Multispecies Statistical Catch-At-Age Model
VADER

Presentation to SEDAR 102
August 13, 2025

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Overview

- Brief introduction of the model
- Step through current output
- Bottom-up feedback exploration
- Next steps with VADER

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Introduction

- In contrast to VPA, the framework used in past for modeling ERP species, the statistical catch-at-age (SCA) version has attributes of accounting for error in input data through statistical estimation of model parameters

- These models can also quantify resulting parameter uncertainty

- SCA models are one of the preferred methods for single-species assessments
  - Most of the existing SS assessments for ERP are versions of SCAA

Introduction - Model

- Species: Atl Menhaden, Striped Bass, Bluefish, Weakfish, Atl Herring, and Spiny Dogfish

- Six input data series are required for each species:
  - total commercial catch in weight (TMT)
  - total survey catch in number/tow
  - age proportions for both catch (#s) and survey catches
  - average individual weight-at-age
  - age-specific predator diet info

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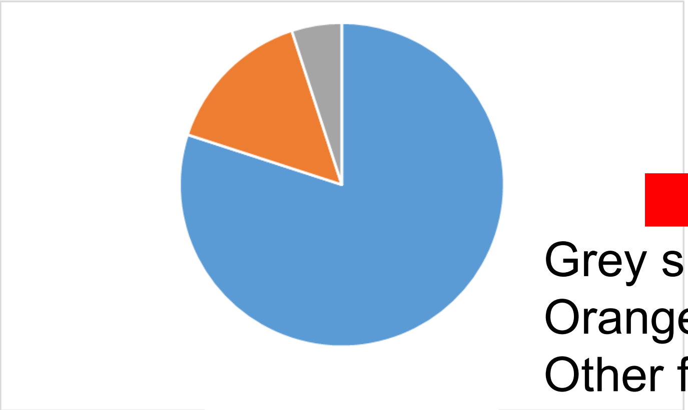
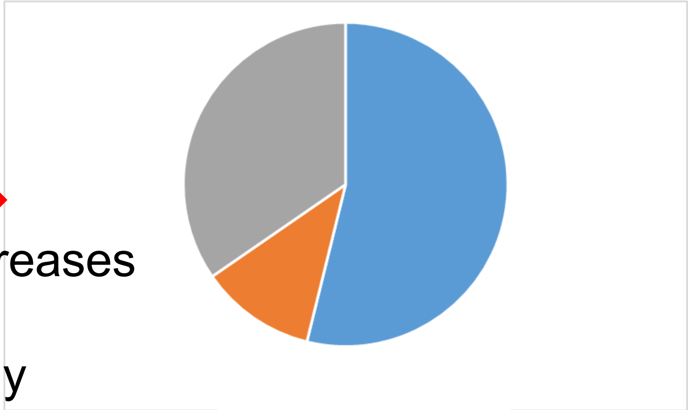
Introduction - Model

- **Additional data requirements include:**
  - **Consumption:biomass (C/B) estimates**
  - **Biomass of "other food" in the ecosystem**

- **There is an assumed constant, time-invariant total ecosystem biomass, permitting the biomass of available other food to vary annually**
  - **Data note 1: currently using an old estimate from EWE**



Grey species population increases
Orange species stays static
Other food varies accordingly



Introduction - Model

- Equations for progression of year class abundance, catch-at-age, and fishing mortality-at-age follow those traditionally used in age-structured assessments

- M values based in part on values used in recent stock assessments, but partitioned into two components for prey:
  - Predation (M2)
  - Residual natural mortality (M1)

- Have added dynamic M for STB, more detail to follow

Introduction - Model

- FI surv catch related to age-specific abundances assuming age-invariant catchability and age-specific selectivity
  - Species-specific catchabilities calculated from deviations between predicted absolute and relative abundance

- Calculation of predation mortality is calculated from suitability coefficients, incorporating preference for particular prey by predator

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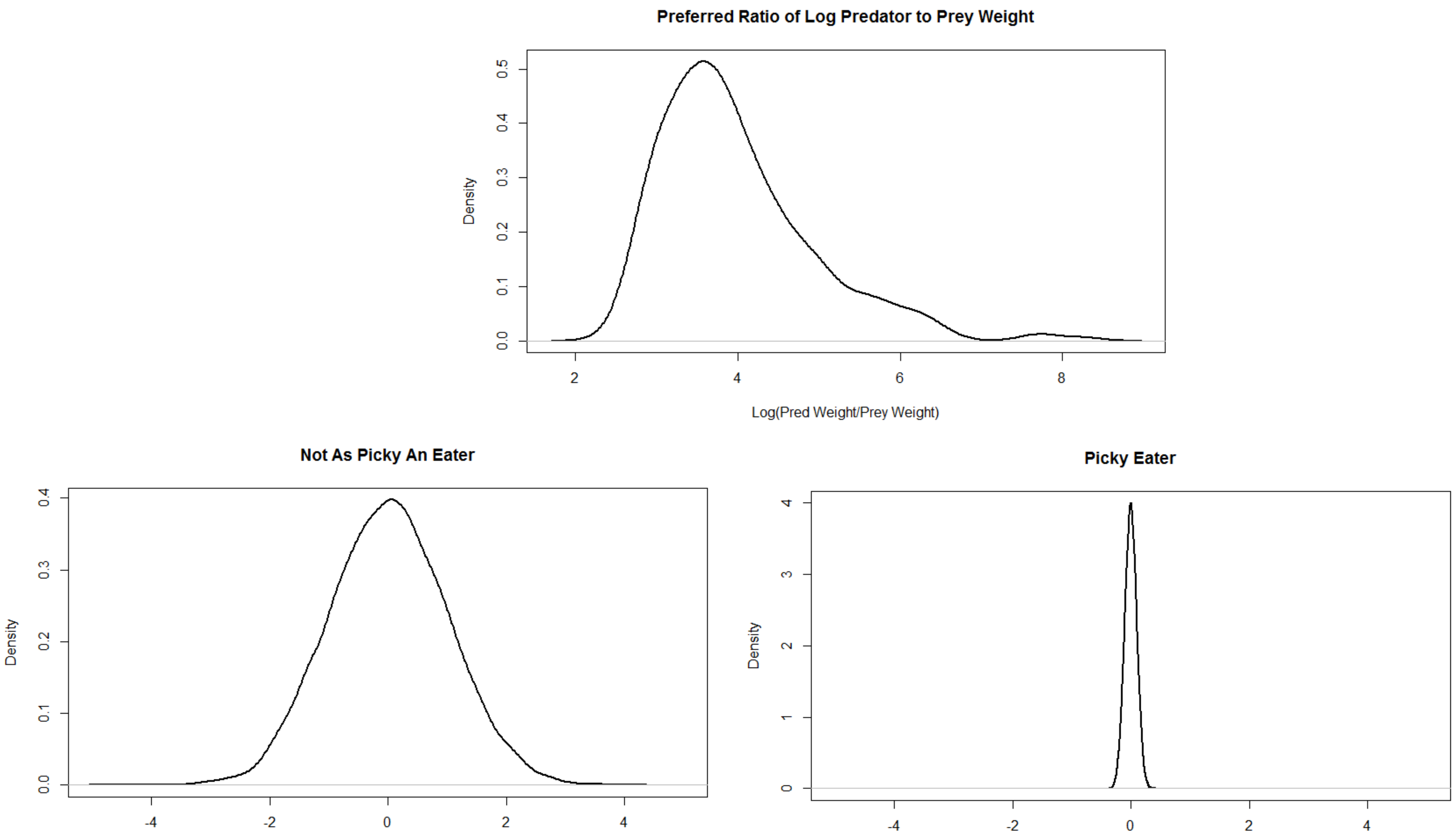
Introduction - Model

- Predator size-preference for prey modeled as lognormal function of predator-to-prey weight ratio

- Parameters for mean and variance in this ratio (i.e. how selective the predator species is with regard to the size of its prey)
  - calculated externally and input
  - Data note 2: not updated for this assessment

- Species preference is relative to generic “other food”

Introduction - Model



Introduction - Model

- Assumption that predators are not food-limited corresponding to a Type-II functional response
- All species in the model are explicitly modeled
- The set of estimated model parameters includes age-specific abundances in the first year, annual recruitment in subsequent years, annual age specific fishing mortality rates, age-specific fishery and survey selectivity coefficients, and the vulnerability parameters

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Introduction - Model

- Due to estimation of age- and species-specific abundances in the first year, the model does not depend on an assumption of equilibrium

- Subsequent years, annual recruitment is estimated as a mean parameter plus a vector of annual deviation parameters that sum to zero

- Model parameters estimated with maximum likelihood techniques, programmed in AD Model Builder (13.3)
  - RTMB version also exists, ran into a problem as RTMB does not recognize lists, so have had to reconfigure

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Introduction - Model

- Approach with priors was implemented through penalized likelihoods
  - Yr1
  - Recruitment
  - Biomass

- Statistical estimation of model parameters allows the assumption that commercial catch, survey catch and food habits data are subject to error

- Total commercial catch and total survey catch were assumed to be lognormally distributed

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Introduction - Model

- Commercial catch-at-age proportions, survey age proportions and predator food habits were assumed to follow Dirichlet multinomial distributions
- Data inputs borrowed from existing single species assessments
  - Data is simplified in many cases and aggregated, i.e. for menhaden do not differentiate between reduction and bait catch, all coalesced into total removals
  - Only a subset of existing surveys are used
- The simplification is intentional as the model is complex by default, so there is an effort to minimize the number of parameters being estimated where possible

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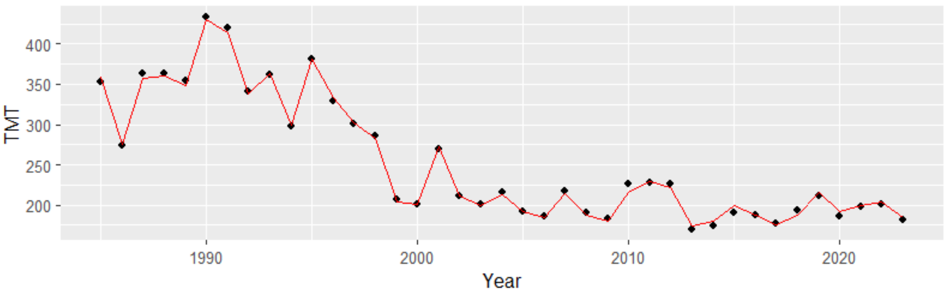
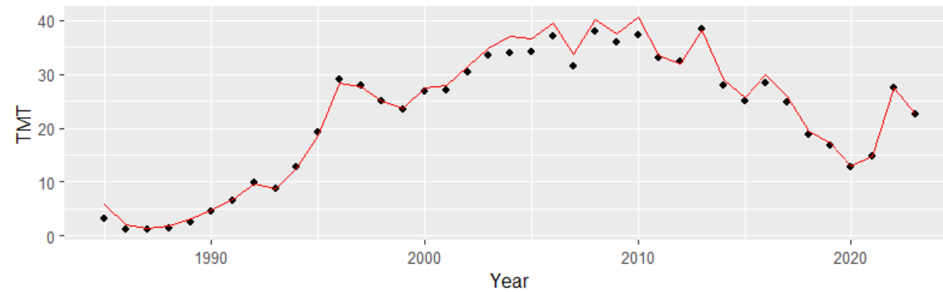
Output - Catch

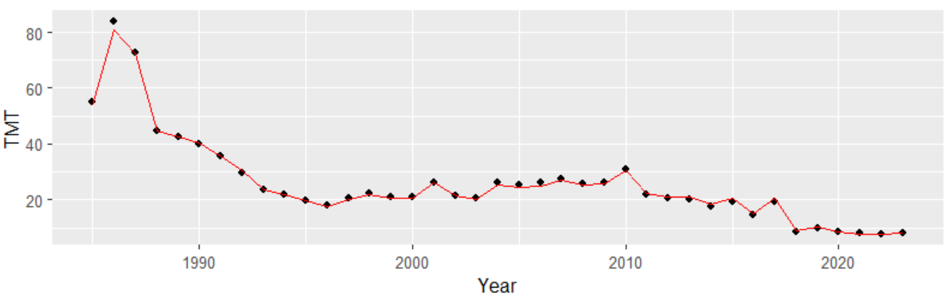
Menhaden



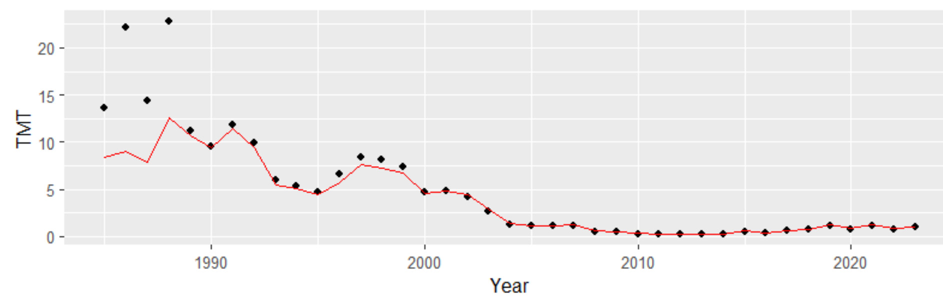
Striped Bass



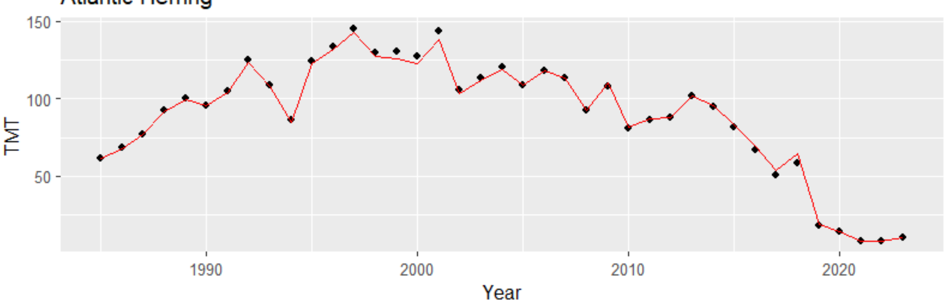
Bluefish



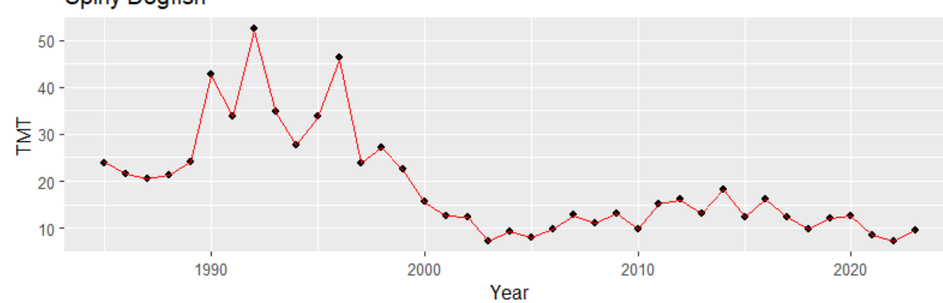
Weakfish



Atlantic Herring



Spiny Dogfish



Output - Survey

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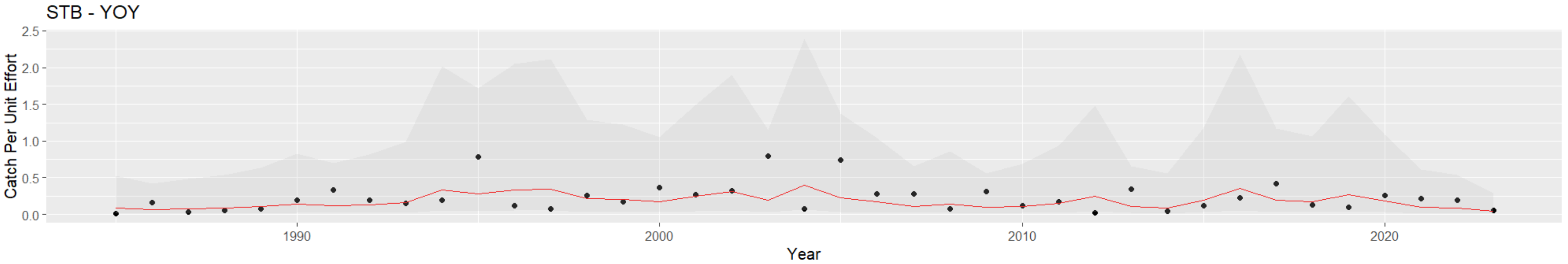
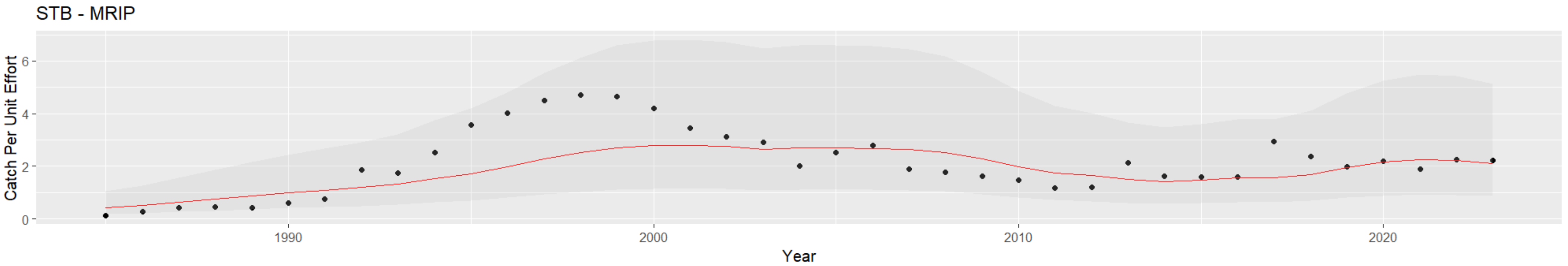
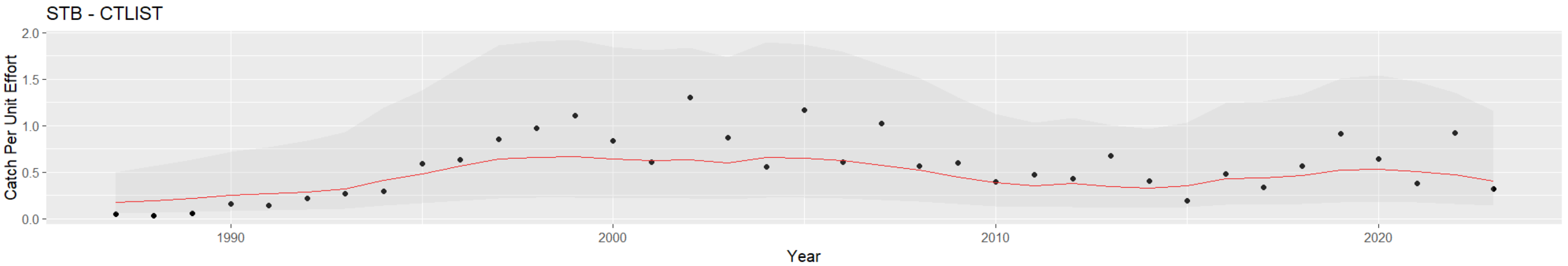
Output - Survey







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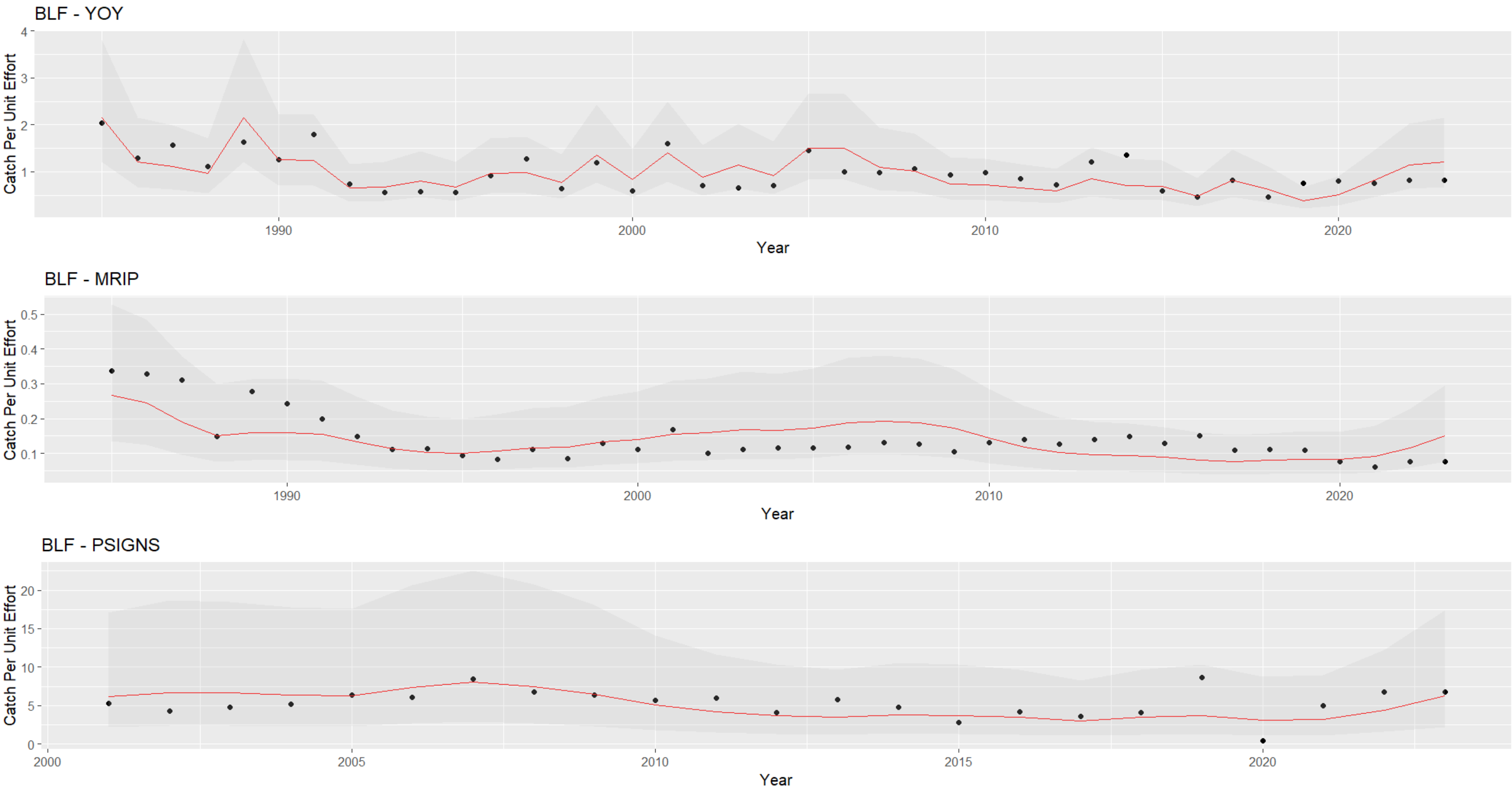
Output - Survey



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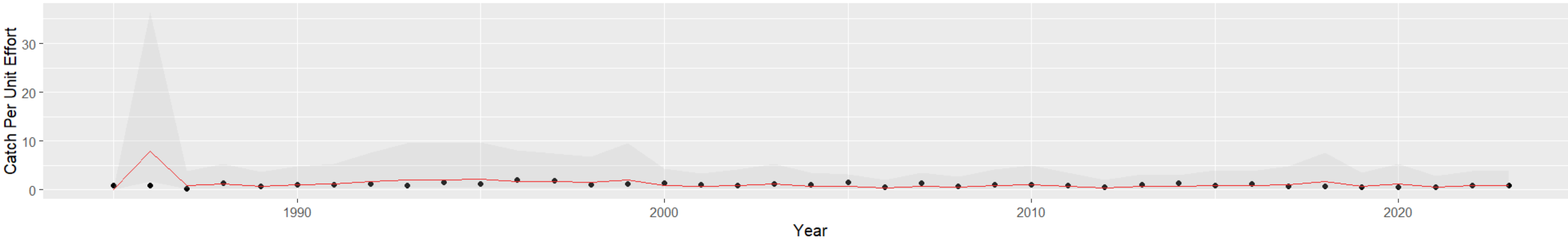
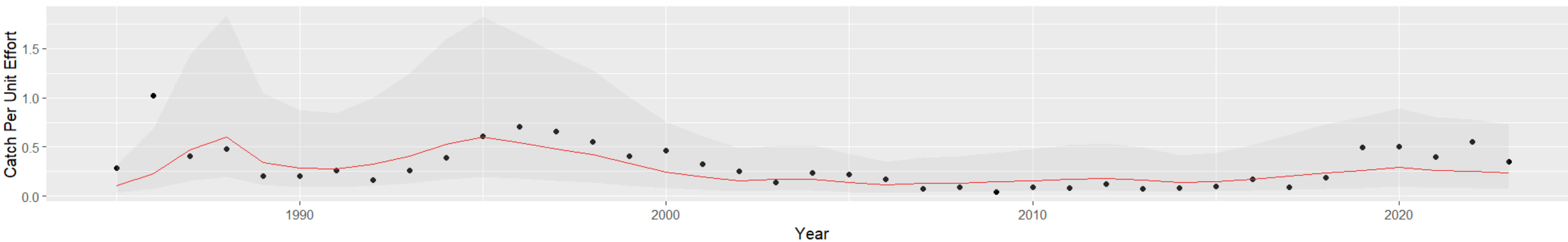
Output - Survey

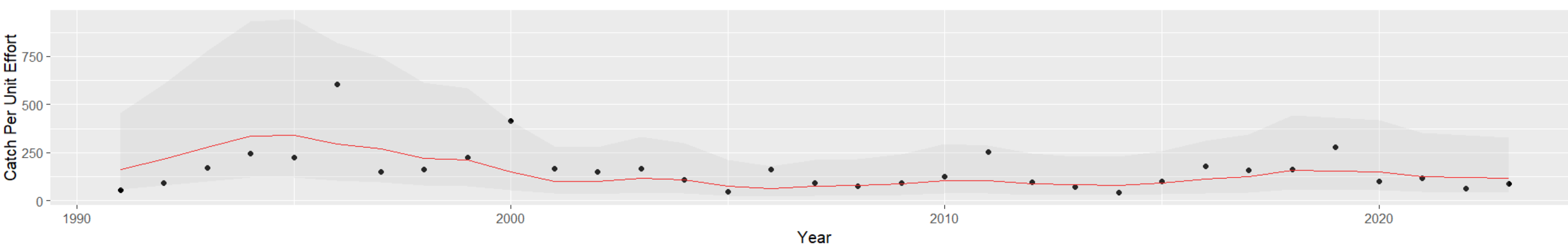
WKF - YOY



WKF - MRIP



WKF - DE30



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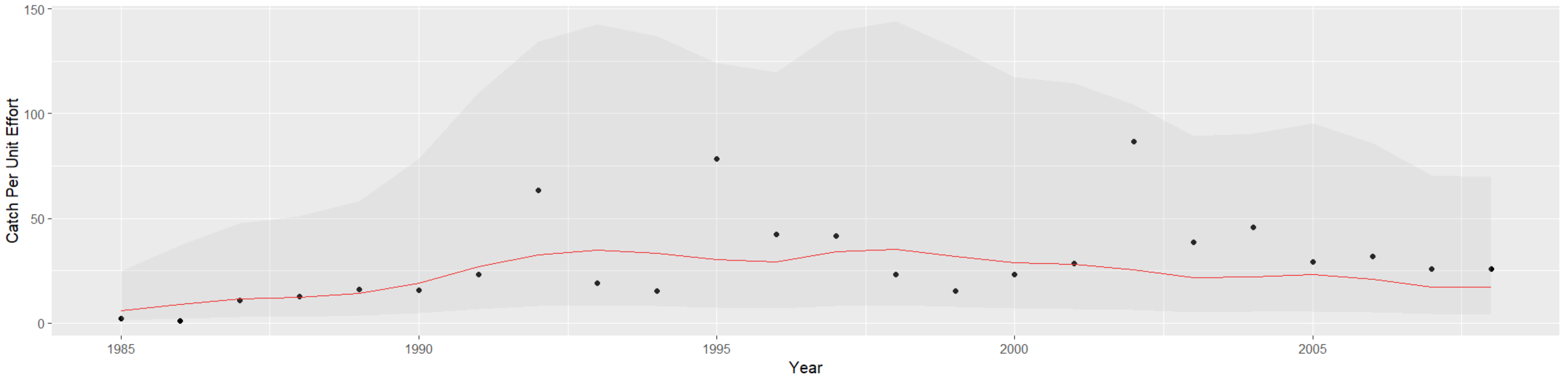
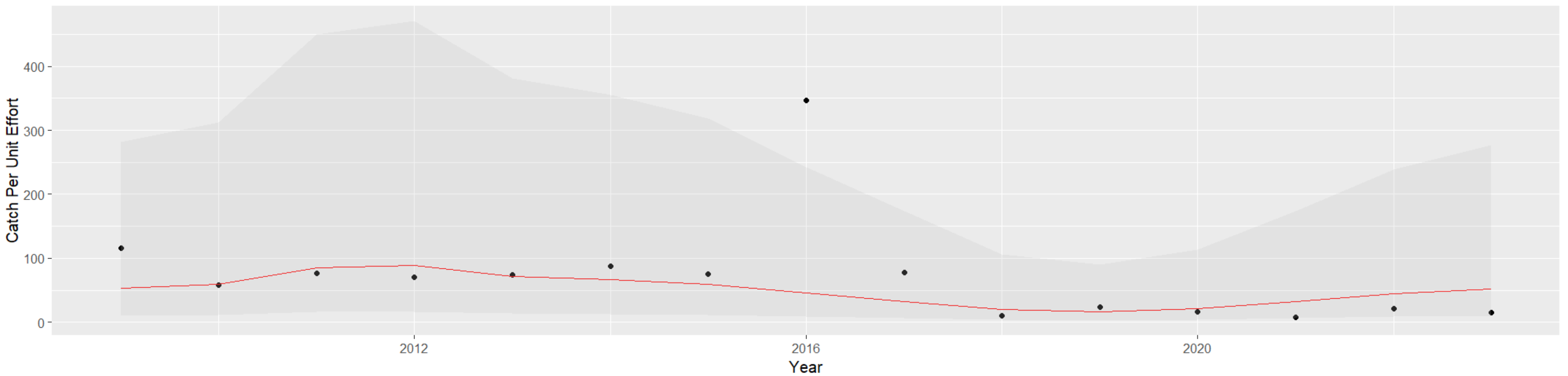
Output - Survey

HER - Albatross



HER - Bigelow



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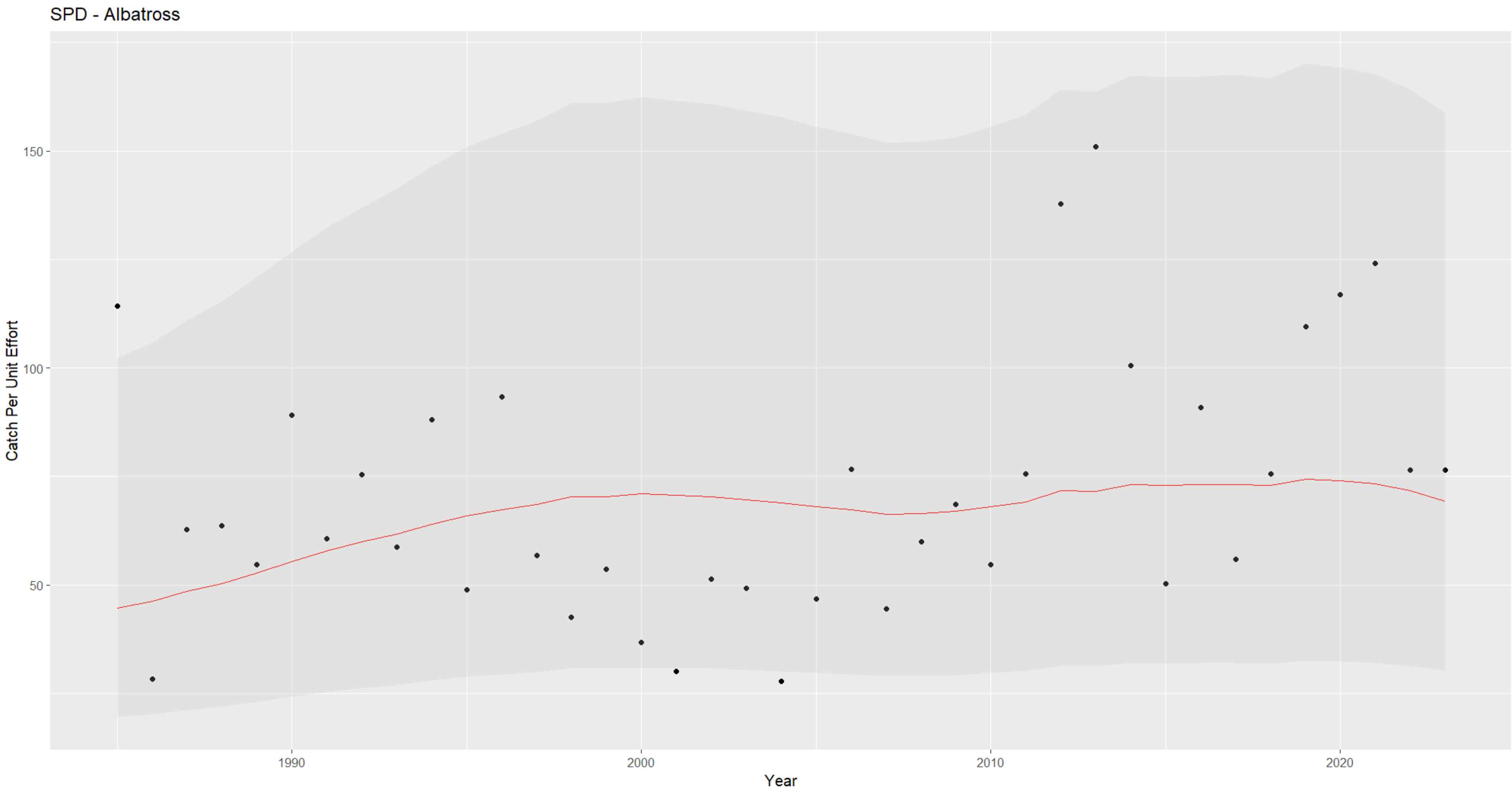
Output - Survey



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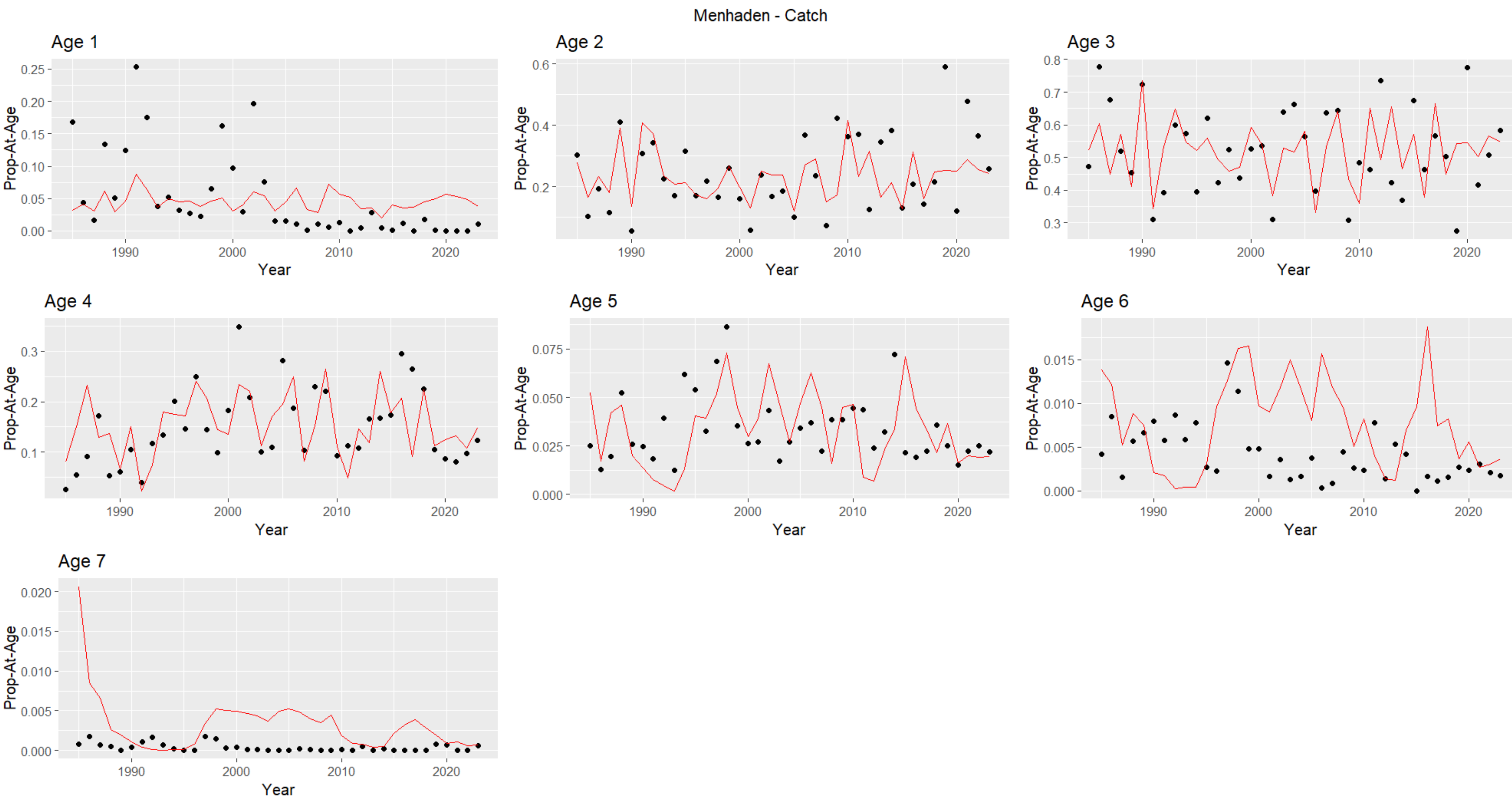
Output – Catch-At-Age



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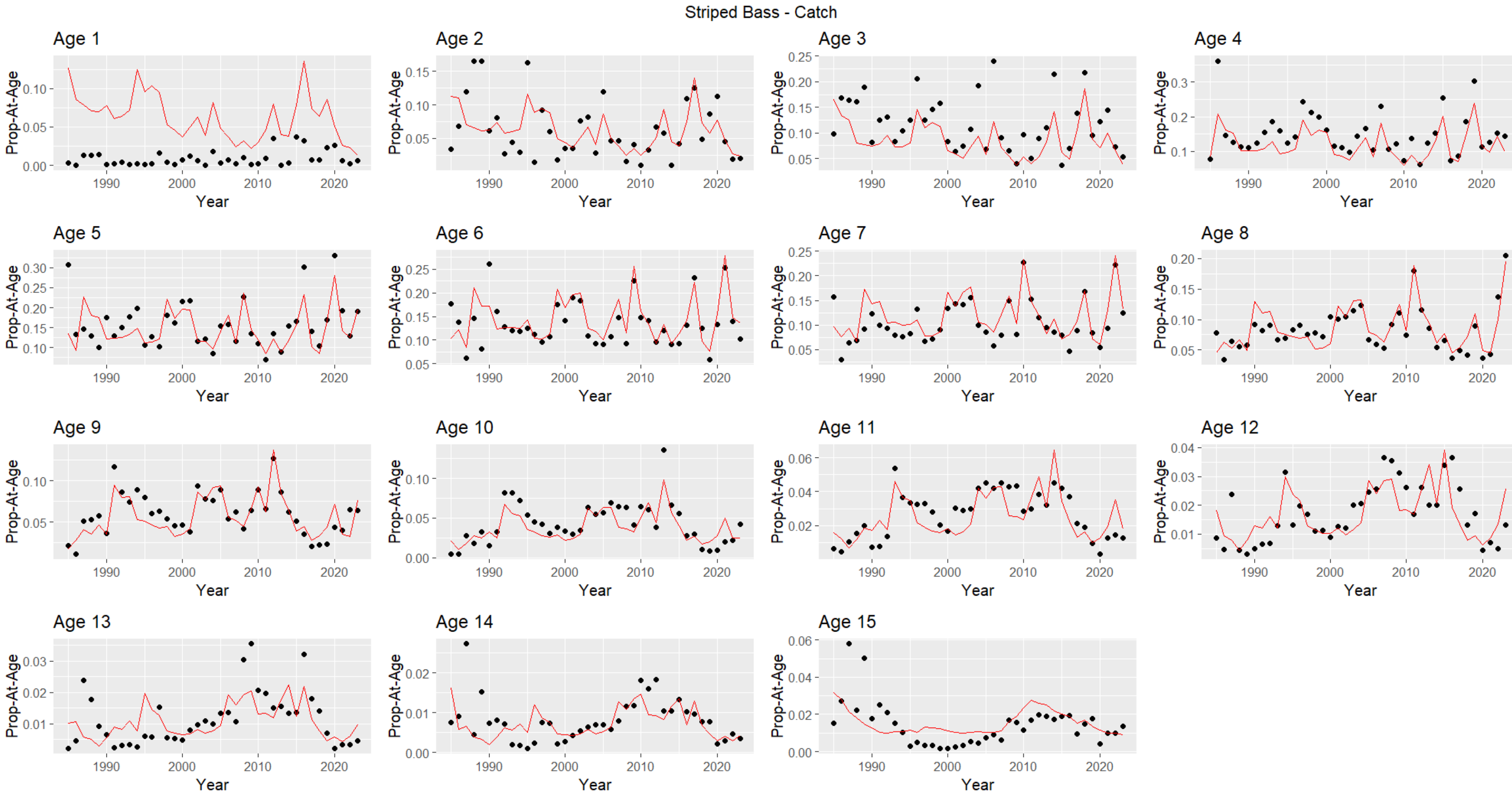
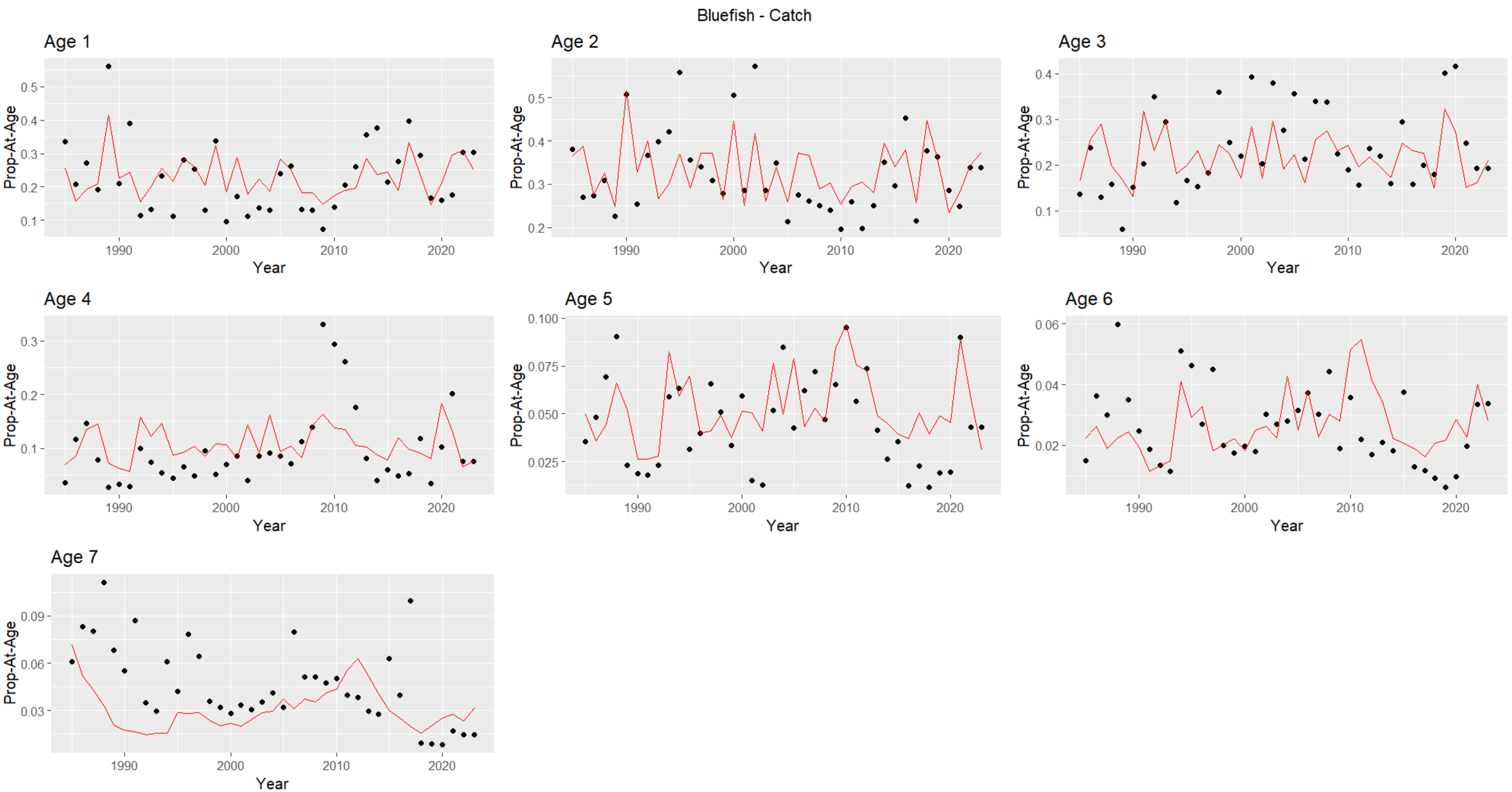
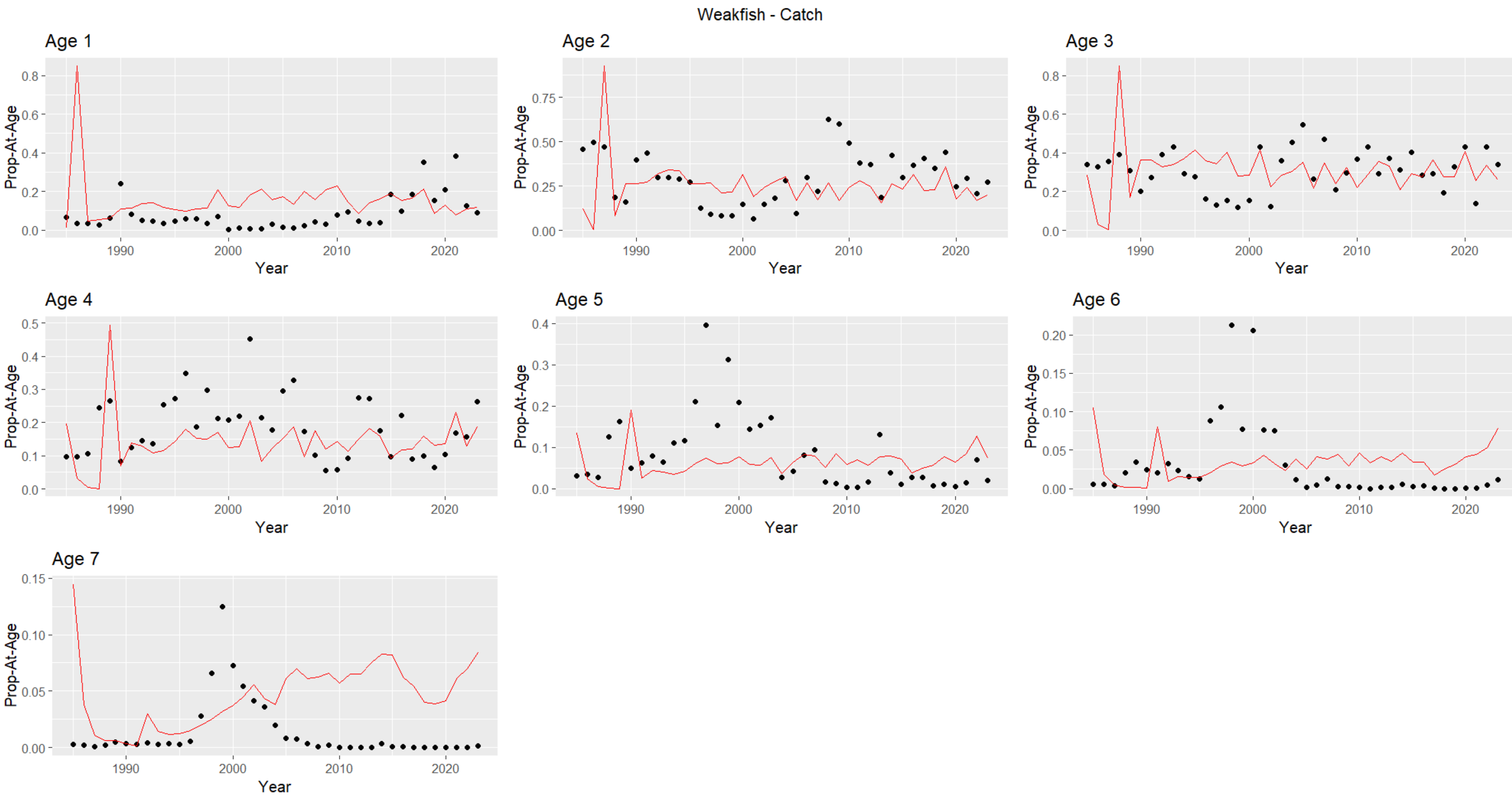
Output – Catch-At-Age



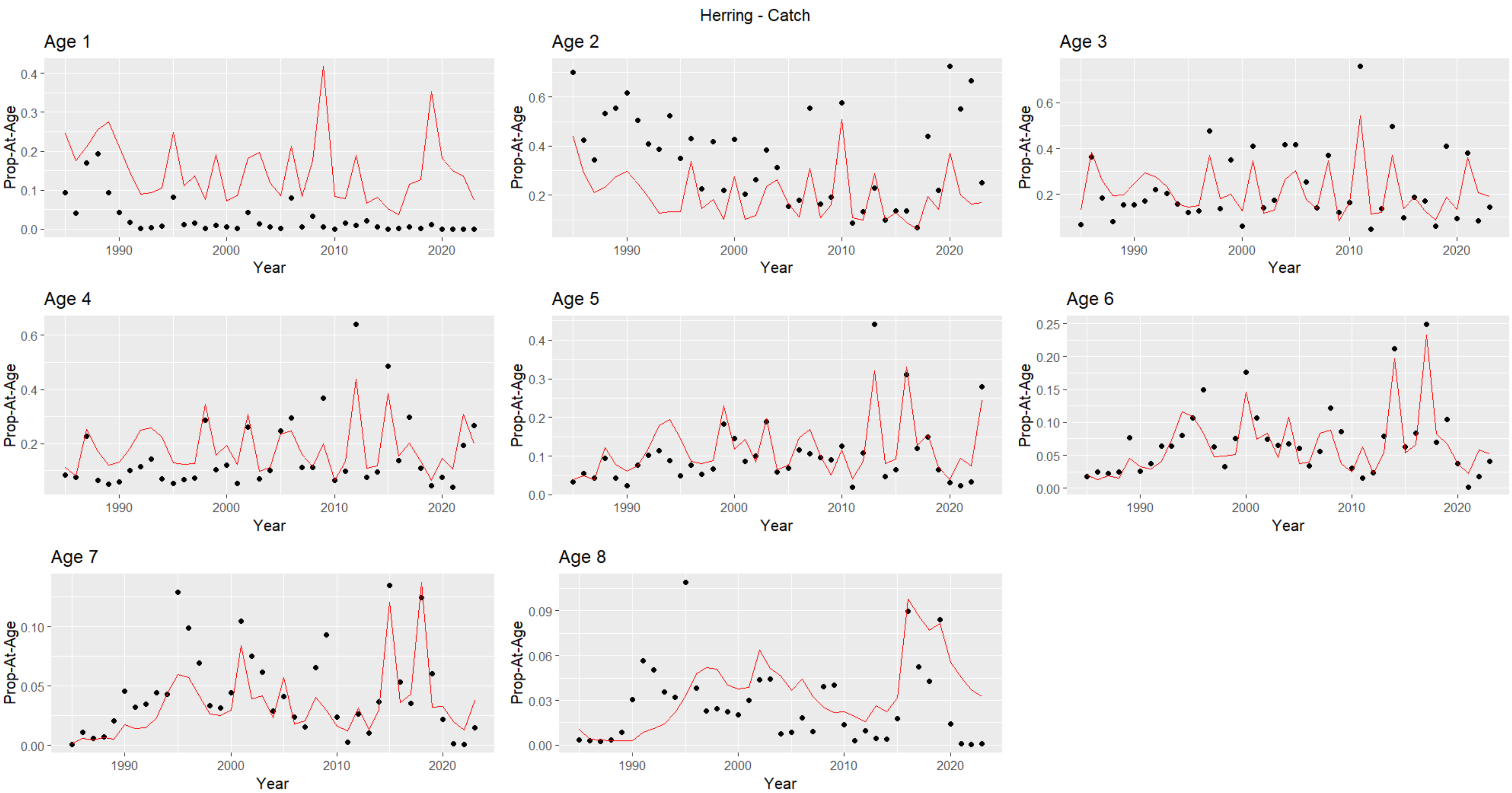
Output – Catch-At-Age



Output – Catch-At-Age



Output – Catch-At-Age



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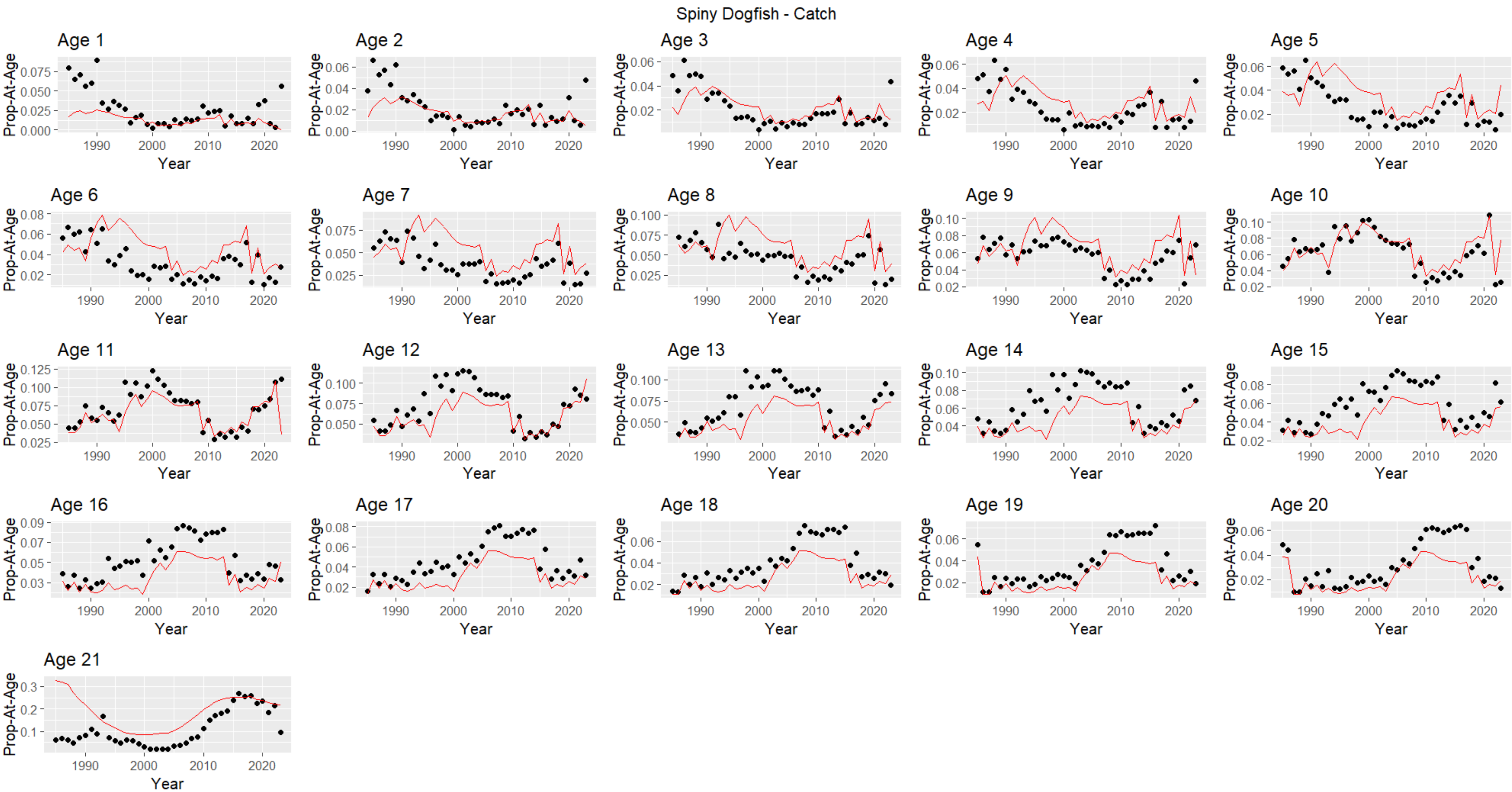
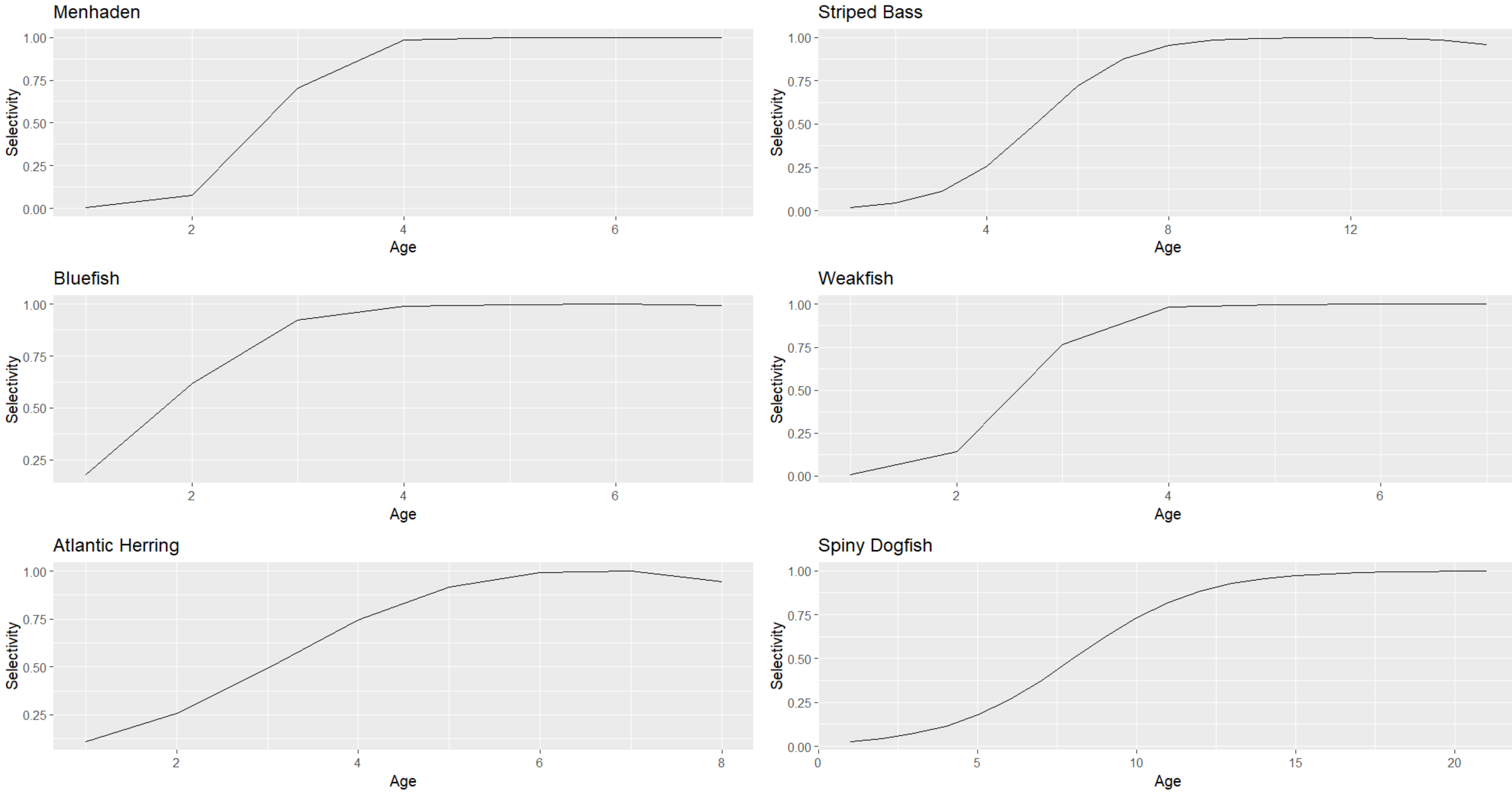
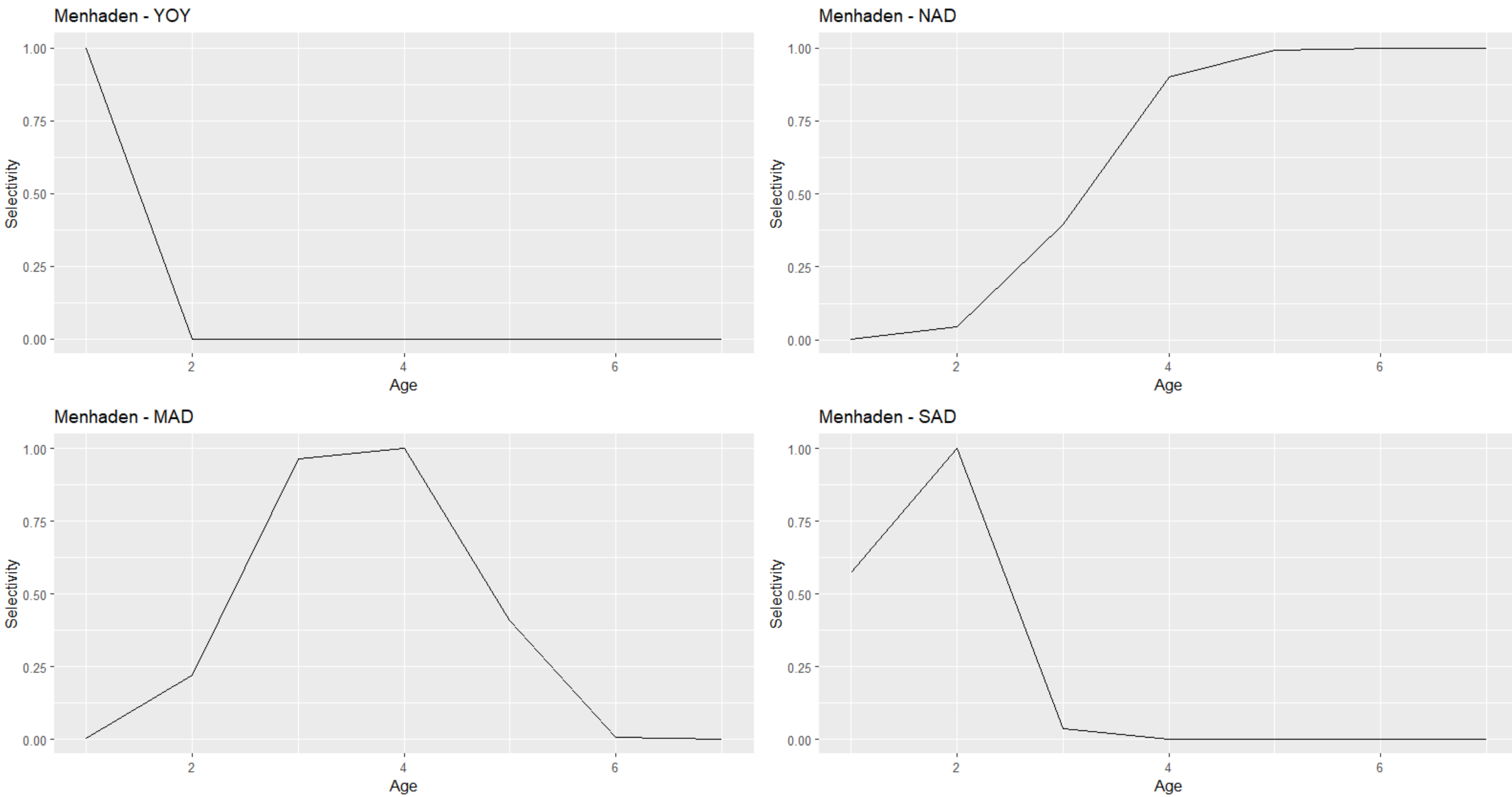
Output – Catch-At-Age



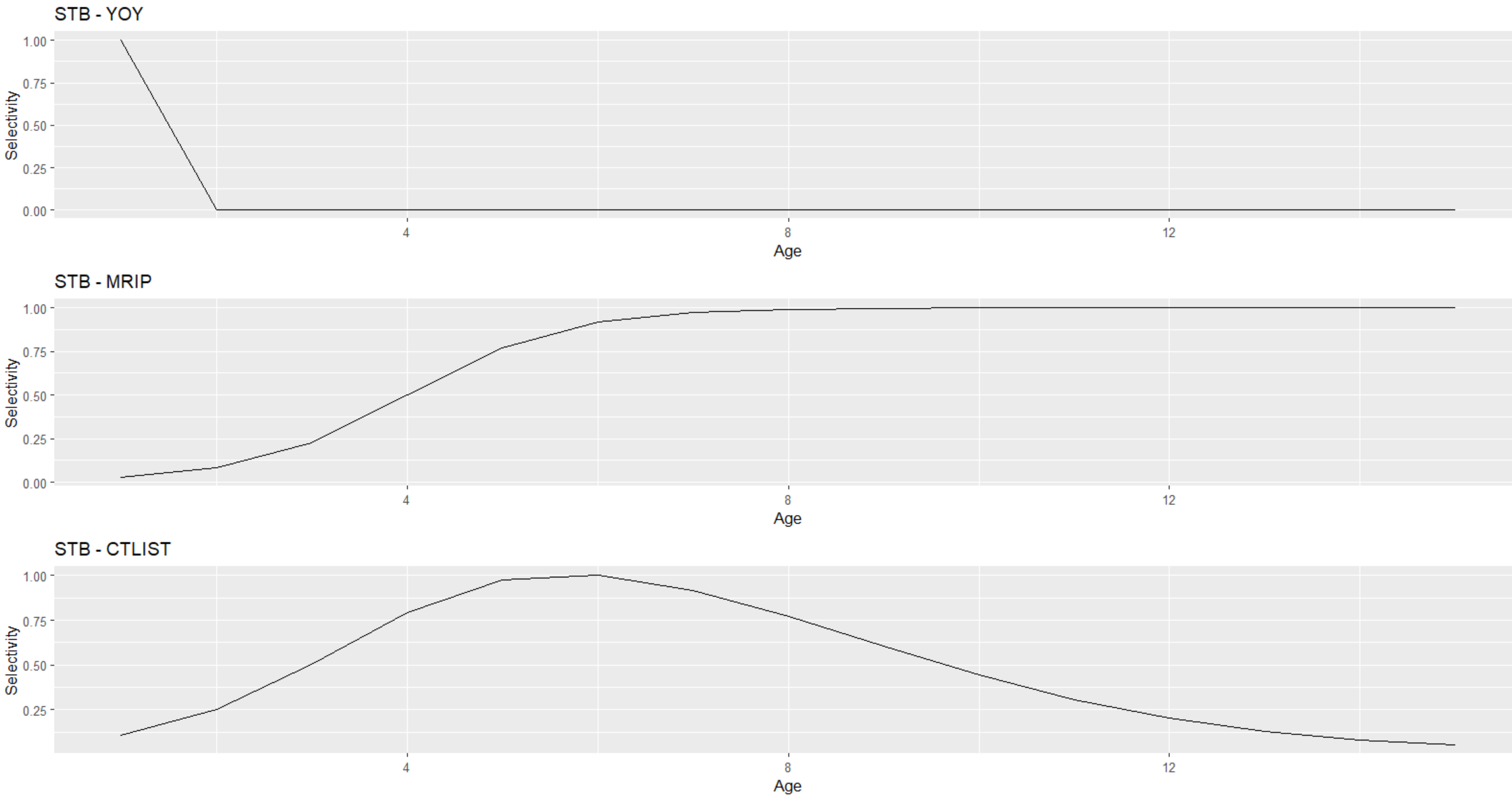
Output – Catch Selectivity



Output – Survey Selectivity



Output – Survey Selectivity



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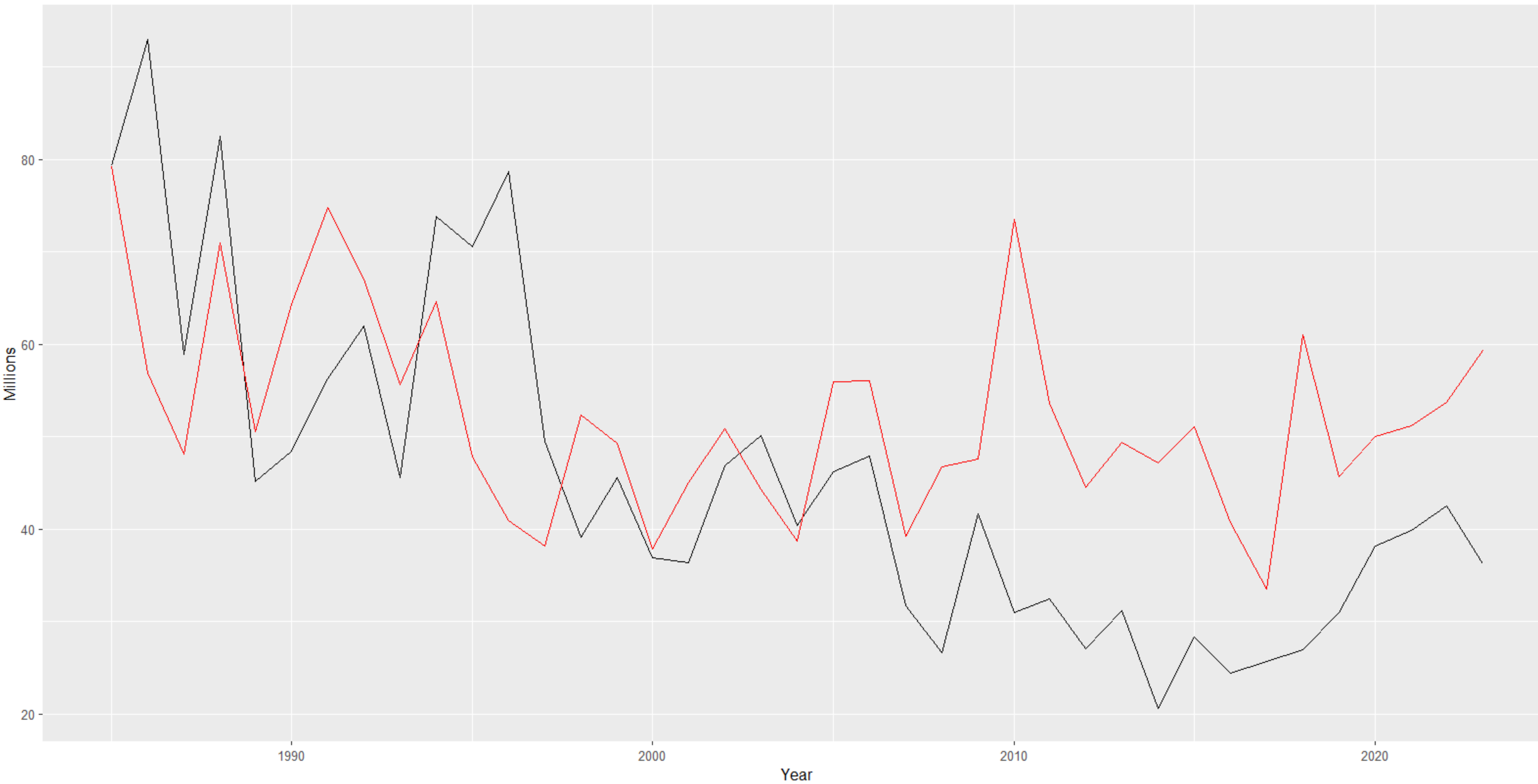
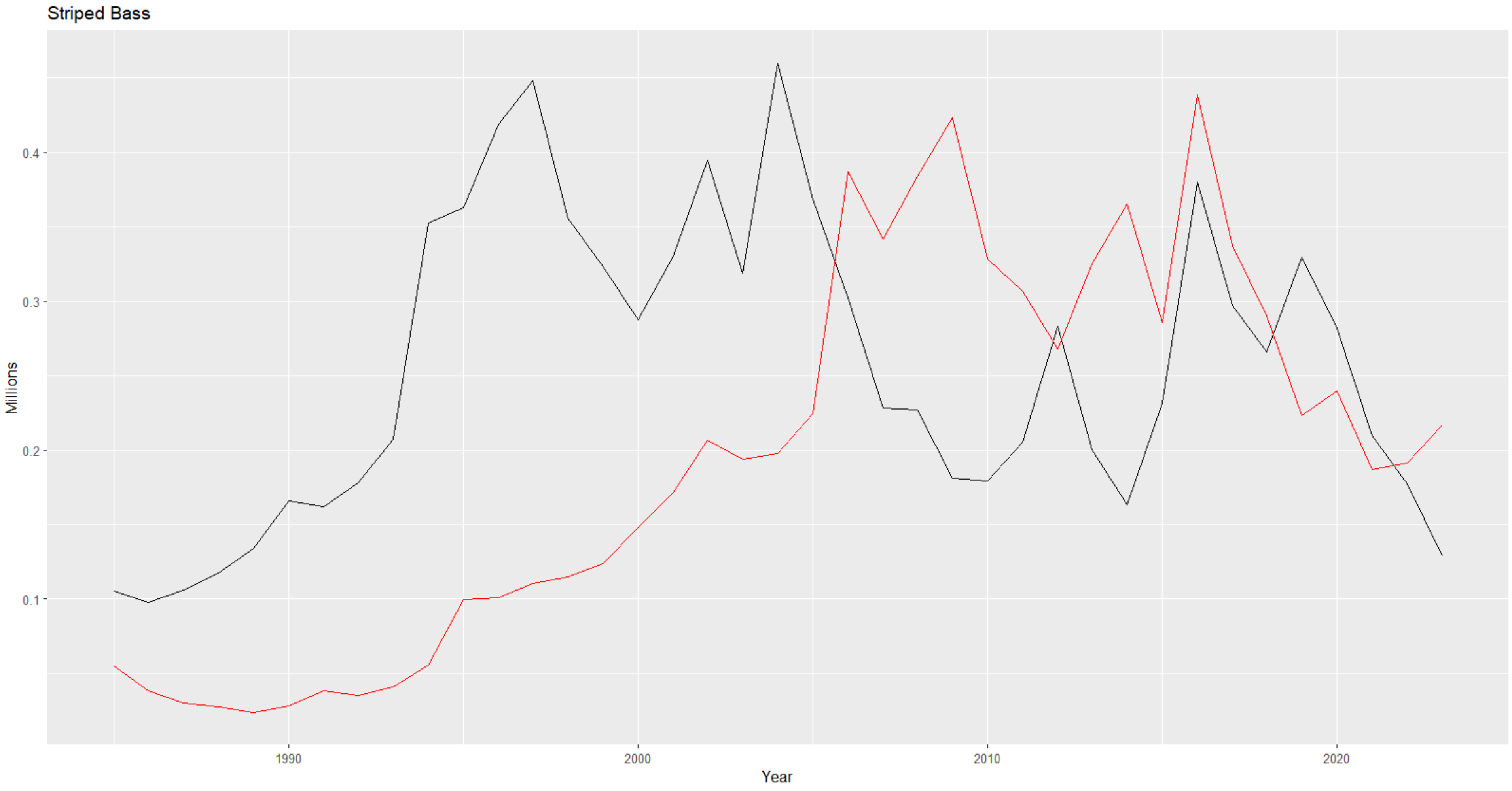
Output – Comparisons

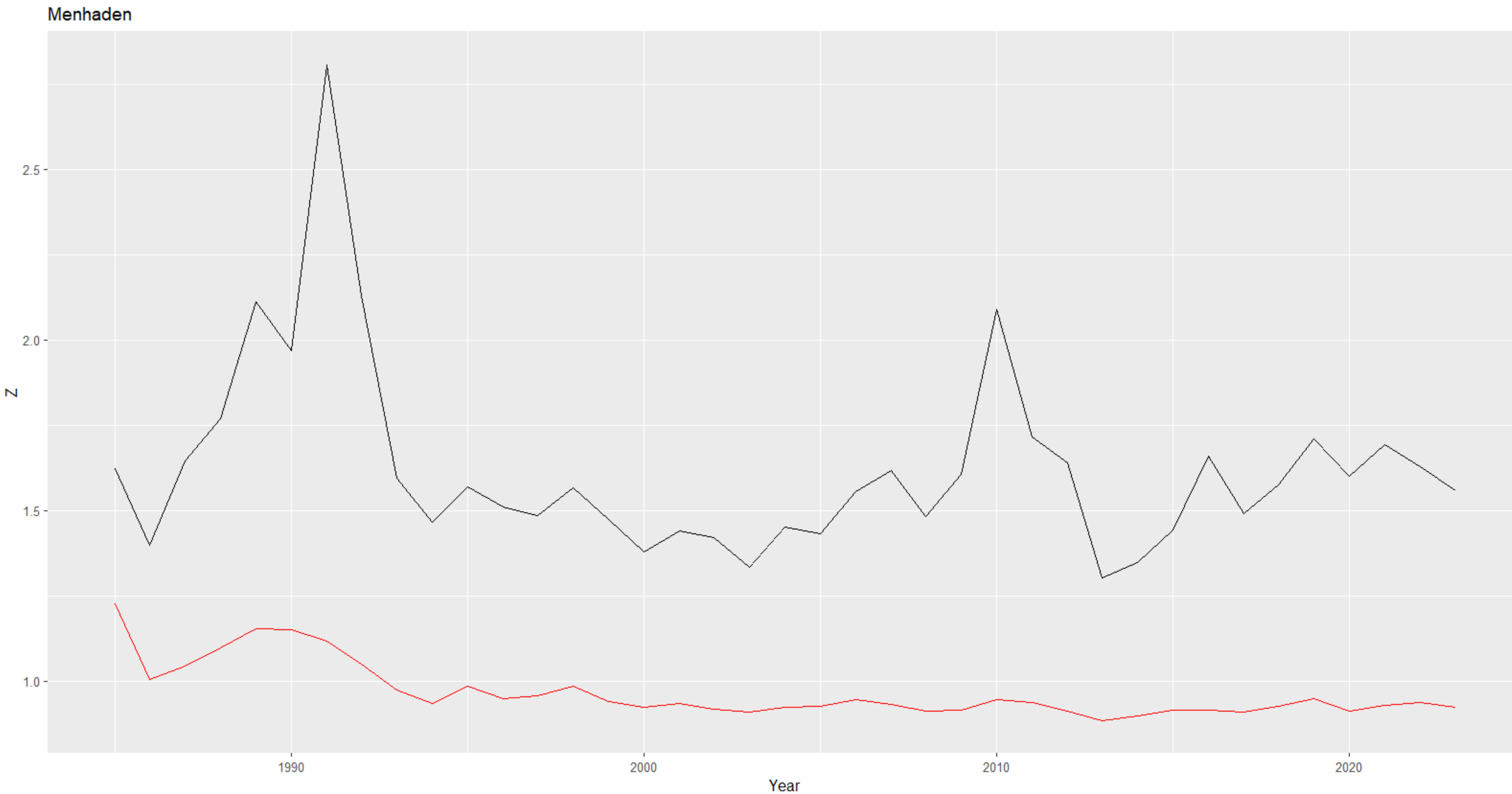
Menhaden



Output – Comparisons

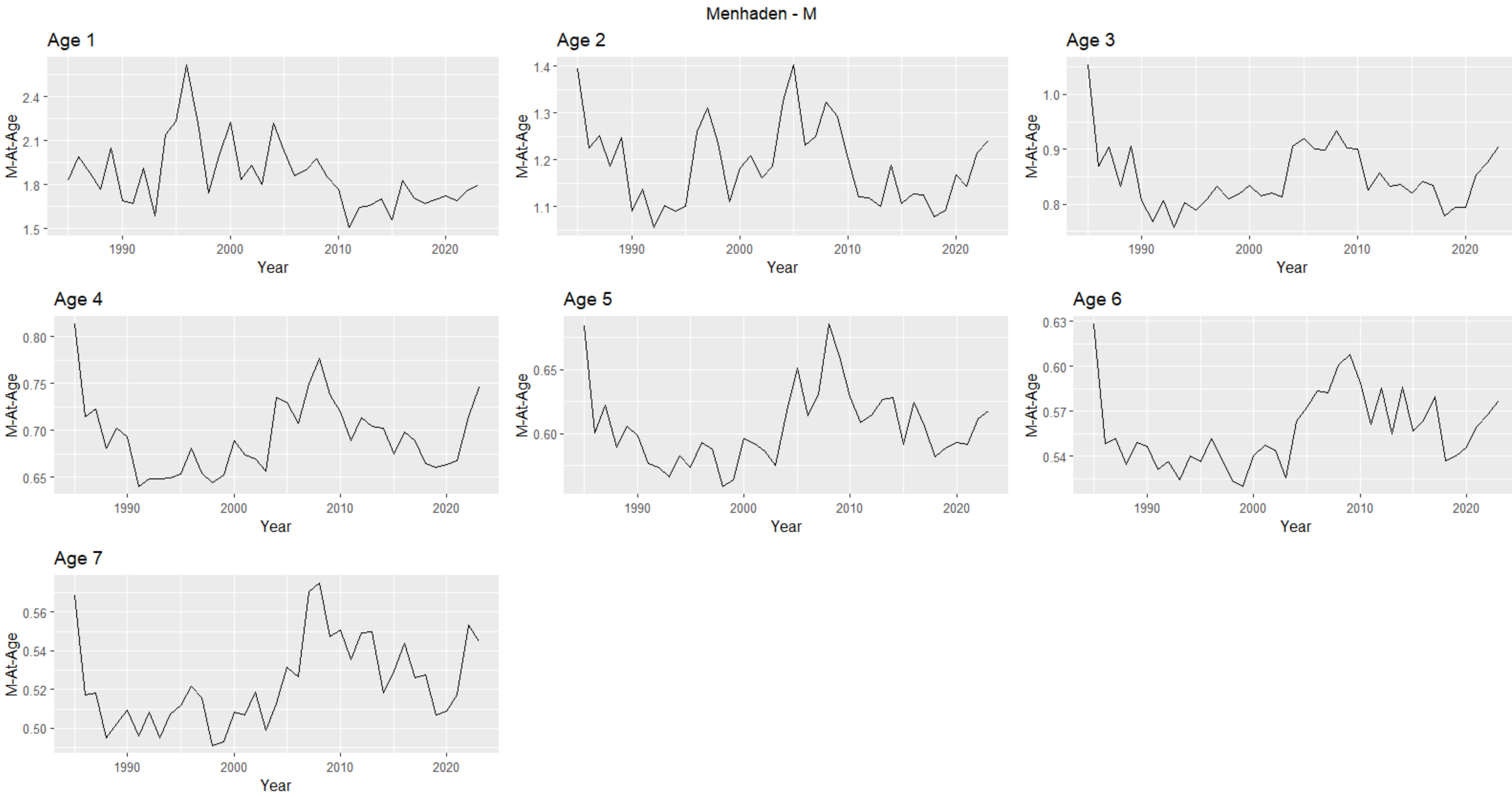


Output – Comparisons



Output – Comparisons

Output – Menhaden M



Bottom-Up Feedback

- After last benchmark, clear guidance from Peer Review Team to focus on bottom-up feedback for VADER
  - Investigated several ways to do this including work by Szalai (2003) and Schiano et al. (2023, 2025)

- Schiano et al. (2023) dynamic M1 used in their simulation model, and after consultation with the ERP WG, chose this as the mechanistic way to incorporate into VADER

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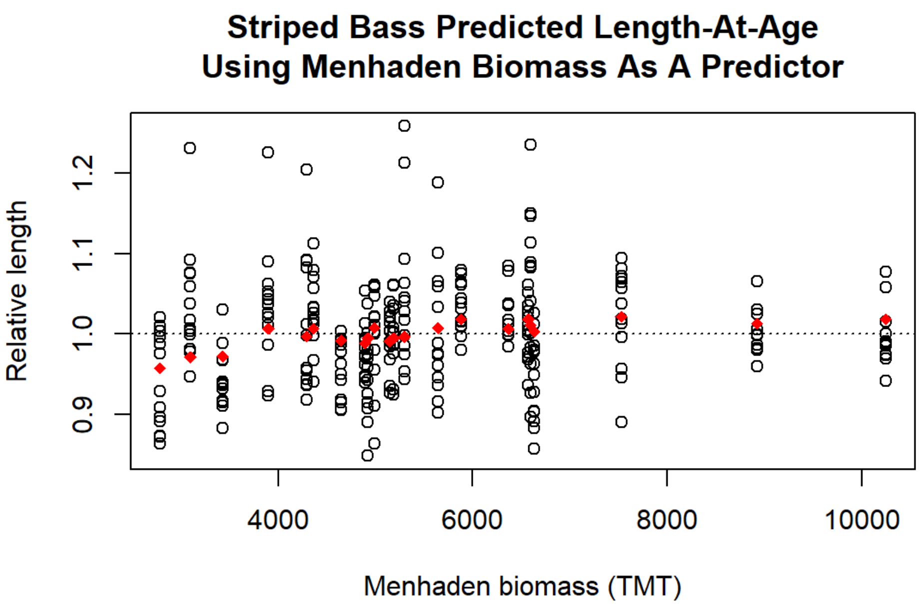
Bottom-Up Feedback

- **First step in bottom-up feedback exploration is to investigate information available to inform the model on these effects in our system**
  - **During methods workshop, presented some info (working paper 9), showed a link between stb length and menhaden levels, and WG approved use of Schiano et al. model to develop dynamic M1 for STB**

Bottom-Up Feedback

- Menhaden biomass added to non-linear model as a predictor of stb length (used nls() for parameter solution and stats)

$$RelLength = \frac{\alpha * Biomass_{Men}}{\beta * Biomass_{Men} + SSB_{striped\ bass}}$$




```
Parameters:
   Estimate Std. Error t value Pr(>|t|)
aW   0.6357     0.1498   4.243 2.99e-05 ***
bW   0.6115     0.1497   4.084 5.76e-05 ***
```

- Some evidence of prey dependence on LAA

Bottom-Up Feedback

- To recap, looked at:
  - STB WAA being impacted by menhaden biomass
  - STB WAA being impacted by all modeled prey biomass
  - STB LAA being impacted by menhaden biomass
  - STB LAA being impacted by all modeled prey biomass
- Only one that indicated a relationship was LAA relative to menhaden biomass
  - Mild relationship but statistically significant

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Bottom-Up Feedback

- **Add update slide from reviewer request – prey weighted by importance**

Bottom-Up Feedback

- Add update slide from reviewer request – add temp covariate

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Bottom-Up Feedback – Schiano et al. function

M is conditioned on relative weight by year, season, and age

$$RelW_{t=1,a} = 100 * \frac{W_{y-1,t=1,a}}{Ws_{t=1,a}}$$

Relative weight of striped bass in the first season

$$RelW_{t,a} = 100 * \frac{W_{y,t-1,a}}{Ws_{t-1,a}}$$

Relative weight of striped bass after the first season

RelW=relative weight
W=achieved weight
Ws=standard weight
y=year
t=season
a=age

Bottom-Up Feedback – Schiano et al. function

M is conditioned on relative weight by year, season, and age

$$Mc_{y,t,a} = 3.28 * M_{y,t,a}\Phi\left(\frac{70.52 - RelW_{y,t,a}}{16}\right)$$

Natural mortality for striped bass with low relative weight

$$+M_{y,t,a}\left(1 - \Phi\left(\frac{70.52 - RelW_{y,t,a}}{16}\right)\right)$$

M=natural mortality
Mc=conditional weight
RelW=relative weight
y=year
t=season
a=age
Φ=cumulative density for normdist

First term – M calculation for poor condition
--3.28*M = M experienced by fish with low relW
--phi()=proportion of fish in age class that have low relative W

Second term – M for fish not in poor condition * proportion not in poor condition

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Bottom-Up Feedback – Schiano et al. function

M is conditioned on relative weight by year, season, and age

$$Mc_{y,t,a} = 3.28 * M_{y,t,a}\Phi\left(\frac{70.52 - RelW_{y,t,a}}{16}\right)$$

Natural mortality for striped bass with low relative weight

$$+M_{y,t,a}\left(1 - \Phi\left(\frac{70.52 - RelW_{y,t,a}}{16}\right)\right)$$

M=natural mortality
Mc=conditional weight
RelW=relative weight
y=year
t=season
a=age
Φ= cumulative density for normdist

Multiplier for poor condition fish

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Bottom-Up Feedback – Schiano et al. function

Hoenig, J.M., Groner, M.L., Smith, M.W., Vogelbein, W.K., Taylor, D.M., Landers, D.F., et al. 2017. Impact of disease on the survival of three commercially fished species. Ecol. Appl. **27**(7): 2116–2127

Table 1. **Estimated relative survival of striped bass with dermal mycobacteriosis.** Relative survival is measured against survival of fish with no signs of disease. CI = 95% confidence interval. Data includes fish tagged in Fall and Spring from Maryland (2007-2009) and Virginia (2005-2012).

Disease state	Relative survival	Confidence Interval (95%)	p-value	Sample size	Percent of recaptures
None				912	35.5 %
Mild	0.96	0.84 – 1.09	0.50	966	37.6 %
Moderate	0.84	0.70 – 1.00	0.06	393	15.3 %
Severe	0.54	0.42 – 0.68	<0.01	299	11.6 %

Hypothesis – poor condition leads to high disease-based natural mortality. But mortality of starving sbass unknown. Hoenig et al. estimated relative mortality of fish among disease states. So we assumed M for poor condition fish was the same as sbass with severe mycobacteriosis estimated from Hoenig et al.'s tagging study such that low condition individuals experienced higher relative natural mortality.

Value calculated as the weighted avg of moderate and high disease relative M implied by relative survival estimates

1) M=0.15
2) Survival rate=exp(-0.15)=0.86
3) Relative survival of severe/moderate relative to none is 0.71 = (0.84*0.153+0.54*0.116)/(0.153+116)
4) M for severe /moderate is –ln(0.71*0.86) = 0.49
5) Scaling factor for severe/moderate disease M is 0.49/0.15 = **3.28**

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Bottom-Up Feedback – Schiano et al. function

M is conditioned on relative weight by year, season, and age

$$Mc_{y,t,a} = 3.28 * M_{y,t,a}\Phi\left(\frac{70.52 - RelW_{y,t,a}}{16}\right)$$

Natural mortality for striped bass with low relative weight

$$+M_{y,t,a}\left(1 - \Phi\left(\frac{70.52 - RelW_{y,t,a}}{16}\right)\right)$$

M=natural mortality
Mc=conditional weight
RelW=relative weight
y=year
t=season
a=age
Φ= cumulative density for normdist

Poor condition threshold and variance

Bottom-Up Feedback – Schiano et al. function

Jacobs, J.M., Harrell, R.M., Uphoff, J., Townsend, H., and Hartman, K. 2013. Biological reference points for the nutritional status of Chesapeake Bay striped bass. N. Am. J. Fish. Manag. 33(3): 468–481

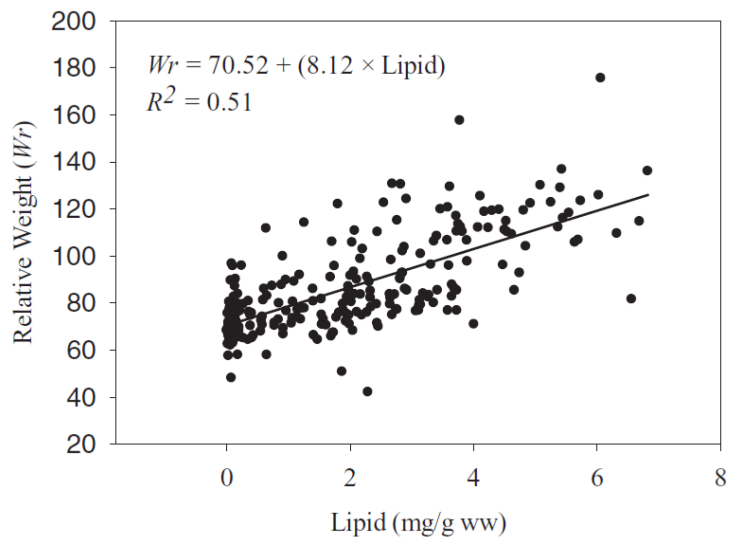
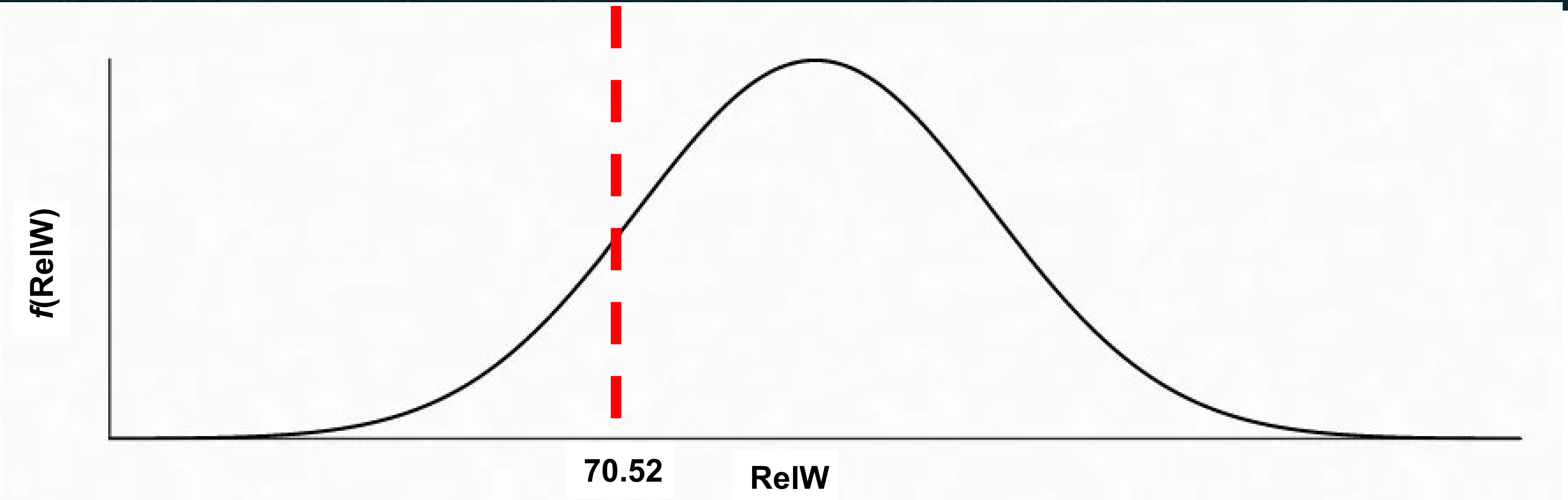


FIGURE 2. General relationship between relative weight (W_r) and anterior dorsal muscle lipid in Striped Bass. Model selection exercises demonstrated only marginal improvement with the inclusion of source or sex as additional explanatory variables (Table 2). While W_r clearly relates to measured lipid, the model fit is poor, with a high degree of variability in W_r at any given lipid level.

Low condition fish have RelW<70.52=intercept of RelW ~ lipid).

Variance (16) estimated from regression on data-thieved version of data in Fig. 2.

Bottom-Up Feedback – Schiano et al. function



Assume relative WAA is normally distributed with a mean from the population and a variance of 16.

We used phi (cumulative normal function) to calculate the proportion that would be below 70.52 (threshold WAA when higher M kicks in).

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Bottom-Up Feedback – Schiano et al. function

- **Schiano work standardizes weights of striped bass based on empirical info on length**

$$Ws_a = 0.001 * 10^{-4.924} * L_{t,a}^{3.007}$$

- **The $L_{t,a}$ parameter is an average length at age for the first season of the year (t subscript is season)**
- **We used the otolith derived LAA data from Schiano et al. (2023), and averaged the 4 seasons into a single annual vector (could change to a weighted approach to avoid bias)**

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Bottom-Up Feedback – Schiano et al. function

- **From this a relative weight is calculated**

$$RelW_{y,a} = 100 * \frac{W_{y-1,a}}{Ws_a}$$

  - **$W_{y\text{-}1,a}$ is weight-at-age from previous year; Ws_a is the standardized weight (from previous slide)**
  - **So you get this quantity which then gets used in the *M1* calculation**

Bottom-Up Feedback – Schiano et al. function

- Finally, *Mc* is calculated accounting for this relative weight by year and age

$$Mc_{y,a} = 3.28 * M_a \phi\left(\frac{70.52 - RelW_{y,a}}{16}\right) + M_a\left(1 - \phi\left(\frac{70.52 - RelW_{y,a}}{16}\right)\right)$$

  - Model represents hypothesis that striped bass become susceptible to mortality from myco when they are underweight
  - Equation says that fraction of fish w/ relative weight less than 70.52 experience 3.28 times higher natural mortality
    - 16 is the variance of relative weight for an age (assumed constant over ages)

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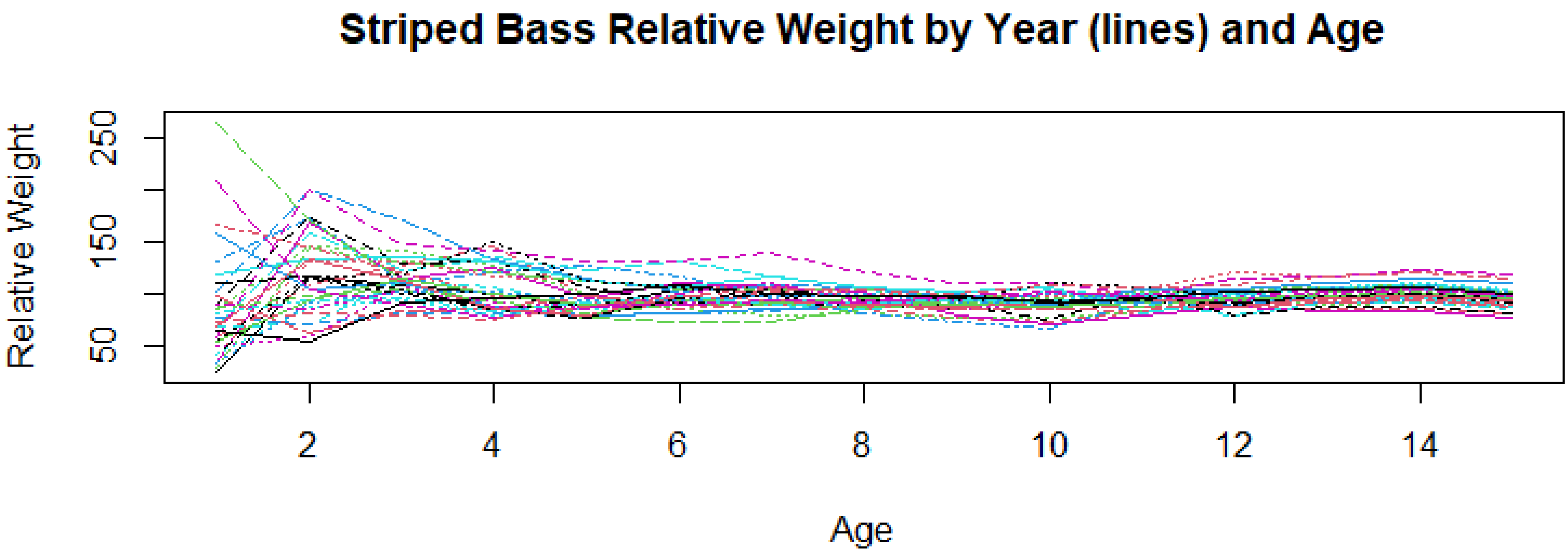
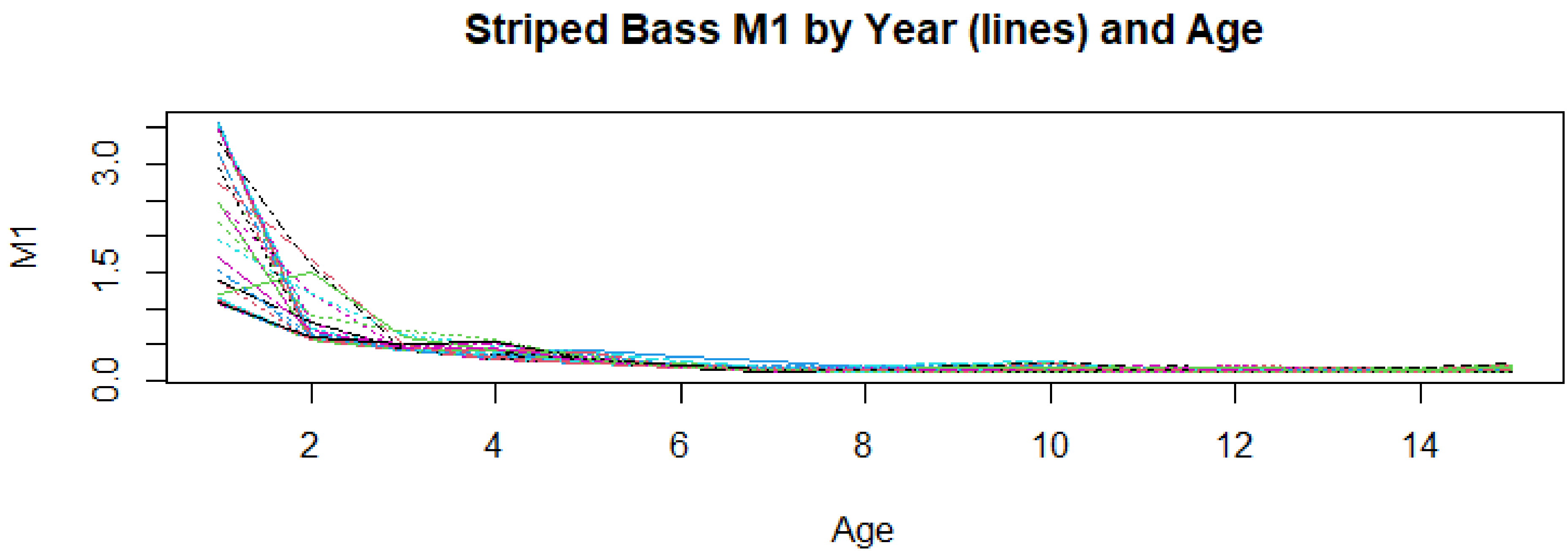
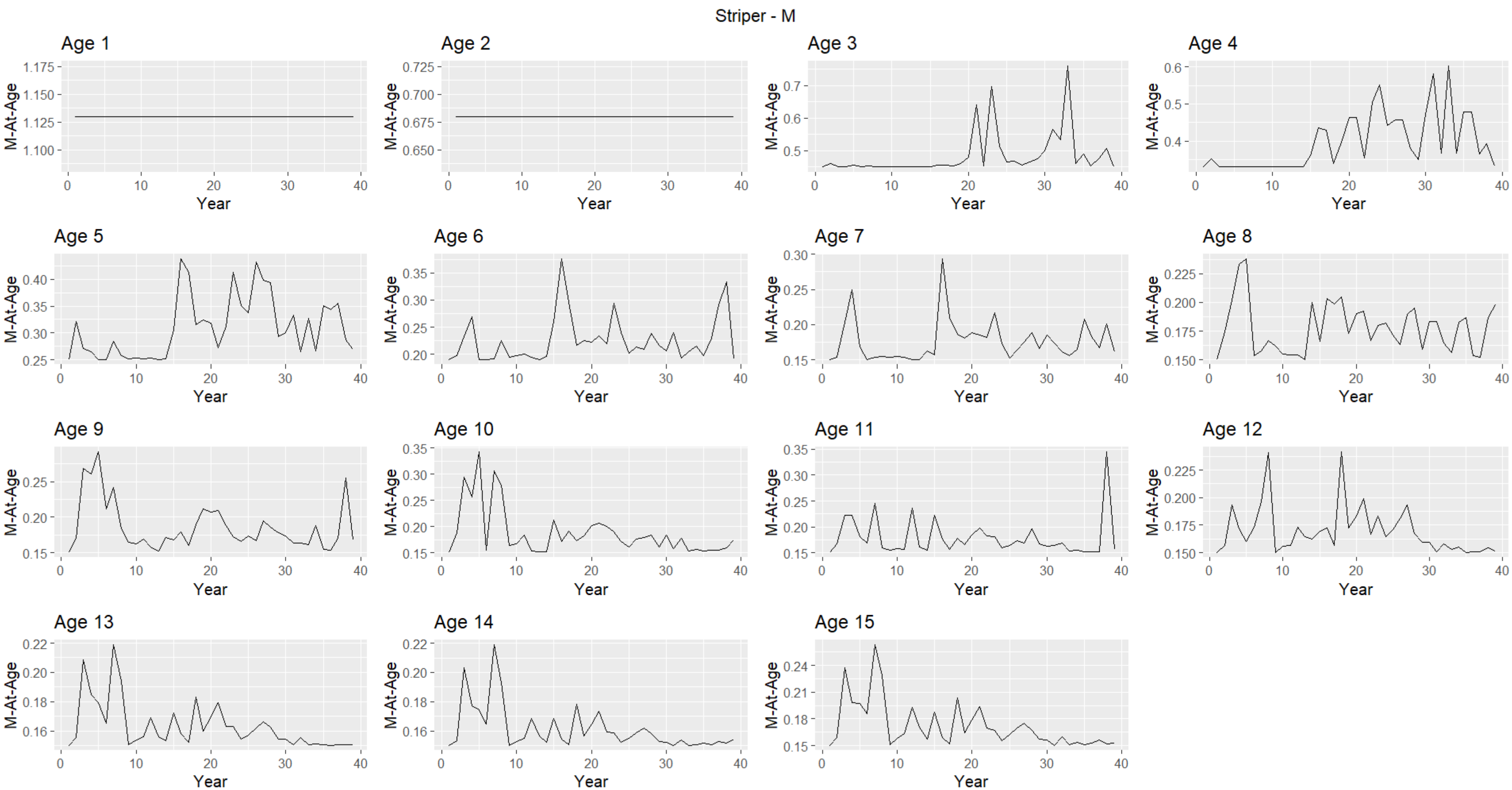
Bottom-Up Feedback



Bottom-Up Feedback



Bottom-Up Feedback



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Bottom-Up Feedback

- Only for STB, all of the constants in the equations are specific to STB so not generalizable

- Additionally, using LAA from otoliths (truncated time series 1998 - 2019), but then WAA from assessment (mix of scales and otoliths)

- For implementation, didn’t use for ages 1 and 2 as Hoenig et al. (2017) only looked at ages 3 – 6

Next Steps and Feedback

- A higher level next step is to complete the recode into RTMB, mainly so I can hand this work off
- There is projection methods for VADER, did not update for this review
- The point of VADER has been to develop a more standard assessment type for the multispecies modeling, is this still valid and worth pursuing?
- Developed a mechanism for variable M for STB, but not truly dynamic, therefore can't produce tradeoff plots without assumptions
  - Should we continue to try and develop this, and if yes
  - Any other ideas beyond what has been tested to date?

Next Steps and Feedback

- A state-space version of Curti's original model was developed but never published, is developing this approach for VADER a logical next step?
  - Could certainly be helpful as a better approach to the residual M1
- Assuming we developed adequate bottom-up feedback in VADER, any thoughts or examples from your experience about how to use the outputs in management?
- Any and all other thoughts that you have for VADER are welcome!