Indirect Methods for Bounding Biomass and Fishing Mortality for Illex Squid and Implications of an Alternative Quota for 2022

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Mid Atlantic Fishery Management Council
Scientific and Statistical Committee

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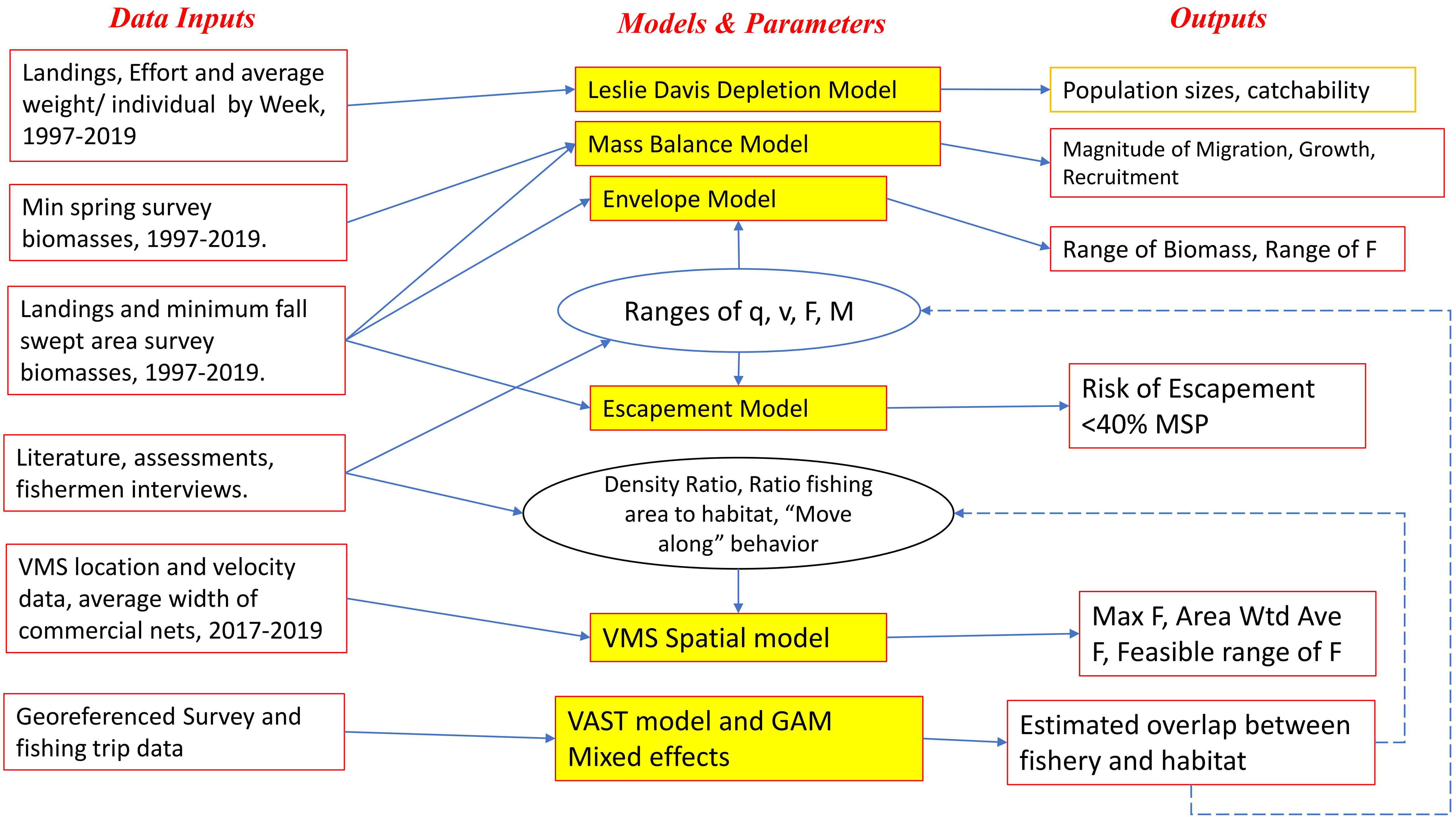
Overview

- Summarize discussion and decisions from 2020
- Update and refine methods used in 2020
- Interrelate approaches
- Update parameters per independent analyses
- Summarize implications of 30,000 and 33,000 mt ABCs for 2021 and 2022.

Conclusions from May 2020 SSC

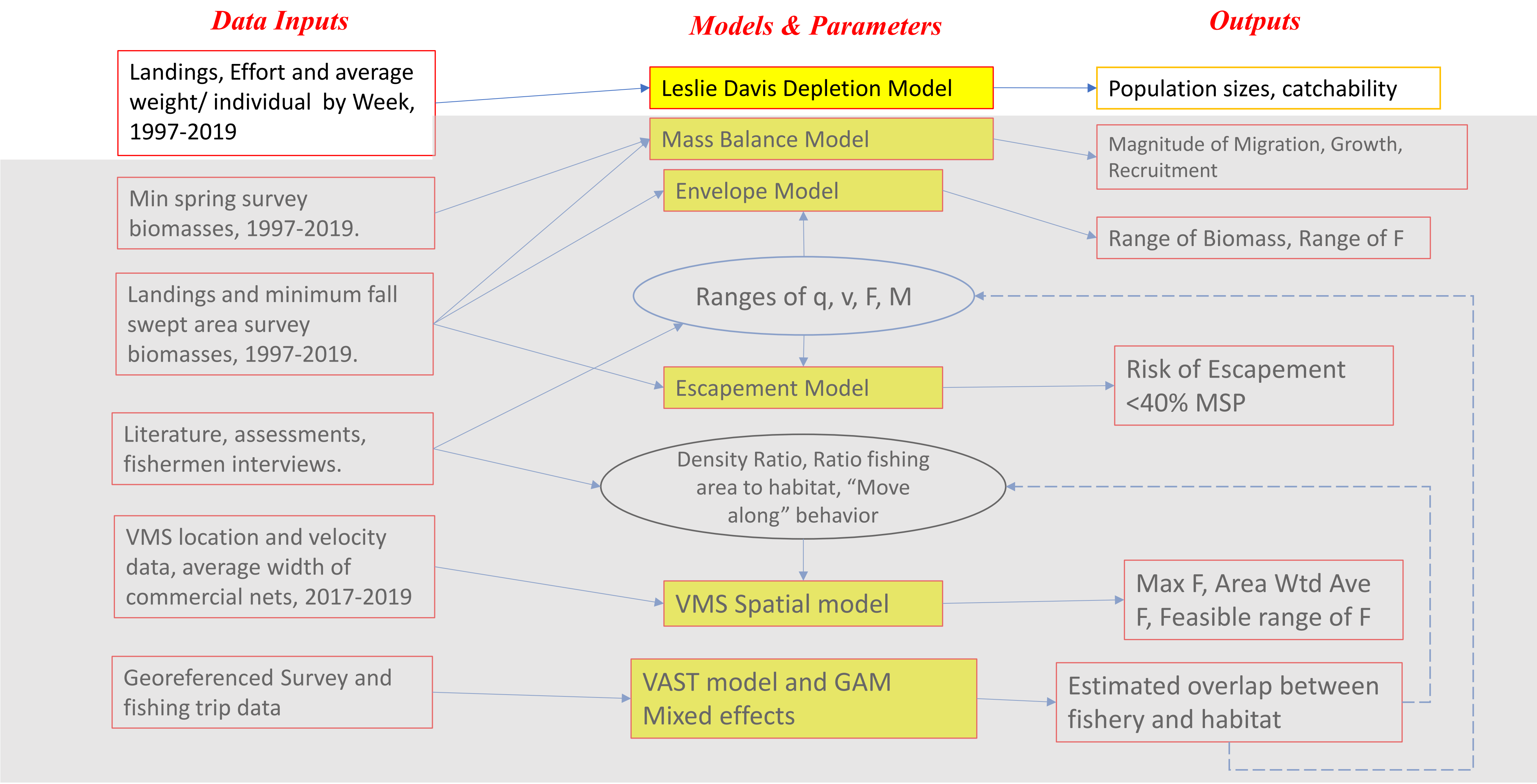
- *"Bottom trawl survey data….were combined to develop an overall probability of occurrence spatial map …Comparison of these maps with estimates of the spatial footprint of the fishery …revealed a low degree of overlap with the survey area irrespective of the cutoff criterion used for the probability of occurrence….. Because the surveyed areas represent only a fraction of the known distribution of Illex, the results of these analyses suggest substantial opportunity for escapement of squid to unfished areas."*
- *"A review of the life history of Illex suggested that it is likely highly resilient to low levels of exploitation because of the presence of multiple cohorts, batch spawning and increased fecundity levels resulting from the presence of larger squid in the population than were present when fecundity was estimated originally."*
- *"The SSC reviewed the material developed by the MAFMC Illex Working Group (WG) and the NEFSC and found clear evidence to support an adjustment of the 2020 ABC (26,000 mt). The WG analyses strengthened SSC contention in its 2017 ABC specification that the stock has been lightly exploited."*

Figure 1. Inter-relationships among methods to establish bounds on biomass and fishing mortality rates for Illex squid.



Depletion

Depletion Model



Leslie-Davis Depletion Model—Theory

The key assumptions of a depletion model are:

1. All individuals have the same probability of being caught in a sample
2. The expected catch in a sample is proportional to sampling effort
3. The catch depends on the cumulative catch of preceding samples
4. All removals from the population are known
5. All additions to the population are known

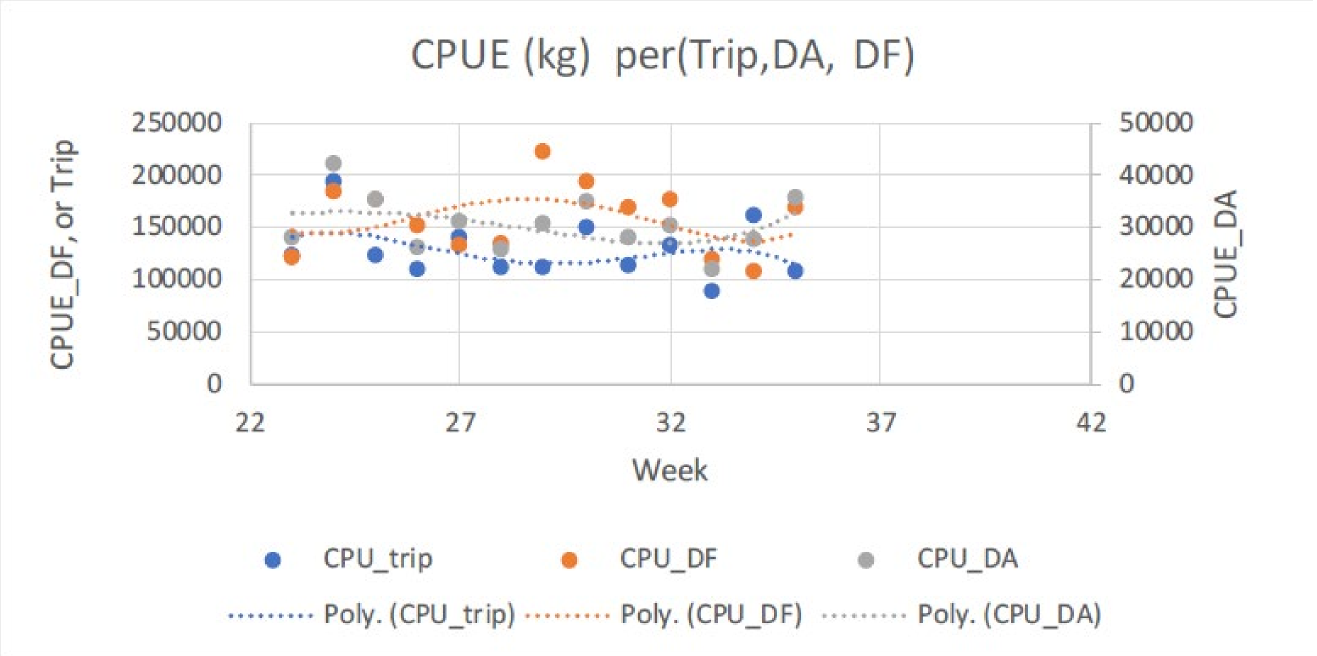
$$CPUE_t = qN_0 - q\sum_{i=1}^{t-1} C_i$$

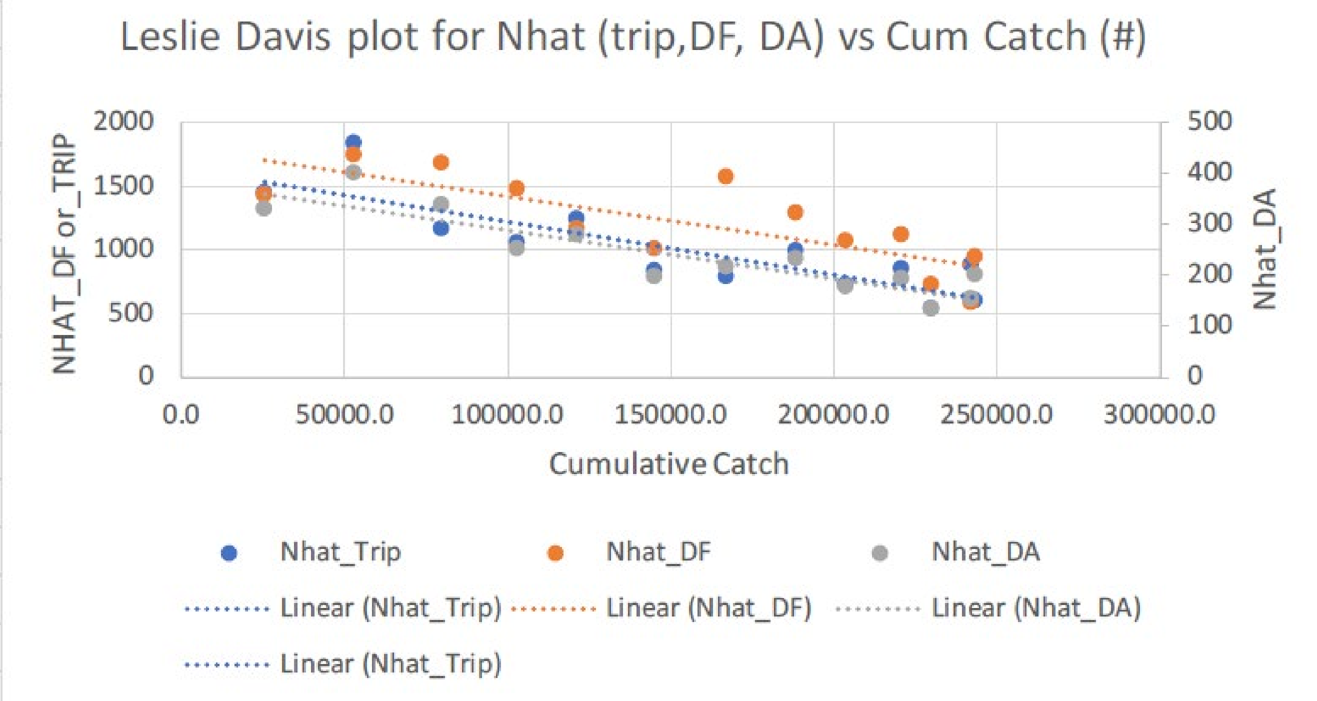
- This is a simple linear regression CPUE(t)=a +b K(t-1) where K(t-1) is equal the sum of catches up to t-1.
- In theory, the estimated total number of individuals in the population occurs when all of the individuals are captured.
- This corresponds to CPUE=0, so that the estimate of N_0 is simply equal to -a/b.

Leslie Davis Model—Practice

1998—GOOD

CPUE	*Per Trip*	*Per Day Absent*	*Per Day Fished*	*Average*	*Max/ Min*
R-square	0.7269	0.8041	0.6161	0.7157	1.31
Slope	-0.0041	-0.0009	-0.0038	NA	0.23
Nhat (millions)	395	404	474	424	1.20



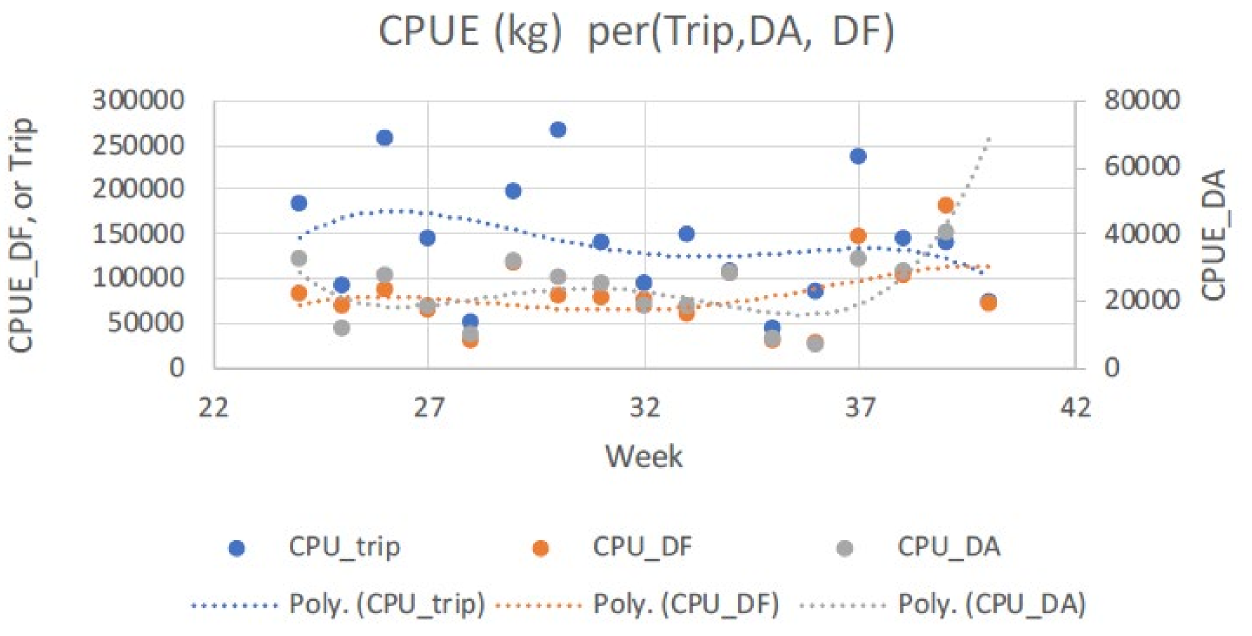


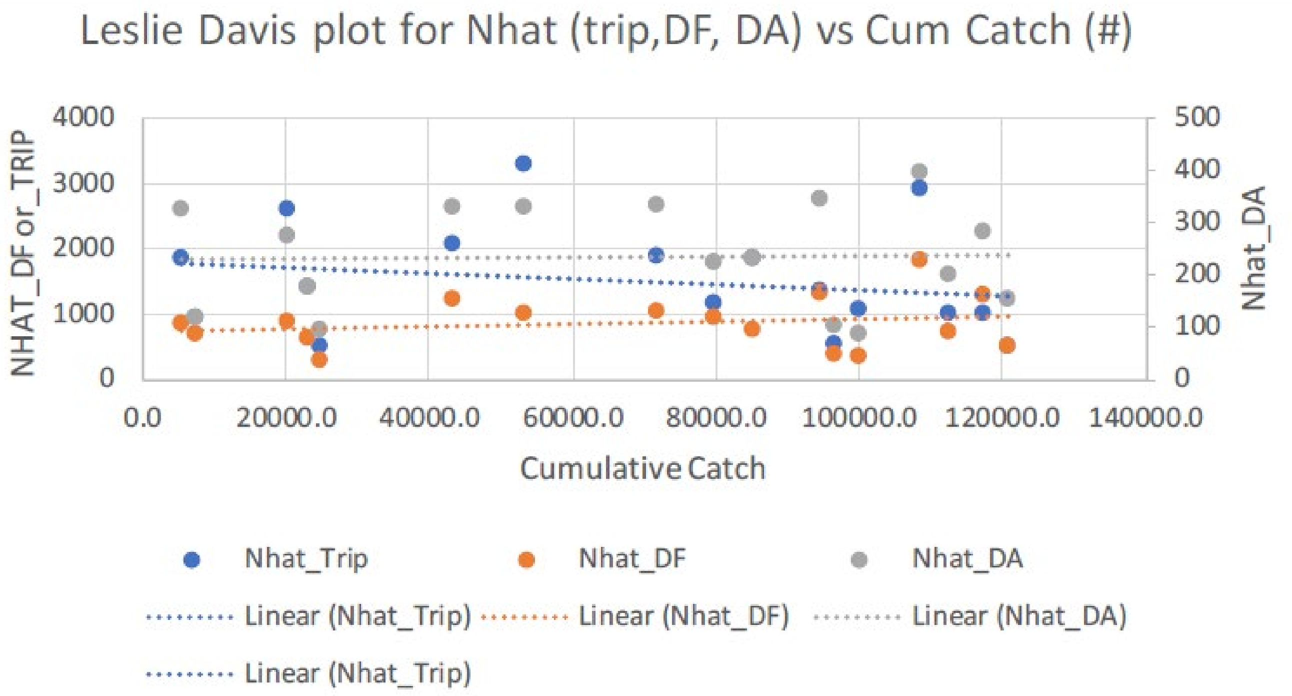
Leslie Davis Model—Practice

2000--UGLY

CPUE	*Per Trip*	*Per Day Absent*	*Per Day Fished*	*Average*	*Max/ Min*
R-square	0.0455	0.0011	0.0367	0.0278	40.72
Slope	-0.0044	0.0001	0.0019	NA	-0.43
Nhat (millions)	413	-2,730	-382	-900	-0.15

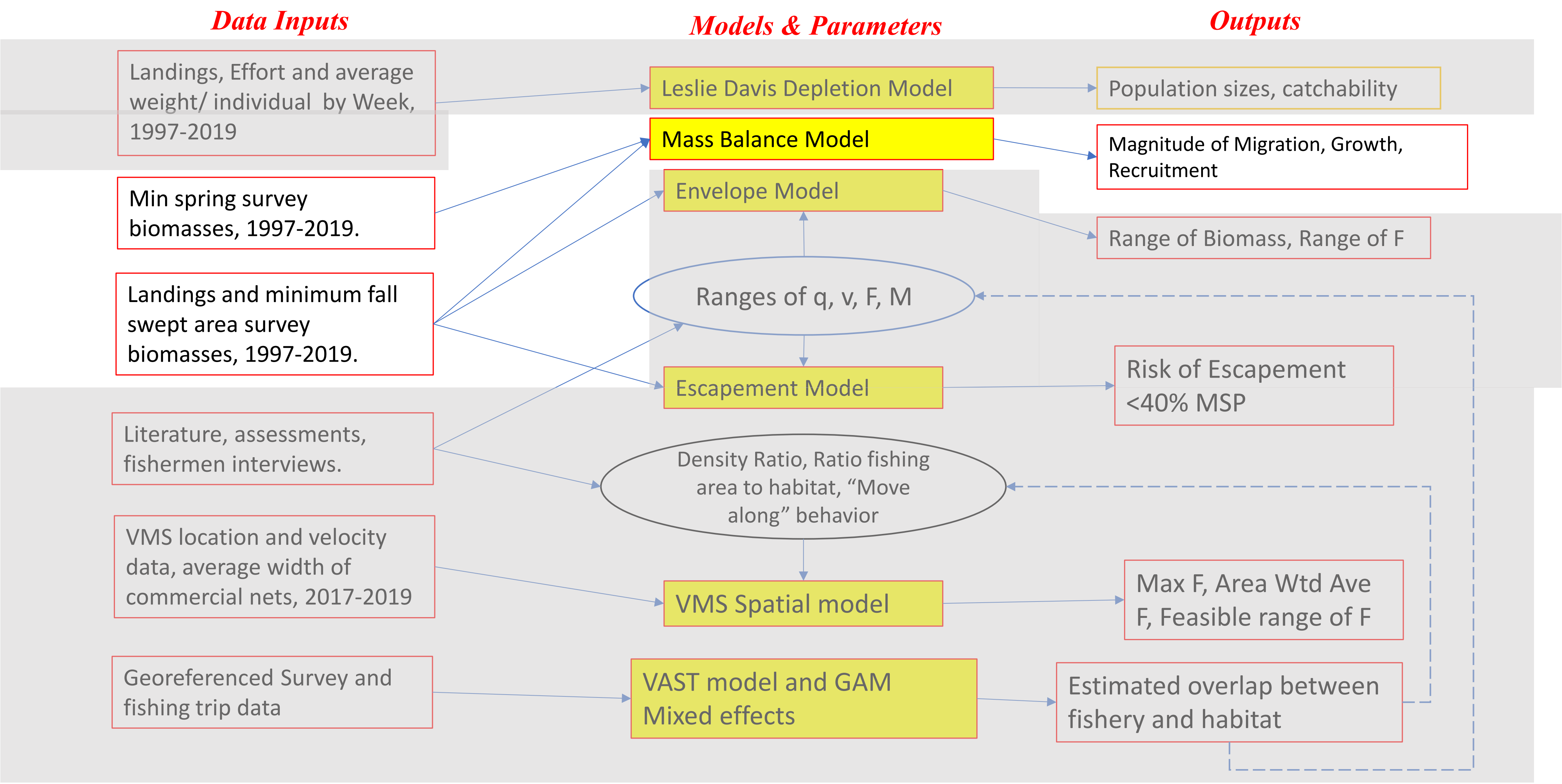
Results of Leslie Davis model were inconsistent over time, suggesting violation of assumptions and possibly high rates of migration through the fishing areas.





Mass Balance

Mass Balance Model



Mass Balance—How much migration could their 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

Consider a simple mass balance problem wherein the biomass in the fall $\mathbf{B_F}$ in any year is equal to the initial biomass in the spring $\mathbf{B_S}$ less the losses from the fishery **C** and natural mortality **L**. These losses are offset by growth in average weight over the course of the fishery **G**, net migration of squid **Mig** into the stock area and new recruits **R**.

$$B_F = B_S - C - L + G + Mig + R$$

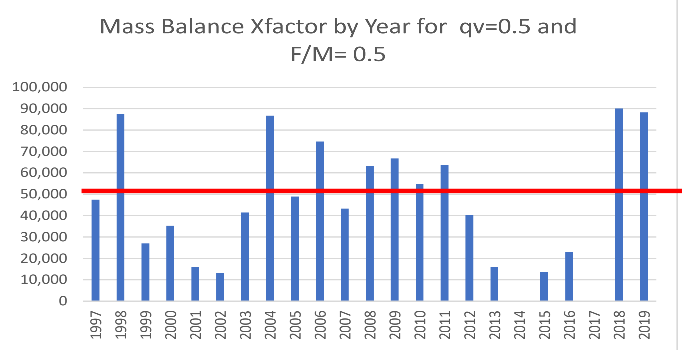
The terms G, Mig and R summarize the processes necessary to offset the losses from the fishery but there are precious little data to estimate the individual components. Instead, consider the them as a pool X such that

$$X = G + Mig + R$$

By letting $\mathbf{I_S = B_S/(qv)}$ and $\mathbf{I_F = B_F/(qv)}$ and a little algebraic pluggation

$$X = (I_F - I_S)/(qv) + (1+\alpha)\,C$$

Where gear efficiency =**q** and availability= **v and a is the ratio of F to M**



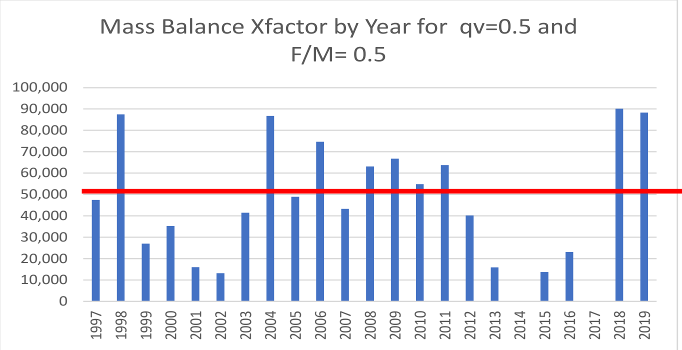
F/M=0.5
Qv=0.5
Ave=49,605

Exploring the parameter space for F/M and qv

Table 1. Estimation of average X factor to balance removals, 1997-2019 given alternative values of F/M and catchability =efficiency x availability

		qv=efficiency x availability													
	49,605	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7
ratio of F to M	0.10	234411	192945	179122	172211	168065	165300	163326	161845	160693	159771	159017	158389	157857	157402
	0.20	165558	124091	110269	103358	99211	96447	94472	92991	91839	90918	90164	89535	89004	88548
	0.30	142607	101140	87318	80406	76260	73495	71521	70040	68888	67966	67213	66584	66053	65597
	0.40	131131	89664	75842	68931	64784	62020	60045	58564	57412	56491	55737	55109	54577	54121
	0.50	124246	82779	68957	62046	57899	55134	53160	51679	50527	49605	48852	48223	47692	47236
	0.60	119655	78189	64366	57455	53309	50544	48570	47089	45937	45015	44261	43633	43101	42646
	0.70	116377	74910	61088	54177	50030	47265	45291	43810	42658	41737	40983	40354	39823	39367
	0.80	113918	72451	58629	51717	47571	44806	42832	41351	40199	39277	38524	37895	37364	36908
	0.90	112005	70538	56716	49805	45658	42894	40919	39438	38286	37365	36611	35983	35451	34995
	1.00	110475	69008	55186	48275	44128	41364	39389	37908	36756	35835	35081	34453	33921	33465
	1.10	109223	67756	53934	47023	42876	40112	38137	36656	35504	34583	33829	33201	32669	32213
	1.20	108180	66713	52891	45980	41833	39069	37094	35613	34461	33540	32786	32157	31626	31170

Envelope



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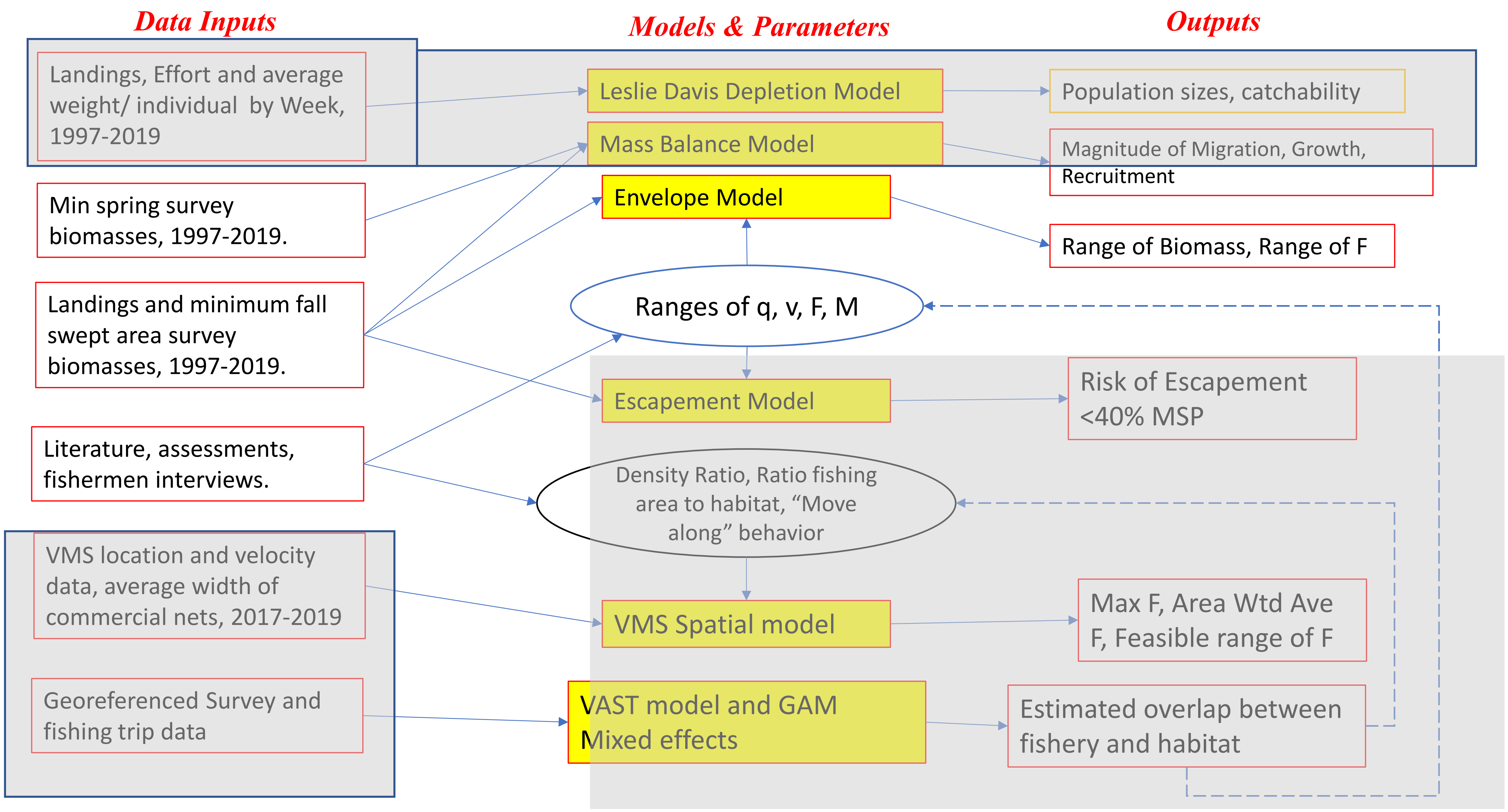
	0.20	165558	124091	110269	103358	99211	96447	94472	92991	91839	90918	90164	89535	89004	88548
	0.30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	66053	65597
	0.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	54577	54121
	0.50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47692	47236
	0.60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43101	42646
	0.70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39823	39367
	0.80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37364	36908
	0.90	112005	70538	56716	49805	45658	42894	40919	39438	38286	37365	36611	35983	35451	34995
	1.00	110475	69008	55186	48275	44128	41364	39389	37908	36756	35835	35081	34453	33921	33465
	1.10	109223	67756	53934	47023	42876	40112	38137	36656	35504	34583	33829	33201	32669	32213
	1.20	108180	66713	52891	45980	41833	39069	37094	35613	34461	33540	32786	32157	31626	31170

Hypothesis—over a broad range of parameters, the spring and fall bottom trawl survey data appear insufficient to describe the magnitude of the intervening removals. Unexplained average production ranges from 31kt to 234kt.

Envelope Model



Envelope Method: Bounding biomass

- The fundamental problem of fisheries: C=FB
  - Is observed catch the result of high fishing mortality on small stock or low mortality on a small stock?
- Using survey and catch data, the Envelope method assumes a range of plausible values for catchability and fishing mortality to develop a constrained range of stock sizes consistent with both sets of assumptions.

Envelope Method

- Key data sources:
  - **Post fishery** fall bottom trawl survey
  - Total landings
- Assume range of
  - catchability (q) ={q_lo, q_hi)
  - availability (v)={v_lo,v_hi}
- Assume range of
  - F={F_lo, F_hi},
  - M={M_lo, M_hi}

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

$$B_0 = B_t\ e^{M\,t} + C_t\ e^{\frac{M}{2}t}$$

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

Envelope Constraints

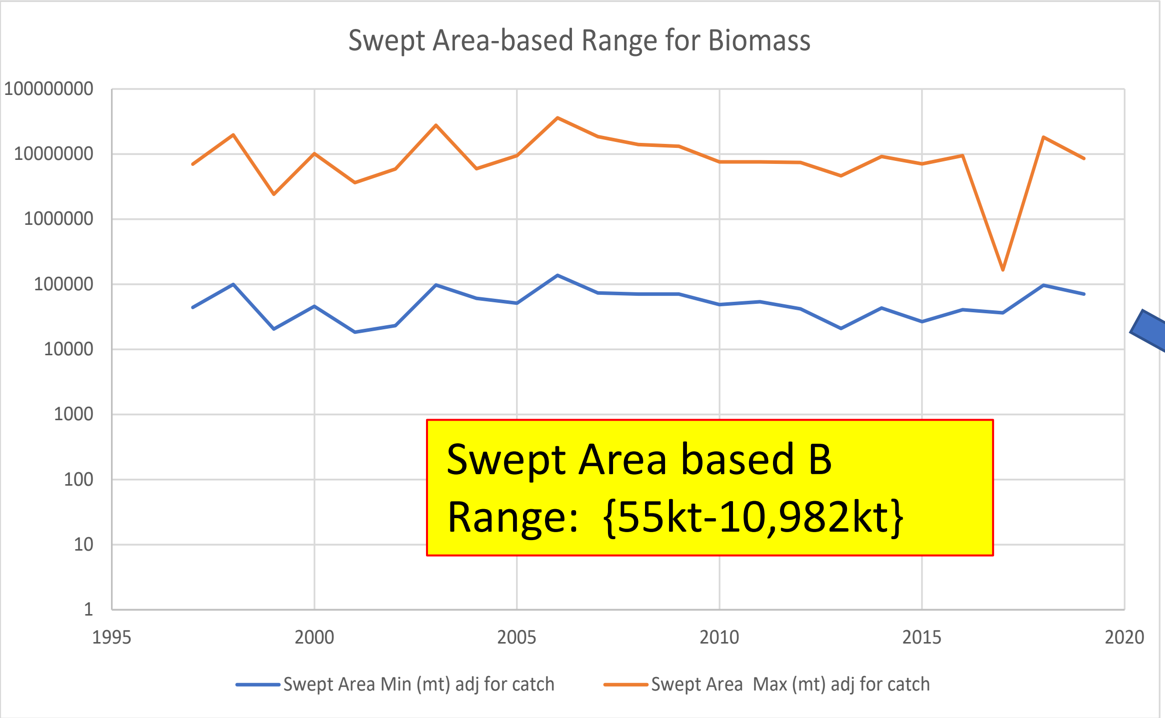
- Find constrained min of maximums, and max of Minimums

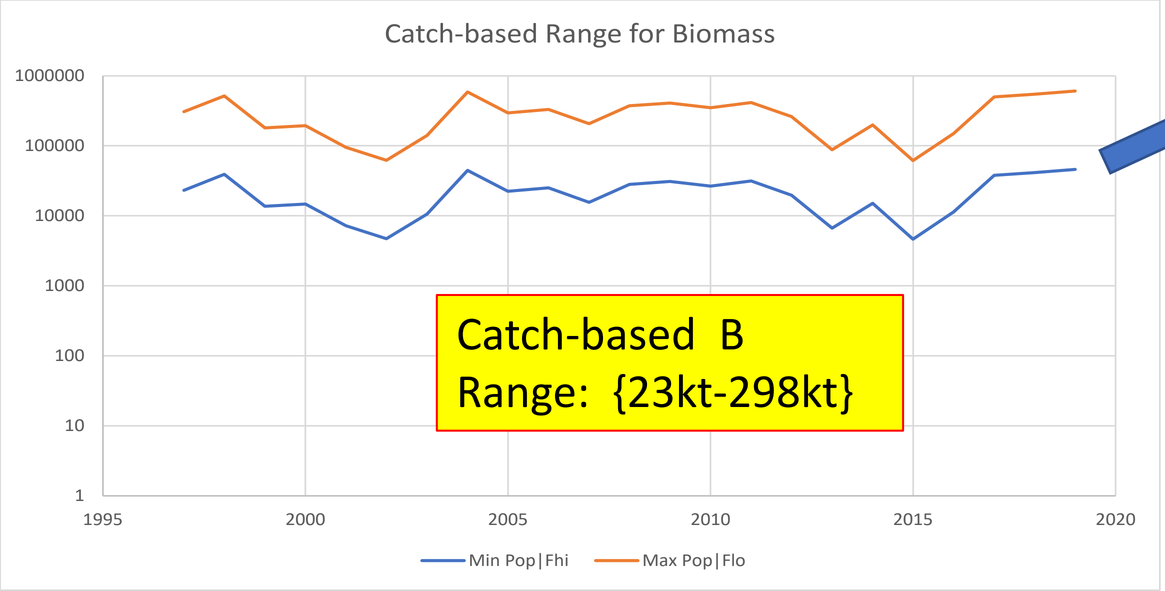
$$\hat{B}_{1,t} = B(I_t, q_{Low}, v_{Low}, M_{High})$$
$$\hat{B}_{2,t} = B(I_t, q_{High}, v_{High}, M_{Low})$$
$$\hat{B}_{3,t} = B'(C_t, F_{Low}, M_{High})$$
$$\hat{B}_{4,t} = B'(C_t, F_{High}, M_{Low})$$

$$\hat{B}_{upper,t} = \min(B_{1,t}, B_{3,t})$$
$$\hat{B}_{lower,t} = \max(B_{2,t}, B_{4,t})$$

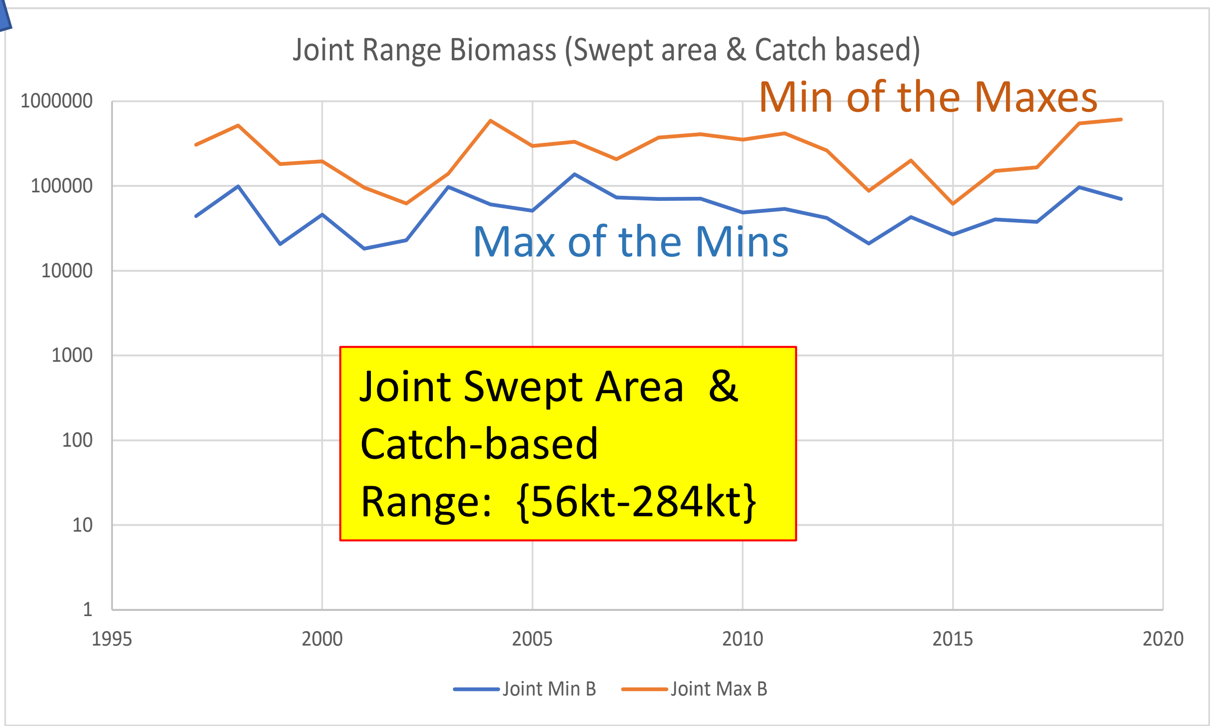
- Find $F_{hat(t)}$ by substituting $B_{upper(t)}$ or $B_{lower(t)}$ for B_o , and C(t) and $M_{assumed}$ into catch equation.

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





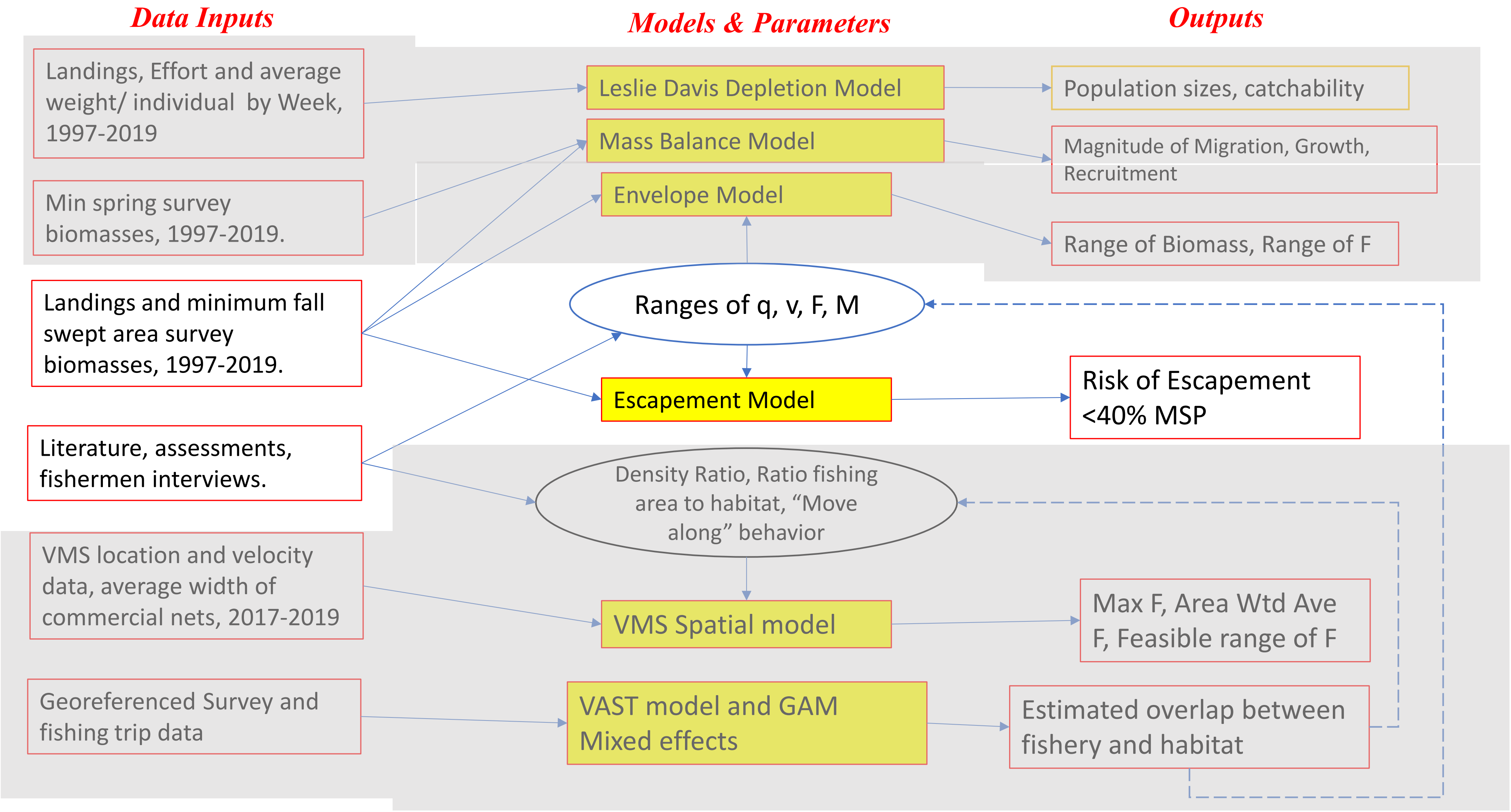
Biomass estimates above the min of the maximums suggest either lower qv or lower F than assumed for extreme range



Biomass estimates below the max of the minimums suggest either higher qv or higher F than assumed for extreme range

Escapement

Escapement Model



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 can be obtained by projecting B0 by the fraction surviving natural mortality:

$$B_{t,without\ fishery} = B_0 e^{-Mt} \qquad (15)$$

"Escapement" is 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.

$$Escapement = \frac{B_t}{B_{t,without\ fishery}} \qquad (16)$$

Escapement can be expressed in terms of observations and parameters as:

$$Escapement = \frac{\frac{AI_t}{aqv}}{\frac{AI_t}{aqv} + C_t e^{-M/2}} \qquad (17)$$

Where the quantity $(A/a)I_t$ is the minimum swept area assuming qv=1.

Table 2. Predicted average escapement fraction given alternative values of M and qv.

		qv=efficiency x availability													
	0.6536	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7
M	0.20	0.85863	0.76150	0.68844	0.63058	0.58318	0.54339	0.50937	0.47985	0.45393	0.43094	0.41039	0.39188	0.37510	0.35981
	0.40	0.86969	0.77775	0.70747	0.65117	0.60464	0.56530	0.53146	0.50195	0.47592	0.45275	0.43196	0.41318	0.39610	0.38050
	0.60	0.88004	0.79325	0.72586	0.67127	0.62575	0.58700	0.55346	0.52406	0.49802	0.47474	0.45378	0.43478	0.41747	0.40160
	0.80	0.88970	0.80799	0.74358	0.69082	0.64645	0.60840	0.57528	0.54610	0.52013	0.49683	0.47578	0.45663	0.43913	0.42305
	1.00	0.89871	0.82198	0.76059	0.70977	0.66666	0.62944	0.59685	0.56799	0.54219	0.51895	0.49787	0.47864	0.46101	0.44477
	1.20	0.90709	0.83520	0.77688	0.72808	0.68634	0.65006	0.61810	0.58965	0.56411	0.54101	0.51998	0.50074	0.48305	0.46671
	1.40	0.91486	0.84768	0.79242	0.74571	0.70544	0.67018	0.63895	0.61101	0.58582	0.56294	0.54204	0.52285	0.50516	0.48877
	1.60	0.92206	0.85941	0.80721	0.76264	0.72390	0.68976	0.65935	0.63201	0.60724	0.58466	0.56396	0.54490	0.52726	0.51088
	1.80	0.92872	0.87042	0.82123	0.77883	0.74169	0.70875	0.67923	0.65256	0.62830	0.60610	0.58567	0.56680	0.54928	0.53297
	2.00	0.93487	0.88072	0.83450	0.79428	0.75879	0.72710	0.69855	0.67263	0.64894	0.62718	0.60710	0.58847	0.57114	0.55496
	2.20	0.94053	0.89034	0.84701	0.80898	0.77515	0.74477	0.71724	0.69214	0.66910	0.64785	0.62816	0.60985	0.59277	0.57677
	2.40	0.94574	0.89931	0.85879	0.82291	0.79078	0.76173	0.73528	0.71104	0.68871	0.66803	0.64881	0.63087	0.61408	0.59832

Table 3. Predicted worst case scenario for escapement given alternative values of M and qv. Entries represent the minimum escapement over the 1997-2019 period.

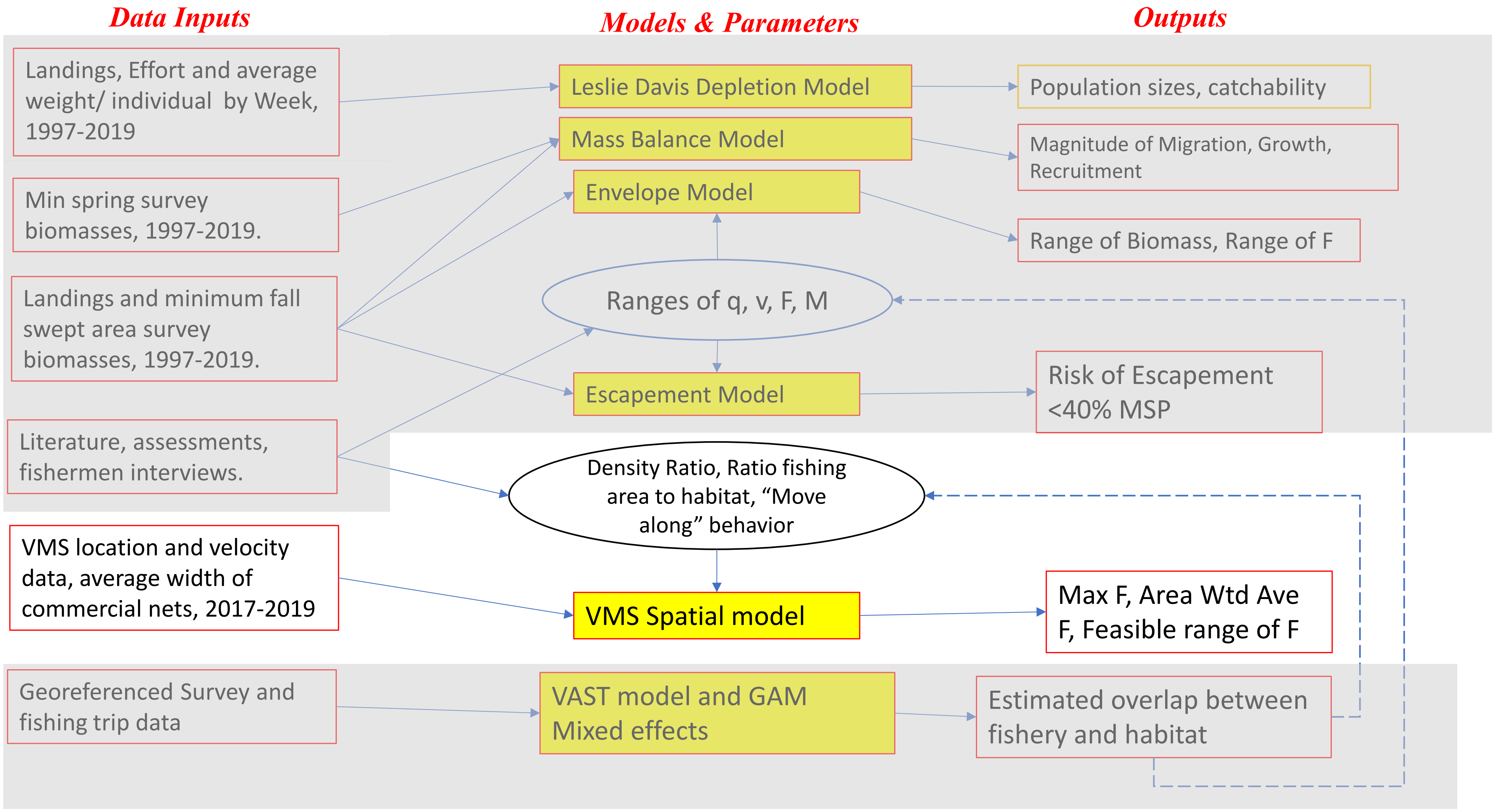
		qv=efficiency x availability													
	0.3386	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7
M	0.20	0.64682	0.47800	0.37907	0.31406	0.26809	0.23386	0.20738	0.18628	0.16909	0.15480	0.14273	0.13241	0.12348	0.11568
	0.40	0.66932	0.50299	0.40287	0.33600	0.28816	0.25225	0.22430	0.20192	0.18360	0.16833	0.15541	0.14433	0.13472	0.12631
	0.60	0.69107	0.52796	0.42715	0.35866	0.30910	0.27157	0.24217	0.21852	0.19907	0.18280	0.16899	0.15712	0.14681	0.13777
	0.80	0.71200	0.55279	0.45177	0.38197	0.33085	0.29180	0.26100	0.23607	0.21549	0.19822	0.18350	0.17082	0.15978	0.15008
	1.00	0.73206	0.57736	0.47664	0.40584	0.35335	0.31289	0.28074	0.25458	0.23288	0.21459	0.19896	0.18546	0.17367	0.16329
	1.20	0.75122	0.60156	0.50162	0.43016	0.37652	0.33478	0.30137	0.27402	0.25122	0.23192	0.21538	0.20104	0.18849	0.17742
	1.40	0.76943	0.62527	0.52660	0.45483	0.40027	0.35740	0.32283	0.29435	0.27049	0.25021	0.23276	0.21758	0.20427	0.19248
	1.60	0.78669	0.64839	0.55144	0.47971	0.42450	0.38068	0.34507	0.31554	0.29067	0.26944	0.25109	0.23509	0.22100	0.20851
	1.80	0.80299	0.67083	0.57603	0.50470	0.44909	0.40452	0.36800	0.33753	0.31171	0.28957	0.27036	0.25354	0.23870	0.22549
	2.00	0.81834	0.69253	0.60025	0.52967	0.47394	0.42882	0.39155	0.36024	0.33356	0.31057	0.29054	0.27293	0.25734	0.24343
	2.20	0.83273	0.71340	0.62398	0.55449	0.49892	0.45347	0.41561	0.38359	0.35615	0.33237	0.31157	0.29322	0.27691	0.26232
	2.40	0.84620	0.73340	0.64714	0.57904	0.52390	0.47835	0.44009	0.40749	0.37940	0.35492	0.33341	0.31436	0.29737	0.28212

Table 4. Fraction of years in which escapement is less than 40% for the period 1997-2019.

		qv=efficiency x availability													
	0.0455	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7
M	0.20	0.00000	0.00000	0.04545	0.13636	0.18182	0.22727	0.27273	0.31818	0.40909	0.45455	0.59091	0.59091	0.63636	0.63636
	0.40	0.00000	0.00000	0.00000	0.04545	0.13636	0.18182	0.27273	0.27273	0.31818	0.40909	0.45455	0.59091	0.59091	0.59091
	0.60	0.00000	0.00000	0.00000	0.04545	0.13636	0.13636	0.18182	0.27273	0.27273	0.31818	0.40909	0.45455	0.59091	0.59091
	0.80	0.00000	0.00000	0.00000	0.04545	0.09091	0.13636	0.18182	0.18182	0.27273	0.27273	0.31818	0.36364	0.45455	0.45455
	1.00	0.00000	0.00000	0.00000	0.00000	0.04545	0.13636	0.13636	0.18182	0.22727	0.27273	0.27273	0.31818	0.31818	0.45455
	1.20	0.00000	0.00000	0.00000	0.00000	0.04545	0.09091	0.13636	0.13636	0.18182	0.22727	0.27273	0.27273	0.31818	0.31818
	1.40	0.00000	0.00000	0.00000	0.00000	0.00000	0.04545	0.09091	0.13636	0.13636	0.18182	0.22727	0.27273	0.27273	0.27273
	1.60	0.00000	0.00000	0.00000	0.00000	0.00000	0.04545	0.04545	0.13636	0.13636	0.13636	0.18182	0.22727	0.27273	0.27273
	1.80	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.04545	0.04545	0.13636	0.13636	0.13636	0.18182	0.18182	0.22727
	2.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.04545	0.04545	0.09091	0.13636	0.13636	0.13636	0.18182	0.18182
	2.20	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.04545	0.04545	0.09091	0.13636	0.13636	0.13636	0.18182
	2.40	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.04545	0.04545	0.09091	0.13636	0.13636	0.13636

VMS

VMS Spatial Analyses



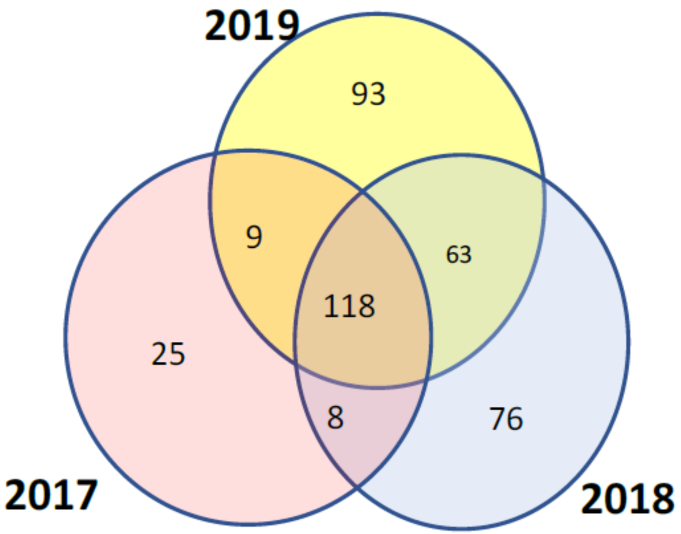
VMS Data

- 2017-2019 only
- Filtered by speed: [2.6 - 3.3 knots]
- Inshore "Loligo" sites excluded
- Locations binned by 3 minute sqr~6.99 nm^2 at 35 deg N Lat= "Cell"
- Net width linked to Permit Type
  - Allowed estimate of area swept in each cell
  - Ping frequency = 1/hour.
  - Area swept/Permit/Cell/Trip = net width x sum of hours at fishing speeds

Total Swept Area by Year

	2017	2018	2019	Total
Total Area Swept (nm^2)	402.2	545.4	940.6	1888.2
Number cells	160	265	283	392
Total Area of cells with fishing activity (nm^2)	1118.4	1852.35	1978.17	2740.08
Ave Area Swept (nm^2)/cell	0.360	0.294	0.475	

Unique Cells fished by Year



- Key fishing sites are used by multiple permits.
- 54 sites were visited by 10 or more different permits
- 75% of total fishing activity took place in these 54 cells

Table 2. Overlap of fishing effort and total swept area, 2017-2019.

# cells	# permits observed fishing in cell	Total Number of Pings	Total Area Swept (nm^2)
163	1	310	28.11
66	2	399	43.36
26	3	214	22.42
16	4	239	24.09
14	5	348	38.65
16	6	544	56.87
10	7	322	32.61
13	8	792	74.55
14	9	1683	134.14
8	10	1381	153.21
8	11	1882	210.16
4	12	648	77.97
9	13	1427	165.58
7	14	2789	342.21
2	15	334	32.41
5	16	1266	93.94
3	17	815	66.18
1	18	289	20.01
3	19	1718	124.66
3	20	1487	106.53
1	21	469	40.51

What are the implications of effort concentration for fishing mortality?

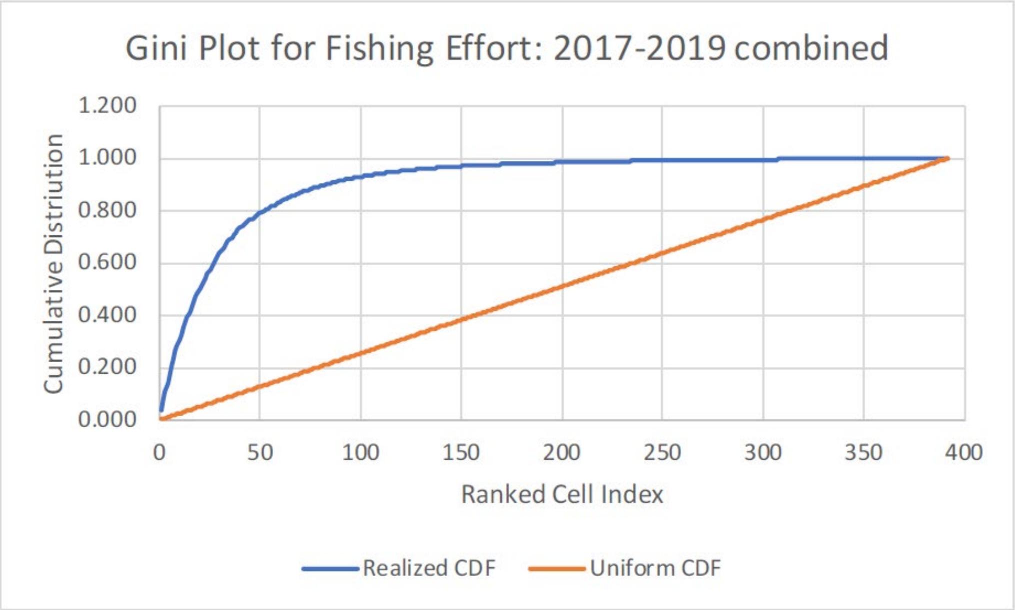


Figure 2. Gini plot of VMS fishing effort for 2017 to 2019 combined. X-axis is index of cells in which fishing occurred, sorted from highest to lowest frequency. Y-axis is cumulative distribution function for observed and hypothetical uniform distribution. Gini Index for pooled 2017-2019 = 0.822. Individual years are higher!

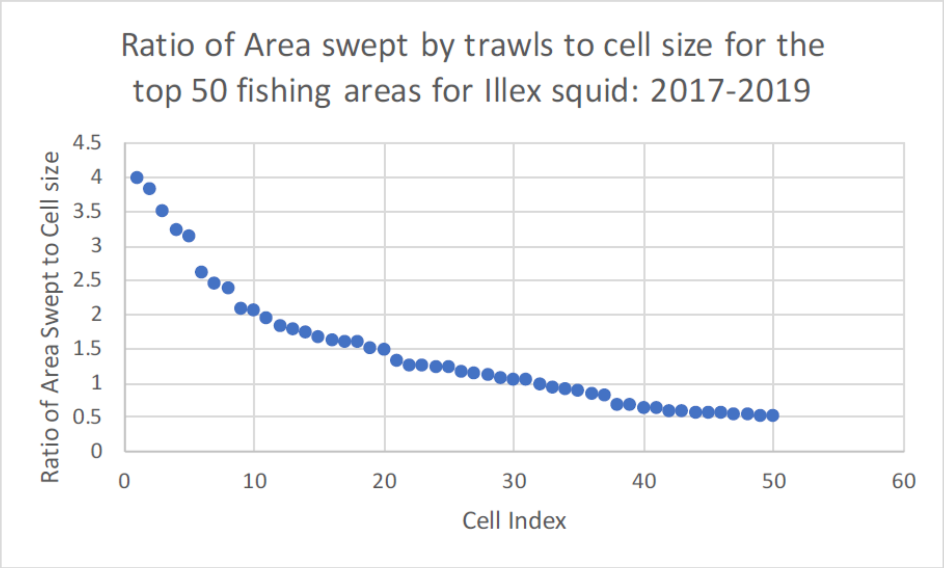


Figure 3. Concentration profile: ratio of total area swept to cell size for the top 50 fishing areas for Illex squid, 2017-2019.

What are the implications of these patterns for fishing mortality rates?

The total swept area (TS)after **n** tows of varying size **ai** is

$$TS = \sum_{i=1}^{n} a_i \qquad (4)$$

The fraction of the population remaining after it has been exploited **n** times by a gear with efficiency **q** and a swept area per tow of **ai**.

$$e^{\left(-\frac{q\,TS}{A}\right)} \qquad (5)$$

Thus the fraction of the population remaining after an area swept of **TS** or a ratio of **TS/A** times.

In the most heavily fished cells, the implied reductions in abundance are equivalent to the implied reductions in catch per unit effort. The "implied" depletion, given the VMS data is depicted in Figure 4.

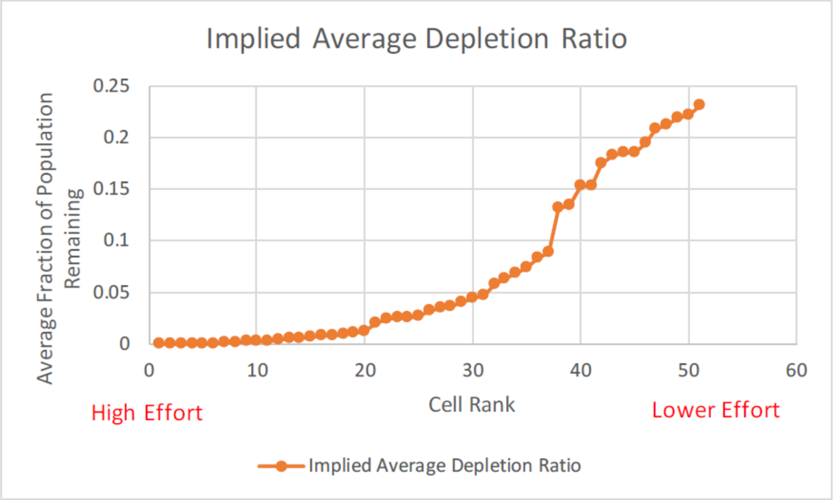


Figure 4. Implied depletion of population based on the ratio of average total area swept by trawls for the 50 most heavily fished cells. A gear efficiency of 100% is assumed for this plot.

Virtual Area Fished.

Let γ represent the ratio of CPUE that induces a movement of a vessel into a new area. Conceptually, this might be related to an economic incentive related to the profitability and an assumed profitability of the next tow. Conversations with fishermen suggested that this may not be a hard and fast rule since many different factors can affect the decision to move to another fishing area. Let $CPUE_o$ represent the initial CPUE and $CPUE_t$ represent the CPUE after time t has elapsed. The ratio of $CPUE_t/CPUE_o=\gamma$ such that a new area is fished when the ratio falls below γ. For economy this ratio can be called a "move along" criterion.

Using the swept area notation from Eq. 5 the CPUE ratio can be written as

$$\gamma = \frac{CPUE_t}{CPUE_o} = e^{\left(-q\frac{TS}{A}\right)} \quad (6)$$

Where q is the gear efficiency, TS is the total area swept in time step **t** and **A** is the area of the cell. Equation 1 can be rearranged to solve for A such that

$$A_V = \frac{-q\,TS}{\ln(\gamma)} \quad (7)$$

Table 5.5.1. Virtual area swept (km2) as a function of assumed gear efficiency and threshold for decline in CPUE with a trip for movement to a new fishing area. Combined years 2017-2019.

	Effective Area	Assumed Gear Efficiency									
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Depletion Ratio Threshold	0.95	4575.5	9151.1	13726.6	18302.1	22877.7	27453.2	32028.7	36604.3	41179.8	45755.3
	0.85	1444.1	2888.2	4332.3	5776.4	7220.5	8664.6	10108.7	11552.8	12996.9	14441.0
	0.75	815.8	1631.6	2447.4	3263.2	4079.1	4894.9	5710.7	6526.5	7342.3	8158.1
	0.65	544.8	1089.6	1634.4	2179.2	2724.0	3268.9	3813.7	4358.5	4903.3	5448.1
	0.55	392.6	785.1	1177.7	1570.3	1962.9	2355.4	2748.0	3140.6	3533.2	3925.7
	0.45	293.9	587.8	881.7	1175.7	1469.6	1763.5	2057.4	2351.3	2645.2	2939.2
	0.35	223.6	447.1	670.7	894.2	1117.8	1341.3	1564.9	1788.4	2012.0	2235.6
	0.25	169.3	338.6	507.9	677.2	846.5	1015.8	1185.1	1354.4	1523.7	1693.0
	0.15	123.7	247.4	371.1	494.8	618.6	742.3	866.0	989.7	1113.4	1237.1

- Wright et al report 12,993 to 15,313 km^2 area fished
- This implies q between 0.3 and 1
- This implies γ (depletion ratio threshold) of ~0.85 to 0.95

Area Weighted Average F

The concept of virtual area fished can now be expanded to compute an area weighted fishing mortality rate. (Table 4). For each cell it is possible to compute the virtual area swept from Eq. 7. When the virtual area fished exceeds the actual cell size the magnitude of the fishing mortality in a given cell **i** is constrained by the defined threshold parameter **γ**. This can be expressed as

$$F_i = \min\left(-\ln(\gamma), q\, TS_i / A\right) \quad (8)$$

The area weighted average F (**F**$_{\mathbf{ave}}$) over the entire set of cells fished in a given year can now be estimated as

$$F_{ave} = \frac{\sum_i^n F_i A_{Vi}}{\sum_i^n A_{Vi}} \quad (9)$$

Note that F_ave is restricted to the areas where fishing is occurring or assumed to occur based on virtual area

Table 5.4.2. Spatially weighted F over all fishing areas as a function of gear efficiency and threshold for decline in CPUE within a trip for movement to a new fishing area. 2017-2019 combined.

	Spatially weighted average F	Assumed Gear Efficiency									
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Depletion Ratio Threshold	0.95	0.0436	0.0468	0.0479	0.0486	0.0491	0.0494	0.0496	0.0498	0.0500	0.0501
	0.85	0.1066	0.1280	0.1370	0.1420	0.1455	0.1477	0.1493	0.1505	0.1514	0.1522
	0.75	0.1388	0.1968	0.2198	0.2312	0.2404	0.2465	0.2511	0.2549	0.2580	0.2603
	0.65	0.1511	0.2469	0.2949	0.3211	0.3359	0.3465	0.3560	0.3637	0.3693	0.3741
	0.55	0.1511	0.2818	0.3572	0.4042	0.4339	0.4534	0.4670	0.4776	0.4878	0.4967
	0.45	0.1511	0.3024	0.4053	0.4769	0.5278	0.5607	0.5871	0.6056	0.6197	0.6310
	0.35	0.1511	0.3024	0.4442	0.5379	0.6110	0.6683	0.7094	0.7410	0.7676	0.7880
	0.25	0.1511	0.3024	0.4540	0.5911	0.6860	0.7659	0.8321	0.8868	0.9287	0.9614
	0.15	0.1511	0.3024	0.4540	0.6059	0.7531	0.8652	0.9535	1.0344	1.1036	1.1643
	0.1	0.1511	0.3024	0.4540	0.6059	0.7579	0.9063	1.0218	1.1144	1.2007	1.2765

Ratio of Max to Min weighted F is 1.2765/0.0436 =29.3

OK, we have a range of potential fishing mortality rates in the areas fished. So what? We still don't have a range on the fishing mortality rate on the entire population.

- This depends on the rate of fishing mortality in the area fished

AND

- The density of squid in the fished and unfished areas

AND

- The ratio of habitat area fished to unfished.

Let **A** represent the total habitat area of Illex and $\mathbf{A_f}$ and $\mathbf{A_u}$ denote the areas were fishing does and does not occur, respectively. Thus

$$A = A_f + A_u \quad (8)$$

Further, let $\mathbf{D_f}$ and $\mathbf{D_u}$ represent the densities of Illex in the fished and unfished areas, respectively. Density can be expressed in either numbers or weight per unit area without loss of generality as long as average weights per individual are the same in each habitat area. The total population size **P** is thus defined as

$$P = A_f D_f + A_u D_u \qquad (9)$$

Beverton and Holt defined effective fishing mortality as the product of the fishing mortality times catch per unit effort summed over all spatial units, divided the sum of catch per unit effort over all spatial units. This is equivalent to a biomass weighted **F**. If we let $\mathbf{F_f}$ and $\mathbf{F_u}$ represent the fishing mortality rates in the fished and unfished areas, then the effective **F**, defined as $\mathbf{F_{eff}}$ is

$$F_{eff} = \frac{F_f A_f D_f + F_u A_u D_u}{A_f D_f + A_u D_u} \qquad (10)$$

Simplifying Eq 10

Equation 10 can be simplified by letting $\mathbf{D_u=\phi\ D_f}$, $\mathbf{A_f=\theta\ A}$, $\mathbf{A_u=(1\text{-}\theta)A}$ and noting that $\mathbf{F_u}=0$ by definition. Substituting these expressions into Eq 10 gives

$$F_{eff} = \frac{F_f \theta A\, D_f + 0\,(1-\theta)A\phi D_f}{\theta A D_f + (1-\theta)A\phi D_f} \qquad (11)$$

Canceling out the relevant symbols leads to

$$F_{eff} = \frac{F_f \theta}{\theta + (1-\theta)\phi} \qquad (12)$$

Table 5.4.3. Estimated fishing mortality on the entire population within the US resource area. Estimates based on the highest spatially weighted F in Table 4 = 1.2765.

Ratio of Area Fished to Total Habitat (theta)	Ratio of Density in Unfished Area to Density in Fished Area (phi)									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95
0.01	0.117	0.061	0.042	0.031	0.025	0.021	0.018	0.016	0.014	0.013
0.03	0.302	0.171	0.119	0.092	0.074	0.063	0.054	0.048	0.042	0.040
0.05	0.440	0.266	0.191	0.148	0.122	0.103	0.089	0.079	0.071	0.067
0.07	0.548	0.349	0.256	0.202	0.167	0.142	0.124	0.110	0.099	0.094
0.09	0.635	0.422	0.316	0.253	0.211	0.181	0.158	0.140	0.126	0.120
0.11	0.706	0.488	0.372	0.301	0.253	0.218	0.192	0.171	0.154	0.147
0.14	0.791	0.573	0.449	0.369	0.314	0.272	0.241	0.216	0.196	0.187
0.15	0.815	0.598	0.473	0.391	0.333	0.290	0.257	0.231	0.209	0.200
0.16	0.837	0.623	0.496	0.412	0.352	0.308	0.273	0.245	0.223	0.213
0.17	0.858	0.646	0.518	0.432	0.371	0.325	0.289	0.260	0.237	0.226
0.18	0.877	0.668	0.539	0.452	0.389	0.342	0.305	0.275	0.250	0.240
0.2	0.912	0.709	0.580	0.491	0.426	0.375	0.336	0.304	0.278	0.266

Range in Table 3 of Wright et al. (rows 0.01–0.07)

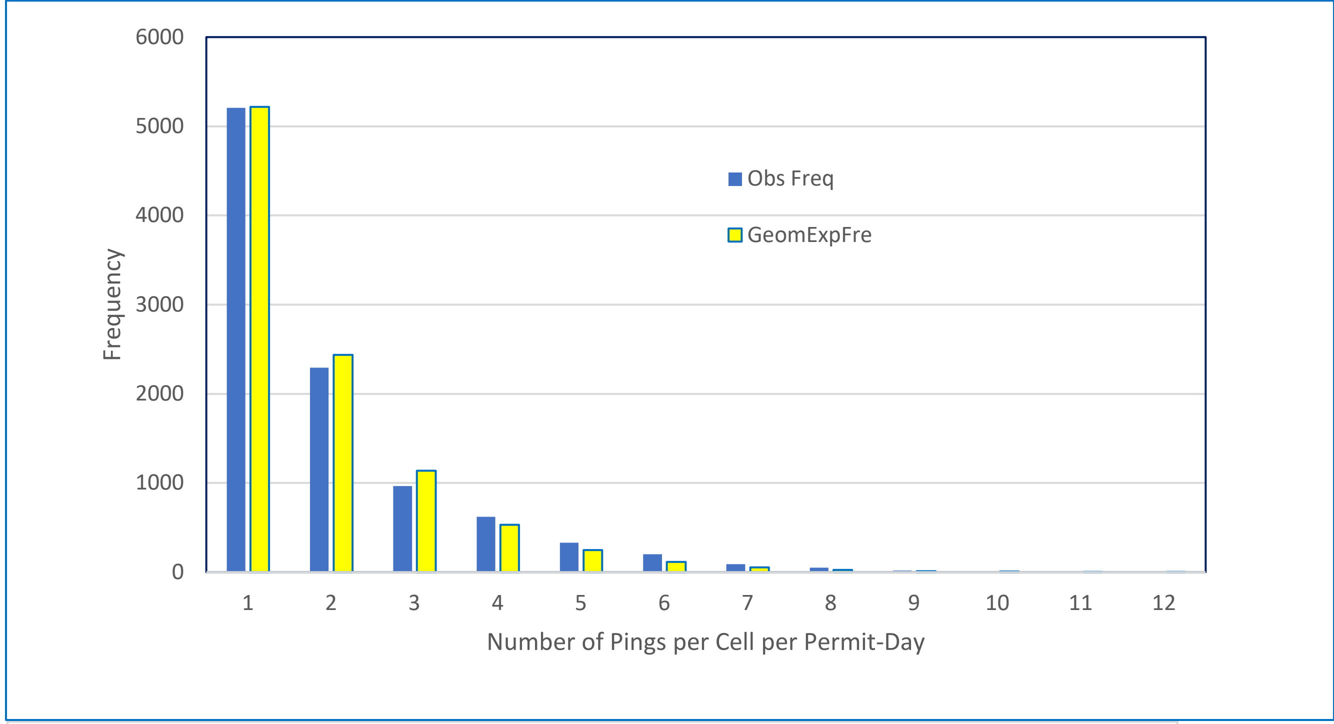
Refinement of VMS

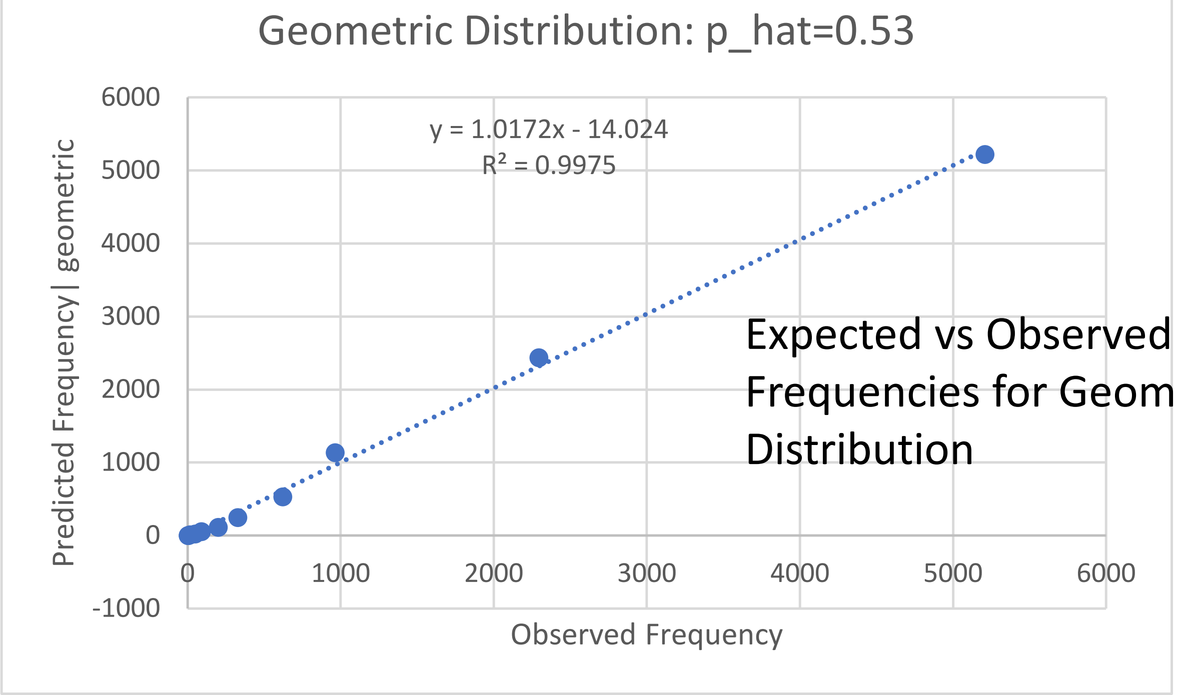
This table summarizes the total number of cells hit within a trip during a given day. The range of depletion depends on the number of hits per cell.
Fishermen behavior is inferred from the maximum number of hits per cell per day. This assumes that the last tow was sufficiently low to result in a "move along" rule. Fishing removal is estimated by assuming an average net width and area swept = 0.097549 nm sqr.
Dividing the average area swept per hour by the total area of a 3 min sqr (6.99 nm sqr) gives an average fraction swept = 0.013955
If the net is 100% efficient, then the reduction in biomass is proportional to the fraction of area swept.

	max # Pings per cell	Total Pings per Day	ave # pings/cell	#Cells	Maximum Depletion Fraction	Average Depletion Fraction
min	1	1	1	1	0.0140	0.0140
max	12	37	7	17	0.1552	0.0937
average	3.27	10.26	1.94	5.19	0.0445	0.0268
Std Dev	2.03	6.80	0.94	2.79	0.0269	0.0128

Distribution of number of repeat visits to a single cell within a given permit-day appears to follow a geometric distribution.

Statistic	*Geometric Distibution, Truncated (1-->inf)*	*Observed*
p_hat	**0.533**	--
E(X)	1.876	1.98
Var(X)	1.642	2.05





Expected vs Observed Frequencies for Geometric Distribution

4.5.1.2_Ratio of densities inside and outside fished area ϕ (Eq. 30)

The ratio of densities of Illex in fished and unfished areas during the period of peak fishing activity is not known because there are no fishery independent surveys coincident with the fishery. However, the NEFSC fall survey overlaps with the fishery in some years and can be used as a first approximation of the parameter ϕ (Eq. 30).

	Ave weight/tow			
Year	*outside D_u*	*inside D_f*	*ratio IN:OUT*	*phi*
2008	5.00	45.28	9.06	0.1103
2009	14.06	105.50	7.50	0.1333
2010	12.20	153.14	12.55	0.0797
2011	15.68	83.85	5.35	0.1870
2012	9.39	127.21	13.55	0.0738
2013	4.97	67.74	13.63	0.0734
2014	10.29	91.68	8.91	0.1123
2015	10.48	37.00	3.53	0.2833
2016	14.20	132.24	9.31	0.1074
2017				
2018	25.57	59.32	2.32	0.4310
2019	10.66	41.81	3.92	0.2550
Grand Total	**11.59**	**87.38**	**7.54**	0.1326
Average	12.05	85.89	8.15	0.17
SD	5.65	39.77	4.03	0.11
min	4.97	37.00	2.32	0.07
max	25.57	153.14	13.63	0.43

4.5.1.3 Ratio of Area Fished to Total Habitat Area (parameter θ , Eq.30)

The analyses of Lowman et al. (2021) was revised by John Manderson to include additional habitat areas surveyed by NEAMAP, MA DMF and DFO Canada (NAFO Area 4VWX). Summary data for this exercise for the fall surveys were kindly provided by Dr. Manderson are summarized below. Details on the methodology used to estimate overlap are provided in Manderson (2021). The different methods result is relative little differences between methods and surprisingly low variations across years. The overall range of θ is 0.27 to 0.48

	Ratio of Fishing area to habitat (theta)	
Year	Overlap: Method 1	Overlap: Method 2
2008	0.30381	0.36934
2009	0.27681	0.36109
2010	0.28897	0.34653
2011	0.34128	0.34622
2012	0.41122	0.38100
2013	0.44802	0.43115
2014	0.48467	0.45846
2015	0.46423	0.44658
2016	0.40276	0.40538
2017	0.34940	0.36314
2018	0.31333	0.35189
2019	0.31620	0.35108
average	0.36672	0.38432
min	0.27681	0.34622
max	0.48467	0.45846

Evaluation of Quota Scenarios:

--Review of 30,000 mt

--Consideration of 33,000 mt

Escapement Scenario:
30,000 mt

Table 5.6.1.1.1 Summary estimates of escapement by year for assumed value of M=0.7 and qv=0.2. Escapements are estimated for all years by assuming a catch of 30,000 mt.

							M estimate
							0.2
BASELINE DATA FROM LISA HENDRICKSON							qv
							0.7
		Min. biomass (mt)		Adjusted Survey and Tot Removal			
Year	US Catch	NEFSC Spring survey	NEFSC Fall survey	NEFSC Spring survey	NEFSC Fall survey	Escapement	
1997	30,000	511	2,730	731	3,899	0.125604	
1998	30,000	226	7,725	322	11,035	0.289033	
1999	30,000	149	929	213	1,328	0.046628	
2000	30,000	35	3,999	50	5,712	0.173848	
2001	30,000	110	1,422	158	2,032	0.069633	
2002	30,000	68	2,322	98	3,317	0.108895	
2003	30,000	23	10,913	32	15,589	0.364795	
2004	30,000	139	2,279	198	3,255	0.107073	
2005	30,000	14	3,696	19	5,280	0.162828	
2006	30,000	121	14,220	173	20,314	0.428029	
2007	30,000	147	7,311	210	10,445	0.277859	
2008	30,000	54	5,462	77	7,803	0.223267	
2009	30,000	404	5,170	577	7,385	0.213882	
2010	30,000	101	2,941	145	4,201	0.134032	
2011	30,000	294	2,937	420	4,196	0.133868	
2012	30,000	1,099	2,895	1,570	4,136	0.132214	
2013	30,000	22	1,827	32	2,610	0.087725	
2014	30,000		3,592		5,131	0.158967	
2015	30,000	217	2,795	310	3,992	0.128213	
2016	30,000	2,641	3,711	3,773	5,302	0.163401	
2017	30,000	314		449			
2018	30,000	382	7,146	546	10,208	0.273292	
2019	30,000	1,901	3,310	2,715	4,729	0.148365	
Average			Average	583	6,450	0.17961	
			Min	19	1,328	0.04663	
			Max	3,773	20,314	0.42803	
			N years where escapement <40%			21	
			Fraction yrs with escapement <4			0.95455	

Table 5.6.1.1.2. Predicted average escapement fractions given the joint range of assumed values of qv and M using the data in Table 5.6.1.1.1. Worst case scenarios represent the minimum value observed under each parameter combination. The fraction of years in which escapement falls below 40% is estimated by counting the number of occurrences and dividing by the number of years. Escapements are estimated for all years by assuming a catch of 30,000 mt.

30,000 mt--AVERAGE ESCAPEMENT: 1997-2019

Table 2. Predicted average escapement fraction given alternative values of M and qv.

		qv=efficiency x availability													
	0.1796	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7
M	0.20	0.71429	0.56863	0.47618	0.41126	0.36275	0.32496	0.29459	0.26959	0.24862	0.23076	0.21536	0.20193	0.19010	0.17961
	0.40	0.73291	0.59101	0.49906	0.43360	0.38422	0.34546	0.31412	0.28819	0.26636	0.24769	0.23154	0.21742	0.20496	0.19387
	0.60	0.75079	0.61304	0.52194	0.45621	0.40613	0.36652	0.33429	0.30749	0.28483	0.26539	0.24851	0.23370	0.22060	0.20893
	0.80	0.76789	0.63466	0.54475	0.47900	0.42840	0.38807	0.35505	0.32745	0.30401	0.28382	0.26623	0.25077	0.23704	0.22479
	1.00	0.78420	0.65579	0.56740	0.50188	0.45096	0.41004	0.37634	0.34802	0.32386	0.30297	0.28470	0.26859	0.25426	0.24143
	1.20	0.79971	0.67636	0.58979	0.52476	0.47371	0.43237	0.39809	0.36914	0.34432	0.32278	0.30388	0.28716	0.27224	0.25885
	1.40	0.81440	0.69631	0.61185	0.54755	0.49658	0.45497	0.42024	0.39075	0.36535	0.34321	0.32372	0.30642	0.29095	0.27701
	1.60	0.82829	0.71559	0.63349	0.57017	0.51947	0.47775	0.44270	0.41278	0.38688	0.36421	0.34418	0.32635	0.31035	0.29590
	1.80	0.84137	0.73416	0.65465	0.59253	0.54229	0.50062	0.46539	0.43514	0.40883	0.38571	0.36521	0.34688	0.33040	0.31548
	2.00	0.85367	0.75199	0.67525	0.61454	0.56496	0.52351	0.48823	0.45777	0.43114	0.40765	0.38673	0.36798	0.35105	0.33569
	2.20	0.86520	0.76904	0.69524	0.63612	0.58738	0.54631	0.51112	0.48056	0.45373	0.42994	0.40868	0.38956	0.37225	0.35649
	2.40	0.87598	0.78529	0.71456	0.65722	0.60948	0.56894	0.53398	0.50344	0.47650	0.45251	0.43099	0.41156	0.39392	0.37782

Table 5.6.1.1.2. Predicted average escapement fractions given the joint range of assumed values of qv and M using the data in Table 5.6.1.1.1. Worst case scenarios represent the minimum value observed under each parameter combination. The fraction of years in which escapement falls below 40% is estimated by counting the number of occurrences and dividing by the number of years. Escapements are estimated for all years by assuming a catch of 30,000 mt.

30,000 mt--WORST CASE SCENARIO: 1997-2019

Table 3. Predicted worst case scenario for escapement given alternative values of M and qv. Entries represent the minimum escapement over the 1997-2019 period.

		qv=efficiency x availability													
	0.0466	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7
M	0.20	0.40643	0.25504	0.18583	0.14616	0.12045	0.10243	0.08910	0.07884	0.07070	0.06408	0.05860	0.05398	0.05003	0.04663
	0.40	0.43076	0.27450	0.20143	0.15909	0.13145	0.11200	0.09756	0.08642	0.07756	0.07035	0.06437	0.05932	0.05501	0.05128
	0.60	0.45543	0.29486	0.21800	0.17292	0.14329	0.12233	0.10672	0.09464	0.08502	0.07718	0.07066	0.06515	0.06044	0.05637
	0.80	0.48032	0.31607	0.23553	0.18770	0.15601	0.13348	0.11664	0.10357	0.09313	0.08461	0.07751	0.07151	0.06638	0.06193
	1.00	0.50531	0.33807	0.25400	0.20342	0.16964	0.14548	0.12734	0.11323	0.10193	0.09268	0.08497	0.07845	0.07285	0.06800
	1.20	0.53027	0.36080	0.27341	0.22011	0.18419	0.15836	0.13887	0.12366	0.11145	0.10144	0.09308	0.08599	0.07990	0.07462
	1.40	0.55509	0.38417	0.29372	0.23775	0.19970	0.17214	0.15127	0.13491	0.12175	0.11092	0.10187	0.09418	0.08757	0.08182
	1.60	0.57963	0.40808	0.31489	0.25635	0.21616	0.18686	0.16456	0.14702	0.13285	0.12118	0.11139	0.10306	0.09589	0.08966
	1.80	0.60378	0.43244	0.33685	0.27587	0.23358	0.20254	0.17878	0.16000	0.14480	0.13223	0.12168	0.11268	0.10492	0.09816
	2.00	0.62744	0.45713	0.35954	0.29629	0.25196	0.21917	0.19393	0.17391	0.15763	0.14414	0.13277	0.12307	0.11469	0.10738
	2.20	0.65050	0.48203	0.38287	0.31755	0.27127	0.23676	0.21004	0.18874	0.17137	0.15692	0.14472	0.13428	0.12524	0.11735
	2.40	0.67288	0.50702	0.40676	0.33961	0.29148	0.25530	0.22712	0.20453	0.18604	0.17061	0.15754	0.14633	0.13661	0.12811

Table 5.6.1.1.2. Predicted average escapement fractions given the joint range of assumed values of qv and M using the data in Table 5.6.1.1.1. Worst case scenarios represent the minimum value observed under each parameter combination. The fraction of years in which escapement falls below 40% is estimated by counting the number of occurrences and dividing by the number of years. Escapements are estimated for all years by assuming a catch of 30,000 mt.

30,000 mt—FRACTION OF YEARS < 40% ESCAPEMENT: 1997-2019

Table 4. Fraction of years in which escapement is less than 40% for the period 1997-2019.

		qv=efficiency x availability													
	0.9545	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7
M	0.20	0.00000	0.09091	0.22727	0.54545	0.68182	0.72727	0.77273	0.81818	0.90909	0.90909	0.90909	0.90909	0.95455	0.95455
	0.40	0.00000	0.09091	0.22727	0.45455	0.68182	0.68182	0.77273	0.77273	0.86364	0.90909	0.90909	0.90909	0.90909	0.95455
	0.60	0.00000	0.09091	0.13636	0.45455	0.59091	0.68182	0.72727	0.77273	0.77273	0.86364	0.90909	0.90909	0.90909	0.90909
	0.80	0.00000	0.04545	0.13636	0.22727	0.50000	0.68182	0.68182	0.72727	0.77273	0.77273	0.86364	0.90909	0.90909	0.90909
	1.00	0.00000	0.04545	0.09091	0.22727	0.45455	0.54545	0.68182	0.68182	0.72727	0.77273	0.77273	0.81818	0.90909	0.90909
	1.20	0.00000	0.04545	0.09091	0.13636	0.27273	0.45455	0.63636	0.68182	0.68182	0.77273	0.77273	0.77273	0.77273	0.86364
	1.40	0.00000	0.04545	0.09091	0.13636	0.22727	0.45455	0.50000	0.63636	0.68182	0.68182	0.77273	0.77273	0.77273	0.77273
	1.60	0.00000	0.00000	0.04545	0.09091	0.13636	0.22727	0.45455	0.54545	0.68182	0.68182	0.68182	0.72727	0.77273	0.77273
	1.80	0.00000	0.00000	0.04545	0.09091	0.13636	0.22727	0.31818	0.45455	0.54545	0.68182	0.68182	0.68182	0.72727	0.77273
	2.00	0.00000	0.00000	0.04545	0.09091	0.13636	0.13636	0.22727	0.45455	0.50000	0.54545	0.68182	0.68182	0.68182	0.68182
	2.20	0.00000	0.00000	0.04545	0.04545	0.09091	0.13636	0.22727	0.22727	0.45455	0.50000	0.54545	0.63636	0.68182	0.68182
	2.40	0.00000	0.00000	0.00000	0.04545	0.09091	0.09091	0.13636	0.22727	0.22727	0.45455	0.50000	0.54545	0.63636	0.68182

Escapement Scenario:
33,000 mt

Table 5.6.1.2.1 Summary estimates of escapement by year for assumed value of M=0.87 and qv=0.24. Escapements are estimated for all years by assuming a catch of 33,000 mt.

							M estimate
							0.87
BASELINE DATA FROM LISA HENDRICKSON							qv
							0.24
		Min. biomass (mt)		Adjusted Survey and Tot Removal			
Year	US Catch	NEFSC Spring survey	NEFSC Fall survey	NEFSC Spring survey	NEFSC Fall survey	Escapement	
1997	33,000	511	2,730	2,131	11,373	0.347451	
1998	33,000	226	7,725	940	32,187	0.601099	
1999	33,000	149	929	622	3,872	0.153465	
2000	33,000	35	3,999	145	16,661	0.438201	
2001	33,000	110	1,422	460	5,926	0.217175	
2002	33,000	68	2,322	285	9,675	0.311750	
2003	33,000	23	10,913	95	45,469	0.680380	
2004	33,000	139	2,279	577	9,494	0.307706	
2005	33,000	14	3,696	57	15,399	0.418921	
2006	33,000	121	14,220	504	59,249	0.735018	
2007	33,000	147	7,311	613	30,464	0.587836	
2008	33,000	54	5,462	225	22,758	0.515845	
2009	33,000	404	5,170	1,682	21,541	0.502113	
2010	33,000	101	2,941	422	12,254	0.364558	
2011	33,000	294	2,937	1,226	12,237	0.364231	
2012	33,000	1,099	2,895	4,579	12,063	0.360916	
2013	33,000	22	1,827	92	7,613	0.262773	
2014	33,000		3,592		14,965	0.411976	
2015	33,000	217	2,795	904	11,644	0.352807	
2016	33,000	2,641	3,711	11,004	15,464	0.419944	
2017	33,000	314		1,310			
2018	33,000	382	7,146	1,592	29,775	0.582282	
2019	33,000	1,901	3,310	7,919	13,793	0.392372	
Average			Average	1,699	18,812	0.42404	
			Min	57	3,872	0.15346	
			Max	11,004	59,249	0.73502	
			N years where escapement <40%			11	
			Fraction yrs with escapement <4			0.50000	

Table 5.6.1.2.2. Predicted average escapement fractions given the joint range of assumed values of qv and M using the data in Table 5.6.1.2.1. Escapements are estimated for all years by assuming a catch of 33,000 mt.

Table 2. Predicted average escapement fraction given alternative values of M and qv.

		qv=efficiency x availability													
	0.1668	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7
M	0.20	0.69588	0.54706	0.45448	0.39028	0.34276	0.30600	0.27661	0.25254	0.23243	0.21536	0.20068	0.18791	0.17669	0.16676
	0.40	0.71518	0.56968	0.47725	0.41230	0.36375	0.32591	0.29549	0.27044	0.24944	0.23154	0.21610	0.20264	0.19078	0.18026
	0.60	0.73377	0.59205	0.50013	0.43465	0.38524	0.34643	0.31505	0.28908	0.26721	0.24851	0.23232	0.21816	0.20567	0.19456
	0.80	0.75161	0.61407	0.52301	0.45727	0.40717	0.36752	0.33525	0.30841	0.28571	0.26623	0.24932	0.23448	0.22136	0.20966
	1.00	0.76867	0.63566	0.54582	0.48007	0.42945	0.38909	0.35603	0.32841	0.30493	0.28470	0.26708	0.25158	0.23783	0.22555
	1.20	0.78495	0.65677	0.56845	0.50295	0.45202	0.41108	0.37735	0.34900	0.32480	0.30388	0.28559	0.26945	0.25509	0.24223
	1.40	0.80041	0.67731	0.59083	0.52583	0.47478	0.43343	0.39913	0.37015	0.34530	0.32372	0.30480	0.28804	0.27310	0.25968
	1.60	0.81507	0.69723	0.61287	0.54862	0.49765	0.45603	0.42129	0.39178	0.36635	0.34418	0.32467	0.30734	0.29184	0.27788
	1.80	0.82892	0.71648	0.63449	0.57123	0.52054	0.47882	0.44376	0.41382	0.38790	0.36521	0.34516	0.32730	0.31127	0.29681
	2.00	0.84197	0.73502	0.65563	0.59357	0.54336	0.50170	0.46646	0.43620	0.40987	0.38673	0.36621	0.34786	0.33135	0.31641
	2.20	0.85423	0.75280	0.67620	0.61556	0.56601	0.52458	0.48930	0.45883	0.43220	0.40868	0.38775	0.36898	0.35203	0.33665
	2.40	0.86572	0.76982	0.69616	0.63713	0.58843	0.54738	0.51219	0.48163	0.45479	0.43099	0.40972	0.39058	0.37325	0.35748

Table 5.6.1.2.2.. Worst case scenarios represent the minimum value observed given the joint range of assumed values of qv and M using the data in Table 5.6.1.2.1. Escapements are estimated for all years by assuming a catch of 33,000 mt.

Table 3. Predicted worst case scenario for escapement given alternative values of M and qv. Entries represent the minimum escapement over the 1997-2019 period.

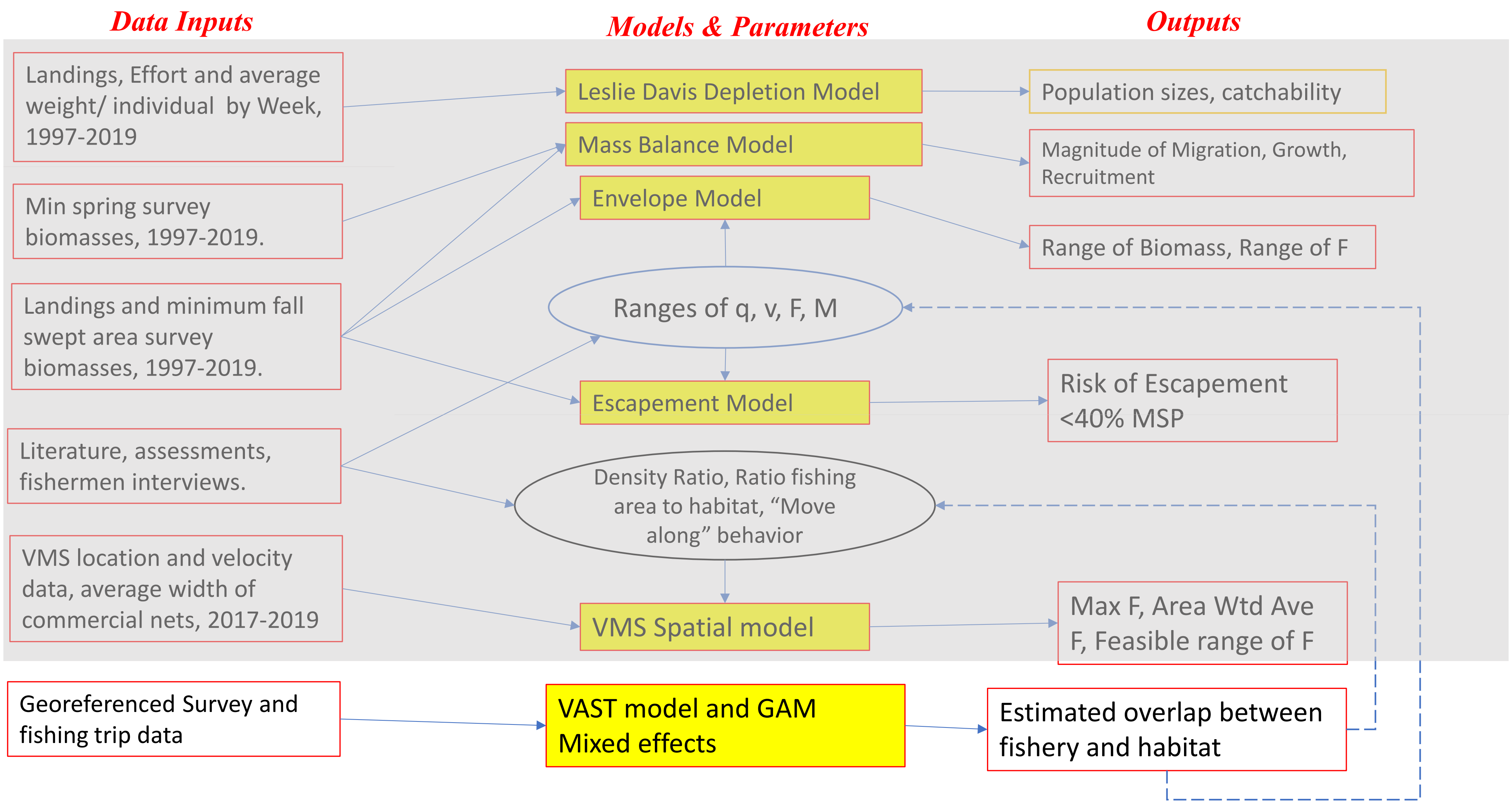
		qv=efficiency x availability													
	0.0426	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7
M	0.20	0.38365	0.23736	0.17183	0.13466	0.11071	0.09399	0.08166	0.07219	0.06469	0.05860	0.05356	0.04931	0.04569	0.04257
	0.40	0.40756	0.25593	0.18654	0.14675	0.12095	0.10286	0.08948	0.07918	0.07101	0.06437	0.05886	0.05422	0.05026	0.04684
	0.60	0.43191	0.27544	0.20219	0.15971	0.13199	0.11246	0.09797	0.08679	0.07790	0.07066	0.06465	0.05958	0.05525	0.05151
	0.80	0.45659	0.29583	0.21880	0.17359	0.14387	0.12284	0.10717	0.09505	0.08539	0.07751	0.07096	0.06544	0.06071	0.05662
	1.00	0.48149	0.31708	0.23637	0.18841	0.15663	0.13403	0.11712	0.10400	0.09353	0.08497	0.07785	0.07183	0.06667	0.06220
	1.20	0.50648	0.33912	0.25489	0.20418	0.17030	0.14606	0.12786	0.11370	0.10236	0.09308	0.08534	0.07878	0.07317	0.06830
	1.40	0.53144	0.36188	0.27435	0.22091	0.18490	0.15898	0.13944	0.12417	0.11192	0.10187	0.09347	0.08636	0.08025	0.07494
	1.60	0.55624	0.38528	0.29470	0.23860	0.20045	0.17281	0.15187	0.13546	0.12225	0.11139	0.10230	0.09458	0.08794	0.08218
	1.80	0.58077	0.40921	0.31590	0.25724	0.21695	0.18758	0.16521	0.14761	0.13339	0.12168	0.11185	0.10350	0.09630	0.09004
	2.00	0.60490	0.43359	0.33790	0.27681	0.23442	0.20330	0.17946	0.16064	0.14538	0.13277	0.12218	0.11315	0.10536	0.09858
	2.20	0.62853	0.45829	0.36062	0.29726	0.25284	0.21997	0.19467	0.17458	0.15825	0.14472	0.13331	0.12358	0.11517	0.10783
	2.40	0.65157	0.48320	0.38398	0.31857	0.27220	0.23761	0.21082	0.18946	0.17203	0.15754	0.14530	0.13482	0.12576	0.11783

Table 5.6.1.2.2. Predicted fraction of years in which escapement falls below 40% given the joint range of assumed values of qv and M using the data in Table 5.6.1.2.1. The fraction of years in which escapement falls below 40% is estimated by counting the number of occurrences and dividing by the number of years. Escapements are estimated for all years by assuming a catch of 33,000 mt.

Table 4. Fraction of years in which escapement is less than 40% for the period 1997-2019.

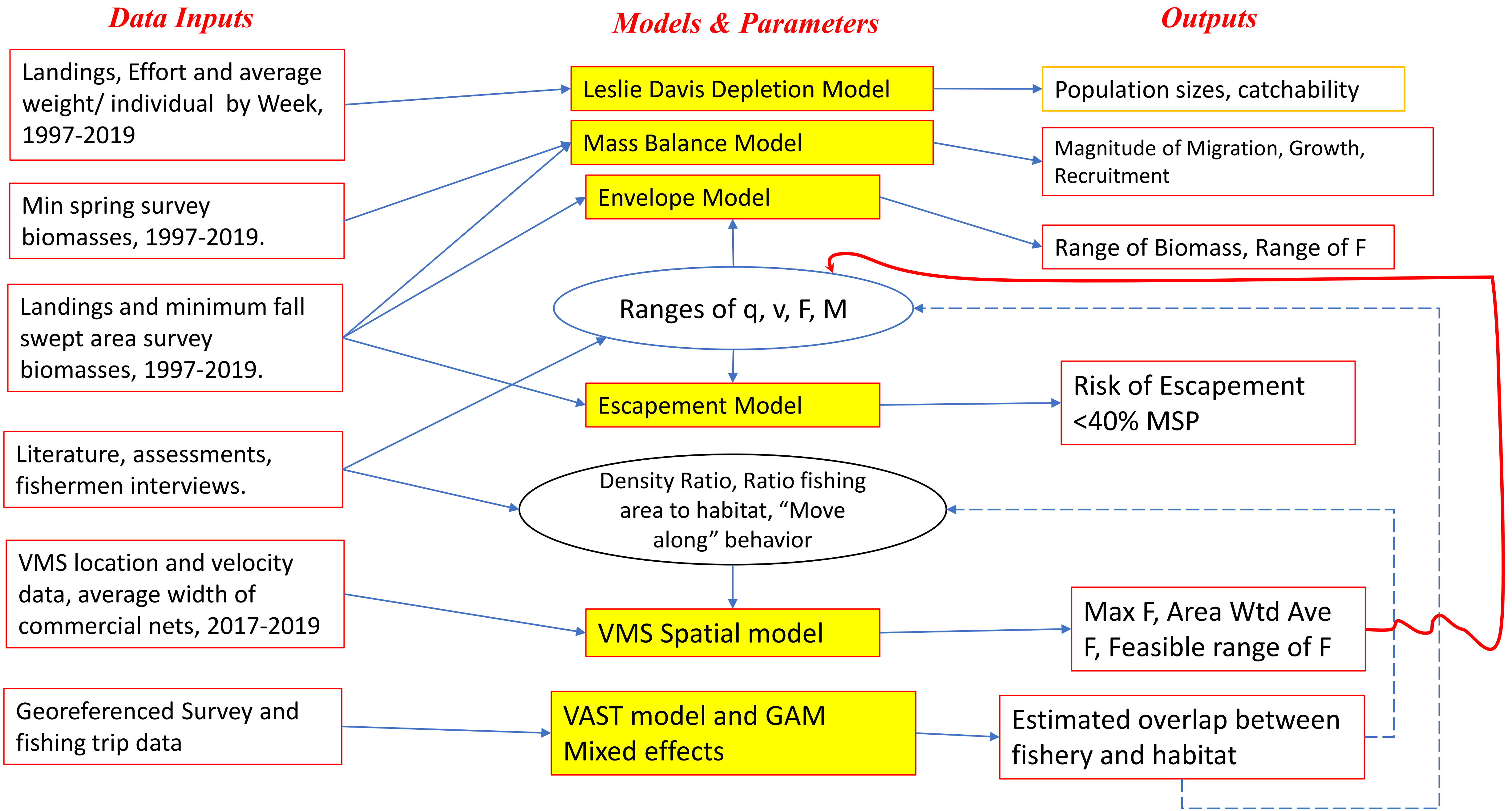
		qv=efficiency x availability													
	0.9545	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	(
	0.20	0.04545	0.13636	0.45455	0.63636	0.68182	0.77273	0.77273	0.90909	0.90909	0.90909	0.95455	0.95455	0.95455	0.954
	0.40	0.00000	0.09091	0.22727	0.54545	0.68182	0.72727	0.77273	0.81818	0.90909	0.90909	0.90909	0.90909	0.95455	0.954
	0.60	0.00000	0.09091	0.22727	0.45455	0.68182	0.68182	0.77273	0.77273	0.86364	0.90909	0.90909	0.90909	0.90909	0.954
	0.80	0.00000	0.09091	0.13636	0.45455	0.54545	0.68182	0.68182	0.77273	0.77273	0.86364	0.90909	0.90909	0.90909	0.909
	1.00	0.00000	0.04545	0.13636	0.22727	0.50000	0.68182	0.68182	0.72727	0.77273	0.77273	0.86364	0.90909	0.90909	0.909
M	1.20	0.00000	0.04545	0.09091	0.22727	0.45455	0.54545	0.68182	0.68182	0.72727	0.77273	0.77273	0.81818	0.90909	0.909
	1.40	0.00000	0.04545	0.09091	0.13636	0.27273	0.45455	0.63636	0.68182	0.68182	0.77273	0.77273	0.77273	0.77273	0.863
	1.60	0.00000	0.04545	0.09091	0.13636	0.22727	0.45455	0.50000	0.63636	0.68182	0.68182	0.72727	0.77273	0.77273	0.772
	1.80	0.00000	0.00000	0.04545	0.09091	0.13636	0.22727	0.45455	0.50000	0.68182	0.68182	0.68182	0.72727	0.77273	0.772
	2.00	0.00000	0.00000	0.04545	0.09091	0.13636	0.22727	0.31818	0.45455	0.54545	0.68182	0.68182	0.68182	0.72727	0.772
	2.20	0.00000	0.00000	0.04545	0.09091	0.13636	0.13636	0.22727	0.36364	0.45455	0.54545	0.68182	0.68182	0.68182	0.681
	2.40	0.00000	0.00000	0.04545	0.04545	0.09091	0.13636	0.18182	0.22727	0.45455	0.50000	0.54545	0.63636	0.68182	0.681

Refining the Parameters



Parameter	***Symbol***	***Equation Number***	***Min Value***	***Max Value***	***Source/Comment***
Catchability (Survey)	**q**	9	0.2	0.5	NTAP experiments, fishermen interviews
Availability	**v**	10	0.27	0.48	Manderson Working Paper 2021
Catchability x Availability	**qv**	10	0.054	0.240	Min and max value products
Move Along Threshold	γ	23	0.01	0.15	Analyses herein 4.5.1.1
Ratio of Average Density outside to inside	ϕ	30	0.07	0.43	Analyses herein 4.5.1.2. Post stratified NEFSC fall survey: inside vs outside fishing cells. Mean for 2008-2019 =0.017
Ratio of fishing area to survey area	θ	30	0.014	0.363	Lowman et al. 2021.
Natural Mortality	**M**	11	0.87	3.92	Hendrickson and Hart 2006

The Big Picture



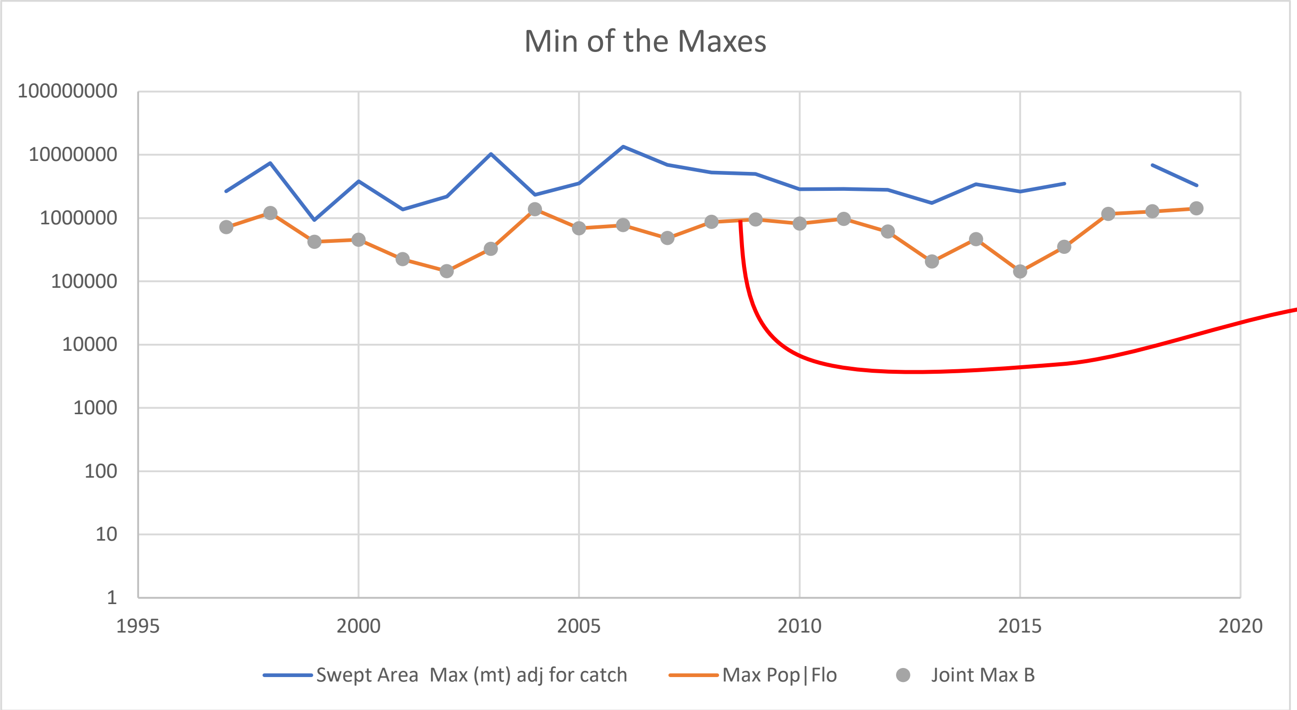
Comparison of original outputs with outputs based on revised ranges of parameters

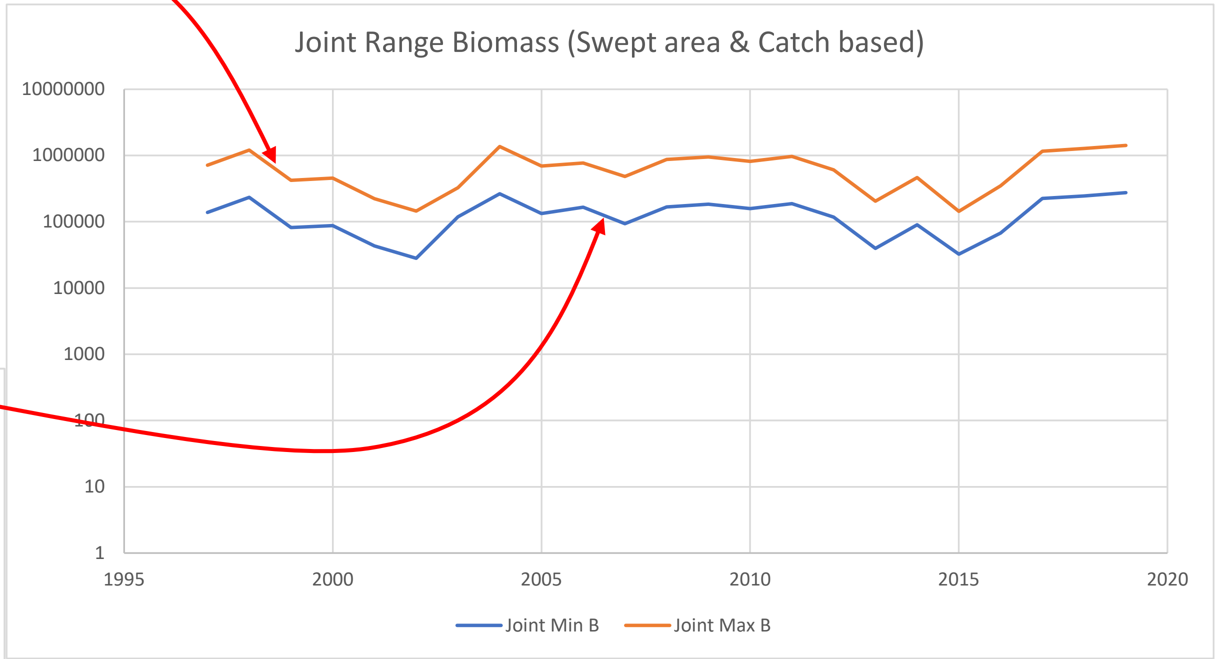
Model	*Output Variable*		*Original Output Range*		*Revised Output Range*	
		ABC	*Min Value_orig*	*Max Value_orig*	*Min Value_rev*	*Max Value_rev*
Envelope	Average Biomass (1997-2019) mt	NA	56,059	284,301	137,961	652,468
Escapement	Average Escapement	Observed Landings	0.3598	0.94574	0.6618	0.9715
	Fraction Yrs <40% MSP	Observed Landings	0	0.6364	0	0.04545
	Average Escapement	30,000 mt	0.17961	0.87598	0.44548	0.93184
	Fraction Yrs <40% MSP	30,000 mt	0	0.95455	0	0.45455
	Average Escapement	33,000 mt	0.16676	0.86572	0.42404	0.92570
	Fraction Yrs <40% MSP	33,000 mt	0	0.95455	0.	0.5
VMS	Spatially Weighted F (24 wk)	NA	0.0436	1.2765	0.0098	0.1455
	Effective F (24 wk) on population.	NA	0.0130	0.9120	0.0820	0.1670

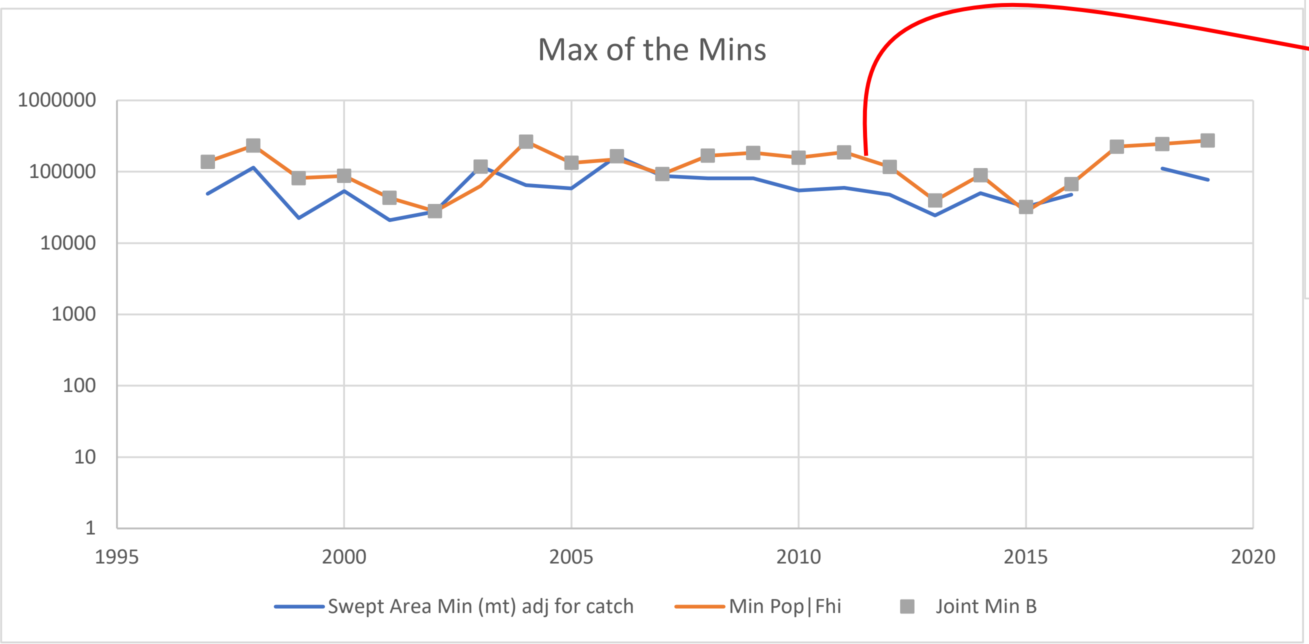
What are the implications of these revised parameter estimates for realized F given alternative quotas of 30,000 and 33,000 mt?

- Procedure
  - Obtain new estimates of biomass from Envelope Method
  - Compute F that would have occurred IF an alternative quota would have been taken.
  - Compare with various proposed biological reference points for F.

For the revised parameter set, the range of biomasses is based primarily on the assumed range of Fs.

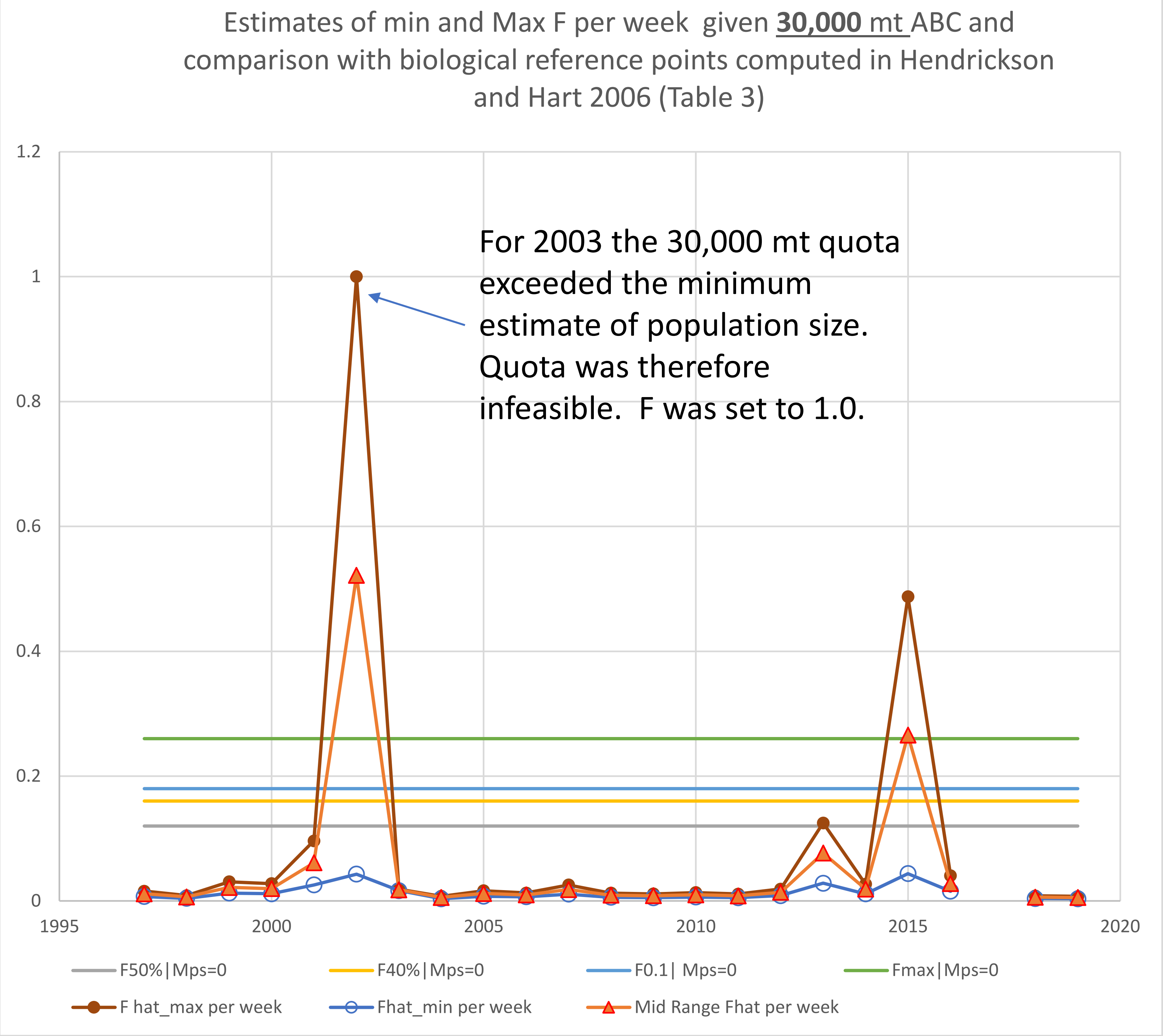




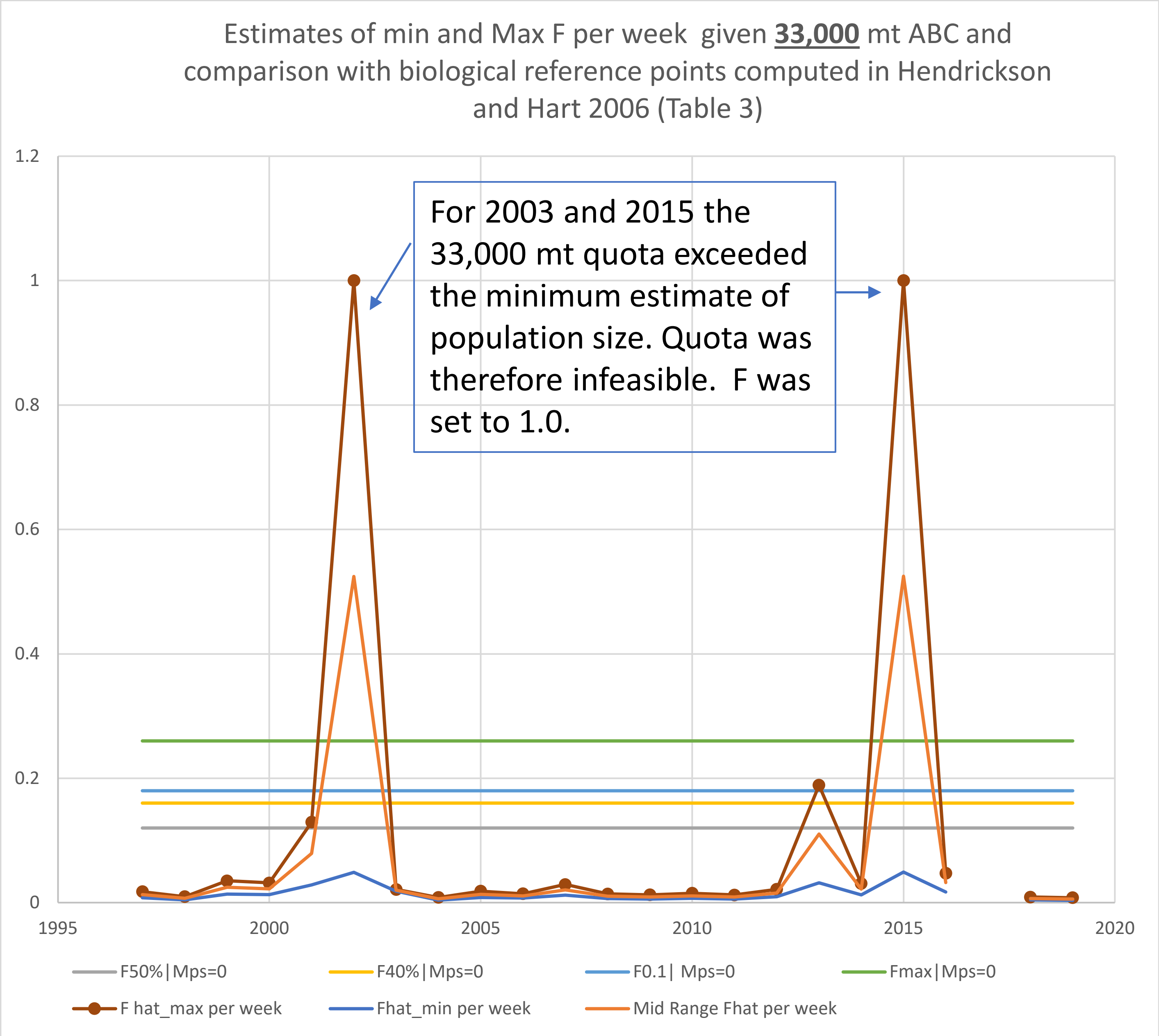


In order to satisfy the outer bounds i.e. Min of the Mins or Max of the Maxes, the range of F would have to be wider. This would mean lower Fs to match the upper max bound, and higher Fs to meet the lower min bound.

Hypothetical effects of a *30,000* mt quota on realized weekly F given revised historical range of population biomasses.



Hypothetical effects of a *33,000* mt quota on realized weekly F given revised historical range of population biomasses.



Comparison with "Reference Points"

- Baseline: Hendrickson and Hart (weekly rates), given alternative assumptions about natural mortality with and without post spawning mortality.
- Escapement: Compare with realized 40% MSP (full season)
- VMS estimates of F
  - {full season = 0.082,0.167}
  - {weekly = 0.003, 0.007}
- Envelope based F's based on alternative 30kt and 33kt Quotas

Table 3

Biological reference point estimates (week^{-1}) for *Illex illecebrosus* from per-recruit models for fixed non-spawning instantaneous natural mortality rates (M_{ns}) of 0.01, 0.06 and 0.14 week^{-1}. M_{sp} is a post-spawning natural mortality rate estimated from the maturation-natural mortality model and M_{tot} is the total natural mortality rate of mature females. Estimates of $F_{40\%}$ and $F_{50\%}$ represent weekly maximum values for fully-recruited females and estimates of $F_{0.1}$ and F_{max} represent weekly maximum values for fully-recruited individuals of both sexes

M (week^{-1})	M_{ns}				
	0.01	0.06	0.14		0.06
M_{sp}	0.63	0.55	0.42		0.00
M_{tot}	0.64	0.61	0.56		0.06
Reference Points (week^{-1})					
$F_{50\%}$	0.85	0.85	0.79	(0.47)[a]	0.12
$F_{40\%}$	1.49	1.53	1.47	(0.83)	0.16
$F_{0.1}$	0.98	0.90	0.88	(0.66)	0.18
F_{max}	3.12	3.04	3.18	(2.66)	0.26

[a] Model run where $M_{ns} = 0.14$ but without adjustments for ageing error.

Caveats—let me count the ways

- Spring and Fall surveys strongly influenced by availability
- Mass Balance suggests large influx of offshore production over a wide range of parameter values
- NEFSC surveys not conducted in 2020
- VMS data for 2020 not yet available
- Unless uniform distributions of parameters and independence of parameters are assumed, the scenarios cannot be used to generate measures of central tendency or dispersion.

Preliminary Conclusions

1. The overall Illex population is likely to be large.
2. Observations suggest relatively low chances of high fishing mortality rates over a broad range of assumed parameter extremes.
3. Spatial analyses of survey and fishery footprint suggest high escapement (Lowman et al. 2021, Manderson et al. 2021)
4. Further refinements of parameters from external information may be possible
5. None of the estimates of area wide fishing mortality suggest fishing mortality rates greater that life history based biological reference point proxies.
6. Increases of quotas to 33,000 create risks to falling below F 40% but the risk is lower than the risks of overfishing associated with current Harvest Control Rules used by the SSC and the risk policy adopted by the Council

Questions/Discussion