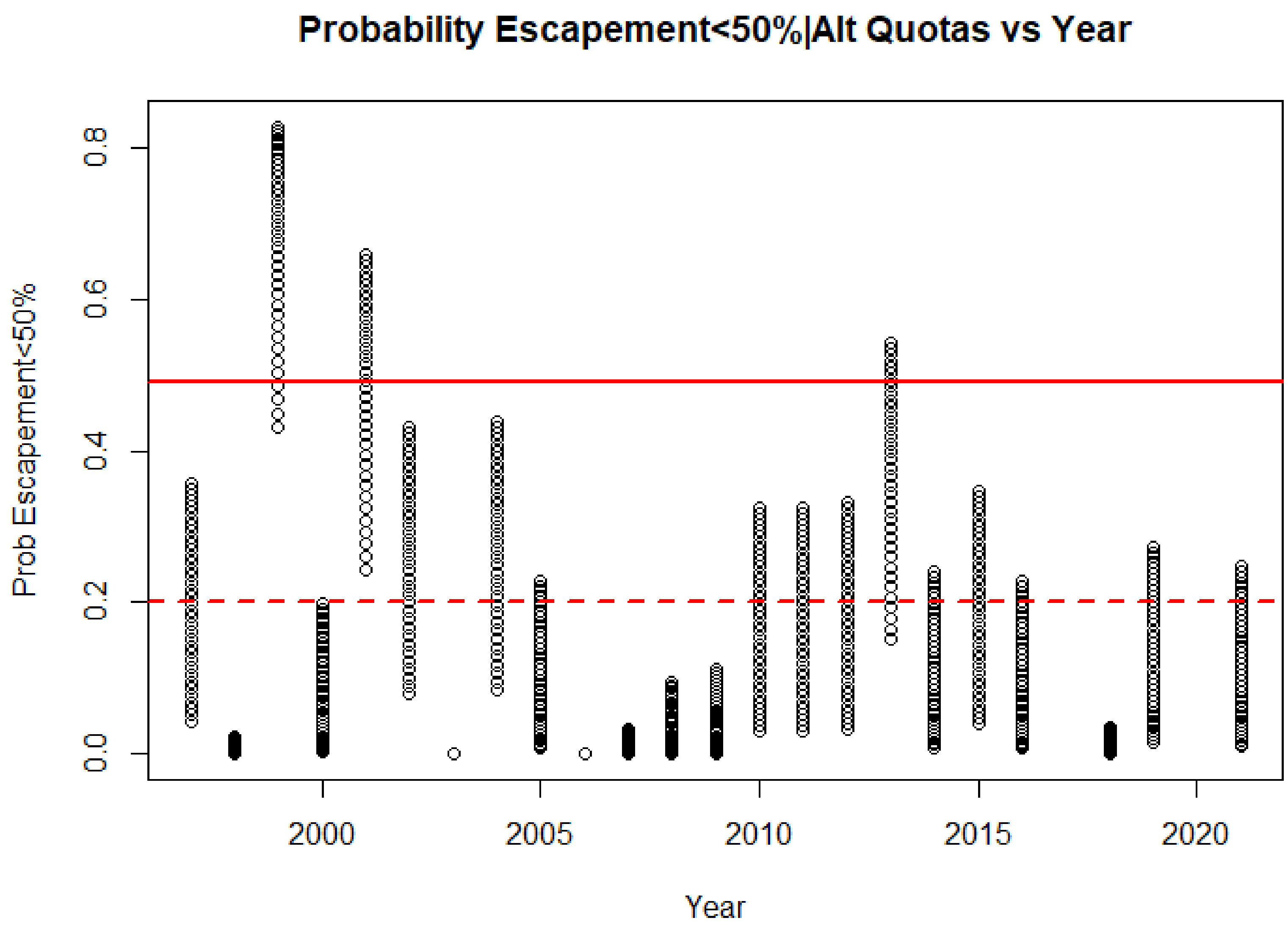
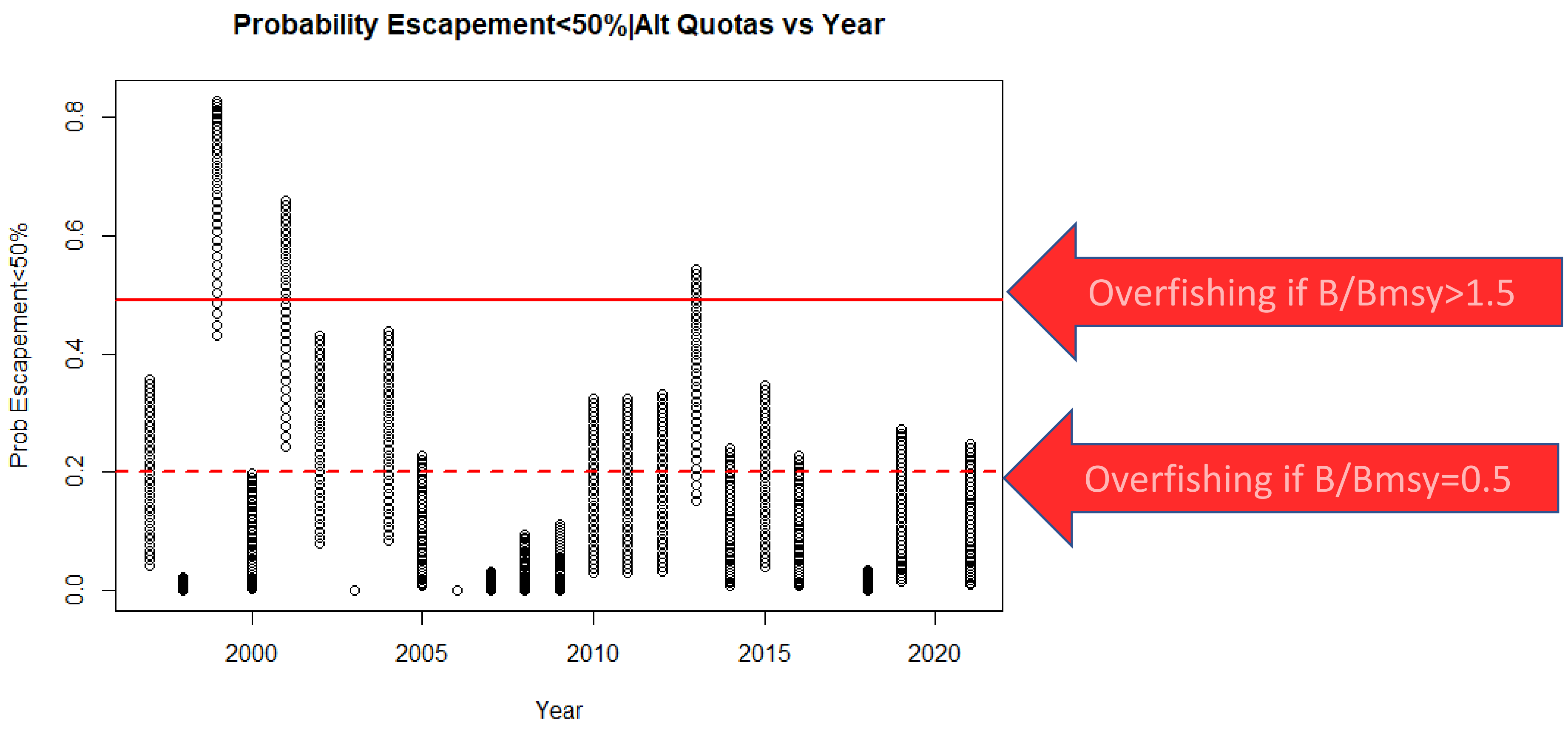
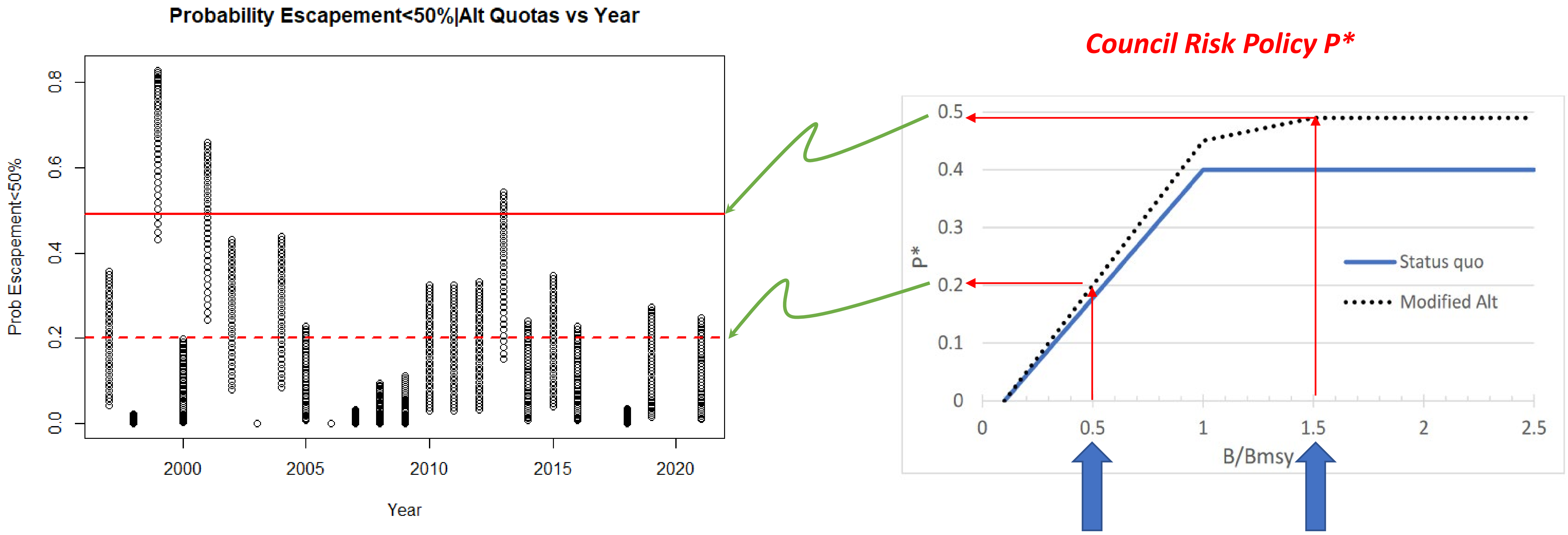


Figure 13. Estimated probability of escapement less than **50%** given alternative catch limits for each year ranging from 24,000 to 60,000. Each dot represents an alternative quota with lowest quotas at bottom and highest at top for each year. The initial population size in each year is based on the 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.



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.



Assumed Status of Illex

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

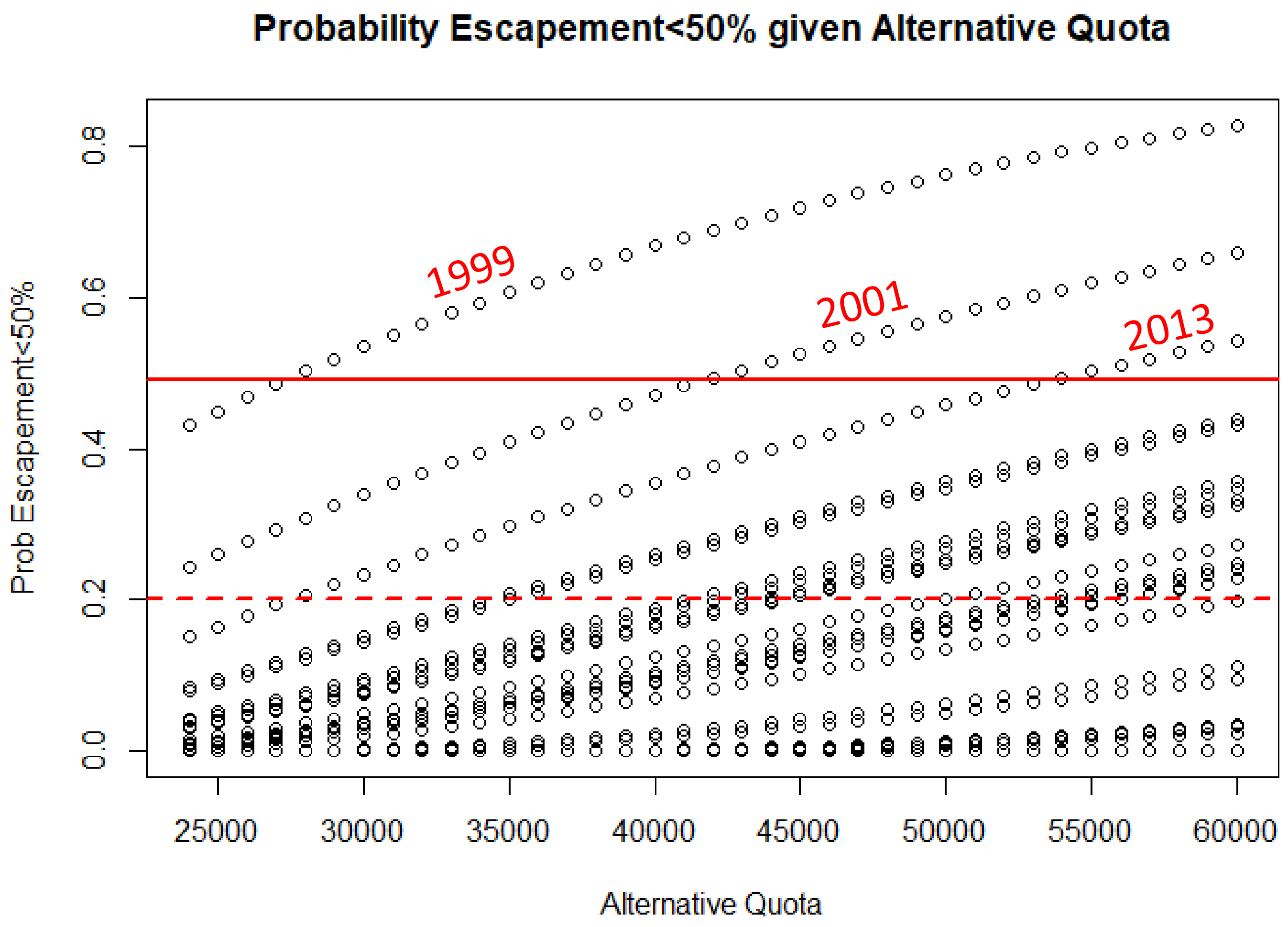
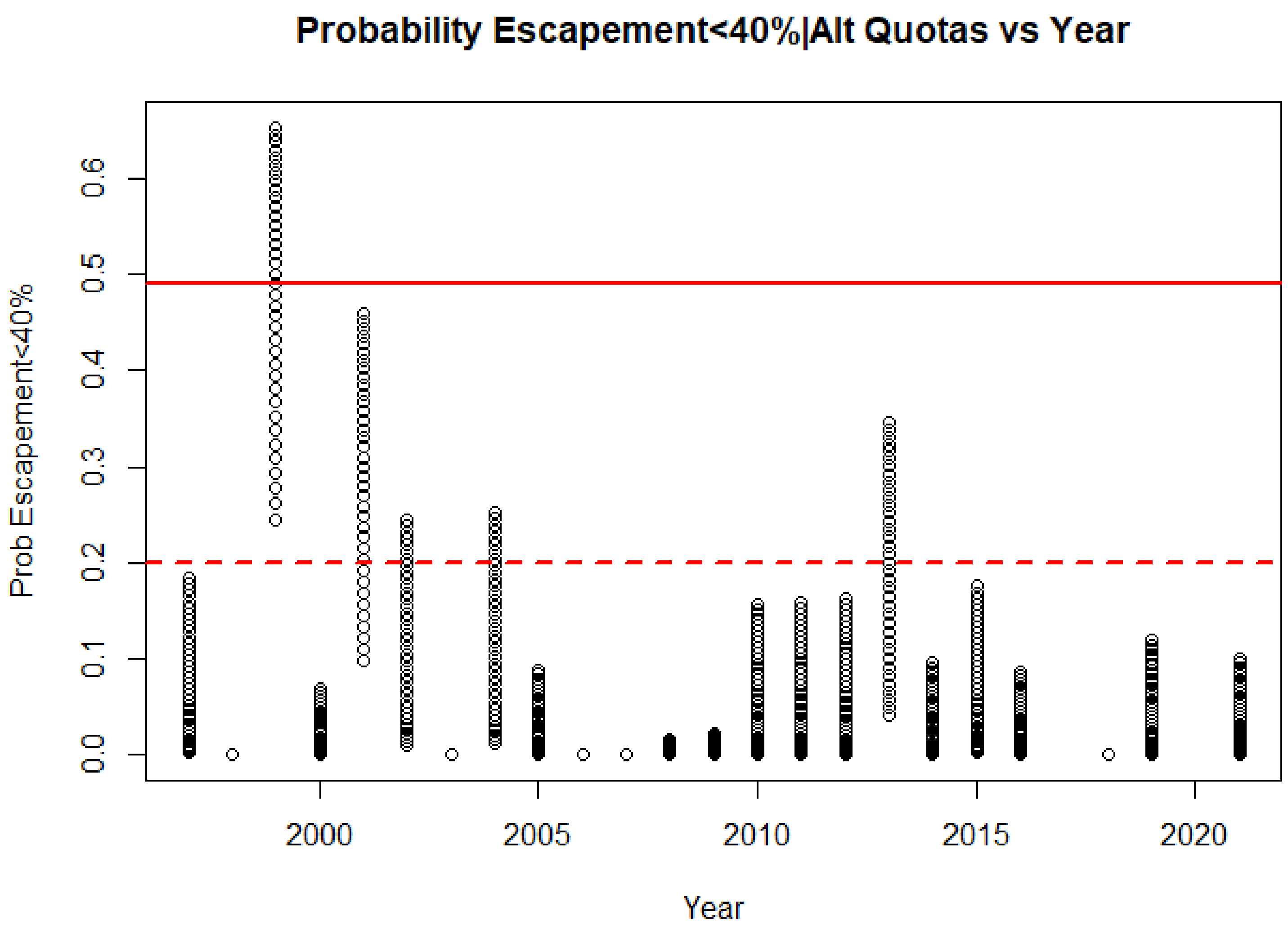


Figure 15. Estimated probability of escapement less than **40%** given alternative catch limits for each year ranging from 24,000 to 60,000. Each dot represents an alternative quota with lowest quotas at bottom and highest at top for each year. The initial population size in each year is based on the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



And now for some numbers….

Probabilities of falling below various Escapement thresholds for ALTERNATIVE quotas from 24,000 to 60,000 mt. Probabilities represent average over all years 1997-2021.

Alternative Quota	Escapement Threshold				
	0.35	0.4	0.5	0.6	0.75
24000	0.0097	0.0180	0.0530	0.1295	0.355
25000	0.0109	0.0201	0.0585	0.1394	0.370
26000	0.0122	0.0223	0.0641	0.1493	0.385
27000	0.0136	0.0246	0.0699	0.1591	0.400
28000	0.0150	0.0271	0.0758	0.1690	0.414
29000	0.0165	0.0297	0.0818	0.1787	0.428
30000	0.0181	0.0324	0.0880	0.1884	0.442
31000	0.0197	0.0353	0.0942	0.1980	0.455
32000	0.0215	0.0382	0.1005	0.2076	0.468
33000	0.0233	0.0413	0.1068	0.2170	0.480
34000	0.0252	0.0446	0.1132	0.2263	0.492
35000	0.0272	0.0479	0.1197	0.2356	0.504
36000	0.0293	0.0513	0.1261	0.2447	0.515
37000	0.0314	0.0547	0.1326	0.2537	0.526
38000	0.0337	0.0583	0.1390	0.2627	0.537
39000	0.0360	0.0620	0.1455	0.2715	0.547
40000	0.0384	0.0657	0.1519	0.2802	0.557
41000	0.0409	0.0695	0.1583	0.2888	0.567

Alternative Quota	Escapement Threshold				
	0.35	0.4	0.5	0.6	0.75
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

Probabilities of falling below various Escapement thresholds for ALTERNATIVE quotas from 24,000 to 60,000 mt. Probabilities represent average over all years 1997-2021.

Alternative Quota	***Escapement Threshold***				
	0.35	***0.4***	***0.5***	***0.6***	***0.75***
24000	0.0097	0.0180	0.0530	0.1295	0.355
25000	0.0109	0.0201	0.0585	0.1394	0.370
26000	0.0122	0.0223	0.0641	0.1493	0.385
27000	0.0136	0.0246	0.0699	0.1591	0.400
28000	0.0150	0.0271	0.0758	0.1690	0.414
29000	0.0165	0.0297	0.0818	0.1787	0.428
30000	0.0181	0.0324	0.0880	0.1884	0.442
31000	0.0197	0.0353	0.0942	0.1980	0.455
32000	0.0215	0.0382	0.1005	0.2076	0.468
33000	0.0233	0.0413	0.1068	0.2170	0.480
34000	0.0252	0.0446	0.1132	0.2263	0.492
35000	0.0272	0.0479	0.1197	0.2356	0.504
36000	0.0293	0.0513	0.1261	0.2447	0.515
37000	0.0314	0.0547	0.1326	0.2537	0.526
38000	0.0337	0.0583	0.1390	0.2627	0.537
39000	0.0360	0.0620	0.1455	0.2715	0.547
40000	0.0384	0.0657	0.1519	0.2802	0.557
41000	0.0409	0.0695	0.1583	0.2888	0.567

Alternative Quota	***Escapement Threshold***				
	0.35	***0.4***	***0.5***	***0.6***	***0.75***
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	[illegible]	[illegible]
50000	0.0659	0.1056	0.2149	[illegible]	[illegible]
51000	0.0689	0.1097	0.2210	[illegible]	[illegible]
52000	0.0720	0.1139	0.2271	[illegible]	[illegible]
53000	0.0750	0.1181	0.2331	[illegible]	[illegible]
54000	0.0781	0.1223	0.2391	[illegible]	[illegible]
55000	0.0813	0.1264	0.2450	[illegible]	[illegible]
56000	0.0845	0.1306	0.2508	[illegible]	[illegible]
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

Highest Quota consistent with Council Risk Policy IF B~0.5 B_{MSY} and Escapement Threshold is 50%

Probabilities of exceeding various F/M thresholds for ALTERNATIVE quotas from 24,000 to 60,000 mt. Probabilities represent average over all years 1997-2021.

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

Alternative Quota (mt)	F/M Threshold				
	0.33	0.5	0.666	1	1.5
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

Probabilities of exceeding various F/M thresholds for ALTERNATIVE quotas from 24,000 to 60,000 mt. Probabilities represent average over all years 1997-2021.

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	[illegible]	[illegible]
32000	0.3133	0.2233	0.1701	[illegible]	[illegible]
33000	0.3190	0.2280	0.1741	[illegible]	[illegible]
34000	0.3245	0.2326	0.1780	[illegible]	[illegible]
35000	0.3300	0.2371	0.1819	[illegible]	[illegible]
36000	0.3353	0.2415	0.1856	[illegible]	[illegible]
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

Highest Quota consistent with Council Risk Policy IF B~0.5 B_{MSY} and F/M Threshold is 0.66

Alternative Quota (mt)	***F/M Threshold***				
	0.33	***0.5***	***0.666***	***1***	***1.5***
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

General Conclusions (1)

- 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).
  - Wide fluctuations in catch levels occur in other squid fisheries (Falklands)
- Median biomass estimates over the past 10 years have ranged from 112 to 461 k mt (Table 2)
- Median escapement percentiles have exceeded 0.765 for this same period (Table 3).
- Exploitation rates are generally low, <0.01/week (Fig. 11)
  - One has to posit much higher average availability and catchability rates than used herein to significantly reduce median stock size or escapement.
- Escapement estimates herein do NOT consider temporal escapement that occurs outside the fishing season. (or as they say in Scottish salmon fisheries "outwith the fishery")

General Conclusions (2)

- Probability of falling below a threshold escapement level is computed for (1997-2021, with 2017 and 2020 excluded).
  - Average probability depends on all of the realized B.0(y) estimates,1997-2021
  - Assumes all initial conditions B.0(y) are equally probable.
- Three low biomass years have been observed: 1999 (70 kt, median),2001 (91 kt median) and 2013 (113 kt, median) (Table 2).
  - A hypothetical quota of 28,000 mt in 1999 would have resulted a median escapement rate of 50% (Table 5).
  - A hypothetical quota of 43,000 mt in 2001 would have resulted a median escapement rate of 50% (Table 5).
  - A hypothetical quota of 55,000 mt in 2013 would have resulted a median escapement rate of 50% (Table 5).
- Based on probabilities averaged over all years:
  - If B_t is stationary and B/Bmsy~1 and Escapement threshold =50% then quotas up to 60,000 mt are possible. (Table 10)
  - If B_t is stationary and B/Bmsy~0.5 then quotas should not exceed 47,000 mt (Table 10) or 40,000 mt if F/M=2/3 criterion (Table 11).

Sources of Uncertainty

- Ranges of parameters for q,v, and M
  - Are they independent?
- Distribution of parameters.
  - Uniform is the ultimate heavy tail distribution (other than Beta(0.5,0.5))
  - Do we actually know more?
- Knowledge of Illex life history
  - Variable growth and maturation rates within and between years
  - Importance of cannibalism?
  - Year round spawning assumed. Fishery supported by births in Jan and Feb. Importance of other seasons unknown.
- Actual Range of Illex offshore
  - Population assumed available within domain of US and Canada surveys.
  - Escapement would be higher if population can complete life cycle without migrating on to shelf.
- Candidate reference points
  - No analyses of stock recruitment dynamics for Illex illecebrosis or others
  - Are % escapement rates sufficient
  - Do empirical or modeling studies support F/M thresholds?

Questions?

Interesting but not essential slides

Miscellaneous Topics

- How much biomass enters system between the midpoint of the spring survey (~April 1) and the midpoint of the fall Survey (~Oct 1)?
- What does the ratio of Catch over the end of year biomass estimate tell you about potential escapement?
- What if losses due to spawning mortality occur over the entire course of the fishing season?
    - How to factor these losses into escapement?

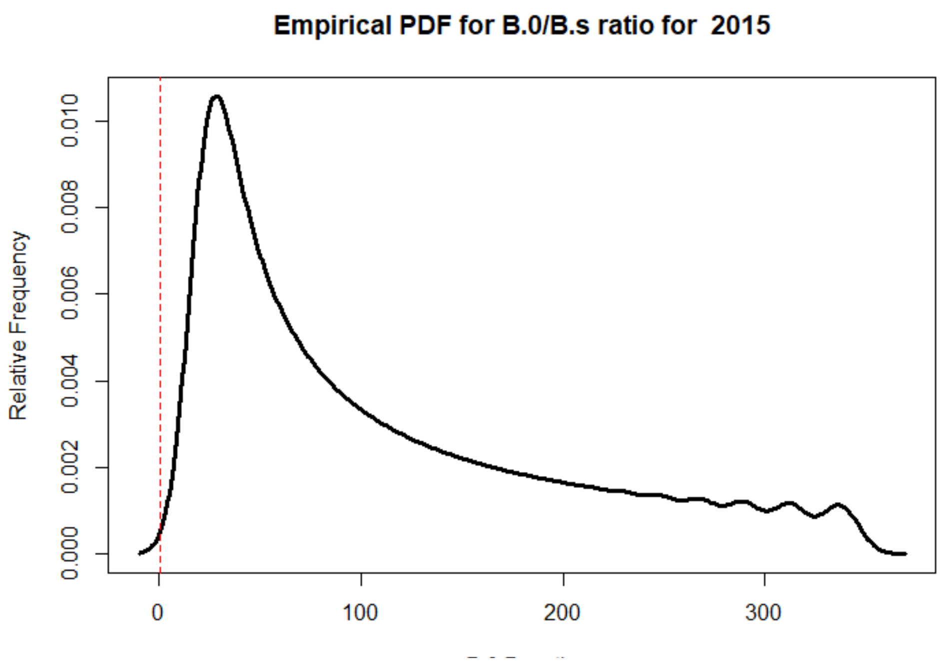
Mass Balance—How much migration could there be?

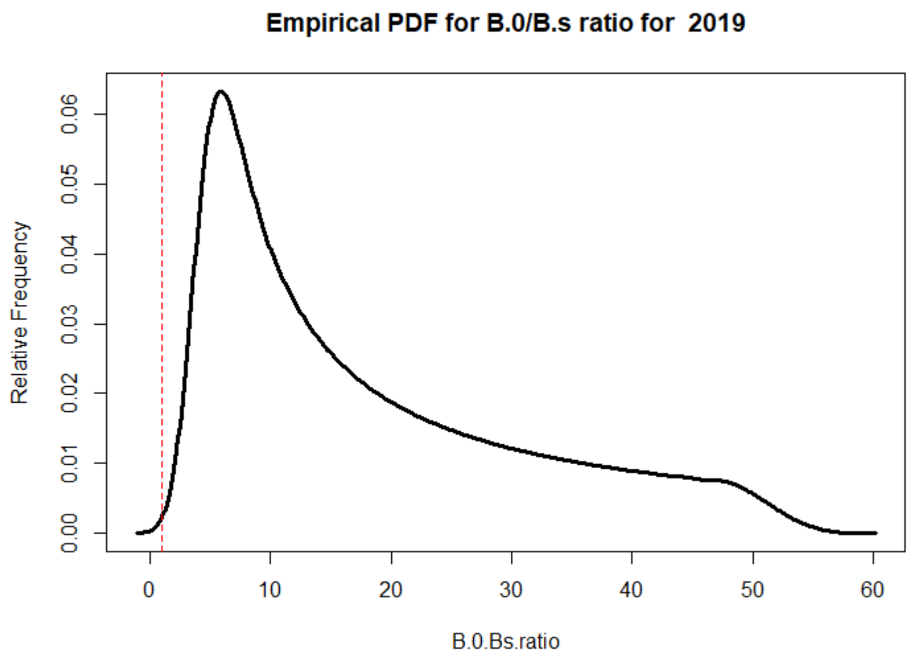
- The NEFSC spring bottom trawl survey (BTS) ends before the offshore fishery starts.
- The NEFSC fall BTS begins after most of the fishery has taken place.
- In between a large number of squid are harvested.
- Consider 2019:
  - Spring BTS minimum swept area = 1,901 mt
  - Commercial landings = 28,495 mt
  - Fall BTS minimum swept area = 3,310 mt
  - EVEN if no natural mortality, the minimum biomass to support observed landings is 28,495+3,310=31,805 mt
  - Ratio B.0|M=0/B.s=31,805/1,901=***16.7***

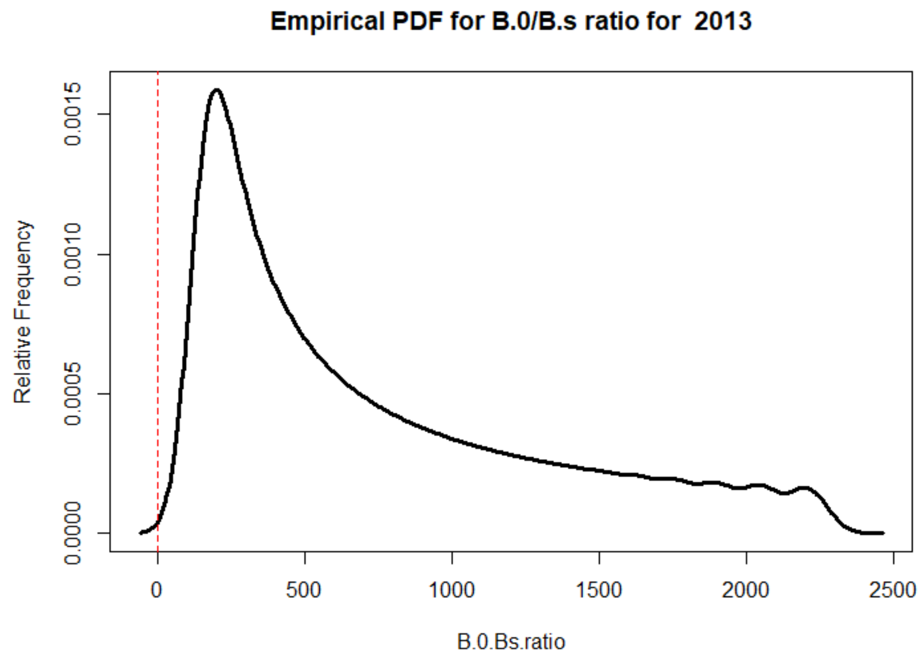
B.0 vs B.s disconnect

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).

Fishery is supported recruitment in season between time of spring and fall surveys



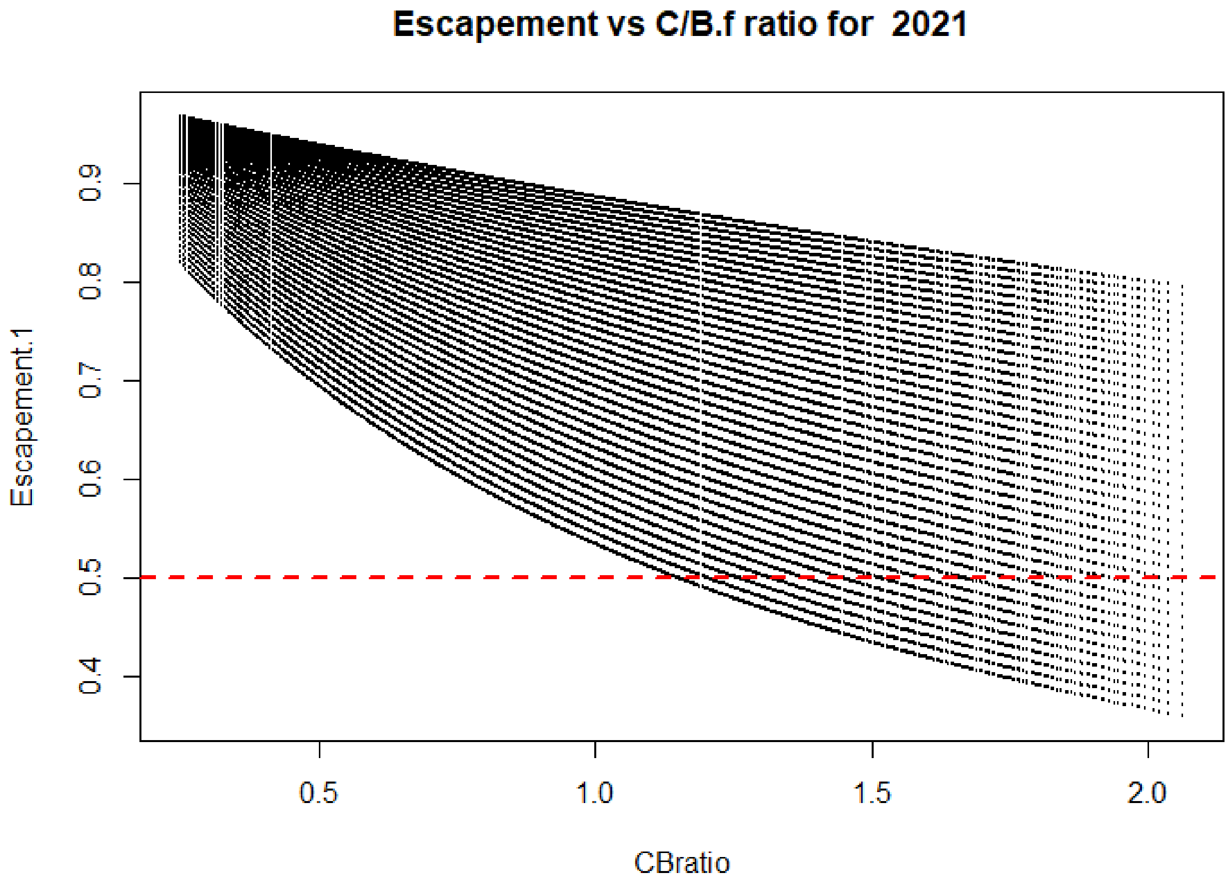


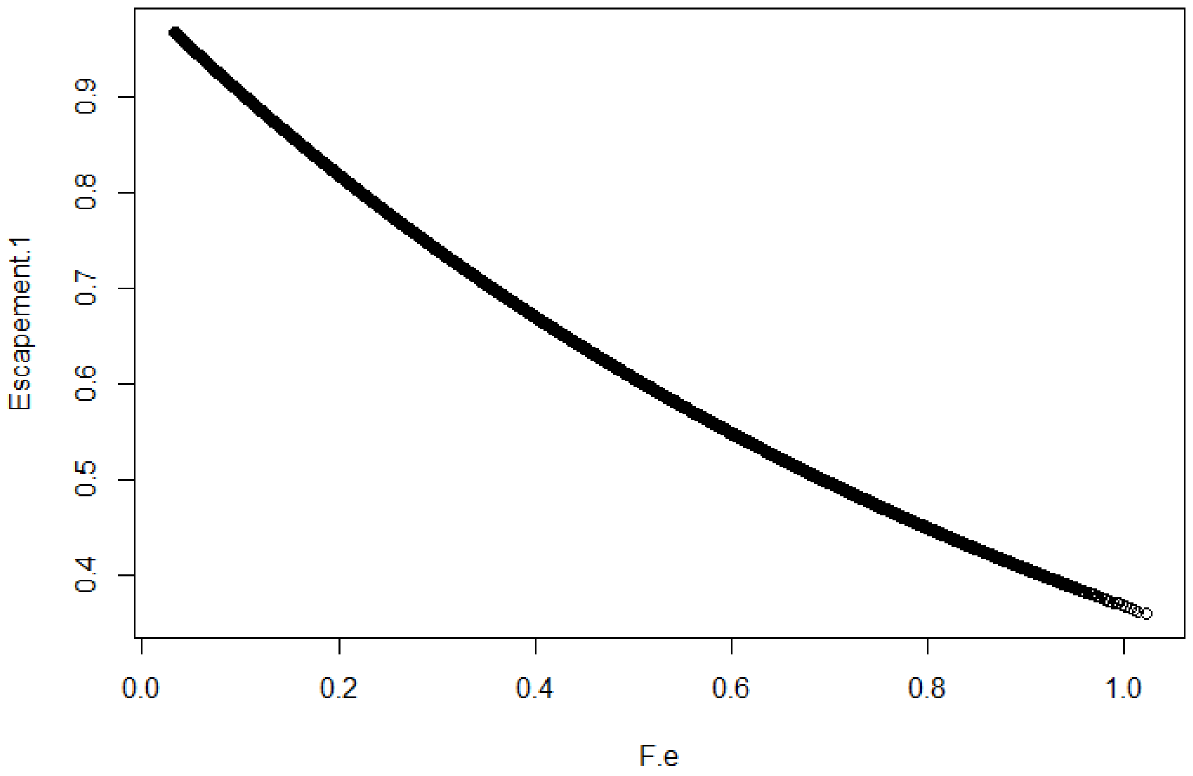


What does Catch over Fall Survey measure?

- Catch over survey biomass is often used as an index of exploitation
- IF survey represents the "average" biomass during the period of exploitation, then C/I approximates the Baranov catch equation
- IF survey represents pre fishery abundance and population is closed, then C/I approximate exploitation rate (probability of dying due to fishing)
- IF survey represents post fishery abundance, then C/I depends on assumed M.
  - $C/B_t = C/(B_0\ e^{-Z})$ per Baranov
  - $C/B_t = C/(B_0\ e^{-M} + C\ e^{-M/2})$ per Pope's approximation

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





Mathematics for continuous loss of spawners

- Assume that spawners are removed from the population and die soon after.
- Let the rate of maturation be K and the accumulated biomass of spawners be defined as $S_t|F>0$
- The numerator of escapement ratio can now be defined as the terminal biomass plus the accumulated biomass of spawners when fishing is occurring ($S_t|F>0$)
- The denominator is the initial biomass decremented for loss due to natural mortality and maturation plus the accumulated spawning biomass in the absence of fishing mortality ($S_t|F=0$)
- Use modified catch equation to illustrate:
  - Bt=B.0 exp(-(F+M+K))
  - St|F>0 = K/(F+M+K) (1-exp(-(F+M+K))) B.0
  - St|F=0 = K/(M+K) (1-exp(-(M+K))) B.0

Comparison of Escapement with and without accounting for in-season spawning effect

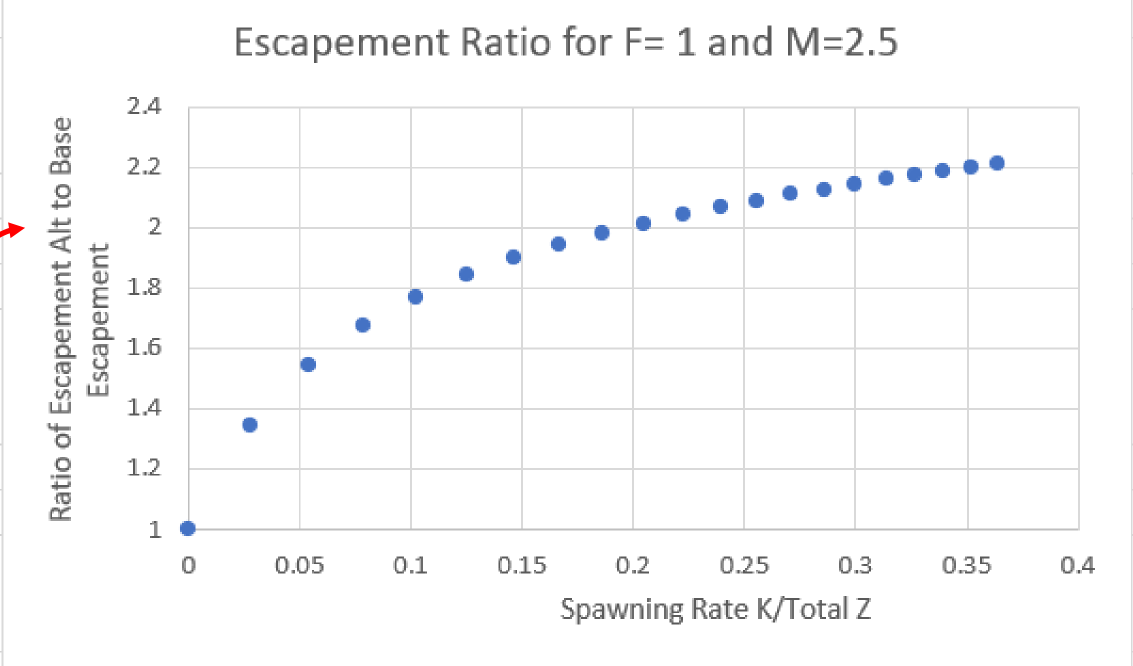
Parameters for Initial Stock Size and Inst. Rates (25 wk $^{-1}$)				
B.0	***F***	***M***	***K***	***Catch***
100,000	1	2.5	0.5	24,542

	B.t| F>0	***Catch***	***Spawners| F>0***	***Loss to Natural Mort***	***total removals***		***check sum***
A	1,832	24,542	12,271	61,355	98,168		100,000
			C				

	B.t|F=0	***Catch***	***Spawners| F=0***	***Loss to Natural Mort***	***total removals***		***check sum***
B	4,979	0	15,837	79,184	95,021		100,000
			D				

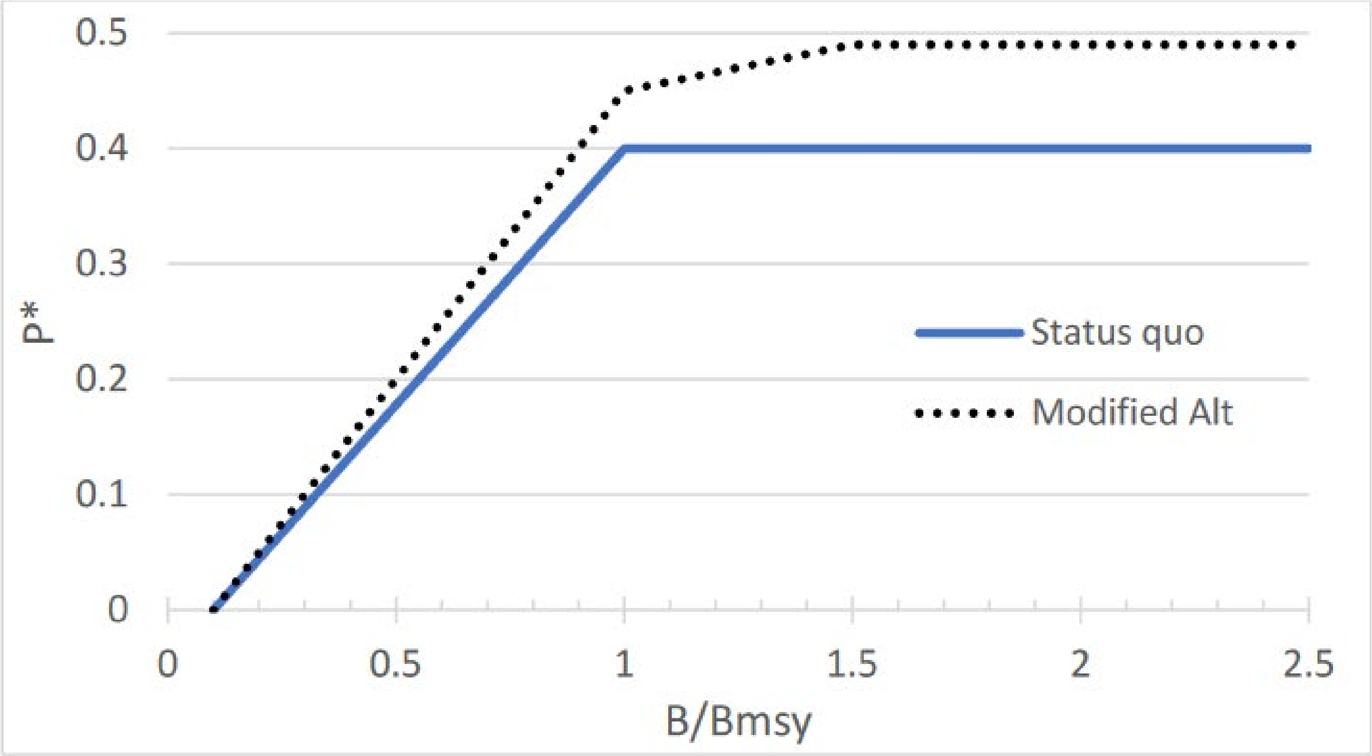
Escapement w/o Spawners	0.3679	<==A/B = E	
Escapement.ALT w/ Spawners	0.6775	<==(A+C)/(B+D) = F	

Ratio of Escapement with spawners to escapement without spawners	
1.8416	<==F/E

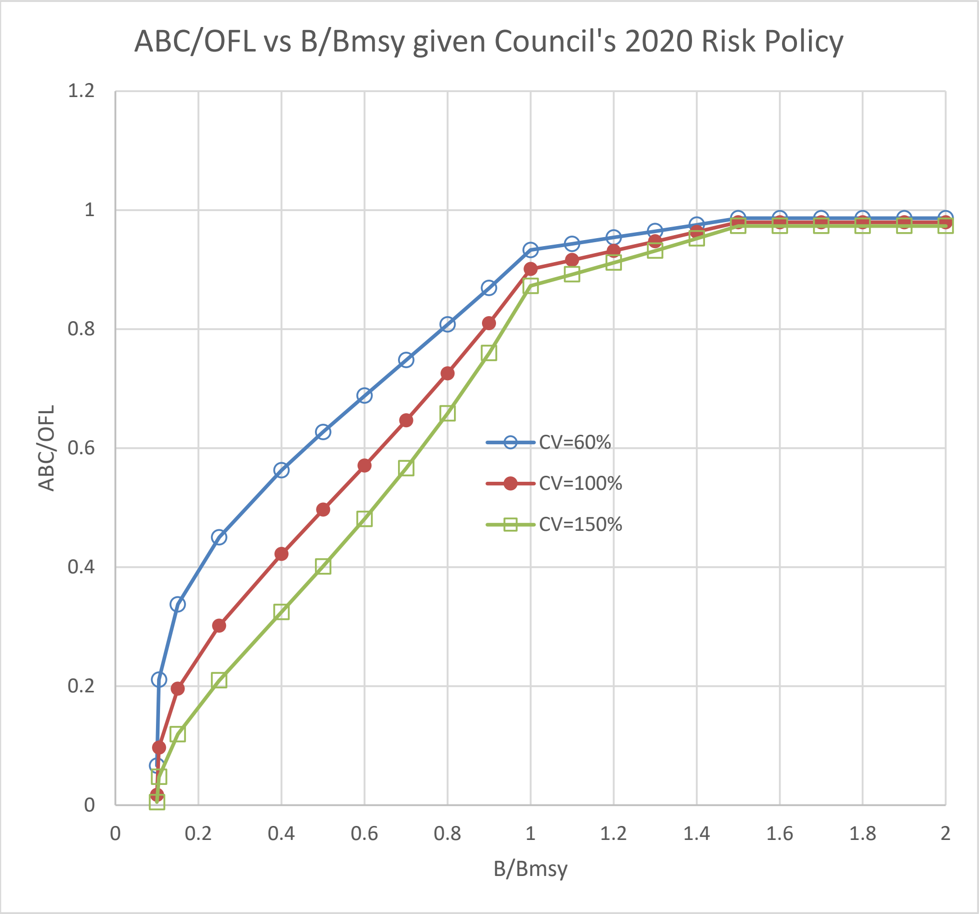


Backpocket slides

Risk Analyses



OFL CV



ABC/OFL vs B/Bmsy given Council's 2020 Risk Policy
ABC/OFL
B/Bmsy
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
CV=60%
CV=100%
CV=150%