I/UCRC Executive Summary **Date**: 10/28/2024

Title: Gulf Menhaden Reference Point and Sustainability Certification

PI: Leaf and Butterworth

Center/Site: Science Center for Marine Fisheries (SCeMFiS)

Statement of Problem: Three aspects of the Gulf Menhaden MSC process that the industry must address for certification are: 1.) that the client must provide evidence of the implementation of a harvest strategy that is designed to take into consideration the ecological role of Gulf Menhaden and is responsive to the state of the stock with respect to its role in the ecosystem; 2.) to provide evidence of implementation that there is a defined harvest control rule that takes into consideration the ecological role of Gulf menhaden which a.) ensures that the exploitation rate is reduced as a point where serious ecosystem impacts could occur is approached and b.) is expected to keep the stock fluctuating around a target level consistent with ecosystem needs; and 3.) to specify well-defined goals and objectives for the fishery and the stock. The work done by SCEMFIS, and industry-supported researchers, has provided much of the requisite analyses to address some of these needs; but some requirements of MSC are still not met; which hinders the MSC certification process.

Deliverables: The proposed work in this project is to deliver three products: 1.) Update the Wilhelm fishery reference point dashboard to include the most recent fishery-independent data; the goal here is to extend the time series for descriptive and possibly further analyses; additionally, a clear description of the allowable catch will be provided when the index value is exceeded; this will be presented as a table for the industry to see (and they have requested that this be included); 2.) D. Butterworth and R. Rademeyer will address additional simulation testing of some alternative candidate reference points/harvest control rules, as suggested at the stakeholder workshop in September 2023 at Gulf Park, MS; 3.) Leaf and Himchak will work directly with industry and state agency representatives if and as necessary, to have an MOU between the two companies and the MSC that the fishery reference points/harvest control rule will be followed and that this will be monitored, and 4.) Work with GSMFC personnel to have the Menhaden Advisory Committee, if and as necessary, affirm or modify the goals and objectives for the fishery.

Status relative to deliverables:

1.) Update the Wilhelm fishery reference point dashboard to include the most recent fishery-independent data; the goal here is to extend the time series for descriptive and possibly further analyses; additionally, a clear description of the allowable catch will be provided when the index value is exceeded; this will be presented as a table for the industry to see (and they have requested that this be included);

We have done this and provided the data to Dr. Butterworth and Ms. Rademeyer. IAB POC P. Himchak has provided this to MSC auditors.

2.) D. Butterworth and R. Rademeyer will address additional simulation testing of some alternative candidate reference points/harvest control rules, as suggested at the stakeholder workshop in September 2023 at Gulf Park, MS;

Dr. Butterworth and Ms. Rademeyer have completed a comprehensive analysis, extending their Harvest Control Rule (HCR) analysis. This was furnished to IAB POC P. Himchak for consideration into the MSC certification process. (Appendix 01).

3.) Leaf and Himchak will work directly with industry and state agency representatives if and as necessary, to have an MOU between the two companies and the MSC that the fishery reference points/harvest control rule will be followed and that this will be monitored, and

This was primarily task of IAB POC P. Himchak.

4.) Work with GSMFC personnel to have the Menhaden Advisory Committee, if and as necessary, affirm or modify the goals and objectives for the fishery.

In a series of meetings, IAB POC P. Himchak and Leaf worked with GSMFC and the Menhaden Advisory Committee to reaffirm the goals and objectives for the fishery (Appendix 02).

Summary of results relative to deliverables:

All objectives have been accomplished.

Challenges to project completion and recommendations addressing the same:

All objectives have been accomplished and challenges have been overcome.

Application of MSE to Gulf Menhaden to Address Issues related to MSC Certification of Ecosystem-related Reference Points

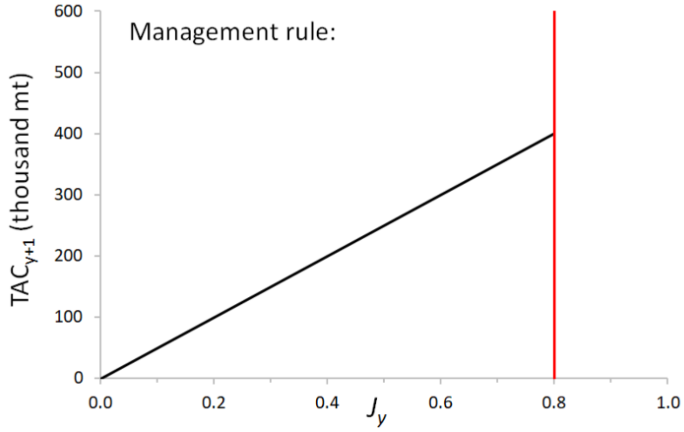
Doug S. Butterworth and Rebecca A. Rademeyer

August 2024

Executive Summary

Management Strategy Evaluation (MSE) is used to test a Harvest Control Rule (HCR, alternatively Management Procedure, MP or Management Rule) for use in setting catch limits for Gulf menhaden (when necessary) which ensures that Ecosystem requirements (for natural predators on menhaden) are respected. Broadly speaking, this require keeping spawning biomass above a relatively high proportion of dynamic SSB0 – closer to, say, 0.75*SSB0 than a conventional single species target of, say, 0.4*SSB0.

The Management rule is based on a single composite index of menhaden abundance. If the index is above a threshold value, no restrictions are placed on catches. However, if the index falls below the threshold, a catch limit is put in place that is proportional to the value of the index, as illustrated in the Figure below.



J_y is a measure of the immediate past level in the combined abundance index for Gulf Menhaden, taken as the average of the last three years (average of I_{y-2} to I_y). The combined abundance index is itself a 4:1 weighted averaging of gillnet and seine data.

Thus, if the relative abundance index J_y is 0.8, a TAC of 400 thousand mt is set; if J_y falls below this 0.8 threshold, this 400 thousand mt TAC is reduced by the same proportion as J_y is less than 0.8.

Under the BAM Base assessment model and maintenance of landings levels in the range that has occurred since 2000, it would seem that no further regulations are necessary. However, the possibility of other dynamics (e.g. a period of poor recruitment) needs to be taken into account; simulations conducted show that in these circumstances application of a simple rule (such as that proposed) to control catches would result in abundance not falling as low as would otherwise be the case.

The performance of the Management rule under simulation testing for a Base case and various robustness Operating Models is completely satisfactory.

Ian important in the context of MSC considerations is that the ratio of SSB to dynamic SSB0 has been close to 0.75 since and 2008, so that any ecosystem requirements are being well taken into account.

The probability of falling below the threshold abundance level, with the consequent need to impose a TAC, is low (about 10% per year) and the expected impact of the catch restriction rule on the annual catch that would otherwise be expected is very small, being about 2.5% or 13 thousand tons less.

Introduction

This paper updates the MP for Gulf menhaden developed by Butterworth and Rademeyer (2019). Further catch data are now available, and the combination of the two abundance indices into a composite index has been slightly modified. The MP input is now based on this new composite index.

Methods

Future projections of the Gulf menhaden resource under the Management Procedure proposed previously by Butterworth and Rademeyer (2019) are updated to take into account of the landings and survey data that have become available since that last analysis.

The new landing data (2019-2023) are given in Table 1 while the combined survey index[1] is given in Table 2 (Leaf, pers. commn).

The Operating Model (OM) taken forward here to reflect the dynamics of the Gulf menhaden population mimics the BAM Base Model developed for the assessment of this resource (SEDAR, 2018). The projection methodology (Appendix A) and the Management Procedure (Appendix B) are as originally described in Butterworth and Rademeyer (2019), with the actual landings (2018-2023) and combined index values up to 2023 replacing the ones previously projected.

The projections

Key aspects of the 20-year (from 2024) projections conducted are as follows, with full details (including some exceptions to the broad statements made below) set out in Appendix A.

- Unless otherwise specified, future dynamics are the same as for the BAM Base Model assessment.
- Future annual landings are drawn at random, with replacement, from the 2000-2017 values. A maximum full fishing mortality (Fmax) is imposed to avoid unrealistic values, i.e. instances where the low size of the resource would make it unlikely that the future intended catch could be taken, so that the fishing mortality required to take the catch is overridden by a value corresponding to Fmax.
- A hockey-stick form is assumed for the stock-recruitment curve, with the break point taken to be at SSB=$1.8\text{x}10^6$ (in billions of eggs) – see Figure 1.
- Future recruitment residuals are drawn at random, with replacement, from the 1978-2017 model estimated residuals.
- Future survey results are computed assuming log-normal observation error, with standard deviation computed from past (2005+) model estimated error. The selectivity and catchability values are taken as estimated for the BAM Base Model.

Robustness tests

Robustness tests were developed in 2019. These tests are listed in Table 1, and fall into two categories.

a) OMs considered to reflect alternative plausible realities to the Base Case OM, for which any MP considered for implementation must evidence reasonably robust performance (Type A).

---

[1] This series is a close approximation of the series that is going to be used in the updated assessment; this is because some data for the final series were not available at the time of this analysis (Robert Leaf, pers. commn).

b) Other OMs whose plausibility is low at best, but which have been included more with a view to check how far the MPs considered can be "pushed" before they provide inadequate performance) (Type B).

The Management Rule

The management rule (management Procedure) is empirical. It overrides and reduces a landing drawn from the historical set only if the value of a combined abundance index falls below a threshold level specified for that index. If the threshold is breached, a TAC is set proportional to the value of the index. The index suggested is a weighted average of the gill net and seine indices. Figure 2 illustrates the rule for the choice of tuning parameter values first made in 2019 and continued here, and also plots historical values of the combined index. Details are given in Appendix B.

Results and Discussion

Base Case

The trajectory of SSB relative to dynamic SSB0 over the assessment period (1977-2018) is plotted in Figure 3.

Figure 4 compares historical estimates and 20-year projections for the 2019 and updated projections for landings, full F, SSB, recruitment, the combined index (3-yr running average) for the Base Case as well as the predicted proportion of cases hitting the threshold.

Figure 5 compares the projections with and without the rule for the Base Case.

Robustness tests

Table 4 summarises some performance statistics (median values across the simulations in each case) for the Base Case and the Type A robustness tests under "no rule" and "with rule". Figures 6 and 7 compare the projections with and without the rule for two of the hardest robustness tests: robustness tests 1.6 and 8.2.

Implications

Important results in the context of MSC considerations are:

a) the ratio of SSB to dynamic SSB0 has been close to 0.75 (see Figure 3) since around 2008, so that any such ecosystem requirements are being well taken into account (see comments in that regard in the Executive Summary);

b) the probability of falling below the threshold abundance level, with the consequent need to impose a TAC, is low (about 10% per year – see Figure 4) and the expected impact of the catch restriction rule on the annual catch that would otherwise be expected is very small, being about 2.5% or 13 thousand tons less (see the with/without rule comparison in Figure 5).

References

Butterworth, D.S. and Rademeyer, R.A. 2019. Extensions of the Application of MSE to Gulf Menhaden. Presented during the Stakeholder Workshop on Management Reference Points for Gulf Menhaden Fisheries. 17-19 July 2019, New Orleans.

SEDAR. 2018. SEDAR 63 – Gulf Menhaden Stock Assessment Report. SEDAR, North Charleston SC. 352 pp. available online at: http://sedarweb.org/sedar-63

Table 1: 2018-2023 Gulf Menhaden total landings

	Landings (kt)
2019	487.0
2020	413.8
2021	360.5
2022	479.6
2023	434.1

Table 2: Updated combined index for Gulf Menhaden.

Year	Index	Year	Index	Year	Index
1989	0.58	2001	0.79	2013	1.59
1990	0.59	2002	0.80	2014	1.47
1991	0.54	2003	0.69	2015	1.50
1992	0.51	2004	0.69	2016	1.52
1993	0.59	2005	0.73	2017	1.55
1994	0.66	2006	0.77	2018	1.66
1995	0.69	2007	1.10	2019	1.55
1996	0.71	2008	1.30	2020	1.68
1997	0.72	2009	1.26	2021	1.50
1998	0.76	2010	1.09	2022	1.80
1999	0.67	2011	1.19	2023	1.79
2000	0.77	2012	1.48		

Table 3: List of the robustness tests used in MP testing. Note that “No refitting” means that the test involves changes in the future only. Type A OMs are considered to reflect alternative plausible realities to the Base Case OM, while the plausibility of Type B OMs is low at best, but these OMs have been included more with a view to check how far any MPs considered can be “pushed” before they provide inadequate performance.

	Base Case	Robustness	No refitting	Type
1. Alternative choices for *M*				
1.1	Lorenzen mortality vector	M'(a)=1.2		A
1.2		M'(a)=M(a)*exp(-0.1(a-2))		A
1.3		M(4+)=1.67		A
1.4		M increases linearly by 40% over next 20 years	x	B
1.5		M increases linearly by 20% over next 20 years	x	B
1.6		Doubling M with a probability of 10%/year	x	A
1.7		Doubling M with a probability of 20%/year	x	B
2. Alternative catch selectivity function				
2.1	S(3) = S(4+) = 0.87	S(3) = S(4+) = 1.0		A
2.2		S(3) = S(4+) = 0.74		A
2.3	S(1) in future as estimated in past	S(1) in future, double that estimated in the past	x	B
3. Indices				
3.1	Linear relationship to abundance: I = q*B	sqrt relationship to abundance I =q*sqrt(B)		B
3.2	Weighting: 4:1 gillnet to seine	Weighting: 1:1 gillnet to seine		A
3.3	Observation error = 0.11	Observation error = 0.2	x	A
3.4		Observation error = 0.3	x	B
3.5		Observation error = 0.5	x	B
3.6	Flat 2+ gillnet selectivity in the future	Increasing 2+ selectivity slope over the next 20 years (to 0.4 age 4 in 20yrs)	x	B
4. Period of future poor recruitment				
4.1	Future rec. drawn at random from past values	Five (2025-2029) years of bad recruitments (50%)	x	B
4.2		From 2025, expected recruitment is halved	x	B
5. Alternative stock-recruitment function				
5.1	Hockey-stick, hinge-point=1.8 billion eggs	Hockey-stick, hinge-point=2.2 billion eggs	x	A
6. Future catches				
6.1	Future catches drawn from past catches*	Under-reporting: Future catches = 1.1TAC (presence of these IUU catches is not	x	B
6.2		Higher catches: Future catches = draw from past catches + 100 000 mt (*)	x	A
6.3		Higher catches: Future catches = draw from past catches + 150 000 mt (*)	x	B
6.4		Higher catches: Future catches = draw from past catches + 200 000 mt (*)	x	B
	* control rule will override			
7. Maximal possible fishing mortality				
7.1	Fmax for projections = 1.05*Fmax historical	Fmax for projections = 1.20*Fmax historical	x	B
8. Combination of different trials				
8.1		Test 3.1 + test 1.4	x	B
8.2		Test 3.1 + test 4.1	x	A
8.3		Test 1.5 + test 4.1	x	A

Table 4: Summary of performance statistics (medians) for the Base Case and the Type A robustness tests under “no rule” and “with rule”. The third column in each block gives the percentage difference for “with rule” compared to “no rule”.

	Base Case			**Rob1.1 (*M* =1.2)**			**Rob1.2 ($M'_a=M_a*e^{-0.1(a-2)}$)**			**Rob1.3 (M_{4+}=1.67)**		
	No rule	With Rule	% diff.	No rule	With Rule	% diff.	No rule	With Rule	% diff.	No rule	With Rule	% diff.
Average landing over 2025-2044	495	482	-2.6	495	480	-3.1	495	484	-2.3	495	480	-3.0
Lowest landing over 2025-2044	380	374	-1.5	380	362	-4.6	380	378	-0.5	380	368	-3.2
Egg in 2025	3.3	3.3	0.0	3.7	3.7	0.0	3.3	3.3	0.0	3.5	3.5	0.0
Egg in 2044	3.2	3.2	0.2	3.4	3.5	2.8	3.2	3.2	0.3	3.3	3.4	2.2
Egg lowest over 2025-2044	2.0	2.0	0.8	2.2	2.2	0.3	2.0	2.0	0.0	2.1	2.1	1.1
AAV 2025-2044	0.15	0.16	6.0	0.15	0.16	7.4	0.15	0.16	5.5	0.15	0.16	7.6
Fraction years rule applied over 2025-2044	-	0.00		-	0.00		-	0.00		-	0.00	
Fraction years rule applied over 2025-2029	-	0.05		-	0.10		-	0.05		-	0.10	
	Rob1.6 (prob. 10%/yr of 2M)			**Rob2.1 (S_3=S_{4+}=1.0)**			**Rob2.2 (S_3=S_{4+}=0.74)**			**Rob3.3 (Obs. error = 0.2)**		
	No rule	With Rule	% diff.	No rule	With Rule	% diff.	No rule	With Rule	% diff.	No rule	With Rule	% diff.
Average landing over 2025-2044	390	355	-9.0	495	482	-2.6	495	482	-2.5	495	482	-2.6
Lowest landing over 2025-2044	93	85	-8.5	380	374	-1.4	380	373	-1.9	380	369	-3.0
Egg in 2025	3.3	3.3	0.0	3.2	3.2	0.0	3.3	3.3	0.0	3.3	3.3	0.0
Egg in 2044	0.2	1.2	403.6	3.1	3.1	0.2	3.2	3.2	0.7	3.2	3.2	0.2
Egg lowest over 2025-2044	0.2	0.4	169.9	2.0	2.0	0.4	2.0	2.0	1.0	2.0	2.0	0.8
AAV 2025-2044	0.21	0.25	17.3	0.15	0.16	6.3	0.15	0.16	7.3	0.15	0.16	6.6
Fraction years rule applied over 2025-2044	-	0.00		-	0.00		-	0.00		-	0.00	
Fraction years rule applied over 2025-2029	-	0.50		-	0.05		-	0.05		-	0.05	
	Rob5.1 (Alt. hockey stick)			**Rob6.2 (Catch + 100 kt)**			**Rob8.2 (Rob3.1 + Rob4.1)**			**Rob8.3 (Rob1.5 + Rob4.1)**		
	No rule	With Rule	% diff.	No rule	With Rule	% diff.	No rule	With Rule	% diff.	No rule	With Rule	% diff.
Average landing over 2025-2044	494	479	-2.9	595	561	-5.7	356	389	9.3	190	291	53.0
Lowest landing over 2025-2044	380	367	-3.5	480	349	-27.2	168	152	-9.5	12	98	722.6
Egg in 2025	3.3	3.3	0.0	3.2	3.2	0.0	3.3	3.3	0.0	3.3	3.3	0.0
Egg in 2044	3.1	3.1	2.6	2.9	2.9	0.2	0.6	3.2	460.3	0.0	1.5	7282.6
Egg lowest over 2025-2044	2.0	2.0	0.2	1.8	1.9	4.3	0.3	0.8	188.6	0.0	0.5	2357.8
AAV 2025-2044	0.15	0.16	4.0	0.13	0.17	36.4	0.20	0.22	7.3	0.23	0.21	-8.7
Fraction years rule applied over 2025-2044	-	0.00		-	0.00		-	0.40		-	0.40	
Fraction years rule applied over 2025-2029	-	0.08		-	0.15		-	0.40		-	0.80	

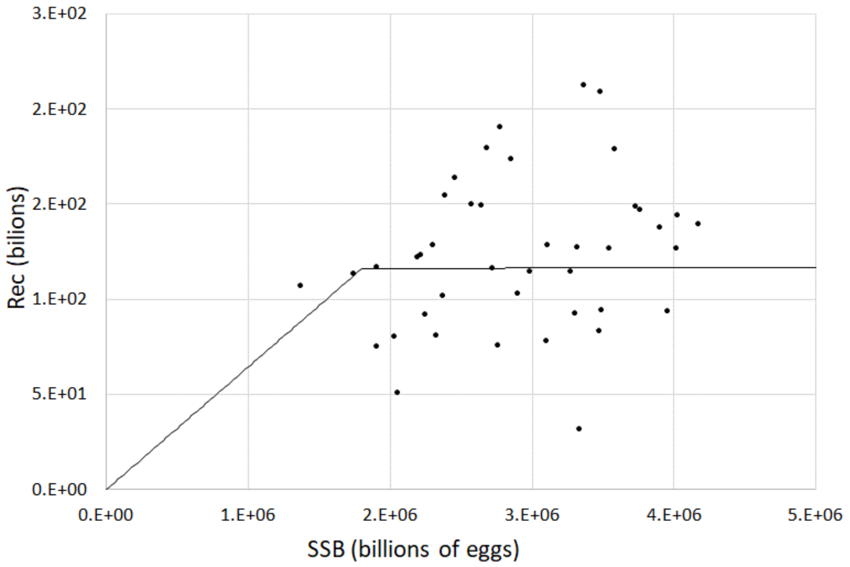


Figure 1: The hockey-stick stock recruitment curve for Gulf Menhaden which is used to compute projected recruitment. The data points are those estimated in the BAM Base Model.

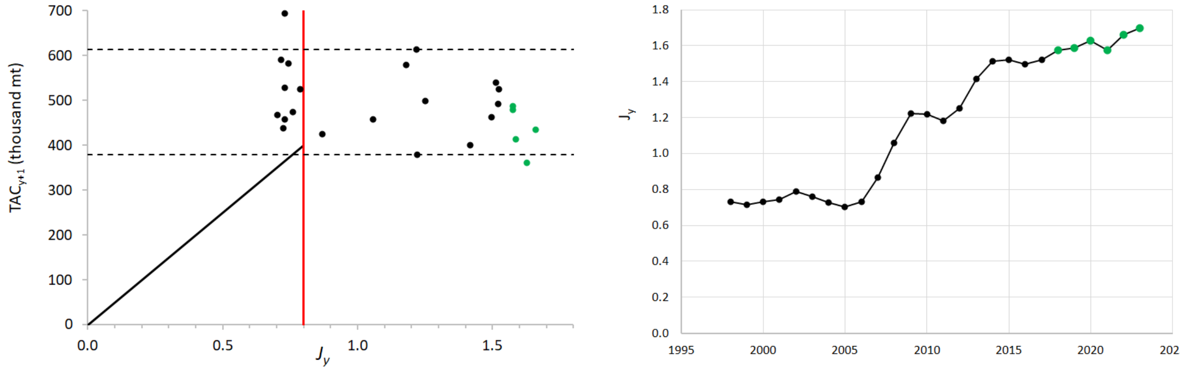


Figure 2: LHS: Illustration of the management rule (Management Procedure). The horizontal dash lines show the 2000-2017 minimum and maximum landing values. The historical (1999-2017) J_y vs. TAC_{y+1} are shown as black dots with the new (2018-2022) values shown as green dots. RHS: Historical combined index J_y values.

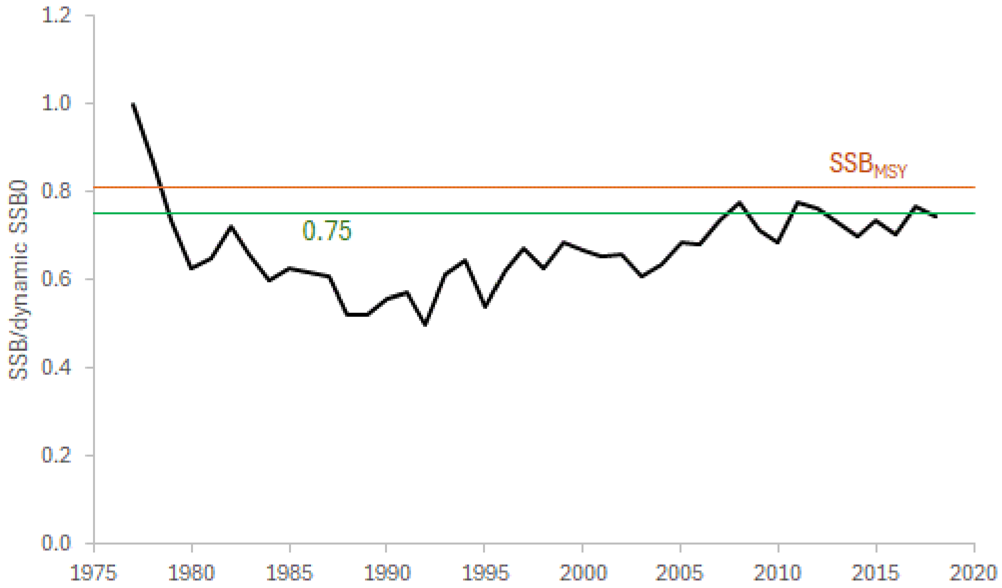


Figure 3: SSB (billions of eggs) relative to dynamic SSB0 for the Base Case over the assessment period. SSB_{MSY} (relative to 2014-2018 average SSB0) and 0.75 are shown as horizontal lines

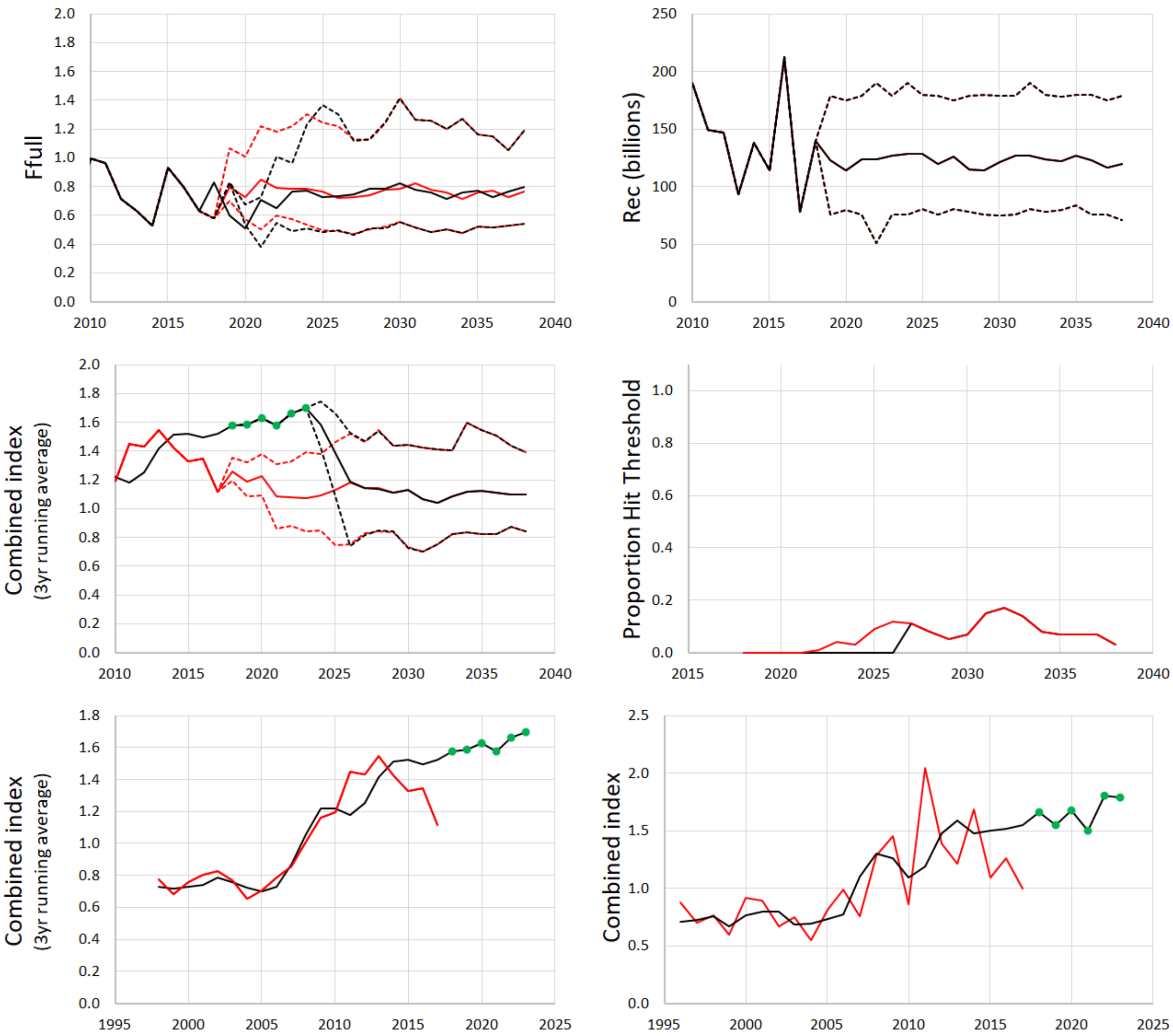


Figure 4: Historical estimates and projected 20-year median and 90%iles for a series of quantities for the Base Case, as in 2019 (red lines) and including the updated data (black lines).

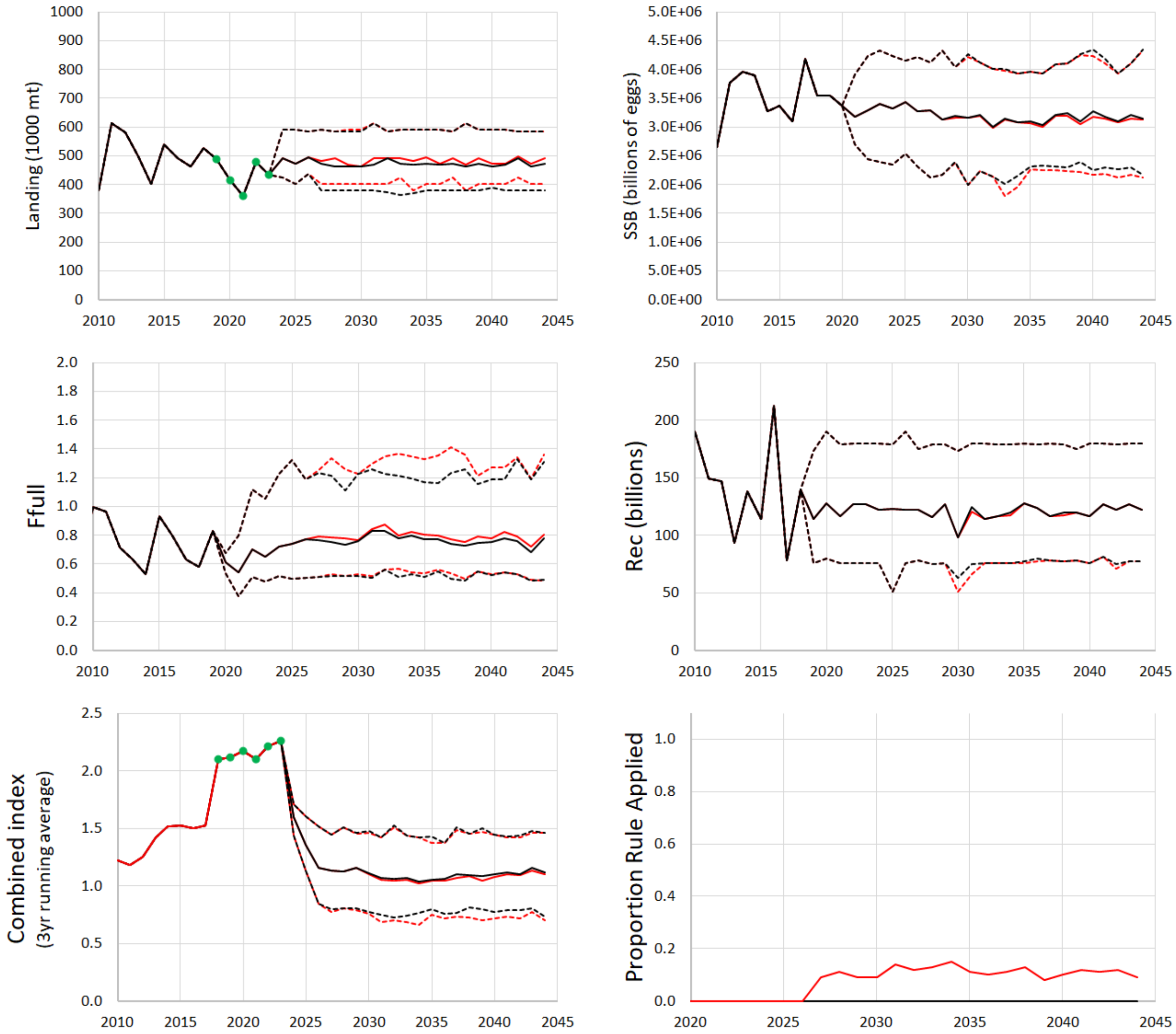


Figure 5: Historical estimates and projected 20-year median and 90%iles for a series of quantities for the Base Case including updated data, without any catch restriction rule (red lines) and with the rule (black lines).

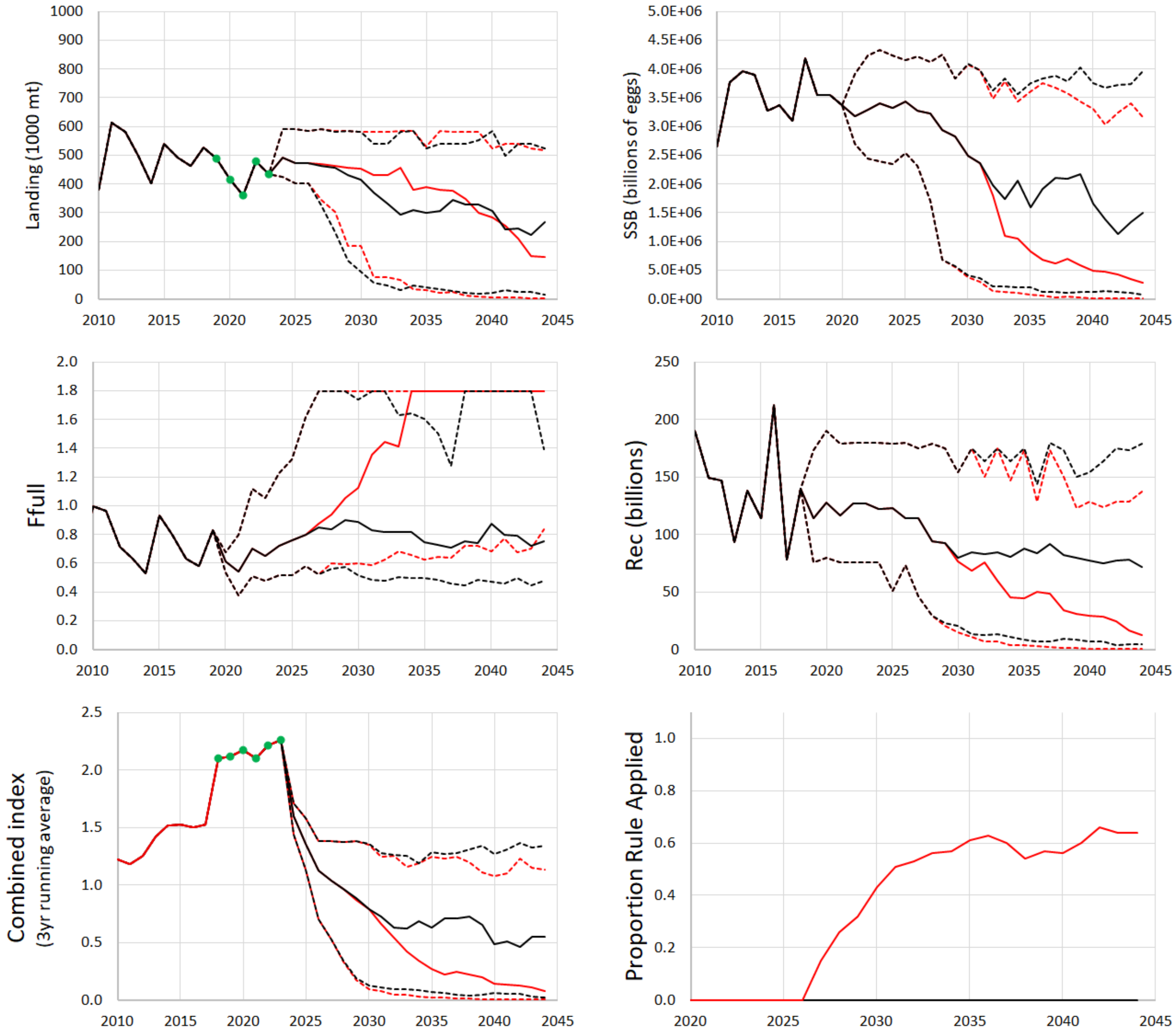


Figure 6: Historical estimates and projected 20-year median and 90%iles for a series of quantities for robustness test 1.6 (doubling *M* with a probability of 10%/year) including updated data, without any catch restriction rule (red lines) and with the rule (black lines).

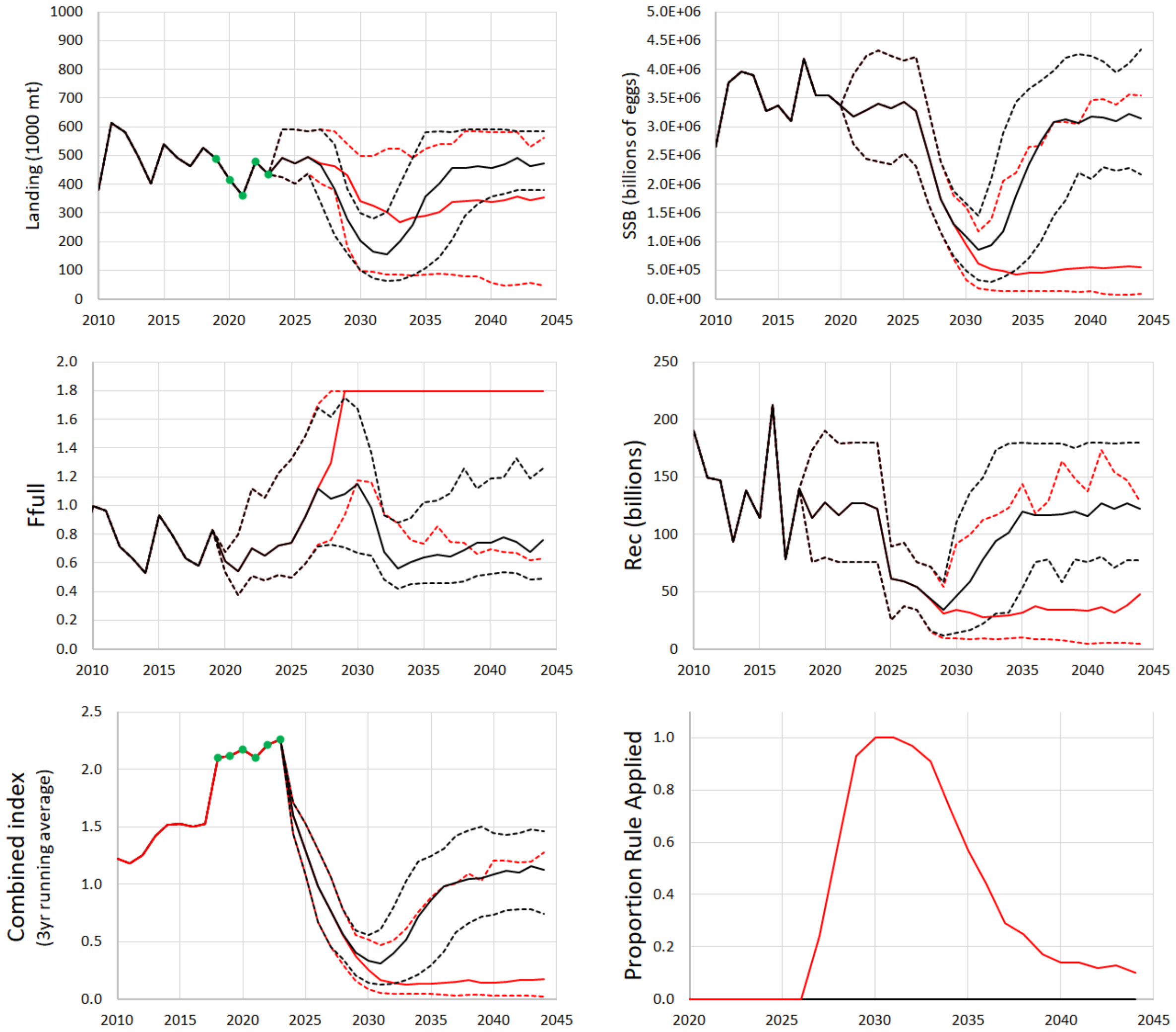


Figure 7: Historical estimates and projected 20-year median and 90%iles for a series of quantities for robustness test 8.2 (sqrt relationship to abundance combined with 5 years of bad recruitments) including updated data, without any catch restriction rule (red lines) and with the rule (black lines).

Appendix A – Projection methodology details

Projections into the future under a specific management rule (MP) are performed using the following steps.

Step 1: Begin-year numbers at age

The components of the numbers-at-age vector at the start of 2018 ($N_{2018,a}$: *a* =1,…, *m* – where *m* is a plus-group) are obtained from the MLEs for an assessment of the resource. The assessment used here is the BAM Base model.

Step 2: Annual landings

Previously for 2018, $L_{2018} =$ 525 635 mt; now for 2023, $L_{2023} =$ 434 100 mt. (A.1)

Previously from 2019, now from 2024 onwards:

L_y is drawn at random, with replacement, from the observed 2000-2017 landings.

Previously from 2020, now from 2024, if the combined abundance index (see equation B2 In Appendix B) for year *y*-1 is below the threshold value, then a TAC applies to year *y* is computed using the MP (harvest control rule) (see equation (B.1) of Appendix B).

Step 3: Landings-at-age (by number)

The $L_{y,a}$ values are obtained under the assumption that the commercial selectivity function (S_a) estimated for the most recent period in the BAM Base Model (1996+) continues in the future. The full fishing mortality F_y is solved iteratively to achieve the annual landing by mass:

$$L_y = \sum_{a=1}^{m} w_a^{mid} N_{y,a} S_a F_y \left(1 - e^{-Z_{y,a}}\right) / Z_{y,a} \qquad \text{(A.2)}$$

where

w_a^{mid} is the time invariant weight-at-age in the middle of the year,

$N_{y,a}$ is the number-at-age vector for age *a* at the start of year *y* (with *m* the plus group),

and

$Z_{y,a} = F_y S_a + M_a$ is the total mortality-at-age vector for age *a* and year *y*.

M_a is the natural mortality-at-age *a* (input).

The numbers-at-age can then be computed for the beginning of the following year (*y*+1):

$$N_{y+1,1} = R_{y+1} \qquad \text{(A.3)}$$

$$N_{y+1,a+1} = N_{y,a} e^{-Z_{y,a}} \quad \text{for } 1 \le a \le m-2 \qquad \text{(A.4)}$$

$$N_{y+1,m} = N_{y,m-1} e^{-Z_{y,m-1}} + N_{y,m} e^{-Z_{y,m}} \qquad \text{(A.5)}$$

If the intended landing is such that the apical fishing mortality (that at the age at which selectivity is 1) exceeds Fmax, then the selectivity for that year for age 1 is increased to 0.8 and the fishing mortality recomputed. If this recomputed apical fishing mortality is still above Fmax, the landings are instead limited to those corresponding to Fmax (and this “widened” selectivity). Fmax has been selected as 5% above the maximum that occurred historically. The choice of 0.8 (increased from the 0.6 suggested in Rademeyer and Butterworth (2019)) has been made so as to reduce the chance that the resource is “protected” from undue depletion through inability to make the intended catch rather than by the management rule (MP), and hence provides a more stringent test of the efficacy of that rule.

Step 4: Recruitment

Expected values (in log space) for future recruitments (R_y) are provided by a hockey-stick stock-recruitment relationship:

$$R_y = \begin{cases} R & if\ SSB_y \geq SSB_{threshold} \\ \frac{R}{SSB_{threshold}} SSB_y & if\ SSB_y < SSB_{threshold} \end{cases} \tag{A.6}$$

where

R is the geometric average of the model estimated past (1977-2017) values,

$SSB_{threshold}$ is a fixed value (1.8 million billion eggs produced),

and

$$SSB_y = \sum_{a=2}^{m} f_a N_{y,a} \tag{A.7}$$

with

$f_a = \rho_a mat_a fec_a$ the reproductive output of a female fish of age *a*,

ρ_a is the proportion of female at age *a*,

mat_a is the proportion mature at age *a*, and

fec_a is the fecundity at age *a*.

When projecting, error is added to this expected value, so that for simulation replicate *s*, if

$S = \{\varepsilon_y = lnR_y - lnR: y = 1977, \dots, 2017\}$, then when projecting:

$R_y^s = Re^{\varepsilon^*}$

where ε^* is drawn at random with replacement from the set I of ε_y values

Although the Recruitment vs Eggs produced plot from the BAM Base Model assessment shows no obvious relationship between the two, clearly there must eventually be some reduction in the number of recruits to be expected as egg production falls. We have taken the fairly standard approach here of assuming a hockey stick relationship where the hinge-point occurs at the lowest historical annual egg production estimated, though for robustness and precaution a slightly higher value of 180 000 billion eggs was chosen so as to avoid undue influence from the lowest two historical values.

Step 5:

The projected values for numbers-at-age are used to generate values of the abundance indices I_{y+1}^i (in terms of numbers), and similarly for following years. Indices of abundance in future years will not be exactly proportional to true abundance, as they are subject to observation error. Log-normal observation error with autocorrelation is therefore added to the expected value of the abundance index in question (in log space), i.e.:

$$I_y^i = q^i B_y^i e^{\varepsilon_y^i} \tag{A.8}$$

with

$$\varepsilon_y^i = \varphi_y^i - \rho^i \varphi_{y-1}^i \tag{A.9}$$

and φ_y^i from $N\left(0, \left(\sigma^i\right)^2\right)$ (A.10)

where

B_y^i is the abundance available to and indexed by the survey:

$$B_y^i = \sum_{a=1}^{m} S_a^i N_{y,a} e^{-Z_{y,a} T^i/12} \tag{A.11}$$

T^i is the timing of the survey (in month) ($T^i = 6$ for the gill net index and 3 for the seine index).

The autocorrelation coefficient ρ^i for the gillnet index, computed from the historical estimated residuals for the Base Case OM is -0.517 and varies considerably if the relative weighting of the two indices is changed. Negative values of auto-correlation enhance the effective precision of an index, the realism of which is questionable. It was therefore decided to set $\rho^{gill} = 0$ in projections. For the seine index, ρ^i is set at 0.134, the value computed from the historical estimated residuals for the Base Case OM.

The survey selectivities are assumed to remain unchanged. The catchabilities are taken to be those estimated in the Base Case OM (the BAM Base Model assessment).

The residual standard deviations σ^i are estimated from the model fit. Since residuals seem to have increased in recent years, the residuals from 2005 onwards have been used for their computation:

$$\sigma^i = \sqrt{\frac{1}{\sum_{y=2005}^{2017} 1} \sum_{y=2005}^{2017} \left(lnI_y^i - ln\hat{I}_y^i\right)^2} \tag{A.12}$$

where I_y^i is the observed index value in year *y* for survey *i* and $\hat{I}_y^i$ is the corresponding model estimated value this yields σ^i =0.11 for the gill net index and 0.41 for the seine index.

<u>Step 6</u>:

Steps 1-5 are repeated for each future year in turn for as long a period as desired.

Appendix B – The Management Rule (Management Procedure)

The management rule (MP) is empirical. It only overrides and reduces a landing drawn from the historical set if the value if a combined abundance index (see below) falls below a threshold level specified for that index. The basis for the associated computations is set out below:

If $J_y < J_{threshold}$:

$$TAC_{y+1} = \gamma J_y \tag{B.1}$$

where

TAC_y is the catch limit that applies for year *y*,

$J_{threshold}$ (no units) and γ (units: thousand mt) are control parameter (tuning) values (the initial choices (baseline MP) are $J_{threshold} = 0.8$ and $\gamma = 500$), and

J_y is a measure of the immediate past level in the abundance indices that are available to use for calculations for year *y*:

$$J_y = \frac{1}{p}\sum_{y'=y-p+1}^{y}\left[\left(w_{gill}\frac{I_{y'}^{gill}}{I_{2017}^{gill}} + w_{seine}\frac{I_{y'}^{seine}}{I_{2017}^{seine}}\right)\Big/\left(w_{gill} + w_{seine}\right)\right] \tag{B.2}$$

with

I_y^{gill} and I_y^{seine} being the observed gill net and seine indices, respectively, in year *y*,

w_{gill} and w_{seine} being the weights given to each index ($w_{gill} = 4$ and $w_{seine} = 1$ for the MP, and correspond roughly to inverse variance weighting given the standard deviations of the residuals in the BAM Base Model fit),

and *p* being a control parameter (*p* = 3 for the MP); this parameter is used to smooth away some of the noise in the index by averaging over a few years rather than consider only the most recent year.

Note the assumption has been made that when a TAC is set in year *y* for year *y*+1, values of these abundance indices will be available for the current year *y*.

9.0 MANAGEMENT OF GULF MENHADEN: ISSUES, MEASURES, CONSIDERATIONS, AND RECOMMENDATIONS

9.1 Definition of the Fishery

The fishery includes three species of menhaden in the U.S. Gulf of Mexico:

Gulf menhaden: *Brevoortia patronus*
Yellowfin menhaden: *Brevoortia smithi*
Finescale menhaden: *Brevoortia gunteri*

The primary fishery is the reduction purse-seine fishery. Relatively minor amounts of menhaden are harvested by other commercial and recreational fisheries as bait.

9.2 Management Unit

The reduction purse-seine fishery in the northern Gulf of Mexico harvests almost exclusively Gulf menhaden, *B. patronus*; other menhaden species and Atlantic thread herring (*Opisthonema oglinum*), represent less than 1% of the catch (Ahrenholz 1981). Considering that *B. patronus* is the only significant species in the fishery and is biologically considered to be a unit stock in the Gulf (Texas to Florida Panhandle), the management unit in this FMP is defined as the total population of *B. patronus* in its range within the U.S. Gulf of Mexico.

9.3 Management Goals

In summary of the following considerations and recommendations, the plan is to provide management with a set of easily understandable strategies to evaluate the actions, encourage compatibility and standardize among resource agencies, facilitate enforcement's role, incorporate ecosystem services as that information becomes available, and reduce management conflicts to provide optimum benefits. Menhaden management should continue to develop collaboration among all stakeholder agencies and entities that directly or indirectly affect Gulf menhaden resources in the estuarine and marine environment. In addition, Gulf menhaden are a critical species in healthy estuarine systems, and any management strategy must incorporate Gulf menhaden both as an ecosystem resource, as that information becomes available, and a fishery resource. Given the following considerations and recommendations, management goals for future evaluation are:

- Maintain the Gulf menhaden population at a level to sustain their ecosystem role; and, to the extent practicable, maintain economically viable fisheries, with continued support for important social and cultural aspects of the associated fishing communities.

- Improve the states' role in monitoring the resource through improved data collection methods, reporting, and knowledge of menhaden's role in the ecosystem.

- Evaluate the effects of changes in the environment (e.g., sea level rise, marsh loss, fresh water diversions) in order to help estimate trends in future stock carrying capacity.

- Develop methods to identify environmental factors that affect menhaden stocks, and more fully integrate those factors into stock assessments.

The MAC's goals are representative of the associated management authorities. The management goals for our fisheries, fish stocks, and ecosystems are responsible use of these valuable resources, identifying and promoting ecosystem function, and promoting the sustainability of the resources entrusted to our agency.

9.3.1 Specific Objectives

The following sections contain specific objectives to achieve the management goals. These objectives are priority items that require action to meet management goals and improve data for the next benchmark assessment. Objectives are divided into three categories: management, population dynamics, and environment. Each objective may address one or more of the management goals as they are inter-related.

9.3.1.1 Management Objectives

- Determine the status of Gulf menhaden resources through SEDAR or a similar comprehensive process with a benchmark stock assessment conducted every five years:

This is completed every three years through SEDAR and GDAR. Currently undergoing an update assessment with terminal year 2023. As the recent SEDAR documents and processes (SEDAR 31, SEDAR 63) attest, each stock assessment effort for Gulf Menhaden is comprehensive, transparent, and consistent in organization and deliverables. All aspects of the stock SEDAR stock assessment (the data, the model, and the reference points for the determination of stock and fishery status) are peer reviewed and those reviews are publicly available.

- Establish standardized ageing programs in the region for Gulf menhaden by 2015.

Ageing of fishery-independent samples continues to occur but the effort is limited. There continues to be extensive efforts, managed by the GSMFC and NOAA, to perform sampling and make age determinations from the commercial fishery. The menhaden port sampling program, in tandem with the deck logs (CDFRs), represent one of the longest continuous commercial sampling efforts in the Gulf of Mexico and one of the longest in the United States. The sampling program has been evaluated recently to determine whether the program adequately characterizes the size and age structure of the catch – necessary because of the significant changes in the spatial extent and magnitude of the fisheries in the last three decades. This was done through a simulation study to evaluate current menhaden fishery sampling targets and to examine the relative performance of a suite of alternative targets. The results indicate that the current sample protocol is adequate and that reducing the number of fish that is sampled per trip from the current target of 10 to as few as four would have a minimal effect on estimates of mean size and proportions at age in the catch. Similarly, increasing the number of sampled trips will not greatly improve the characterization of catch size or age composition.

> *Nesslage, G. M., Leaf, R. T., Wilberg, M. J., Mroch III, R. M., & Schueller, A. M. (2020). A Simulation-Based Evaluation of Commercial Port Sampling Programs for the Gulf and Atlantic*

Menhaden Fisheries. North American Journal of Fisheries Management, 40(4), 995-1006.

9.3.1.2 Population Dynamics Objectives

- Within two years of the completion of each assessment, evaluate potential for additional research or monitoring programs to help measure stock and recruitment variation, based on the analyses conducted and recommendations of the most recent benchmark stock assessment.

A critical need, that continues to be assessed is the changes to sampling design in the states that contribute data to the assessment (i.e. Louisiana, Mississippi, and Alabama). Long-term independent monitoring continues with additional sampling protocols being implemented including expanding gillnet sampling in Louisiana since the BP disaster along with new or adjusted sampling sites contributing to the adult index. Using statistical evaluation, seine sampling stations used for the juvenile index have also been adjusted as habitats have changed. For example, at some sampling stations, land loss due to subsidence, storms or anthropogenic activities, has forced the station locations to move inland (e.g., shoreline seines, gill nets). In October of 2010, new fixed stations were added for each gear. In addition, increases in funding for fishery-independent monitoring has resulted in increased sampling effort spatially and temporally for seines in Mississippi and Louisiana contributing to the recruitment index. Details are available in the assessment documents for Gulf Menhaden.

- Select key predatory finfish species, then process and identify their stomach contents to species (across several life history stages) for two years across five Gulf states using standardized protocols.

Recent work to understand the trophic connectivity of Gulf Menhaden to finfish of management and conservation interest. Recent work has highlighted, though the investigation in the literature and through modeling, the identification of the 'key predatory finfish species' of Gulf Menhaden. The two papers below investigated, through meta-analysis of published and unpublished diet data the connectivity of predators to various prey taxa in the Gulf of Mexico. Both papers showed a lack of specificity to menhaden as critical prey for the predators examined. There is high trophic connectivity between fishes in the northern Gulf of Mexico and all measures used to understand trophic dynamics in the region indicated that the prey field was exceptionally diverse.

Leaf, R. T., & M. C. Oshima. (2019). Construction and evaluation of a robust trophic network model for the northern Gulf of Mexico ecosystem. Ecological Informatics, 50, 13-23.

Oshima, M. C., & R. T. Leaf. (2018). Understanding the structure and resilience of trophic dynamics in the northern Gulf of Mexico using network analysis. Bulletin of Marine Science, 94(1), 21-46.

- On annual and standardized bases, collect and process sub-samples of Gulf menhaden from state fishery-independent surveys, focusing on size and age composition, maturity schedules, and genetic component of the samples.

Ageing of some fishery-independent samples has occurred. However, this is an area (the evaluation of *biostatistical characteristics of the fishery-independent data) that has just begun. The evaluation of maturity schedules however has been extensive – though this is not updated annually. Work by Brown-Peterson et al. (2017) indicated that males and females reach 50% maturity at 140.8 mm and 137.2 mm fork length, respectively and recruit into the commercial fishery at this size. Analysis of fishery-dependent data from 1964 - 2014 indicated that somatic condition was lower during the late 1980s and late 2000s and that reproductively active fish from 2014 were significantly larger and had greater gonadosomatic index values than those from 1964 - 1970. Histological analysis performed on fish from 2014 through 2016 revealed spawning-capable and actively spawning fish of both sexes from early October through mid-March. Females have indeterminate fecundity, are batch spawners, and spawn every 2.1 – 4.3 days, although oocyte recruitment shows some characteristics of determinate fecundity. Mean relative batch fecundity was 107.8 eggs/g ovary-free body weight (standard error 17.1). Estimates from age-structured assessment models based on updated fecundity and maturity measures resulted in a 100–1000× greater production of eggs than previous estimates.*

The TPWD explored the genetic variability and population structure of Gulf Menhaden compared with Yellowfin and Finescale Menhaden by Anderson and Torres (2016). Results found Gulf Menhaden conformed to the expectation of genetic homogeneity over the range of the species along the Northern Gulf of Mexico (Florida to Texas) and suggested that all samples collected from Florida to Texas resided in a single genetic cluster. This was in contrast to Yellowfin Menhaden which showed significant genetic divergence among localized populations in Florida waters east of Apalachicola and suggested two genetic clusters for that species. Evidence of Finescale Menhaden was only found from the Laguna Madre area. Analysis also found genetic evidence of only Gulf Menhaden within the present-day Gulf fishing grounds roughly from Sabine Lake, TX to Moss Point, MS.

> *Brown-Peterson, N. J., Leaf, R. T., Schueller, A. M., & Andres, M. J. (2017). Reproductive dynamics of Gulf menhaden (Brevoortia patronus) in the northern Gulf of Mexico: effects on stock assessments. Fishery Bulletin, 115(3), 284.*
>
> *Anderson, J. D. and Torres A.D. (2016). Genetic Variability and Population Structure of Gulf Menhaden Compared with Yellowfin Menhaden Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 8:425–435*

- Sample seasonally using a Gulf-wide standardized gear for pelagic baitfish species in estuarine habitats to quantify abundance and importance of menhaden as a prey item in relation to co-occurring prey species; develop a time series of indices of abundance.

The fishery-independent sampling of Gulf Menhaden in the northern Gulf of Mexico is extensive. Although no standardized approaches for sampling the stock have been implemented among the states, the sampling has been statistically standardized (see the Gulf Menhaden stock assessment for an analysis of sensitivity that includes the use of hierarchical models to combine Alabama's and Mississippi's fishery-independent sampling). The assessment team continues to explore the inclusion of data for the assessment (either in the base model or in sensitivity). The time series of relative abundance of Gulf Menhaden is currently best represented by the Louisiana gillnets and seine sampling from Louisiana, Mississippi, and Alabama. Other methodologies have been explored and are highlighted below.

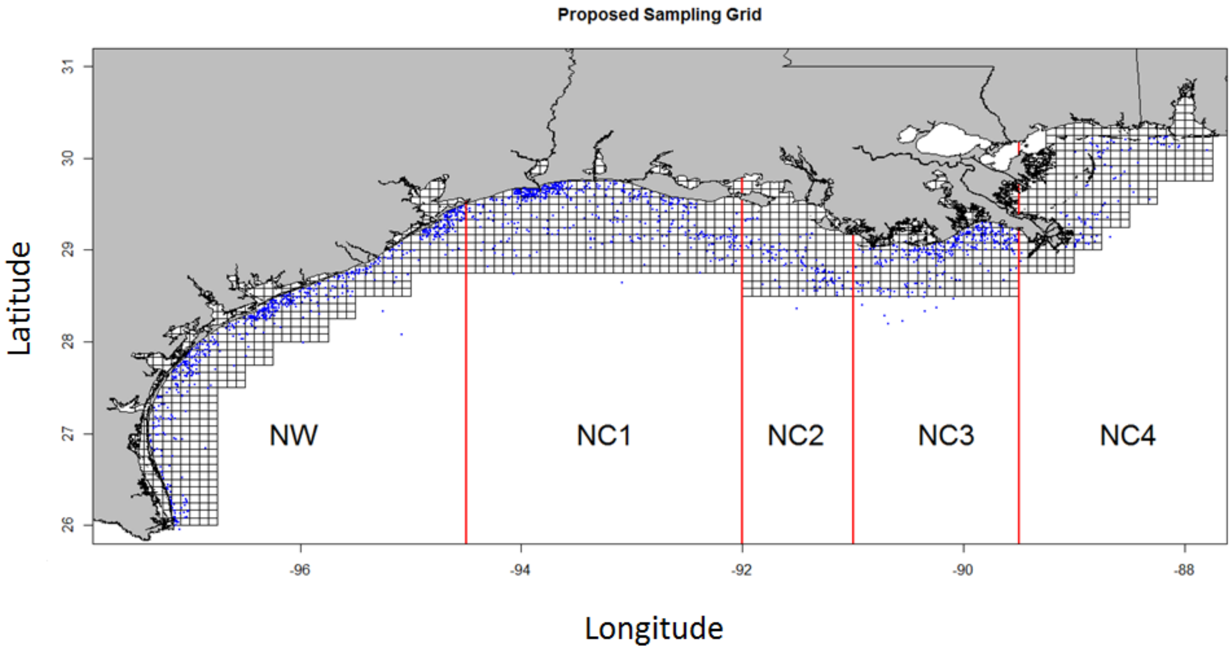
Push Net Survey - Alabama explored a dedicated pelagic baitfish survey from 2017-2019 in coastal rivers. The gear was a surface trawl that was pushed from poles extended beyond the bow of the vessel after sunset. Preliminary work demonstrated a diel shift for menhaden to surface waters at dusk and throughout the night. The intent was to develop a recruitment index and compare catch rates and indices between the seine and dedicated pushed surface trawl. Juvenile Gulf Menhaden demonstrated an affinity for freshwater and transitioned to higher salinity water with growth. Gulf Menhaden was the dominate species in the catch indicating this is a good juvenile species-specific survey design. Larger menhaden and mullet species could be observed at the water's surface outswimming the gear being pushed at 2.5 knots speed through the water. Catch per unit effort was similar between the seine and surface trawl, but variance was three time as great for the seine. No significant difference was detected in the index of abundance. A caveat of fishing the coastal rivers was elucidated in 2019 during a wet spring. Prolonged rains eliminated the catch in the rivers and at seine sites as juveniles did not need to enter the estuary far to encounter freshwater. The vessel and gear did not perform well in the open waters of Mobile Bay.

Electrofishing Survey - Louisiana utilizes a number of standardized fishery-independent surveys to measure relative abundance and size compositions of estuarine finfish. The seine survey is the primary gear used to sample estuarine finfish along marsh edges. The effectiveness of standardized seine sampling in producing unbiased estimates of relative abundance of certain species has been brought into question due to a combination of factors such as low or highly variable catch rates, accelerated marsh erosion rates that cause sampling inefficiencies, as well as seasonal fluctuations in water levels which also cause sampling inefficiencies.

From 2016 - 2023, LDWF began a comprehensive monthly sampling survey of Saltmarsh Topminnow (Fundulus jenkinsi), Bayou Killifish (F. pulvereus), and Diamond Killifish (F. xenicus) populations in the Barataria Bay estuary utilizing standardized quantitative electrofishing at established seine stations where each species has been observed in past samples. Standard seine samples were also collected at each station monthly allowing side-by-side comparisons of the catch rates and variability in catches across these stations. When compared to the seine catch rates, the electrofishing samples had substantial increases in catch rates for all LDWF assessment species, with the exception of Black Drum and Gulf Menhaden which was hoped could contribute to the recruitment and juvenile indices in the assessment.

Aerial Survey - The MAC, industry, and state agencies made efforts to expand sampling to describe the distribution and relative abundance of the stock outside the coastal zone fishing grounds with a proposal to perform aerial surveys of Gulf Menhaden schools, intending to fund the proposal with the NSF GOALI program. Though the proposal was not submitted, the group performed significant work to understand how such a survey could succeed. It was a fruitful effort to engage with stakeholders, and the group still hopes that a survey can succeed in the future with a grant proposal.

The proposed work involved understanding the relationship between school size and biomass by working collaboratively with the industry to monitor catches from schools for which surface area estimates were determined. Digital images were to be analyzed with specialized photogrammetric software (Adobe Photoshop CS6 Extended), with school biomass expected to vary with total surface area (m²) and shape characteristics. Geographic and temporal characteristics, such as distance to shore, depth, time of day, and days since Sunday, would also be predictor variables. Given a photo or *series of photos of a menhaden school, an unbiased estimate of surface area could be determined using the camera height and plane angle parameters, with the mean biomass estimate derived using regression estimates along with metadata and school shape. To determine the sampled area of each transect, the total area covered would be calculated by summing the interpretable areas of individual photographs taken at a 2,500 feet elevation with a 28 mm lens, adjusting for altitude and vertical deviation. For each geographic strata identified in the stratified random sampling design (NW, NC1, NC2, NC3, and NE), the mean biomass (lb)/area (m²) and variance would be calculated. Sub-stratum estimates would then be combined for a gulf-wide abundance estimate. The large amount of data collected, including digital photo data and metadata, would be organized, managed, and disseminated through a comprehensive data management, storage, and distribution plan to facilitate the sharing of raw and processed data products.*



Proposed strata for aerial sampling from Texas to the Alabama/Florida boundary line.

However, the MAC and industry determined that the logistics of flying transects so far offshore was unreasonable considering the limitations of the small spotter planes and the liability associated with offshore flights. In addition, the ability of the spotter pilots to confidently identify menhaden from other schooling fish was questioned and the lack of water clarity further complicated the use of standard photography or LIDAR type equipment. Preliminary work on the Atlantic coast drove some of the desire to apply the technology and sampling methods to the Gulf but it was quickly realized that other methods would need to be designed.

9.3.1.3 Environment Objectives

- Compare analysis of habitat changes (e.g., marsh loss and freshwater diversions) to indices of abundance of juvenile and adult Gulf menhaden to determine net effects.

Efforts to understand environmental impacts on the stock has been conducted historically. Similarly, the *impacts of Mississippi River discharge are included as part of the sensitivities in previous assessments. "Guillory et al. (1983) noted that relatively 'cold, dry' winters were associated with good recruitment, whereas 'warm, wet' winters were associated with poor recruitment." Page 3-10 Gulf Menhaden FMP (2015).*

Recent additional work to explore the impacts of increased freshwater changes include work to understand inter-annual oil dynamics and inter-annual changes in growth of age-1 y and age-2 y fish. Similarly, the interannual changes in fatty acid composition of Gulf Menhaden, and its environmental determinants, have been described. Leaf (2017) evaluated patterns in oil yield to a suite of seasonal environmental data series including: the magnitude of spring Mississippi River discharge, spring wind vectors, and the preceding winter El Nino conditions. Two uncorrelated ($r = 0.06$, $p = 0.81$) population-level predictor variables were identified that have explanatory power to describe temporal patterns in oil content ($L\ kg^{-1}$); a weight-at-length power function parameter (a) and the von Bertalanffy asymptotic fork length (L_∞, mm FL): $L\ kg^{-1} = -0.158 - 0.026 * a - 0.00163 * L_\infty$ ($p < 0.05$, $R^2 = 0.42$). Analysis of the impacts of environmental variables on the oil content of Gulf Menhaden was evaluated and indicated that contrasts spring Mississippi River discharge and the preceding winter (December–February) El Nino Southern Oscillation index resulted in significant impacts. Midway et al. (2020) evaluated the growth dynamics of $n = 299{,}185$ Gulf Menhaden samples collected across the Gulf of Mexico from 1977 to 2016. Using hierarchical models of age-1 growth and age-2 growth they found that wind V (negative effect) and Atlantic Multidecadal Oscillation (AMO) (positive effect) influenced age-1 Gulf Menhaden growth and AMO was the only significant predictor (weak negative effect) of age-2 Gulf Menhaden growth. Leaf et al. (2018) investigated the temporal dynamics of both fatty acid and oil content of Gulf Menhaden. They found that pronounced temporal (January to October) variation in mean oil content and the existence of significant differences ($p < 0.001$) in the composition of fatty acids of muscle tissue collected in different months. Mean eicosatetraenoic acid (EPA), docosahexaenoic acid (DHA), and long chain polyunsaturated fatty acid (LC-PUFA) levels exhibited significant seasonal differences ($p < 0.05$), and in the case of DHA and LC-PUFA, both exhibited mean tissue-specific differences ($p < 0.05$).

Midway, S. R., Schueller, A. M., Leaf, R. T., Nesslage, G. M., & Mroch III, R. M. (2020). Macroscale drivers of Atlantic and Gulf Menhaden growth. Fisheries Oceanography, 29(3), 252-264.

Leaf, R. T., Trushenski, J., Brown-Peterson, N. J., & Andres, M. J. (2018). Temporal dynamics of lipid and fatty acid characteristics of Gulf Menhaden, Brevoortia patronus, in the northern Gulf of Mexico. Regional Studies in Marine Science, 24, 1-9.

Leaf, R. T. (2017). Environmental determinants of Gulf menhaden (Brevoortia patronus) oil content in the northern Gulf of Mexico. Ecological Indicators, 82, 551-557.

9.4 Management Measures and Considerations to Attain Management Goals

The following is a discussion of relevant issues related to the effective management of menhaden through the setting of goals and objectives. The process begins with consideration of those items of careful reflection that have a direct bearing on Gulf menhaden. Items to consider were compiled from outputs and data gaps identified through the assessment process, comments from resource managers, and public comment. Next, based upon considered items, recommendations are proposed actions to bring about resolution of those items. The final steps are the setting of goals and objectives. Goals are the ambitious end to which objectives are directed, and objectives are the measurable action(s) to which effort/resources are directed. The final goals and objectives in no way restrict any agency from addressing any of the considerations or recommendations.

9.4.1 Management

9.4.1.1 Stock Status

Limit reference points (limits) are the basis for determining stock status, i.e., whether overfishing is occurring or a stock is overfished. When the fishing mortality rate (*F*) exceeds the fishing mortality limit (F_{limit}), then overfishing is occurring; the rate of removal of fish by the fishery exceeds the ability of the stock to replenish itself. When the reproductive output measured as spawning stock biomass (*SSB*) or population fecundity (*FEC*) falls below the spawning stock biomass (SSB_{limit}), then the stock is overfished, meaning there is insufficient mature female biomass (*SSB*) or egg production (population fecundity, or *FEC*) to replenish the stock.

The Magnuson-Stevens Fishery Conservation and Management Act of 2007 states that management measures define an overfished condition and a target level for the stock. The biomass limit for an overfished menhaden stock was previously proposed as $0.5*SSB_{MSY}$ (Vaughan et al. 2007). The suggested target for spawning biomass, or population fecundity (*FEC*), should be near B_{MSY} (or its proxy). The target level chosen for fishing mortality is less clear, other than the stipulation that F_{target} be sufficiently below the F_{limit}.

9.4.1.2 Reference Points and Control Measures for Management

Reference points are typically defined only for fishery removals that allow for 'natural' removals through a separate mortality term. The natural mortality term (*M*) is often constant, but is sometimes allowed to vary with age and time when data are sufficient. Reference points based on *MSY* treat this natural mortality term as 'lost yield' in that fishing mortality is typically increased in populations with a high *M* and decreased in population with a low *M*. The difficulty with this approach is that it does not consider the value of natural mortality to the ecosystem in the form of prey biomass for other stocks (e.g., large predators). Awareness of the issue of accounting for the role of Gulf menhaden as a prey resource has increased in recent years due in part to changes in the status of Atlantic menhaden (ASMFC 2010) and a general increase in both public and regulatory awareness of the importance of ecosystem issues. During the completion of SEDAR32A, there was considerable discussion relative to these factors of ecosystem value (SEDAR 2013). In addition, those factors were also discussed for defining potential fishery reference points. However, it was concluded that the data were simply insufficient for inclusion in the current benchmark assessment.

In SEDAR32A, the BAM model did not produce a reliable estimate of maximum sustainable yield, MSY was infinite (SEDAR 2013). Given the constraints of the assessment results, levels of effort in reference to the MSY proxy (fecundity (SSB)) were selected as reference points by the MAC and approved by the GSMFC. Estimates of biomass associated with a reference target ($F_{35\%}$) and limit ($F_{30\%}$) levels were calculated at $F_{35\%}$, (663,583 mt) and $F_{30\%}$ (680,765 mt). These harvest levels will serve as accountability measures to ensure the fishery remains viable. Based on the reference points approved by the GSMFC, the Gulf menhaden stock is neither overfished nor is overfishing occurring.

If two consecutive fishing years produce harvests exceeding the target $F_{35\%}$, a stock assessment update will be requested. If harvest surpasses the limit $F_{30\%}$ in a single year, a stock assessment update will be requested.

A phase plot for fishing years 1977 to 2011 the base run of the Gulf menhaden assessment with fishing mortality benchmarks of $F_{30\%}$ and $F_{35\%}$ was generated (Figure 9.1). The plot includes the associated spawning stock biomass (fecundity) benchmarks of $SSB_{30\%limit}$ and $SSB_{35\%target}$.

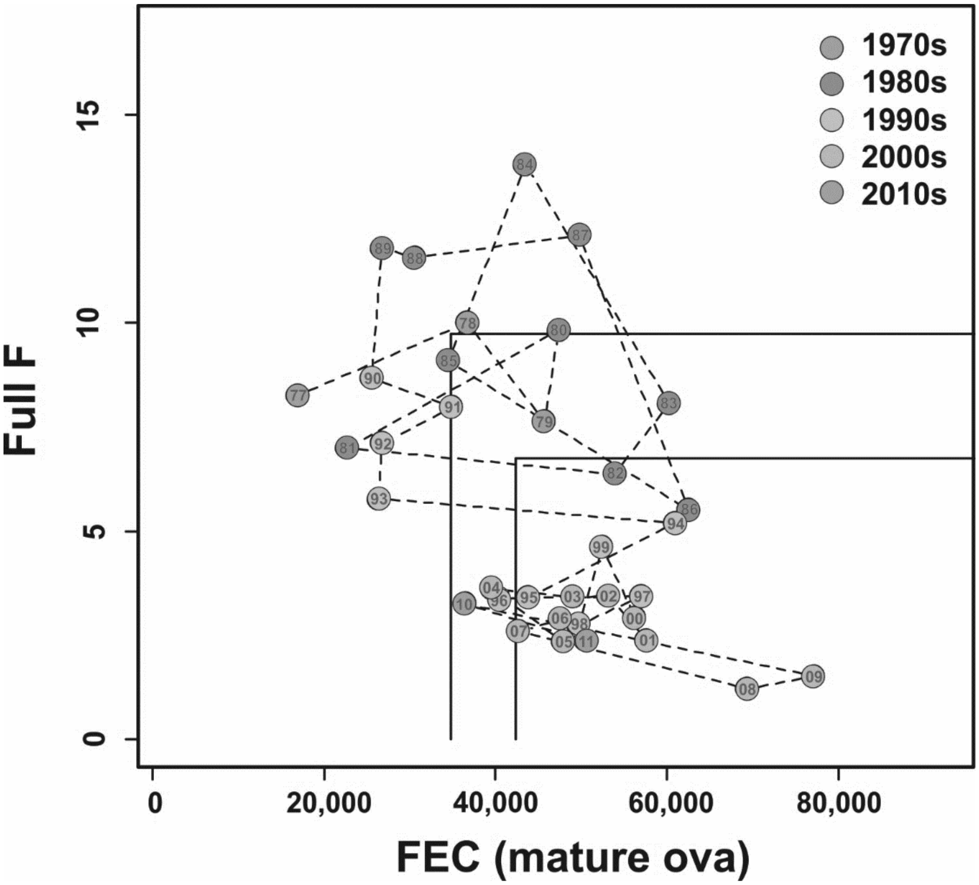


Figure 9.1 Phase plot for fishing years 1977 to 2011 from the base run of the Gulf menhaden assessment with fishing mortality benchmarks of $F_{30\%}$ and $F_{35\%}$ and with the associated spawning stock biomass (fecundity in billions of eggs) benchmarks of $SSB_{30\%}$ and $SSB_{35\%}$ (SEDAR 2013).

Considerations

- In the SEDAR32A benchmark assessment of Gulf menhaden (SEDAR 2013), the primary model did not successfully find a stock-recruitment relationship and could not produce reliable estimates of *MSY* and F_{MSY}. Under these circumstances, proxy values for *MSY* are typically based on yield-per-recruit calculations and used to estimate reference points for harvest targets and limits in fisheries such as *F* as some percent SPR. Because Gulf menhaden spawn offshore during winter prior to the start of the fishing season, almost all fish reach maturity and spawn before being targeted by the fishery. Subsequently, a large proportion of age-1 individuals survive to become age-2s and are therefore able to spawn before being harvested by the fishery. If this selectivity in the fishery continues, F_{MSY} would be expected to continue as infinite.

- A number of alternative management reference points were offered in SEDAR32A, and the assessment panel agreed to make a general statement that given commonly applied benchmarks in the region, the Gulf menhaden stock is likely not undergoing overfishing and is likely not overfished (SEDAR 2013).

- Considerable discussion occurred before and after the completion of the SEDAR32A benchmark assessment for Gulf menhaden regarding the alternative reference points for management (SEDAR 2013). The most critical concern of managers was that there was too much uncertainty regarding estimates of biomass for Gulf menhaden. The bio-statistical data from the commercial reduction fishery does not include many younger or older fish. Therefore, the only appropriate action that could be taken by the state agencies would be to manage for effort or harvest levels.

Recommendations

1. The states agencies should adopt Gulf-wide management reference points for the Gulf menhaden fishery of a target of 663,583 mt ($F_{35\%}$ fecundity *SSB*) and a limit of 680,765 mt ($F_{30\%}$ fecundity *SSB*).

2. A benchmark stock assessment should be conducted every five years in conjunction with an FMP revision.

3. If two consecutive years of fishing produce harvests exceeding the target $F_{35\%}$, a stock assessment update will be requested.

4. If harvest surpasses the limit $F_{30\%}$ in a single year, a stock assessment update will be requested.

5. Forecasts of year class strength utilizing the state agencies' fishery-independent data should be provided to the MAC prior to the fishing season to help track fluctuations in population abundance and year class strength.

In SEDAR 63 (SEDAR 2018) the assessment panel suggested some alternative reference points. For fishing mortality rate, the benchmark of F=M was suggested as a threshold, and for spawning stock biomass as measured in fecundity, the benchmark of SSB25% at F=0 was suggested as a threshold. Both of these benchmarks have been used in other fisheries. The fishing mortality rate benchmark represents *the fish that would normally die due to natural mortality and can be taken by fishing instead; while, the SSB metric represents 25% of the equilibrium fecundity when fishing is not occurring. The SSB-based metrics were not paired with the F-based metrics because the spread in the associated SSB metric was smaller than one standard deviation of the variability in the SSB time series. Based on these benchmarks, the stock status of the base run is not overfished and overfishing is not occurring. Moreover, most of the sensitivity runs and the MCB uncertainty analysis runs resulted in a current stock status of not overfished and overfishing not occurring.*

The SEDAR 63 efforts documents the extensive discussions surrounding the formulation of alternative reference points to those mentioned above (Section 8.2), including ecosystem-based fishery reference points –(ERP).

These efforts to 1. Formulate reference points and to 2. Discuss their appropriateness for the Gulf Menhaden fishery and stock motivated the hosting of a series of three stakeholder workshops. The final workshop took place in September of 2023. In the workshops, participants reviewed the Goals and Objectives identified by the participants in the previous two workshops and outlined the pros and cons of a number of reference point options including ecosystem-based ones. The participants included all the Gulf states' management agencies, NOAA Fisheries, and several non-governmental entities and tried to reach consensus on what reference point options were viable at this time (https://www.gsmfc.org/publications/GSMFC%20Number%20320.pdf).

To understand if managers have sufficient reference points (RP), the workshop concluded that:

- *We have RPs that we've spent time considering during the benchmark assessment (F and SSB RPs). We also have an index-based approach (related to the industry Harvest Control Rule - HCR) and ERPs derived from an ecosystem model that need further exploration and evaluation.*
- *Though the current RPs have not been tested nor run through simulations, they have been considered in previous assessments and workshops and vetted by CIE reviewers during SEDAR. To determine the appropriateness of a RP, it should be simulation tested using an HCR to see how it performs under a range of potential future conditions. Testing is required to ensure that what is believed to be an appropriate RP is not, in fact, catastrophic when applied in the real world.*

9.4.1.3 Measures to Support Management

A number of research needs which are listed in Section 10.0 were enumerated as a result of the SEDAR32A stock assessment (SEDAR 2013). Many of these items include data gaps which have been acknowledged in previous FMP revisions and continue to hinder the ability of the Gulf states to develop many the necessary data elements required in today's data-hungry assessment models. While the reduction fishery for Gulf menhaden enjoys comprehensive, detailed, and accurate fishery-dependent data streams, fishery-independent data collection for Gulf menhaden by the Gulf states has often suffered due to limited funds, resources, and personnel.

As mentioned above, and as has been documented in the recent SEDAR assessments (since SEDAR 27), a variety of data evaluation and statistical assessment have been performed on the monitoring efforts for Gulf Menhaden.

9.4.2 Population Dynamics

9.4.2.1 Fishery-Independent Monitoring

The NOAA Beaufort Lab has maintained a fishery-dependent sampling program for Gulf menhaden since 1964; it provides detailed information on daily vessel landings, nominal or observed fishing effort, and port samples (on a port/week basis) for size and age composition of the catch. These data are used to annually estimate the numbers-at-age of fish landed (the catch-at-age matrices); they form the foundation of the statistical catch-at-age model used to assess the status of the Gulf menhaden stock in the Gulf of Mexico (SEDAR 2013). The Gulf states have been monitoring juvenile to adult menhaden population in the estuarine to near shore waters for decades. With the exception of Louisiana, this information has been seldom used to predict year class strength or age composition due to the robust nature of the population. It is important that the states begin enhancing their programs by incorporating additional components such as ageing samples from the fishery-independent surveys in the estuarine and near shore waters for comparison to the offshore fishery-dependent samples to help predict production, regulate harvest, and direct management practices.

Fishery-independent monitoring, based on applied scientific and statistical protocols, provides an essential component for making science-based management decisions regarding Gulf menhaden in state waters. Fishery-independent monitoring is standardized and replicated over relevant spatial and temporal scales and therefore gives a better picture of the source population, unbiased by size-selective harvest. This typically includes sampling larvae, juveniles and/or adults to develop data to determine recruitment, growth and survival, natural mortality, and standing stock biomass.

Most fishery-independent monitoring programs involve various gears deployed in a random statistical design by scientists to collect larvae, juveniles, and adults. This information is used to develop abundance indices (state seine and gill net surveys) and ultimately involved in assessing the status of present and future stocks.

The comprehensive nature of the fishery-independent monitoring of Gulf Menhaden is well described in the assessment documents for the stock.

Additional data includes genetic information which may better define the management unit and the potential for multiple stocks or genetic populations.

Considerations

- The current benchmark stock assessment for Gulf menhaden (SEDAR32A) utilizes data from several fishery-independent monitoring programs conducted by the Gulf states (see Section 9.4.1.1). State seine surveys, as well as trawl surveys, are used to develop independent indices of juvenile abundance. State gill net surveys are used to develop independent indices of adult abundance.

- Not all the state monitoring programs provide length, weight, and age data associated with Gulf menhaden. Basic population characteristics are collected that could be useful in future assessments across the entire range of the population, not just where the fishery occurs.

- Validation of age composition from the fishery-independent sampling programs could address some of the data gaps identified in SEDAR32A.

- The existing Southeast Area Monitoring and Assessment Program (SEAMAP) surveys and gear are not designed to sample juvenile menhaden, thus a recruitment index from these data are unavailable. Sampling protocols should be developed to this end, with sampling efforts directed to coastal bays and river systems where juvenile menhaden spend up to their first year of life.

- The GSMFC's MAC has discussed and designed a fishery-independent surface-trawl survey for juvenile Gulf menhaden from Florida to Texas based on original survey work of Ahrenholz et al. (1989). However, funding for a pilot survey has been unavailable; nevertheless, extant juvenile surveys conducted by the Gulf States appear adequate for assessment purposes.

- Although there are inshore state surveys for juvenile Gulf menhaden, there is no analogous survey in the northern Gulf of Mexico proper that targets adults. In SEDAR32A, the lack of an index of adult abundance on the fishing grounds was identified as a major impediment for accurate assessment menhaden populations (SEDAR 2013). The extant fishery-independent sampling program in the northern Gulf of Mexico SEAMAP utilizes trawl gear which is inappropriate for menhaden.

- Species overlap of Gulf and yellowfin menhaden occurs east of the Mississippi River and Gulf and finescale menhaden overlap west of the Mississippi River. Separation of adult specimens can usually be determined in the field by characteristic and meristic differences. However, these differences are not as pronounced in sub-adults. Identification issues led to the exclusion of some data from the species' range extremes in the SEDAR32A data analysis (SEDAR 2013).

Recommendations

1. The Gulf states and NOAA Fisheries need to evaluate the available fishery-independent data and explore ways to combine the data from each state or develop state only indices in order to provide a coast-wide index which would benefit the stock assessment by providing information on trends in abundance over time.

2. The states should implement fishery-independent surveys that include capture of juvenile menhaden in a consistent manner in order to provide information to determine menhaden recruitment in the rivers and upper bays of the northern Gulf of Mexico and provide an index of juvenile abundance for future stock assessments.

3. The states should generate updated estimates of fecundity, maturity schedules, and sex ratios, preferably from both fishery-dependent and fishery-independent samples.

4. The states should implement additional independent sampling of offshore pelagic stocks that include menhaden; gear should be designed to provide data on adult indices beyond the nearshore waters and to provide information on other pelagic ecosystem components.

5. The states should consider re-establishing a Gulf menhaden tag/recovery study. Many more tools exist today to simplify tag/recapture of fishes, and an updated tag/recapture study would allow for a contemporary estimate of natural mortality.

6. The states should design and implement studies including genetic identification (mtDNA fingerprinting) for all menhaden species in independent samples to ensure positive identification of young specimens, improve estimates of juvenile abundance for the species, monitor potential range expansions, and determine of extent of hybridization in the three menhaden species, especially in the sympatric zones to the east and west.

9.4.2.2 Fishery-Dependent Monitoring

Fishery-dependent monitoring involves collecting and analyzing landings data and is intended to sample both the resource and the fishery. Typically, fishery-dependent sampling generates larger sample sizes than fishery-independent monitoring at lower cost. Landings data are often used by fisheries managers to monitor population changes by analyzing trends in catch and effort and are critical in evaluating management practices. Monitoring data can include size-at-age and biomass of landings, the number of fishermen, amount of observed fishing effort, fishing locations, and other parameters that represent actual fisheries activities.

Long-term, fishery-dependent monitoring provides an essential component in making science-based management decisions, and analyses and results are critical elements in all adaptive management strategies. Fishery-dependent monitoring reports generally have a longer and more consistent history than fishery-independent data sets; however, there are some considerations when utilizing this type of data. Deficiencies in reporting requirements, regulatory changes, and enforcement may affect the utility of commercial landings.

The primary purpose of fishery-dependent monitoring is to gather data on catch and effort, size-at-age, and various somatic growth parameters. These data are critical for accurate stock assessments. The NOAA Beaufort Laboratory, in cooperation with the menhaden reduction industry, monitors landings of Gulf menhaden. Clerical staff at the menhaden factories supply landings data to the Beaufort Lab on a daily or weekly basis – timely intervals unavailable in most fishery monitoring systems. Several Gulf states also collect similar catch data from the menhaden fishery via trip ticket programs.

Crews of menhaden vessels also complete daily logbooks, or CDFRs, enumerating each purse-seine set with data on estimated catch, fishing time and location, and several weather variables. CDFR data sets are maintained at the Beaufort Lab and vessel compliance has been nearly 100%. CDFRs are a rich source of spatial and temporal information for the Gulf menhaden fishery.

Considerations

- Port sampling efforts for Gulf menhaden have an unfortunate history of tenuous funding.

Annual funding for this activity often requires “eleventh-hour” decisions by federal, state, and/or Commission managers to ensure continued data collection.

- NOAA Fisheries has other data priorities that do not necessarily include Gulf menhaden. There has always been a struggle to continue federal support for the data collection program when the fishery is prosecuted primarily in state waters.

- NOAA Fisheries, the Gulf states, and the industry all collect or report landings. The individual state data programs are not reviewed with the NMFS data programs regularly to evaluate effectiveness and duplication of effort.

- The current unit of nominal fishing effort used in the Gulf menhaden fishery is the vessel-ton-week (VTW). The NOAA Beaufort Lab has evaluated other units of nominal fishing effort, such as number of trips, number of days with at least one set, and number of sets, but found the vessel-ton-week to be a satisfactory unit of nominal fishing effort, given existing data. Evaluation of other potential measures of fishing effort should continue.

- There are inherent biases using observed effort data derived from purse-seine fisheries that rely on spotter planes to locate concentrations of fish schools.

Recommendations

1. NOAA Fisheries should continue to support their Menhaden Program and personnel at their NOAA Beaufort Lab; NOAA Fisheries should also maintain sufficient funding for Gulf menhaden port sampling programs and maintenance of long-term Gulf menhaden data sets.

2. NOAA Fisheries should continue to re-evaluate use of CDFRs as an alternate measure of nominal fishing effort for the Gulf menhaden fishery.

3. NOAA Fisheries and the Gulf states could review their individual efforts to determine if they are adequately obtaining the necessary information for management decisions. If they are determined to be insufficient, appropriate changes to laws, regulations, and policies could be sought.

4. The NMFS should evaluate the feasibility of using spotter plane logs to estimate spatial and temporal changes in abundance of Gulf menhaden.

9.4.2.3 Predator/Prey Relations

Most inferences concerning feeding behavior of Gulf menhaden are based on studies of Atlantic menhaden. One key research need is information on Gulf menhaden food habits, which would improve this facet of specificity in ecosystem models. This includes direct analysis of diet, as well as examinations of feeding behavior, in response to key prey items. Direct diet enumeration is difficult due to the planktonic nature of the prey, but biochemical techniques such as analysis of stable isotope ratios (Litvin and Weinstein 2004, Rooker et al. 2006) and fatty acid profiles (Rooker et al. 1998), provide valuable tools for diet analysis of filter feeders. These techniques can also be used to examine the role of Gulf menhaden as a prey item for higher trophic level piscivores (see Section 3.2.7), which will allow for a more precise inclusion of menhaden in food web models of the Gulf of Mexico.

Population dynamics objectives need to quantify menhaden role in the ecosystem by determining their abundance in the environment and stomach contents of predators relative to other pelagic species that serve as the forage base in the food web.

Considerations

- An emphasis on quantifying the trophic role of menhaden in the Gulf of Mexico is an important step in the shift towards ecosystem-based management.

Recommendations

1. Establish methods to determine the trophic role of Gulf menhaden in the Gulf of Mexico.

Recent modeling work in the region to understand the 1.) connectivity of Gulf Menhaden to predators and 2.) the impacts of removal and ecosystem changes have been made. The following work has been instrumental in discussions by the MAC and assessment group in understanding ecosystem impacts of the fishery:

> *Berenshtein, I, S. R. Sagarese, M. V. Lauretta, A. M. Schueller, & D. D. Chagaris. (2023). "Identifying trade-offs and reference points in support of ecosystem approaches to managing Gulf of Mexico menhaden." Frontiers in Marine Science 9: 935324.*
>
> *Sagarese, S. R., Nuttall, M. A., Geers, T. M., Lauretta, M. V., Walter III, J. F., & Serafy, J. E. (2016). Quantifying the trophic importance of Gulf menhaden within the northern Gulf of Mexico ecosystem. Marine and Coastal Fisheries, 8(1), 23-45.*
>
> *Robinson, K. L., Ruzicka, J. J., Hernandez, F. J., Graham, W. M., Decker, M. B., Brodeur, R. D., & Sutor, M. (2015). Evaluating energy flows through jellyfish and gulf menhaden (Brevoortia patronus) and the effects of fishing on the northern Gulf of Mexico ecosystem. ICES Journal of Marine Science, 72(8), 2301-2312.*
>
> *Robinson, K. L., Ruzicka, J. J., Gili, J. M., Hernandez, F. J., Decker, M. B., & Graham, W. M. (2014). Role of large coastal jellyfish and forage fish as energy transfer pathways in the northern Gulf of Mexico.*

All the previous work listed culminated into a series of stakeholder workshops from 2019-2023 where ecosystem-based reference points were evaluated and discussed by industry, stakeholders, and state resource managers. While the models are not actionable at this time, consideration was given and recommendations for needed data were provided back to the ecosystem modelers to make the information more applicable to the Gulf Menhaden stock. The group identified inconsistencies in the model including; several of the predator/prey groups were not always representative of the northcentral Gulf of Mexico, inclusion of prey from the west Florida shelf were not B. patronus, and *spatial overlaps of predators and prey was assumed which were not accurate. For example, grouper and snook occurring in the shallow waters of the northern Gulf are not common as they are along the west Florida shelf. Prey switching by predators needs further exploration and inclusion into models given the strong evidence that the prey field in the northern Gulf of Mexico is very diverse.*

9.4.3 Environment

9.4.3.1 Habitat Monitoring

Because menhaden are short-lived and occupy a low trophic level in the food web, their abundance and the subsequent fishery are highly sensitive to habitat changes. Both short-term and long-term changes can drastically affect populations. Habitat alterations over the life of the fishery have probably had an overall negative impact; however, they have not been quantified. Habitat losses have resulted from both natural and man-induced forces; however, alterations by humans have posed the greatest threat to the menhaden industry. Hurricanes, erosion, sea level rises, subsidence, and accretion are natural sources of wetland loss. Some human activities have accelerated or exacerbated the effects of some of these factors as described in Section 4.7.

Considerations

- Since menhaden are estuarine-dependent during their early life stages, states could increase efforts to identify critical habitats and monitor potentially negative changes.
- The effects that environmental factors have on catchability of different fishery-independent and fishery-dependent gears may inform the model concerning changes in catchability over time.
- The GSMFC's TCC Habitat Subcommittee has been made inactive due to budgetary issues related to the dissolution of the joint relationship with the Gulf of Mexico Fisheries Management Council. The Subcommittee traditionally reviewed and provided monitoring of habitat-related projects and reported to the Commission on issues of concern within the region.

Recommendations

1. The Gulf states need to explore environmental factors that play a crucial role in Gulf menhaden recruitment dynamics and catchability (both fishery-dependent and fishery-independent).
2. Reassess the status of the GSMFC's Habitat Subcommittee and prioritize funding to support its activation for issues related to habitat and habitat loss in the Gulf of Mexico.

9.4.3.2 Sustaining and Protecting Freshwater Sources

The importance of freshwater to Gulf menhaden recruitment, growth, and survival is well-known (see Section 4.7.3.1). Growing reliance on freshwater diversion projects to control flooding, create reservoirs, enhance coastal development opportunities, and ensure drinking and irrigation water supplies threaten the ecological stability of estuarine systems that depend upon short-term and long-term variations in river stages and flow rates. This is especially problematic for managers in estuaries that receive fresh water from a single drainage basin.

Typically, short-term changes in river stages, volumes, and flow rates are part of the ecology of coastal estuaries, and estuarine organisms can cope or even thrive under the changing conditions. However, when freshwater input is disrupted for prolonged periods, serious adverse impacts to estuarine ecology may result.

Water control projects that disrupt the flow of fresh water for prolonged periods may result in serious adverse impacts to juvenile Gulf menhaden ecology. Some major freshwater control projects are underway in the Gulf states, and others are planned (see Section 4.7.3.1.3). For example, Alabama, Florida, and Georgia are currently involved in negotiations and litigation over activities which affect the amount of fresh water reaching Apalachicola Bay from the Apalachicola, Choctawhatchee, and Flint rivers. Interstate agreements which affect water usage in large river drainage basins should consider the positive and adverse effects of water use practices on estuarine ecology.

Management Considerations

- Properly planned and implemented freshwater control projects may have long-term positive ecological and economic impacts. In many instances, fisheries resource managers have little influence on the processes that shape coastal development, but it remains important that fisheries resource issues are included in regional and local comprehensive planning.

- Water management for alternative objectives can be contrary to biological management objectives in estuarine systems.

- Freshwater diversion may biologically change both the area from which water is diverted and the area receiving diverted fresh water. Production of some species (e.g., oysters) may be enhanced at the expense of other species (e.g., shrimp). Thus, biological, social and economic value disputes are possible, while the cumulative environmental impacts and benefits are difficult to determine.

- Depending on the freshwater source and the drainage basin, diversion projects may decrease water quality and increase sedimentation in an area which may enhance some species at the expense of others (e.g., oysters).

- Diversion projects and reservoirs can impact the nature of high flow events and result in declines in important nutrient and sediment loads critical for habitat maintenance and primary production.

Management Recommendations

1. Resource managers should review and evaluate all available information relating to

freshwater control projects, habitat restoration, water use policies and practices during the planning process. Such review includes an assessment of the biological, hydrological, ecological, geomorphological, social, and economic impacts that are likely to result from a project or practice in order to provide accurate projections of a project's impacts on estuarine resources. The project design, objectives and implementation should include collaborative efforts to involve all stakeholders who, through their actions, could directly or indirectly impact Gulf menhaden resources in the estuarine and marine environment.

The Louisiana Coastal Protection and Restoration Authority (CPRA) has created a Coastal Master Plan for the state of Louisiana and provides extensive input for the modeling and science involved in any diversion or coastal restoration project.

Louisiana Coastal Master Plan
https://coastal.la.gov/our-plan/2023-coastal-master-plan/2023-plan-appendices/

Habitat Suitability Modeling for Juvenile Menhaden
https://coastal.la.gov/wp-content/uploads/2023/08/C10_2023HSIModel_Feb2023_v3.pdf

Habitat Suitability Modeling for Adult Menhaden
https://coastal.la.gov/wp-content/uploads/2023/08/C10_2023HSIModel_Feb2023_v3.pdf

9.4.3.3 Water Quality

Pollution represents a serious threat to estuarine communities at the local level, but the cumulative impacts of all types of pollution threaten estuarine species on a regional level (Section 4.7.3.2). Pollutants include a wide variety of substances that are introduced into the environment, including solid wastes, nutrients, chemicals (petrochemicals), toxic substances (pesticides, herbicides), and other harmful and deleterious substances. Pollutants degrade water quality and habitat, and expose estuarine populations to serious threats. Pollutants and contaminants can stress and ultimately kill estuarine-dependent organisms directly or in combination with other factors, impair reproduction, and adversely affect survival of all life stages. In some instances, pollutants may act indirectly to degrade the environment; for example eutrophication, reduced water quality, food web disruption, altered species diversity, and increased occurrence of HABs. The discharge of nutrients by river systems, such as the Mississippi River, has produced the largest, most persistent zone of hypoxia in the U.S. (Section 4.7.7.1). The direct effect of this area on menhaden populations is unknown, but it may concentrate schools of Gulf menhaden closer to shore as they avoid areas of low DO.

Management Considerations

- Since hypoxic conditions generally occur in the bottom-half of the water column, surface-dwelling menhaden may be less affected than demersal finfish and invertebrates.

- Increased nutrient discharge may provide increased forage for menhaden initially in the form of small phytoplankton and increased zooplankton.

Management Recommendations

1. The Gulf states water quality agencies should encourage improved multi-jurisdictional coordination to identify, permit, and monitor pollution and river nutrient loads including those sources contributing to the persistence and expansion of the ‘dead zone’.

2. Resource managers must continue to work toward a more comprehensive approach to managing estuaries amidst a growing threat from pollution, including engagement in comprehensive planning for coastal development activities.