Empirical Exploration of Feasible Bounds on Butterfish Stock Size and Fishing Mortality Rates, 1975-2011

Tim Miller and Paul Rago
Northeast Fisheries Science Center
National Marine Fisheries Service
Woods Hole, MA 02543
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Summary

An empirical approach is applied to Atlantic butterfish survey and catch data to explore the likely range of stock size and fishing mortality rates under a broad range of assumptions. Survey data were expanded to total swept area biomasses for assumed catchabilities ranging from 0.1 to 1.0. Catch data were used to estimate historical biomass estimates by assuming that the observed catches were the realization of consistently high fishing mortality rates (e.g., F=0.8) or consistently low F (e.g., 0.01). The effects of variation in natural mortality over the range of 0.8 to 1.1/yr was also explored. These assumptions imply a range of potential biomass estimates that can be used to define an envelope of feasible stock sizes consistent with the survey results and sufficient to support the observed catches. Results of an analytical stock assessment model (SARC 49, NEFSC 2010) comport well with the envelope of estimates of F and biomass from this method.

An examination of the relative abundance scenarios suggest that overfishing is unlikely to be occurring in 2011 even under the most extreme assumptions of 100% survey catchability and F=0.8. A sensitivity analysis indicates that a five-fold increase in catches in 2011 would not have resulted in overfishing. Based on survey results, stock biomass appears to have increased by more than three-fold since 2006. The empirical model results are insufficient to recommend catch advice for a directed fishery, but strongly support the contention that discard limits of 3,600 mt would have almost no chance of inducing overfishing.

Introduction

Stock assessment models typically incorporate two primary sources of information: estimates of total catch (landings plus discards), and fishery-independent indices of abundance. The former quantities provide estimates of population scale, the latter quantities provide measures of trend. Total catch provides some insight into the scale of the population but, without additional information, it is impossible to determine if total catch is the result of a low fishing mortality rate applied to a large population or a high fishing mortality rate applied to a small population. Fishery-independent stock size estimates from trawl surveys, expressed in terms of average catch per tow, approximate the true population size subject to an arbitrary scalar that reflects gear efficiency, availability, and the variability in the realization of the sampling design. Collectively, these factors are called catchability and denoted as the parameter q.

Here we propose a simple approach to reconcile these stock size perspectives that provides a feasible range or “envelope” of population sizes. The purpose of this exercise is not to replace the delay-difference model used in this most recent Atlantic butterfish assessment (NEFSC 2010). Rather, the objective is to demonstrate that the assessment model results are plausible and consistent with simpler measures of stock size. Coherence between the envelope of derived stock sizes and the model-based estimates allows us to draw some general conclusions about the implications of recent catches with respect to the probability of overfishing.

Envelope Method

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

$$B_t = \frac{I_t}{q}\frac{A}{a} \tag{1}$$

where the catchability or efficiency q, is an assumed value. The average area swept per tow is *a* and the total area of the survey is *A*. The biomass consistent with observed catch can be obtained from the Baranov catch equation as

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

$$B_f = B_0 e^{-(F+M)f} \tag{2}$$

where F is unknown. The second equation in Eq. 2 adjusts the biomass to the time of year when the survey occurs, thus keeping Eq. 1 and 2 consistent. Thus biomass can be written as a function of arbitrary scalars q and F. These equations can be generalized and written as

$$\begin{aligned}\hat{B}_{1,t} &= B(I_t, q_{Low})\\ \hat{B}_{2,t} &= B(I_t, q_{High})\\ \hat{B}_{3,t} &= B'(C_t, F_{Low}, M)\\ \hat{B}_{4,t} &= B'(C_t, F_{High}, M)\end{aligned}. \tag{2}$$

Prior information on the suitable range for q can be obtained from analyses of relative survey catchability as detailed in the main body of the SARC 49 report (NEFSC 2010). The suitable range of F values can be obtained from analogy with other fisheries or, more simply, by selecting a wide range of values.

By inspection, it is evident that $B_{1,t}$ and $B_{3,t}$ constitute an upper range, and $B_{2,t}$ and $B_{4,t}$ constitute a lower range. Upper and lower bounds consistent with these estimates are

$$\begin{aligned}\hat{B}_{upper,t} &= \min(B_{1,t}, B_{3,t})\\ \hat{B}_{lower,t} &= \max(B_{2,t}, B_{4,t})\end{aligned}. \tag{3}$$

Values of biomass that exceed the $\hat{B}_{upper,t}$ imply catchabilities smaller than q_{low} or fishing mortalities less than F_{low}. Conversely, values of biomass less than $\hat{B}_{lower,t}$ imply catchabilities greater than q_{high} or fishing mortalities greater than F_{high}. These bounds describe a set of feasible options that are consistent with the assumed ranges of q and F. In theory, a more sophisticated population model would be within this feasible range.

Envelope Results

For Atlantic butterfish, we specified a range of survey efficiencies $q = 0.1$ to $q = 1$ and fishing mortality rates $F = 0.01$ to $F = 0.8$. We assumed the same natural mortality rate as NEFSC (2010), $M = 0.8$. Total catches (which include estimated discards) have increased slightly since the last assessment, but the fall survey index has increased much more (Fig. 1 and Table 1). Using estimates provided by Miller et al. (2010), we calibrated the annual indices for 2009-2011 in *Albatross IV* units so that the time series is comparable.

Figure 2 illustrates the application of the envelope method using equations 1 to 4. Results suggest that biomasses necessary to support observed catches in the early 1980's were as high as 400,000 mt. Current population sizes since 2001 are likely to have been below 100,000 mt. The trend in minimum biomass estimates (high *F*, high *q*) is less pronounced but similar in relative trend. A comparison with biomass estimates from the final model run (Fig. 3) revealed biomass estimates consistent with low catchability, low fishing mortality, or both. The model biomass estimates were nearly coincident with $\hat{B}_{upper,t}$ defined in Equation 4.

Envelope method without the fishing mortality assumption

Assessment models commonly assume that the efficiency of the survey is constant over time, but it is unlikely that fishing mortality is constant from year to year. Given assumed values of survey efficiency and natural mortality and known annual total catch and relative biomass indices, Equation 2 can be used to estimate fishing mortality in year y. The annual fishing mortality rate can be determined numerically, and subsequently the January 1 stock biomass as well. The equation to satisfy is

$$C_y = \frac{F_y}{F_y + M}\left(1 - e^{-(F_y+M)}\right)B_y(0) \tag{5}$$

where $B_y(0)$ is the biomass at the start of year y, which is related to the survey index I that occurs after fraction f of the year has passed,

$$B_y(0) = B_y(f)e^{(F_y+M)f} = \frac{I_y(f)}{q}\frac{A}{a}e^{(F_y+M)f} . \tag{6}$$

Results of Envelope method without the fishing mortality assumption

For these results, we use the same survey efficiency range and natural mortality rate as above, but we also produce results for a greater natural mortality rate of 1.1 because evidence was provided in SARC 49 that M could be greater than the assumed rate (NEFSC 2010). We specified the NEFSC fall survey to occur 0.75 (=f) through each year.

We also thought it worthwhile to explore fishing mortality rates associated with increased catches for recent years based on the implied annual January 1 biomasses under the various assumptions on survey efficiency (q) and natural mortality (M). More specifically, given the average January 1 stock biomasses between 2005-2011 implied by the realized catches, we determined the range of fishing mortality over a range of assumed total catches.

Based on the simple model, the implied fishing mortality was relatively high between 1975 and 1982 under all q and M scenarios, but, as expected, annual values were lower when assumed natural mortality was higher and survey efficiency was lower (Fig. 4). The fishing mortality rates estimated at SARC 49 (NEFSC 2011) generally fall within the range of those implied under the range of q and M assumptions, but closer on average to those associated with the $q = 0.1$ assumption. The implied January 1 biomasses were generally greatest between 1980 and the early 1990s under all q and M assumptions, but those from 2009-2011 (since the last assessment) are in the same range (Figure 5). As with fishing mortality, the January 1 biomasses from SARC 49 are generally within the range of those implied under the different q and M assumptions.

Even at the most conservative biomasses ($q = 1$ and $M = 0.8$) during recent years (2005-2011), the fishing mortality is less than any of the proposed overfishing reference points when total catch is less than 9,400 mt (i.e., over 5 times greater than the average annual catch during 2005-2011, 1,850 mt) (Fig. 6)

Discussion and Conclusions

The simple models we used here have some important underlying assumptions:

1) Fish are fully selected at the same ages by the surveys and fishery.
2) All recruitment to the stock occurs at the beginning of the year.
3) The entire stock is available to the trawl survey.

These three assumptions are not likely to apply to the actual butterfish stock, but these inconsistencies will affect the results in predictable ways. When the first assumption does not hold and the fishery selects younger fish on average than the survey, then survey efficiency is effectively lower and actual fishing mortalities would be lower than those implied by the second model that does not require a fishing mortality assumption. Conversely, if the fishery selects older fish on average, the fishing mortality rates would be higher than those provided by the model.

Butterfish are likely to recruit to the fishery over some period of the calendar year and this violation of assumption 2 would cause all annual fishing mortality rates provided by the model to be higher than actual values. Assumption 3 is violated when only a fraction of the stock is available to the survey. In these instances, effective efficiency would be lower than that assumed and model-based fishing mortality rates would be higher than the actual values. Therefore, violating the latter two assumptions would likely lead to over-estimation of fishing mortality rates which makes the model results conservative and current catches levels would be even less likely to exceed candidate reference points over a broad range of assumptions.

The analyses presented herein do not constitute an assessment in the formal sense, but may be sufficient for defining reasonable bounds on catch limits. We note that uncertainty in survey and catch data are not included in the determination of feasible bounds. Further work on this approach might include formal consideration of the uncertainty in survey and catch data and its implications for likely ranges of biomass and fishing mortality.

Major Conclusions

Based on the available data and exploration of a wide range of assumptions related to survey catchability, natural mortality, fishing mortality, and total catch we conclude the following:

1. All existing evidence suggests that current F must be low.
2. The empirical evidence from the analysis of survey data suggests that F is much lower than M=0.8. Increasing assumed M to levels above 1.1/yr will make the contribution of F to total mortality even less important.
3. Survey data suggest stock biomass has increased in the last four years.
4. Unless survey catchability greatly exceeds unity, the maximum feasible F on butterfish is less than 0.2 for values of natural mortality up to 1.1/yr.
5. Commonly used reference points based on yield per recruit or spawning biomass per recruit greatly exceed the maximum feasible fishing mortality rate for butterfish.

The maximum fishing mortality over recent years (2005-2011) is below any of the corresponding reference points from SARC 49. Even a five-fold increase in total catch is highly unlikely to increase estimated F above F40% (Fig. 6). Moreover, this is attained only when survey efficiency is assumed to be 100% (q=1). At a more realistic catchability of q=0.1, the implied F would be less than 0.1 even the true catch exceed the estimated catch by a factor of 5.

References

Miller, T. J., Das, C., Politis, P. J., Miller, A. S., Lucey, S. M., Legault, C. M., Brown, R. W., and Rago, P. J. 2010. Estimation of Albatross IV to Henry B. Bigelow calibration factors. NEFSC Ref. Doc. 10-05.

NEFSC. 2010. 49th Northeast Regional Stock AssessmentWorkshop (49th SAW) Assessment Report. NEFSC Ref. Doc. 10-03.

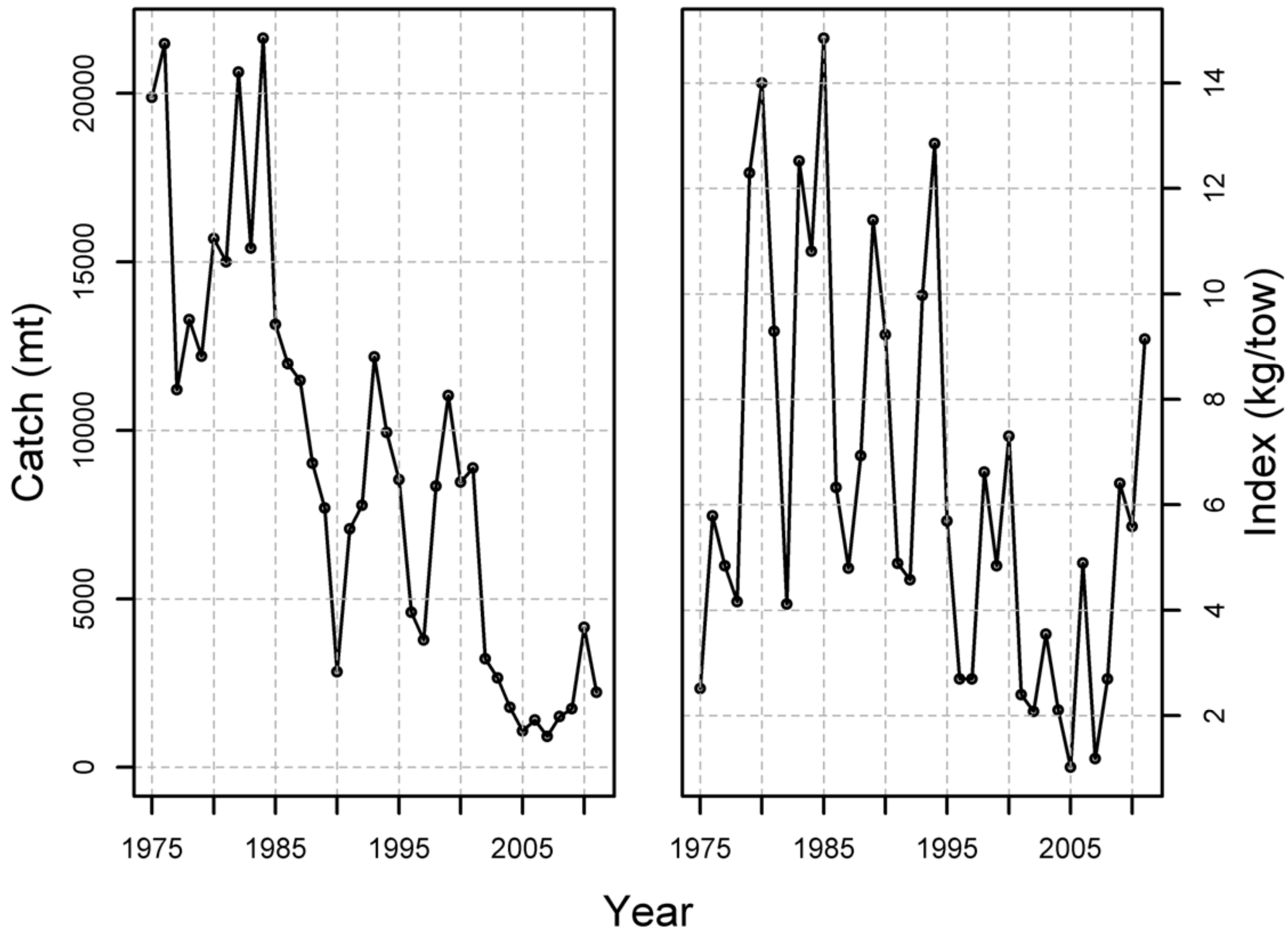

Figure 1. Annual total catches and fall NEFSC biomass indices for Atlantic butterfish.

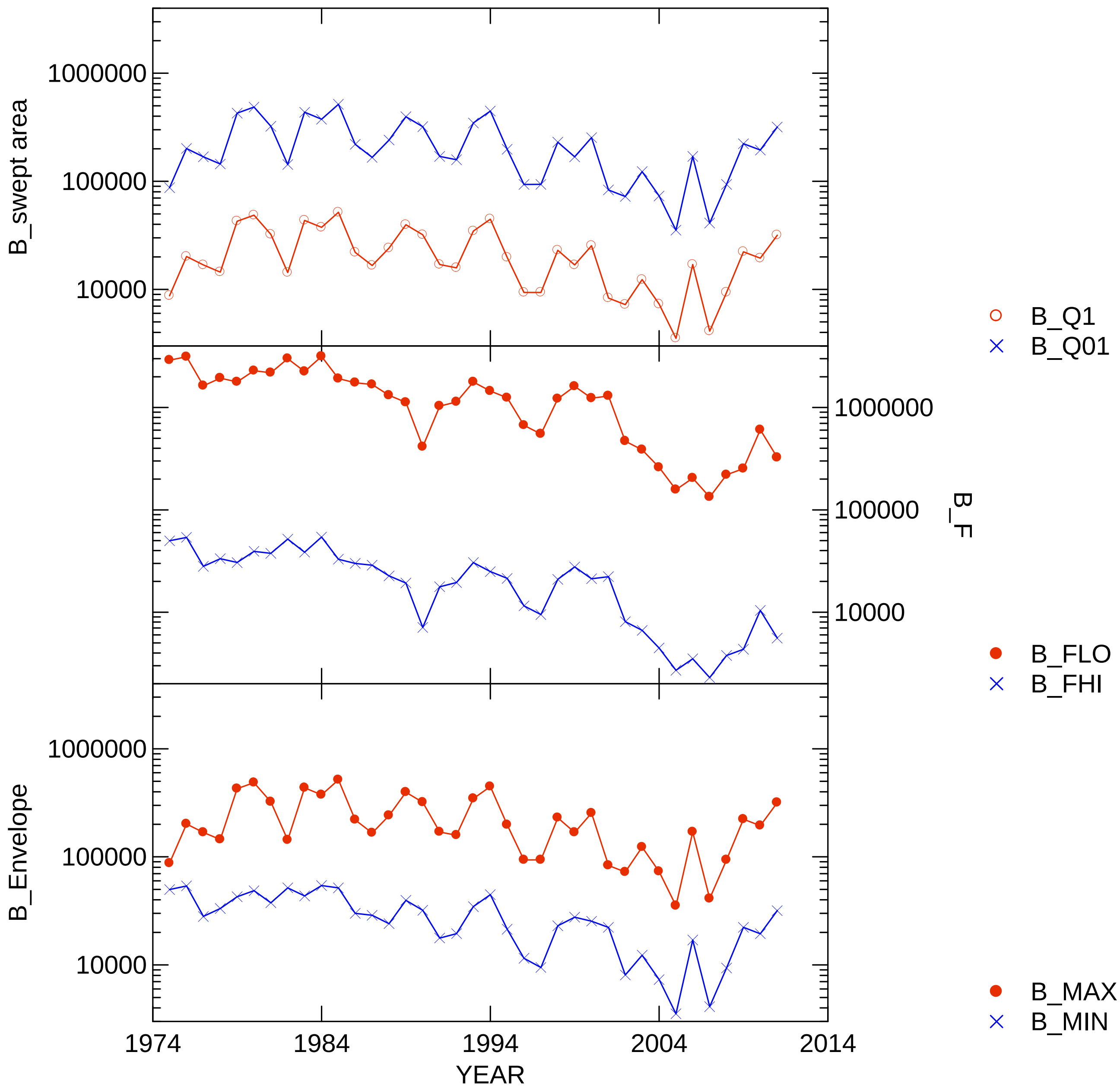

Figure 2. Summary of upper and lower bounds for biomass (mt) based on assumed survey catchability range (0.1,1.0) (top panel, Eq. 1), assumed range of F (0.01, 0.8) (middle panel, Eq. 2) and envelope consistent with both assumptions (lower panel, Eq. 4).

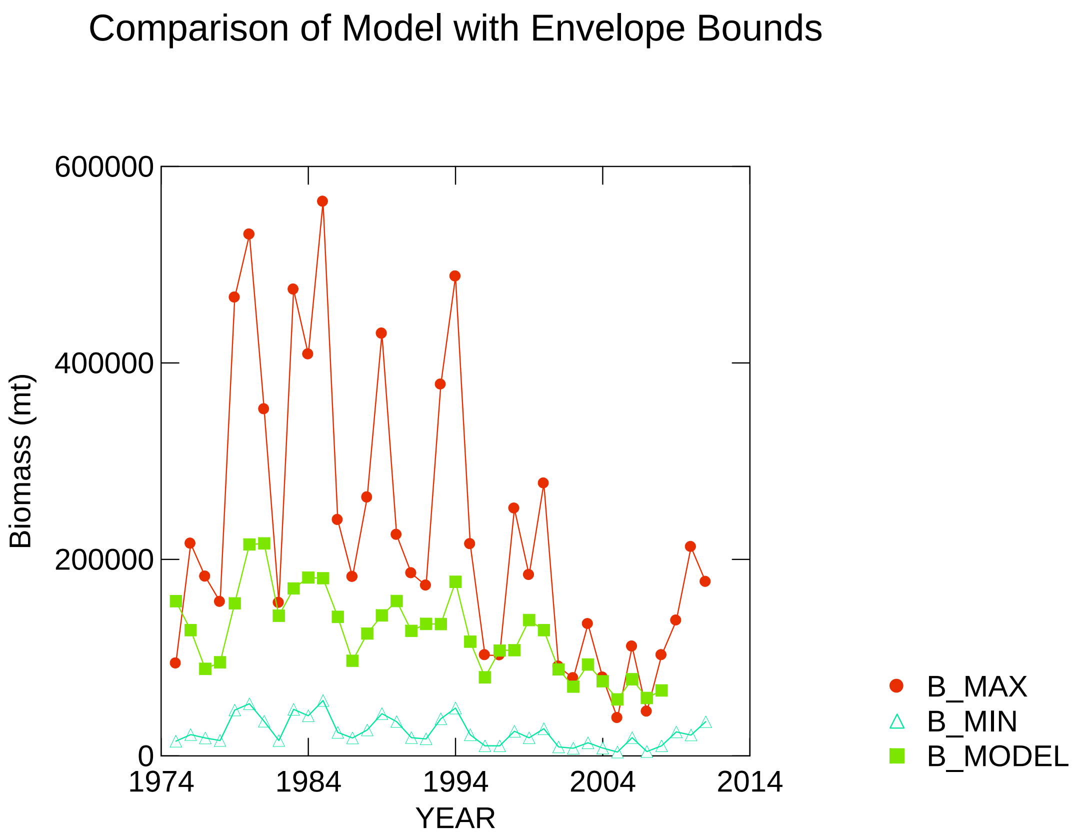

Figure 3. Comparison of envelope range (Eq. 4) for 1975 to 2011 with KLAMZ model estimates for 1975 to 2008 (SARC 49).

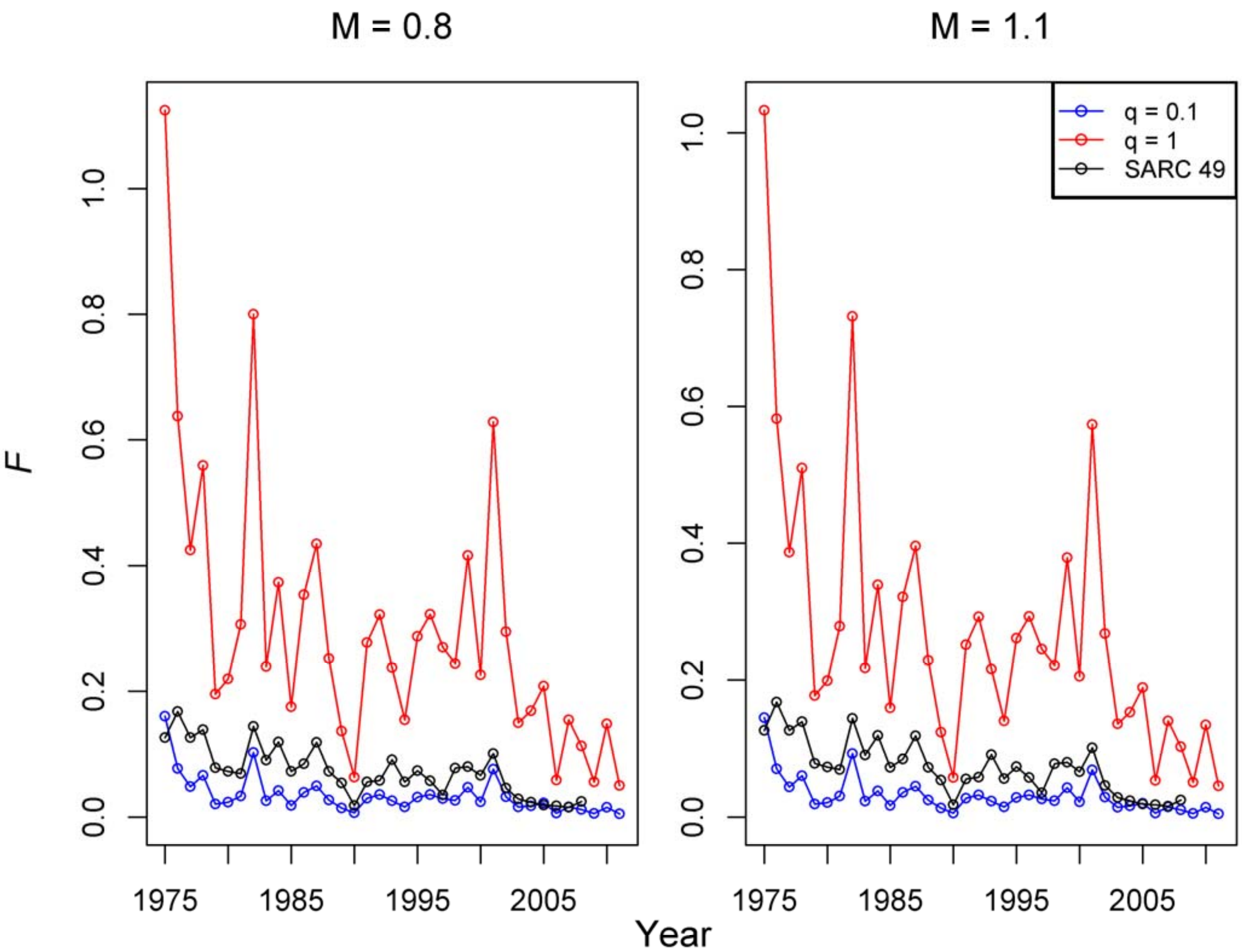

Figure 4. Implied annual fishing mortality rates under two different survey efficiency and natural mortality assumptions and the fishing mortality rate estimates from SARC 49 (NEFSC 2010). See Equation 5.

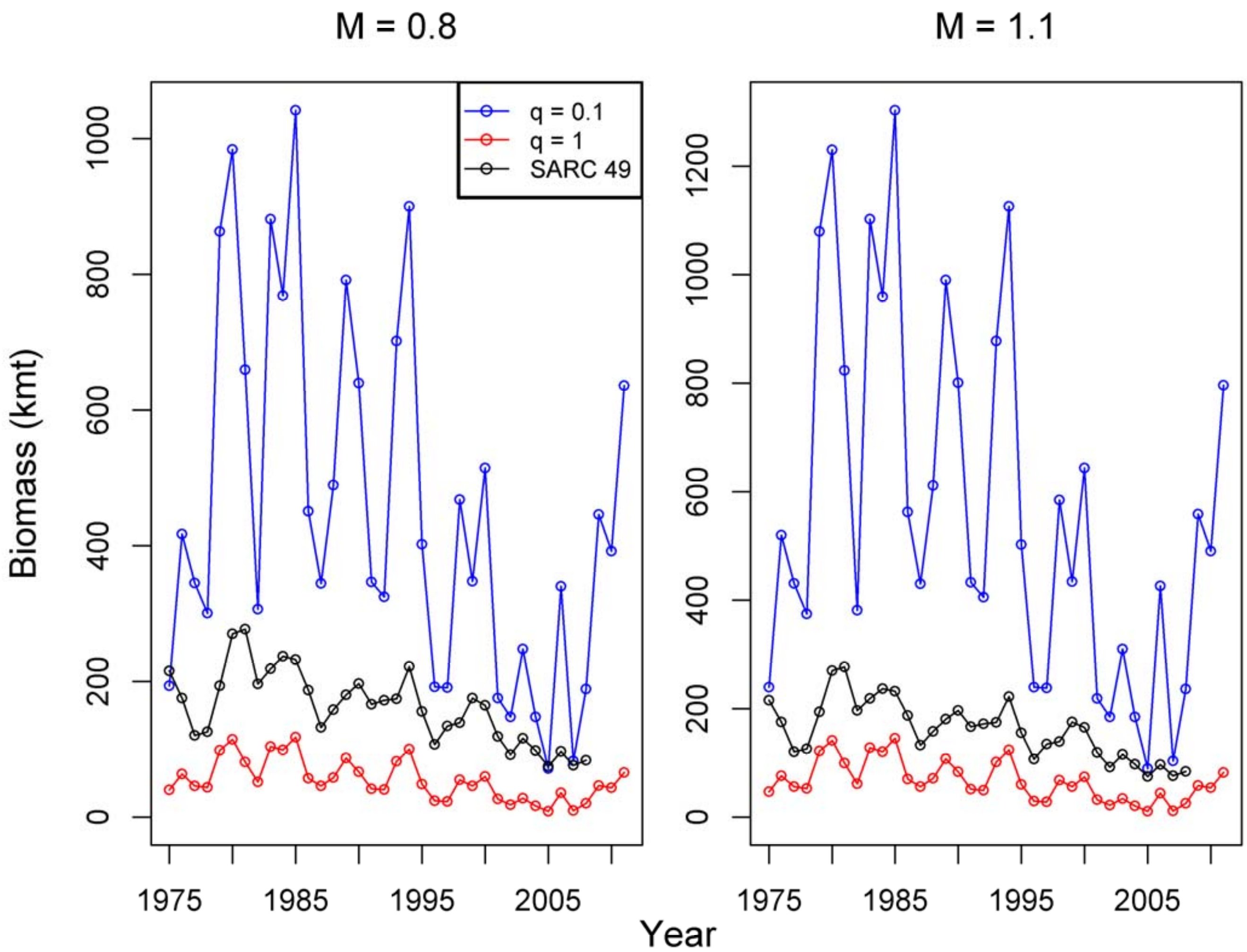

Figure 5. Implied annual January 1 butterfish stock biomass under 2 different survey efficiency and natural mortality assumptions and the biomass estimates from SARC 49 (NEFSC 2010). See Equation 6.

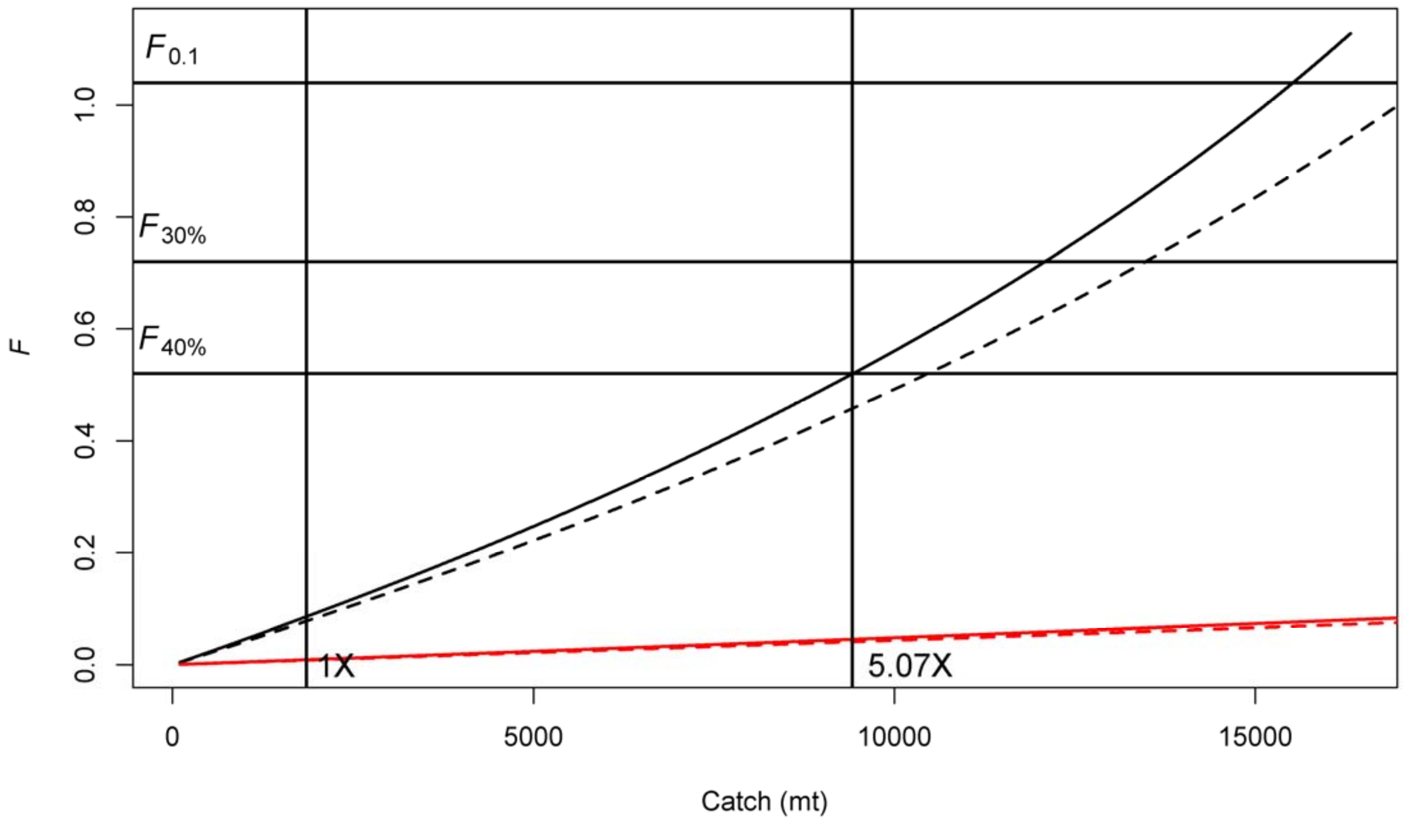

Figure 6. Relationship of implied fishing mortality rate to catch based on average 2005-2011 January 1 biomasses derived under different survey efficiency (black: q = 1, red: q = 0.1) and natural mortality rate (solid: M = 0.8, dashed: M = 1.1) assumptions. Overfishing reference points are from SARC 49 (NEFSC 2010). Vertical lines are for average 2005-2011 total catch (1X) and the total catch associated with the most conservative stock size (q = 1 and M=0.8) and overfishing reference point ($F_{40\%}$) (5.07 times average 2005-2011 catch).

Table 1. Annual NEFSC fall bottom trawl survey biomass index (kg/tow), survey area (*A*), average swept area per tow (*a*), landings (mt) discards (mt) and combined total catch(mt).

Year	index	CV	*A*	*a*	Landings	Discards	Total Catch	CV
1975	2.51	0.31	41947	0.0112	14737	5148	19885	0.41
1976	5.79	0.23	41777	0.0112	15813	5663	21476	0.40
1977	4.84	0.31	42220	0.0112	4608	6599	11207	0.94
1978	4.16	0.16	42220	0.0112	5314	7971	13285	0.88
1979	12.29	0.23	42503	0.0112	3753	8443	12196	1.02
1980	14.00	0.54	42443	0.0112	6564	9126	15690	0.87
1981	9.29	0.30	42536	0.0112	6255	8744	14999	0.87
1982	4.11	0.29	42385	0.0112	10415	10214	20629	0.72
1983	12.52	0.23	42446	0.0112	5373	10037	15410	0.95
1984	10.81	0.30	42342	0.0112	12144	9494	21638	0.61
1985	14.85	0.24	42536	0.0112	5437	7703	13140	0.81
1986	6.33	0.19	42503	0.0112	4582	7397	11979	0.81
1987	4.80	0.29	42541	0.0112	4578	6905	11483	0.74
1988	6.93	0.19	42503	0.0112	2107	6921	9028	0.93
1989	11.40	0.29	42220	0.0112	3216	4480	7696	0.49
1990	9.23	0.23	42398	0.0112	2298	533	2831	0.07
1991	4.89	0.37	42593	0.0112	2189	4887	7076	0.68
1992	4.57	0.26	42436	0.0112	2754	5025	7779	0.35
1993	9.97	0.23	42443	0.0112	4608	7577	12185	0.20
1994	12.85	0.35	42536	0.0112	3634	6300	9934	0.23
1995	5.69	0.27	42428	0.0112	2067	6466	8533	0.38
1996	2.69	0.27	42593	0.0112	3555	1047	4602	0.16
1997	2.70	0.23	42503	0.0112	2794	986	3780	0.27
1998	6.62	0.39	42593	0.0112	1966	6378	8344	1.29
1999	4.84	0.30	42593	0.0112	2110	8927	11037	0.29
2000	7.30	0.25	42536	0.0112	1449	7015	8464	0.19
2001	2.40	0.40	42476	0.0112	4404	4474	8878	0.24
2002	2.08	0.22	42518	0.0112	872	2348	3220	0.91
2003	3.54	0.20	42401	0.0112	536	2114	2650	1.15
2004	2.10	0.36	42428	0.0112	537	1246	1783	0.21
2005	1.02	0.30	42353	0.0112	437	642	1079	0.13
2006	4.89	0.22	42541	0.0112	554	845	1399	0.43
2007	1.18	0.39	42593	0.0112	674	241	915	0.16
2008	2.70	0.22	42593	0.0112	451	1054	1506	0.44
2009	6.41	0.25	42593	0.0112	435	1298	1733	0.20
2010	5.59	0.30	42593	0.0112	575	3576	4152	0.31
2011	9.14	0.27	42593	0.0112	662	1565	2227	0.12

Table 2. Range of biomass estimates (mt) based on assumed range of catchability {0.1, 1.0} and assumed range of F{0.01,0.8}. The effective constraint denotes the parameter that defines the envelope bound.

	Biomass range based on assumed q {0.1,1.0}		***Biomass range based on assumed F {0.01,0.8}***		***Envelope Limits (mt)***		***Effective Constraint***	
Year	***B swept area (q=1)***	***B swept area (q=0.1)***	***B(Flo=0.01)***	***B(Fhi=0.8)***	***max B***	***Min B***	***Max Bio***	***Min Bio***
1975	8,734	87,343	2,901,363	49,830	87,343	49,830	q_min	q_max
1976	20,134	201,337	3,133,572	53,818	201,337	53,818	q_min	q_max
1977	16,836	168,358	1,635,194	28,084	168,358	28,084	q_min	q_max
1978	14,465	144,650	1,938,418	33,292	144,650	33,292	q_min	q_max
1979	42,747	427,471	1,779,556	30,563	427,471	42,747	q_min	F_hi
1980	48,618	486,176	2,289,331	39,319	486,176	48,618	q_min	F_hi
1981	32,300	322,998	2,188,473	37,586	322,998	37,586	q_min	q_max
1982	14,303	143,026	3,009,908	51,694	143,026	51,694	q_min	q_max
1983	43,546	435,465	2,248,449	38,616	435,465	43,546	q_min	F_hi
1984	37,506	375,058	3,157,238	54,225	375,058	54,225	q_min	q_max
1985	51,638	516,382	1,917,261	32,928	516,382	51,638	q_min	F_hi
1986	22,002	220,021	1,747,841	30,019	220,021	30,019	q_min	q_max
1987	16,654	166,539	1,675,508	28,776	166,539	28,776	q_min	q_max
1988	24,099	240,985	1,317,199	22,623	240,985	24,099	q_min	F_hi
1989	39,646	396,460	1,122,917	19,286	396,460	39,646	q_min	F_hi
1990	32,003	320,029	413,057	7,094	320,029	32,003	q_min	F_hi
1991	16,993	169,933	1,032,407	17,731	169,933	17,731	q_min	q_max
1992	15,843	158,429	1,135,045	19,494	158,429	19,494	q_min	q_max
1993	34,625	346,245	1,777,907	30,535	346,245	34,625	q_min	F_hi
1994	44,681	446,808	1,449,510	24,895	446,808	44,681	q_min	F_hi
1995	19,781	197,807	1,244,968	21,382	197,807	21,382	q_min	q_max
1996	9,363	93,630	671,542	11,534	93,630	11,534	q_min	q_max
1997	9,375	93,749	551,532	9,472	93,749	9,472	q_min	q_max
1998	23,018	230,181	1,217,526	20,911	230,181	23,018	q_min	F_hi
1999	16,832	168,316	1,610,417	27,658	168,316	27,658	q_min	q_max
2000	25,390	253,897	1,234,955	21,210	253,897	25,390	q_min	F_hi
2001	8,319	83,192	1,295,416	22,248	83,192	22,248	q_min	q_max
2002	7,237	72,367	469,886	8,070	72,367	8,070	q_min	q_max
2003	12,304	123,036	386,586	6,640	123,036	12,304	q_min	F_hi
2004	7,317	73,173	260,178	4,468	73,173	7,317	q_min	F_hi
2005	3,532	35,318	157,454	2,704	35,318	3,532	q_min	F_hi
2006	16,995	169,949	204,195	3,507	169,949	16,995	q_min	F_hi
2007	4,111	41,112	133,552	2,294	41,112	4,111	q_min	F_hi
2008	9,372	93,721	219,681	3,773	93,721	9,372	q_min	F_hi
2009	22,279	222,787	252,817	4,342	222,787	22,279	q_min	F_hi
2010	19,441	194,412	605,795	10,404	194,412	19,441	q_min	F_hi
2011	31,796	317,956	324,964	5,581	317,956	31,796	q_min	F_hi