Recreational Fishery Fleet Dynamics Model

Principal Investigators:
Dr. Jason E. McNamee
Deputy Director, RI Department of Environmental Management (RIDEM)

Corinne Truesdale
Principal Biologist, RIDEM Division of Marine Fisheries

Savannah Lewis
Fishery Management Plan Coordinator, Atlantic States Marine Fisheries Commission

September 2021

Introduction
The management alternatives presented are constructed in the context of their eventual application to the specification setting process for summer flounder and black sea bass. The application could also be extended to other species that have recreational management programs such as scup and bluefish. The project is informed by extending work by Dr. John Ward (Ward 2015) on quantifying the historical effects of changes in management measures on discards and harvest. These management effects produced by this work could be integrated into a harvest control rule as a way of emulating fishery responses (and their uncertainty) to summer flounder and black sea bass management measures, to demonstrate the implications of selecting various management configurations and to understand the relative value of different management options

Background
Given the current use of conservation equivalency (CE) and regional approaches in summer flounder and black sea bass management, which allow states or groups of states the ability to use differing recreational management measures provided that state specific harvest falls within pre-specified harvest targets, and the desire to explore new strategies for recreational management at the MidAtlantic Fishery Management Council (MAFMC), it is important to investigate new techniques that may be more effective than this yearly and somewhat ad hoc approach to recreational management. Underlying the current process are the assumptions of similarity between years in the fishery for both fishing behavior and in the population dynamics of summer flounder and black sea bass. The process ignores many dynamic factors including implementation error in the new management procedure, changes to discard rates based on the new management regime, growth in the population of fishers, and inter-annual changes in availability of the resource to anglers. It was noted during the process for Addendum XXVIII that current methods for developing CE measures each year are subject to variability and uncertainty, and the performance of this strategy has not been good historically. Additionally, the process rarely allows for a re-evaluation of the performance of the chosen management in the following year to quantify how the program is working, beyond accounting for harvest limit adjustments that are needed in the following year to meet new management objectives.
This project was designed to develop a new methodology that can perform better over time by accounting for more of the known population dynamics, allowing for transparency in the specification setting process, including the assessment of uncertainty in management choices and thereby allowing for the application of risk tolerances and policies to choices, and allowing for more stability through time in the management program.

Moving from an ad hoc harvest-based approach to setting specifications to a model-based approach may allow for more inter-annual stability in recreational management by not being directly subject to single year swings in Marine Recreational Information Program (MRIP) harvest estimates. The MRIP survey is the method used to collect recreational catch information (see: https://www.fisheries.noaa.gov/topic/recreational-fishing-data). A model-based approach may also better account for important population dynamics that are currently being ignored, such as recreational discards and future changes in availability due to cohort strength. Proposed advantages of a model-based approach are: performance of projections will be enhanced as stability will be increased in specification-setting, thus improving buy-in and knowledge of regulations by the fishing public; and the inclusion of more factors in the model-based projections than the status quo conservation equivalency process, potentially impacting future performance.

The model-based strategies could offer value to managers by providing context of existing versus new recreational management specifications for recreational summer flounder and black sea bass fisheries, thus allowing them to optimize the eventual management regime they select. All of the various options for management specifications will be reviewed at different regional configurations to provide trade-off information with regard to the management unit chosen. Variations of these approaches will also be explored that better use the inherent uncertainty in the system by translating this into uncertainty-based setting of the management program. In other words, the management system will only change if the recreational harvest exceeds or underperforms relative to a threshold of uncertainty that exists in the output from the various models. These offer a potential for enhanced stability in management setting and these approaches better recognize the fact that the harvest estimates and population information are both derived from statistical methods.

To model the effects of management specifications on recreational harvest of black sea bass and summer flounder, we selected an approach using Generalized Additive Models. Generalized Additive Models (GAMs) are extensions of generalized linear models in which the linear predictor incorporates the summation of smooth nonparametric functions of predictor variables (Wood 2006). Thus, the relationship between any of the smoothed predictor variables and the response variable may be nonlinear. As with other GLMs, the response variable may follow any from the exponential family of distributions (Wood 2006). The general structure of the model may be written:

$$g(\mu_i) = \mathbf{X_i}^*\boldsymbol{\Theta} + f_1(x_{1i}) + f_2(x_{2i}) + f_3(x_{3i}, x_{4i}) + ...$$

where

μ_i is the expected value of Y_i, the response variable, and $Y_i \sim$ some exponential family distribution

$\mathbf{X_i}^*$ is a row of the model matrix for strictly parametric model components, $\boldsymbol{\Theta}$ is the vector of associated parameters, and the f_j are smooth functions of the covariates x_k. The smoothing functions are flexible and can use one of several bases including polynomials, cubic splines, thin plate regression splines, and P-splines. Estimation of the model is done via maximum likelihood, with a penalty term based on the second derivatives of the smoothing functions (e.g. penalizing the ‘wiggliness’ of the splines to avoid overfitting).

The advantages of using GAMs over other regression techniques include: straightforward interpretation of marginal effects of the predictors due to the additive structure of the model; the ability to capture nonlinear patterns by fitting smoothers to the data without *a priori* knowledge of their distribution; and the ability to control the wiggliness of the predictor functions to assess the tradeoffs between variance and bias.

Methods

Recreational fishery fleet dynamics model

Crucial to short-term fishery forecasts is a consideration of how changes to recreational management measures such as minimum size, bag limits, and season length affect recreational harvest and discarding rates. A recreational fishery fleet dynamics model was developed that predicts both harvest and discards using the historical MRIP dataset along with an understanding of the management measures in place during the same period of time.

Data
The MRIP dataset uses the newly calibrated MRIP data timeseries (see: https://www.fisheries.noaa.gov/feature-story/fishing-effort-survey-calibrating-recreational-catch-estimates), and the data were queried to produced harvest and discards at a year-state-Wave level of granularity. This dataset of harvest and discards was overlaid with state-year-Wave specific historical management measures dating back to 1993 for the case of summer flounder, and 1998 for black sea bass, the years coastwide recreational management measures were put into place for each of the species. A "Wave" is a term used for two-month time periods within a year (e.g. January through February is Wave 1, March through April is Wave 2, etc.). The state regulations in place were refined to the Wave level. In cases where management plans did not line up well with the existing Wave structure of MRIP, the management that was in place for the majority of the wave was used. In other words, if the bag limit changed within a wave, the bag limit that was in place for the longest amount of time in that Wave was used.

The final dataset includes several metrics broken down by year, state, and Wave. Both landings and discards are in number of fish as estimated by MRIP. Bag limit, minimum size, and season length by year, state, and Wave (where applicable) were compiled from past fishery management plan review information. The recreational harvest limit (RHL) and spawning stock biomass (SSB) were pulled from past stock assessment reports. Additional metrics added include regional groupings, type of management (coastwide, regional, or state by state), and a lagged recruitment value (black sea bass only). To get the lagged recruitment value, age was estimated based on the minimum size of each state in each wave and year using a Von Bertalanffy growth curve. Values for the growth curve came from the 2016 Black Sea Bass Benchmark Stock Assessment (NEFSC, 2016). One year was then subtracted from each age to determine how many years the recruitment value needed to be lagged. The stock assessment estimates recruitment (R) as the number of recruits at age 1. The recruitment value for each row was the recruitment value counted back from the current year by the number of years lagged. For example, if the minimum size of a fish was 12 inches in 2007, then the fish was estimated to be 4 years of age; the number of years to lag recruitment by is 3, and the recruitment value used in year 2007 was from age-1 fish in 2004.

Model structure
From this survey generated catch information, and the knowledge of the management structure in place in each state, a series of Generalized Additive Models (GAMs) were built to model the effects of management on harvest and discards. The "gam" function from the "mgcv" package (Wood 2006) was used in the statistical software R for the analysis (R core team 2021).

By using available information on recreational fishing to evaluate plausible alternatives for these relationships, we can account for uncertainty in the management responses of recreational fishery fleet dynamics. Since a statistical model was used, estimates of uncertainty can also be produced. The estimated uncertainty from these analyses can be used to describe alternate states of nature in the recreational fleet dynamics model when projecting a new series of management measures into the future.

The general form of the recreational fleet dynamics model is:

$$
\begin{aligned}
HarvestorDiscards &= s(Year) + s(Minimum\ Size) + s(Wave) + State + s(SeasonLength) + s(Bag) \\
&+ Recruitment + SpawningStockBiomass + RecreationalHarvestLimit \\
&+ s(MinimumSize, RHL) + s(Bag, RHL) + s(Year, RHL)
\end{aligned}
$$

Where an *s* indicates variables in the GAM that are smoothed, *Year* is the calendar year the harvest and regulations occurred in, *Minimum Size* is the regulatory minimum size in place for each year-state-Wave combination, $Wave$ is the two month period in which the catch occurred as defined by MRIP (waves go from 1 to 6 for the year), $State$ is the state in which the harvest occurred (states of MA – NC were used in the analysis), $SeasonLength$ is the length of the open fishing days in the specific Wave (e.g. days open can go from 1 to 61 or 62 depending on the Wave), Bag is the regulatory bag limit (or number of fish an individual angler is allowed to take on a trip) in the a particular year-state-Wave combination. Other covariates were tested in the model including Recreational Harvest Limit (RHL), Recruitment (lagged by the number of years it would take for the recruit to enter the recreational fishery), and Spawning Stock Biomass (SSB) from the stock assessment (black sea bass: NEFSC 2018; summer flounder: NEFSC 2019). These covariates were tested as elements that could provide information on availability of the stock to anglers, but the SSB covariate did little by way of explaining variability in the model with the exception of the summer flounder discard model. This may be due to the fact that regulations were set based on uncalibrated MRIP data in years past, so the link between this variable and eventual harvest and discards by anglers is confounded by this change in estimation method. Finally, a set of interaction terms were run. These were chosen to help explain some of the changes that were occurring in the fishery over time that may have been counteracting each other, such as decreasing bag limits and increasing minimum size in recreational management as the population was increasing to constrain harvest.

A gamma distribution was selected for the model (with a log link) after model testing, with the gamma distribution performing the best relative to the existing data. Other distributions were considered including Poisson and negative binomial since the harvest and discards are in numbers of fish and therefore discrete, but the gamma distribution offered some of the same attributes such as not dropping below zero and flexibility in the shape of the distribution, and performed best during model testing, so this was the selected distribution for the model.

For the “gam” function, the “REML” method was used for the smoothness selection of the model. Also called “Restricted Maximum Likelihood”, this approach maximizes the scaled average of the likelihood over all possible values for the model parameters to find the variance parameters for the model (Wood 2017). Several bases were considered for the smoothers included in candidate models, including cubic splines, P splines, and low-rank thin plate splines. Ultimately, low-rank thin plate splines (the default basis in the mgcv package) were selected as the base for the smoothers, as this method does not require knots to be equidistantly placed over the range of the data, and—unlike other bases—can be used to represent smooths of more than one predictor (Wood 2006; Perperoglou et al. 2019).

Separate models were developed for harvest and discards.

Given the level of refinement in the dataset, the general model can be applied to the coast, can be run as a stand-alone state specific model, and can be run as different regional configurations. It can also be run in a retrospective fashion to predict previous years to determine model performance. These all lead to flexibility in this model as a management tool, allowing for changes to occur through time, while allowing a consistent underlying method to be used even with these changes.

In addition to the estimated mean prediction, a function was used that samples from the uncertainty within the model to produce an observation, or a single estimate within the envelop of uncertainty in the model. This function simulates data from a multivariate normal distribution conditioned on the covariance matrix from the GAM model. This function is used to produce a single observation over multiple realizations for use in projecting the outcome of a specific regulatory set up (bag limit, minimum size, and season length set up) and helps to understand the uncertainty that is possible within this single management choice.

Model testing
A series of nested models based on the general model described above and all working from the same dataset were tested (Tables 5 - 8). In addition to various combinations of covariates and interaction terms, variations on the number of knots (the upper limit of the amount of complexity of model to be fitted), smoothing methods, and interaction methods were also tested. The models were all compared via Akaike information criterion (AIC) using the AIC function in R.

The final models had the following form:

Black sea bass:

$$Harvest = Year + s(Minimum\ Size) + s(Wave) + State + s(SeasonLength) + s(Bag) + Recruitment + s(Bag, RHL) + s(Year, RHL) + RHL$$

$$Discards = Year + s(Minimum\ Size) + s(Wave) + State + s(Bag) + s(Bag, RHL) + s(Year, RHL)$$

Summer flounder:

$$Harvest = Year + s(Minimum\ Size) + s(Wave) + State + s(SeasonLength) + s(Bag) + s(Minimum\ Size, RHL) + s(Year, RHL)$$

$$Discards = Year + s(Minimum\ Size) + s(Wave) + State + s(SeasonLength) + s(Bag) + SSB + s(Year, RHL)$$

Evaluating performance
Several diagnostics were run on the models. The first was to examine the statistical table and the effect plots from the models. This was done to determine the statistical significance of the effects as well as examining that the effects were logical.

An additional set of diagnostics were run through the gam.check function in the mgcv package. This function plots four standard diagnostic plots, some smoothing parameter estimation convergence information, and the results of tests which may indicate if the smoothing basis dimension for a term is too low. The four plots are various residual plots. Please refer to the package documentation for the specifics on the various tests, but suffice it to say, the diagnostic analysis is less straight forward than traditional glm interpretation, therefore care is needed when interpreting these diagnostics.

A final analysis was done to determine the efficacy of the approach. Given that the model is conditioned on the existing historical dataset, a retrospective analysis can be done to determine if the model can recreate previous MRIP estimates. This was accomplished by creating a prediction dataframe based on the exact bag limit, minimum size, and minimum size that were in place in the states during the year being analyzed. The final model was then run 1,000 times sampling from the posterior uncertainty in the model. The prediction and the actual summed landings for the year being analyzed are then overlayed on top of each other for examination.

Results

Recreational fishery fleet dynamics model

Output from the recreational fishery fleet dynamics model indicated logical outcomes from the effects of the historical management measures. In general, harvest increased when regulations were liberalized (e.g. increased season length or RHL) and harvest decreased when regulations were made more restrictive (Table 1 and Figure 1, 1a). There were some counterintuitive effects, which was the reason for incorporating some of the interaction terms. Generally, the final model effects appear to align with the understanding of what these various effects should be having on landings and discards.

The effect of Wave within the model was also logical, increasing both harvest and discards from spring with a peak in the summer and then decreasing into the fall and winter. And finally, the effect of the different states on harvest and discards also made intuitive sense in that large states with high levels of fishing for summer flounder and black sea bass had the strongest effect (e.g. NY and NJ) while smaller states with less fishing had negative effects (e.g. DE and MD), all of which were relative to the reference state of CT (Tables 1 and 2, and Figures 1, 1a and 3, 3a).

The model diagnostics are largely good for both the harvest and discard models. Residuals are generally normally distributed with a mean of zero, though there is some degree of a positive tail for both the harvest and discard models depending on the species. There is no patterning in the residuals, therefore they appear to be random with even variance across the range (Figures 2, 4, 11, and 13). The diagnostics on the number of knots used also appear to be adequate with non-significant findings for most of the variables with the exception of the black sea bass discard model (Table 2 and 4). Varying the number of knots was tested, but this diagnostic was not able to be improved for the black sea bass discard model.

Bag limit is statistically significant, but only has minor effects on harvest and discards (Tables 1 and 2, Figures 1, 3, 10, 12). The effect was different depending on the species, but generally has only a weak effect on the models. Some of the effects were counter intuitive so the interaction was included in the models as it may be that bag limits were being driven down as landings kept increasing as a way to try and constrain harvest, particularly in the northern states. The effect of the interaction basically flattens the effect out, indicating that bag limit is not a strong management tool for these species.

Season length is also significant in some cases (Tables 1 and 2) and generally had a positive effect on harvest and discards, meaning as season length increases, so does harvest and discards (Figures 1, 10, and 12), though tends to plateau at a threshold of open days.

A retrospective analysis was done to look at the performance of the model relative to years past. A five-year retrospective analysis was performed where the management measures in place for each of the past years was used to predict the harvest in that same past year, and then this model prediction was compared to the actual harvest estimate produced by the MRIP program in that year. Figures 8, 9, 14, and 15 show the results of the retrospective analysis. What can be seen is that the model largely is able to predict, within the range of uncertainty in the predictions, the observed MRIP harvest estimate for that year.

Discussion

One of the key features of this work was the development of the recreational fleet dynamics model that can be used for management purposes. The model appears to perform well relative to being able to predict within the range of the MRIP estimates, and the output from the model is in line with the logical outcome of different management changes. The recreational fleet dynamics model has benefits to the overall management program for the recreational summer flounder and black sea bass fisheries in that this approach can be used as a new tool in the year to year management of this fishery versus the current approach of independently analyzing the effects of the different management options (e.g. bag limit, season length, and minimum size). The modeling approach developed in this project could be preferred as it can more rigorously account for the interactions between these different measures in a more synthetic way, it is based off of empirical information not just from the most recent years but from all years in the time series, it is a single tool that can be used consistently by all states involved, and it has the attribute of generating uncertainty estimates, which is critical if the objective of regulatory stability is favored by managers. This tool can also be used in the development of the so called "Harvest Control Rule" approach to recreational management in that it can be used a priori to set the various steps in the management system in a way that accounts for uncertainty, and gets the fishery in to a range that will align with the needed harvest limits given current stock status.

Changes will need to be made to the existing management process to accommodate the findings of this work. There is currently a need to adjust annually to make sure harvest is remaining under the RHL. In more recent time, there has been some move to incorporate some flexibility in to the process by allowing for some subjective use of the uncertainty in the harvest estimate from MRIP, so there is some precedent to incorporating a technique like that highlighted by this work. The approach should be further refined and made more systematic by incorporating a control rule structure around the process. The following is an example of an approach that could be used as a control rule in the recreational fishery for summer flounder or black sea bass, and with proper development, could be extended to other similar recreational fisheries:

1. Determine spatial extent to be used (state-by-state, regional, coastwide)
2. Use the recreational fleet dynamics model to estimate harvest for the current fishing year (conversely, the direct estimate from MRIP could be used with its internally estimated uncertainty bounds)
3. If the RHL for the given spatial extent falls within the 95% confidence bounds of the estimated harvest in year t, do not change regulations, otherwise,
4. If the RHL for the given spatial extent falls outside of the 95% confidence bounds of the estimated harvest in year t:
    a. Generate a harvest estimate for year t+1 using the recreational fleet dynamics model for the appropriate spatial extent
    b. Modify the regulatory parameters in the model until the estimated year t+1 harvest includes the RHL within its 95% confidence bounds
5. Set the result from step 3 or 4 as the management program in year t+1, and repeat the process at the end of year t+1

This control rule maintains an annual process, however regulations may or may not change in any given year based on the current year's harvest and uncertainty estimates. Modifications could include increasing or decreasing the 95% confidence bounds to some other value based on the Councils risk tolerance, increasing the time step to something other than 1 year to enact the process, and changing from harvest estimates to catch estimates in an effort to account for mortality that includes discards rather than only harvest.

Overall this approach appears to be effective and can provide a better alternative to the current management strategy being used for the two species examined in this work. The application could be extended to other fisheries as well, namely bluefish and scup.

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Table 1 – Model output from the recreational fishery fleet dynamics GAM for the harvest model
Black Sea Bass:

```
Family: Gamma
Link function: log

Formula:
x ~ Year + s(MinLen, k = 4) + s(Wave, k = 5, bs = "cc") +
    State + s(SeasonLen, k = 4) + s(Bag_trunc, k = 5) + LagRecruit +
    te(Bag_trunc, RHL, bs = "fs", k = 6) + s(Year, RHL,
    bs = "fs", k = 5)

Parametric coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)          0.000e+00  0.000e+00      NA       NA
Year                 4.886e-03  1.053e-04  46.402  < 2e-16 ***
StateDELAWARE        7.432e-01  2.459e-01   3.022 0.002603 **
StateMARYLAND        6.643e-01  2.466e-01   2.693 0.007245 **
StateMASSACHUSETTS   1.040e+00  2.682e-01   3.877 0.000116 ***
StateNEW JERSEY      2.796e+00  2.431e-01  11.503  < 2e-16 ***
StateNEW YORK        1.882e+00  2.408e-01   7.815 2.06e-14 ***
StateNORTH CAROLINA -1.284e+00  2.521e-01  -5.092 4.58e-07 ***
StateRHODE ISLAND    3.489e-01  2.337e-01   1.493 0.135973
StateVIRGINIA        8.650e-01  2.452e-01   3.528 0.000446 ***
LagRecruit           4.655e-07  2.557e-06   0.182 0.855602
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                    edf Ref.df      F  p-value
s(MinLen)         2.000  2.255  6.396 0.000905 ***
s(Wave)           2.907  3.000 33.443  < 2e-16 ***
s(SeasonLen)      2.480  2.784  6.716 0.000252 ***
s(Bag_trunc)      1.002  1.003  2.515 0.113466
te(Bag_trunc,RHL) 8.588 30.000  0.771 0.000943 ***
s(Year,RHL)       2.002  2.003  5.561 0.004012 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Rank: 57/58
R-sq.(adj) =  0.407   Deviance explained =   49%
-REML = 8400.7  Scale est. = 1.7766    n = 718
```

Summer Flounder:

```
Family: Gamma
Link function: log

Formula:
x ~ Year + s(MinLen, k = 4) + s(Wave, k = 5, bs = "cc") +
    State + s(SeasonLen, k = 4) + s(Bag, k = 5) + te(MinLen,
    RHL, bs = "fs", k = 5) + s(Year, RHL, bs = "fs",
    k = 5)

Parametric coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.000e+00  0.000e+00      NA       NA
Year         5.454e-03  5.637e-05  96.759  < 2e-16 ***
StateDE     -5.077e-01  1.495e-01  -3.395 0.000722 ***
StateMA     -1.095e-01  1.611e-01  -0.680 0.497003
StateMD     -3.843e-01  1.531e-01  -2.510 0.012297 *
StateNC      2.721e-01  1.618e-01   1.681 0.093150 .
StateNJ      2.333e+00  1.562e-01  14.934  < 2e-16 ***
StateNY      1.777e+00  1.573e-01  11.296  < 2e-16 ***
StateRI      1.155e-01  1.571e-01   0.735 0.462435
StateVA      1.349e+00  1.472e-01   9.162  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                  edf Ref.df       F  p-value
s(MinLen)       1.034  1.046   0.029    0.938
s(Wave)         2.952  3.000 160.919  < 2e-16 ***
s(SeasonLen)    1.687  2.032   0.512    0.570
s(Bag)          1.001  1.002   5.932    0.015 *
te(MinLen,RHL) 7.402 21.000   1.359 1.84e-05 ***
s(Year,RHL)     2.003  2.005  22.144  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Rank: 47/48
R-sq.(adj) =  0.728   Deviance explained = 65.2%
-REML = 9720.8  Scale est. = 0.86553   n = 777
```

Table 2 – Model output from the recreational fishery fleet dynamics GAM for the discard model
Black Sea Bass:

```
Family: Gamma
Link function: log

Formula:
x ~ Year + s(MinLen, k = 4) + s(Wave, k = 5, bs = "cc") +
    State + s(Bag_trunc, k = 5) + te(Bag_trunc, RHL, bs = "fs",
    k = 6) + s(Year, RHL, bs = "fs", k = 5)

Parametric coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)          0.000e+00  0.000e+00      NA       NA
Year                 5.395e-03  6.324e-05  85.309  < 2e-16 ***
StateDELAWARE        1.348e+00  1.694e-01   7.954 7.03e-15 ***
StateMARYLAND        1.928e+00  1.689e-01  11.417  < 2e-16 ***
StateMASSACHUSETTS   6.439e-01  1.993e-01   3.231  0.00129 **
StateNEW JERSEY      3.146e+00  1.678e-01  18.745  < 2e-16 ***
StateNEW YORK        1.996e+00  1.670e-01  11.952  < 2e-16 ***
StateNORTH CAROLINA  1.838e-01  1.704e-01   1.079  0.28108
StateRHODE ISLAND   -7.656e-02  1.623e-01  -0.472  0.63720
StateVIRGINIA        2.122e+00  1.681e-01  12.620  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                     edf Ref.df       F  p-value
s(MinLen)          2.685  2.881  11.721 8.05e-05 ***
s(Wave)            2.971  3.000 254.206  < 2e-16 ***
s(Bag_trunc)       1.005  1.006  13.629 0.000243 ***
te(Bag_trunc,RHL) 14.953 30.000   2.819  < 2e-16 ***
s(Year,RHL)        3.451  3.758   7.652 1.01e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Rank: 53/54
R-sq.(adj) =  -0.0377   Deviance explained = 61.7%
-REML = 9988.8  Scale est. = 0.94714   n = 753
```

Summer Flounder:

```
Family: Gamma
Link function: log

Formula:
x ~ Year + s(MinLen, k = 4) + s(Wave, k = 5, bs = "cc") +
    State + s(SeasonLen, k = 4) + s(Bag, k = 5) + SSB + s(Year,
    RHL, bs = "fs", k = 5)

Parametric coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.000e+00  0.000e+00      NA       NA
Year         5.361e-03  2.842e-04  18.865  < 2e-16 ***
StateDE      6.621e-02  1.648e-01   0.402  0.68807
StateMA     -5.112e-01  1.905e-01  -2.683  0.00751 **
StateMD      8.699e-01  1.713e-01   5.078 5.22e-07 ***
StateNC     -2.134e+00  2.123e-01 -10.054  < 2e-16 ***
StateNJ      3.034e+00  1.570e-01  19.323  < 2e-16 ***
StateNY      2.301e+00  1.581e-01  14.560  < 2e-16 ***
StateRI     -2.461e-01  1.707e-01  -1.441  0.15004
StateVA      2.124e+00  1.647e-01  12.893  < 2e-16 ***
SSB         -2.303e-05  1.112e-05  -2.071  0.03880 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
               edf Ref.df       F  p-value
s(MinLen)    2.225  2.632   8.468 0.000469 ***
s(Wave)      2.976  3.000 192.076  < 2e-16 ***
s(SeasonLen) 2.490  2.804   7.018 0.000133 ***
s(Bag)       1.791  2.235   0.133 0.804725
s(Year,RHL)  3.722  3.936   5.558 0.000232 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Rank: 27/28
R-sq.(adj) =  0.809   Deviance explained = 75.3%
-REML = 6686.2  Scale est. = 0.82874   n = 577
```

Table 3 – Model diagnostic output from the recreational fishery fleet dynamics GAM for the harvest model

Black Sea Bass:

```
Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-0.0009723059,0.0003479933]
(score 8400.707 & scale 1.776635).
Hessian positive definite, eigenvalue range [0.000558008,491.2257].
Model rank =  57 / 58

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                      k'   edf k-index p-value
s(MinLen)           3.00  2.00    0.87    0.61
s(Wave)             3.00  2.91    0.86    0.51
s(SeasonLen)        3.00  2.48    0.88    0.73
s(Bag_trunc)        4.00  1.00    0.88    0.70
te(Bag_trunc,RHL) 30.00  8.59    0.82    0.08 .
s(Year,RHL)         4.00  2.00    0.84    0.23
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Summer Flounder:

```
Method: REML   Optimizer: outer newton
full convergence after 7 iterations.
Gradient range [-0.0009487794,0.0001764516]
(score 9720.797 & scale 0.8655304).
Hessian positive definite, eigenvalue range [2.005894e-05,478.1122].
Model rank =  47 / 48

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                   k'   edf k-index p-value
s(MinLen)        3.00  1.03    0.83   0.005 **
s(Wave)          3.00  2.95    0.89   0.125
s(SeasonLen)     3.00  1.69    0.87   0.055 .
s(Bag)           4.00  1.00    0.92   0.425
te(MinLen,RHL) 21.00  7.40    0.96   0.825
s(Year,RHL)      4.00  2.00    0.96   0.800
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Table 4 – Model diagnostic output from the recreational fishery fleet dynamics GAM for the discard model

Black Sea Bass:

```
Method: REML   Optimizer: outer newton
full convergence after 7 iterations.
Gradient range [-0.0007208378,0.001058024]
(score 9988.771 & scale 0.9471355).
Hessian positive definite, eigenvalue range [0.0005264361,484.9342].
Model rank =  53 / 54

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                      k'   edf k-index p-value    
s(MinLen)           3.00  2.69    0.80  <2e-16 ***
s(Wave)             3.00  2.97    0.74  <2e-16 ***
s(Bag_trunc)        4.00  1.00    0.82   0.005 ** 
te(Bag_trunc,RHL) 30.00 14.95    0.86   0.090 .  
s(Year,RHL)         4.00  3.45    0.91   0.500    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Summer Flounder:

```
Method: REML   Optimizer: outer newton
full convergence after 8 iterations.
Gradient range [-0.003673198,0.006679361]
(score 6686.187 & scale 0.8287427).
Hessian positive definite, eigenvalue range [0.05396554,347.666].
Model rank =  27 / 28

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

                k'  edf k-index p-value  
s(MinLen)    3.00 2.22    0.86    0.02 *
s(Wave)      3.00 2.98    0.89    0.17  
s(SeasonLen) 3.00 2.49    0.90    0.22  
s(Bag)       4.00 1.79    0.89    0.17  
s(Year,RHL)  4.00 3.72    0.92    0.40  
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Table 5 – Model testing configurations with associated AIC scores for the black sea bass harvest model

Model	Yr	Min Size	Wave	State	Open Days	Bag	Recr	SSB	RHL	Interaction: Min Size * RHL	Interaction: Bag * RHL	Interaction: Year * RHL	AIC
1	X	X	X	X	X	X	X	X	X	X	X	X	16769
2	X	X	X	X	X	X	X	X	X	X	X		16769
3	X	X	X	X	X	X	X	X	X	X			16780
4	X	X	X	X	X	X	X	X	X				16780
5	X	X	X	X	X	X	X	X					16781
6	X	X	X	X	X	X	X						16779
7	X	X	X	X	X	X							16778
8	X	X	X	X	X								16787
9	X	X	X	X									16795
10	X	X	X										17191
11	X	X											17293
12	X												17324
Final	X	X	X	X	X	X	X				X	X	16759

Table 6 – Model testing configurations with associated AIC scores for the black sea bass discard model

Model	Yr	Min Size	Wave	State	Open Days	Bag	Recr	SSB	RHL	Interaction: Min Size * RHL	Interaction: Bag * RHL	Interaction: Year * RHL	AIC
1	X	X	X	X	X	X	X	X	X	X	X	X	19929
2	X	X	X	X	X	X	X	X	X	X	X		19929
3	X	X	X	X	X	X	X	X	X	X			19967
4	X	X	X	X	X	X	X	X	X				19974
5	X	X	X	X	X	X	X	X					19998
6	X	X	X	X	X	X	X						19996
7	X	X	X	X	X	X							19999
8	X	X	X	X	X								20023
9	X	X	X	X									20026
10	X	X	X										20454
11	X	X											20742
12	X												20749
Final	X	X	X	X		X					X	X	19933

Table 7 – Model testing configurations with associated AIC scores for the summer flounder harvest model

Model	Yr	Min Size	Wave	State	Open Days	Bag	SSB	RHL	Interaction: Min Size * RHL	Interaction: Bag * RHL	Interaction: Year * RHL	AIC
1	X	X	X	X	X	X	X	X	X	X	X	19405
2	X	X	X	X	X	X	X	X	X	X		19405
3	X	X	X	X	X	X	X	X	X			19405
4	X	X	X	X	X	X	X	X				19404
5	X	X	X	X	X	X	X					19402
6	X	X	X	X	X	X						19403
8	X	X	X	X	X							19404
9	X	X	X	X								19402
10	X	X	X									20044
11	X	X										20282
12	X											20319
Final	X	X	X	X	X	X			X		X	19406

Table 8 – Model testing configurations with associated AIC scores for the summer flounder discard model

Model	Yr	Min Size	Wave	State	Open Days	Bag	SSB	RHL	Interaction: Min Size * RHL	Interaction: Bag * RHL	Interaction: Year * RHL	AIC
1	X	X	X	X	X	X	X	X	X	X	X	13312
2	X	X	X	X	X	X	X	X	X	X		13313
3	X	X	X	X	X	X	X	X	X			13312
4	X	X	X	X	X	X	X	X				13312
5	X	X	X	X	X	X	X					13311
6	X	X	X	X	X	X						13314
8	X	X	X	X	X							13312
9	X	X	X	X								13325
10	X	X	X									14054
11	X	X										12244
12	X											14264
Final	X	X	X	X	X	X	X				X	13310

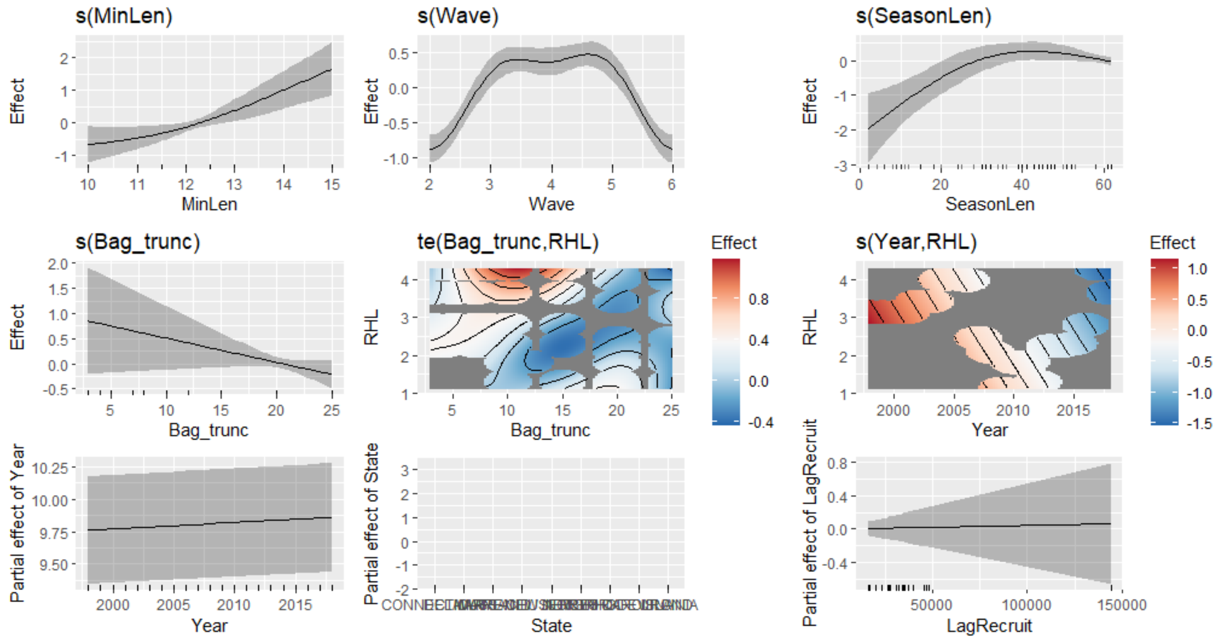

Figure 1 – Output on the covariate effects from the recreational fishery fleet dynamics GAM for the black sea bass harvest model.

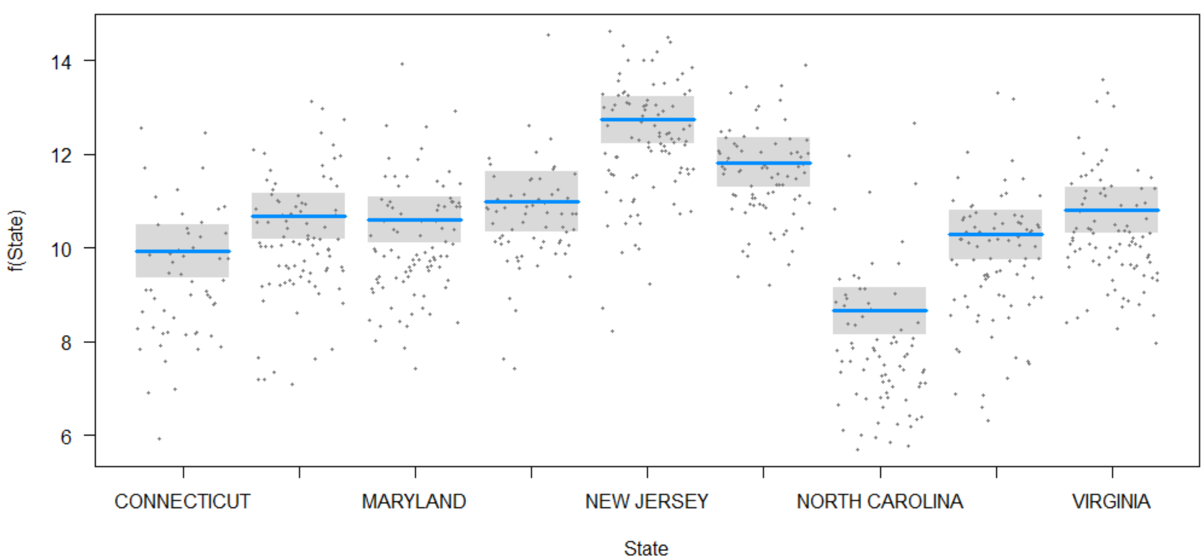

Figure 1a - Output on the covariate effects from the recreational fishery fleet dynamics GAM for the black sea bass harvest model, just partial effects of State.

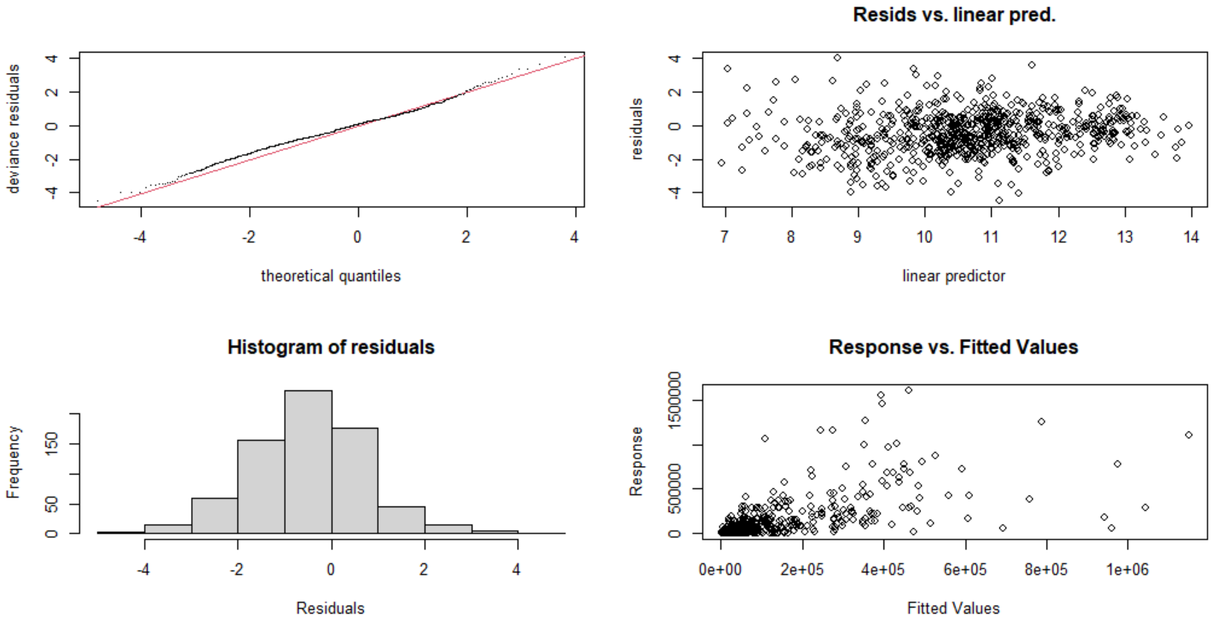

Figure 2 – Model diagnostics for the recreational fishery fleet dynamics GAM for the black sea bass harvest model.

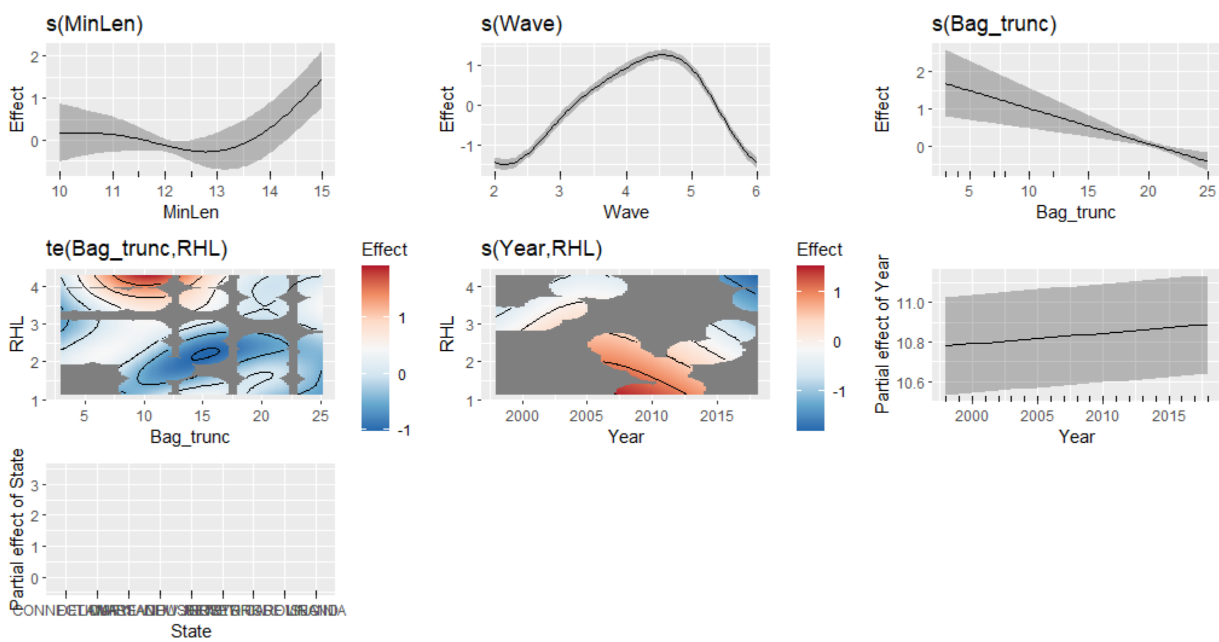

Figure 3 – Output on the covariate effects from the recreational fishery fleet dynamics GAM for the black sea bass discard model.

Figure 3a - Output on the covariate effects from the recreational fishery fleet dynamics GAM for the black sea bass discard model, just partial effects of State.

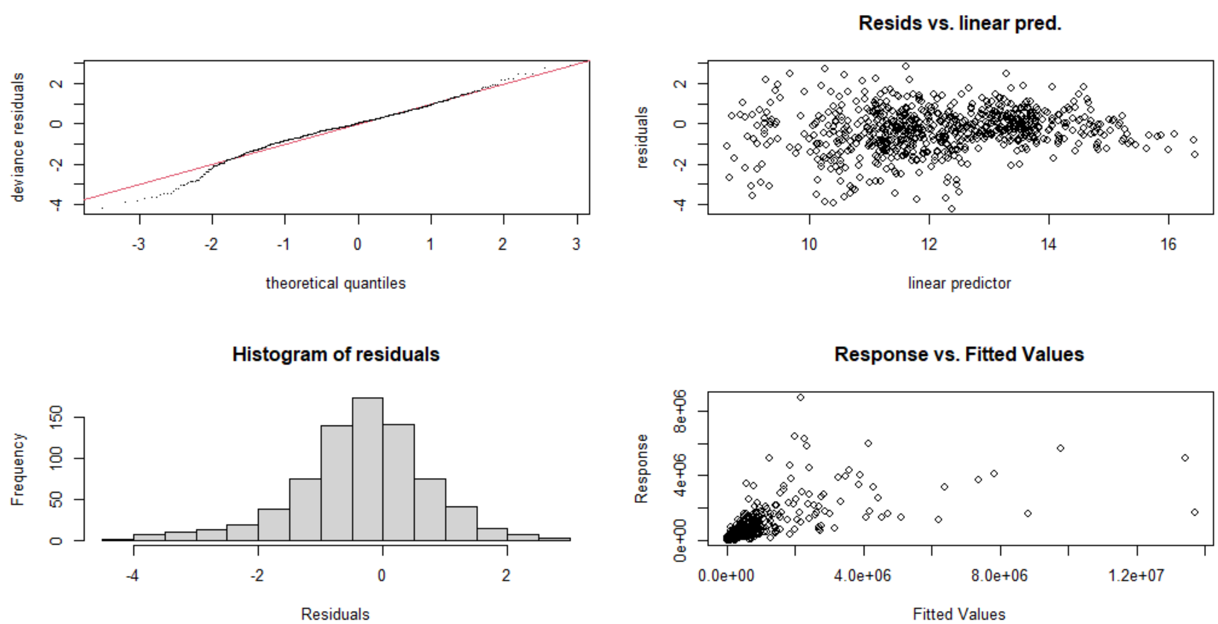

Figure 4 – Model diagnostics for the recreational fishery fleet dynamics GAM for the black sea bass discard model.

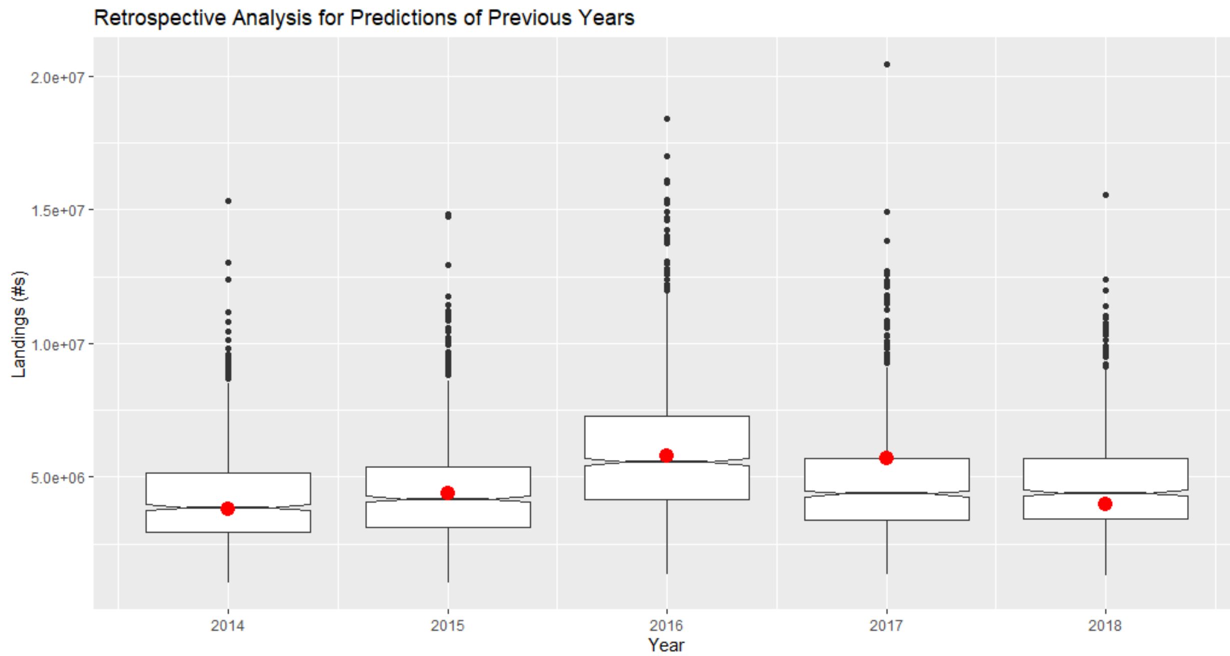

Figure 8 – Retrospective analysis using simulated data from the black sea bass GAM and comparing it to MRIP black sea bass harvest estimate for years 2014 - 2018. The box and whisker plot is the model estimate with uncertainty and the red dot is the “observed” MRIP estimate.

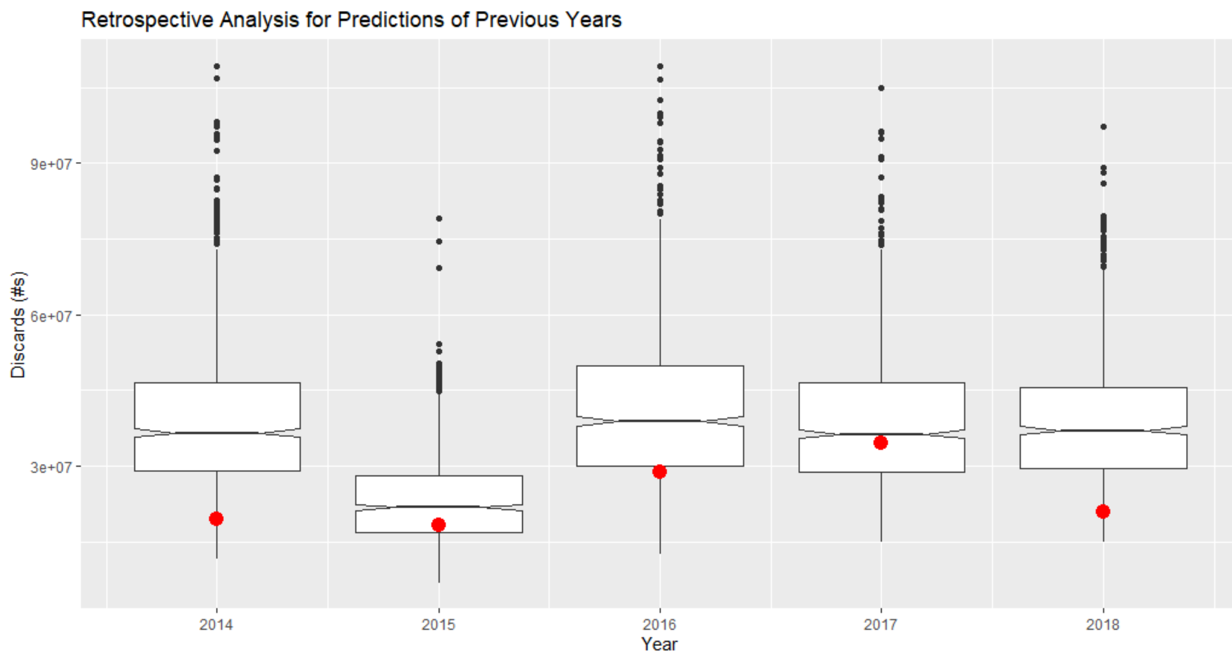

Figure 9 – Retrospective analysis using simulated data from the black sea bass GAM and comparing it to MRIP black sea bass discard estimate for years 2014 - 2018. The box and whisker plot is the model estimate with uncertainty and the red dot is the "observed" MRIP estimate.

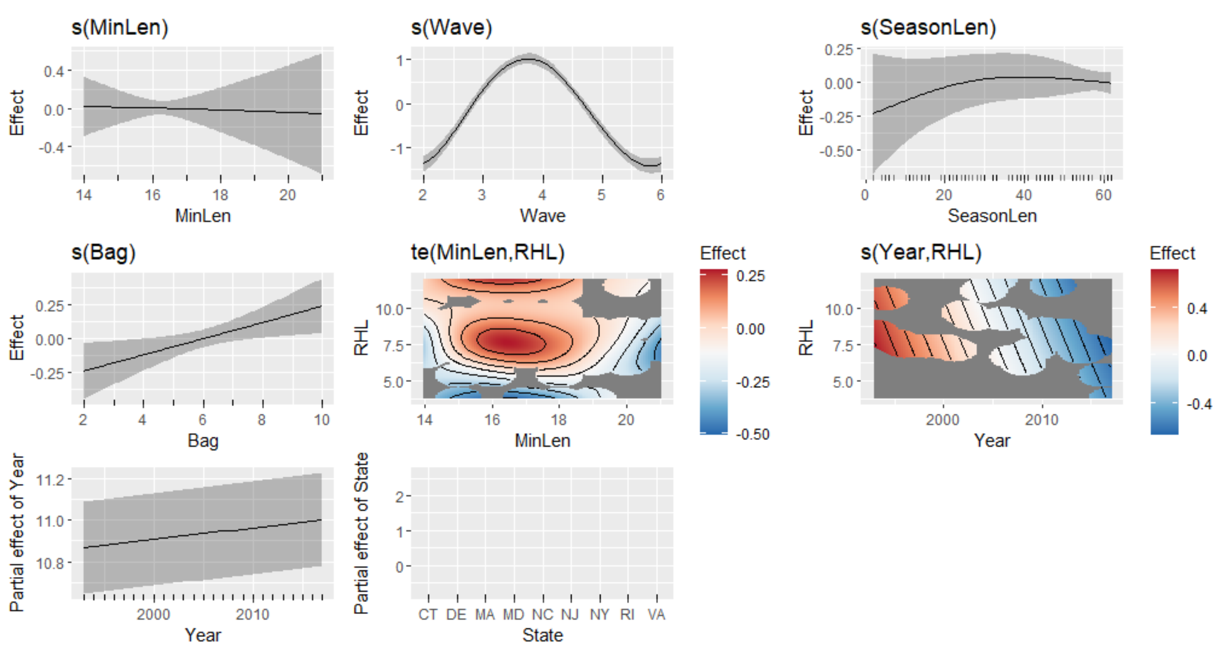

Figure 10 – Output on the covariate effects from the recreational fishery fleet dynamics GAM for the summer flounder harvest model.

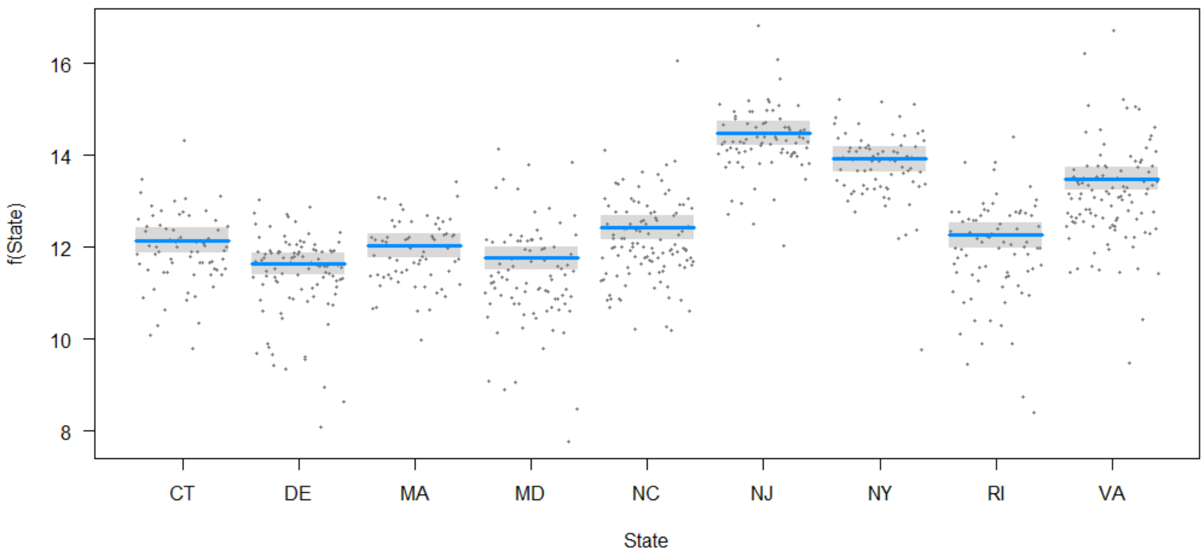

Figure 10a - Output on the covariate effects from the recreational fishery fleet dynamics GAM for the summer flounder harvest model, just partial effects of State.

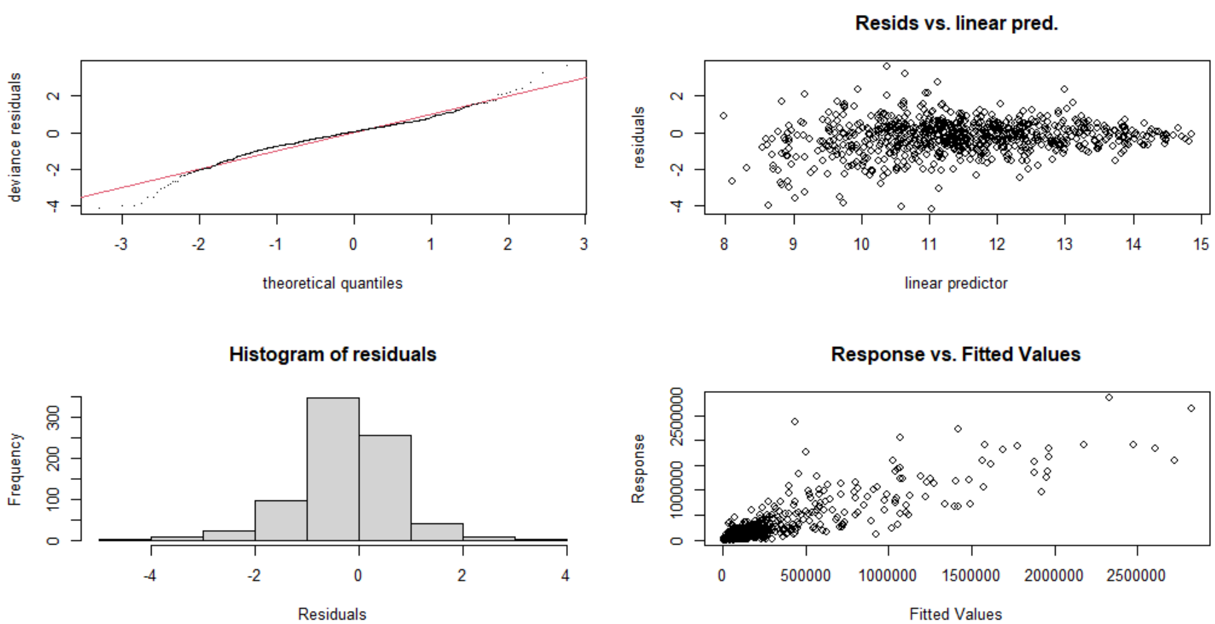

Figure 11 – Model diagnostics for the recreational fishery fleet dynamics GAM for the summer flounder harvest model.

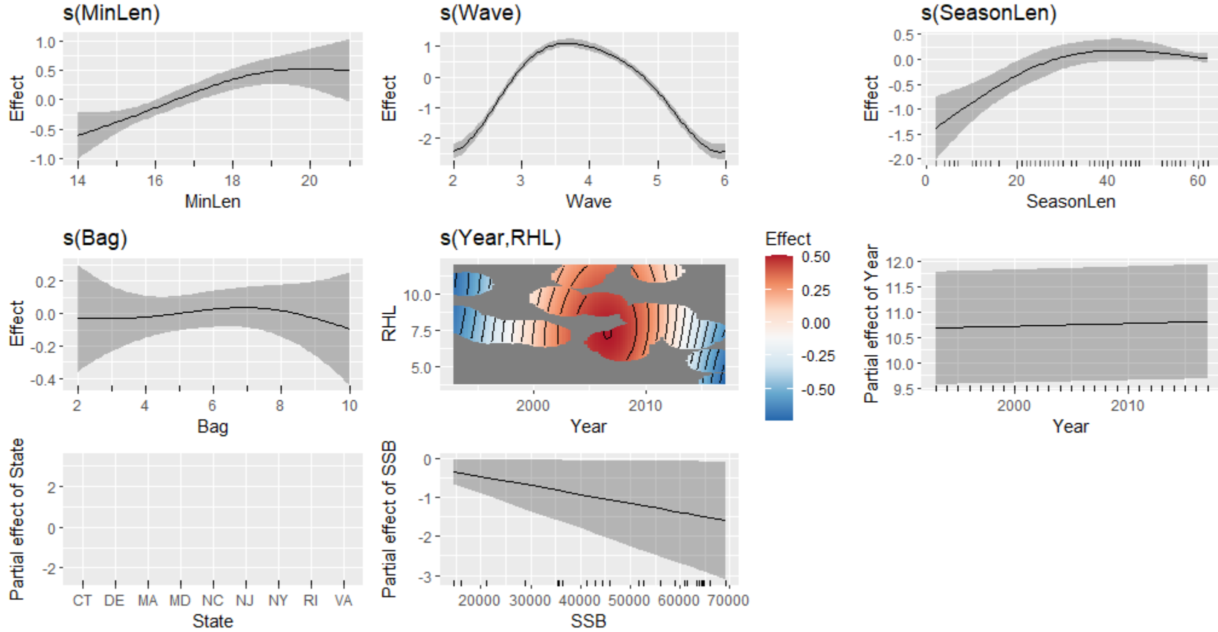

Figure 12 – Output on the covariate effects from the recreational fishery fleet dynamics GAM for the summer flounder discard model.

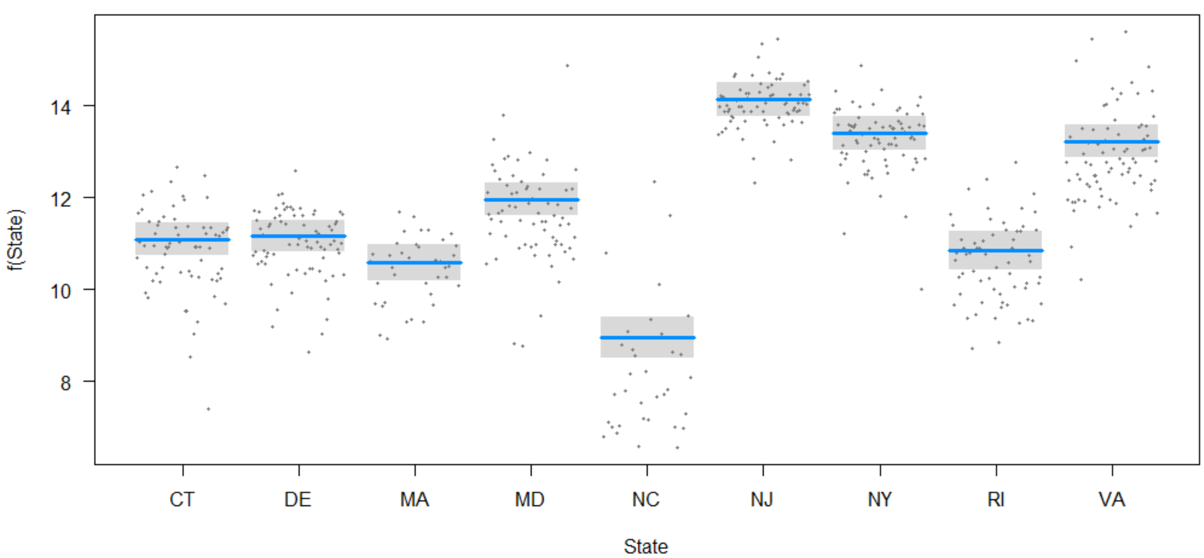

Figure 12a - Output on the covariate effects from the recreational fishery fleet dynamics GAM for the summer flounder discard model, just partial effects of State.

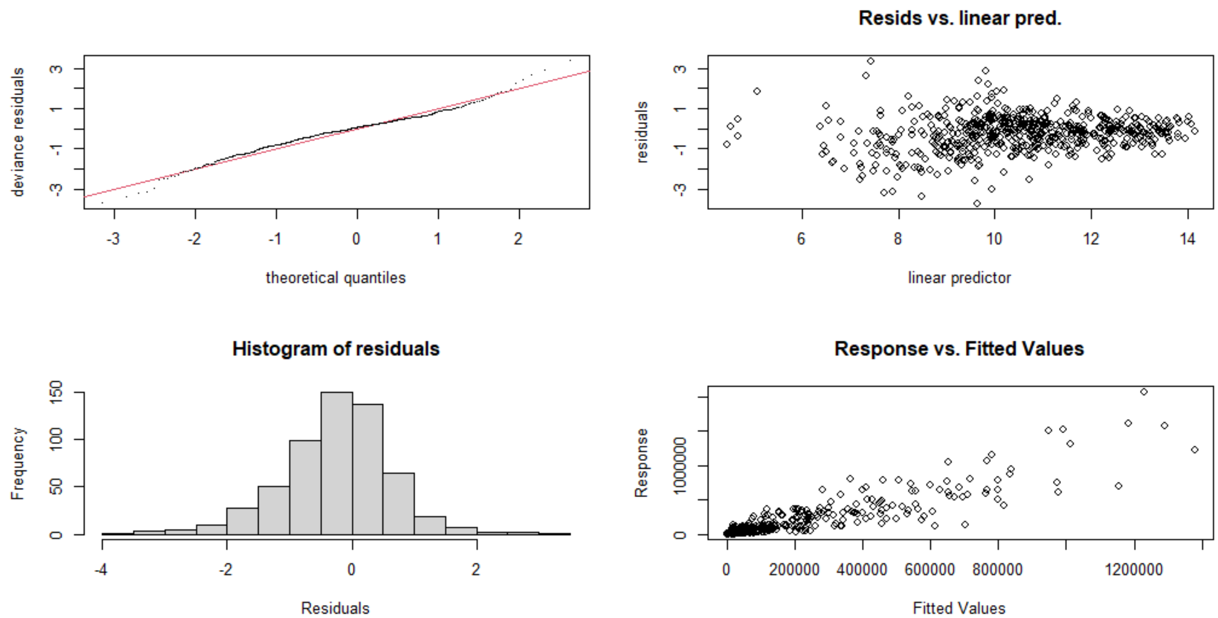

Figure 13 – Model diagnostics for the recreational fishery fleet dynamics GAM for the summer flounder discard model.

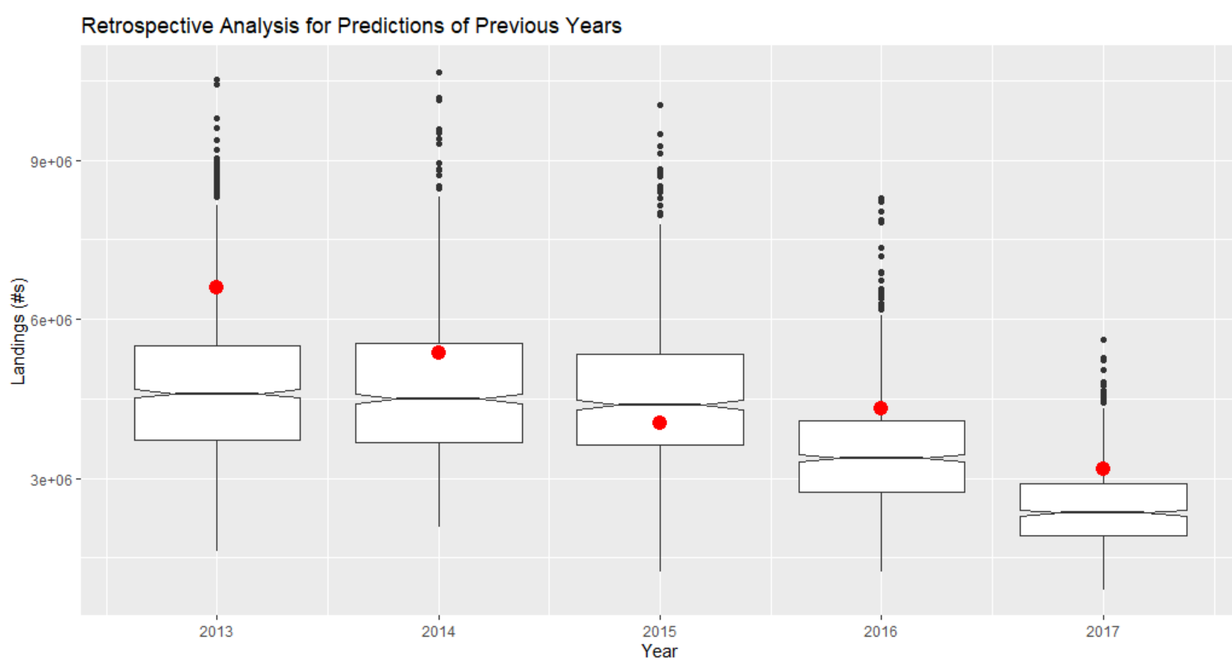

Figure 14 – Retrospective analysis using simulated data from the summer flounder GAM and comparing it to MRIP summer flounder harvest estimate for years 2014 - 2018. The box and whisker plot is the model estimate with uncertainty and the red dot is the "observed" MRIP estimate.

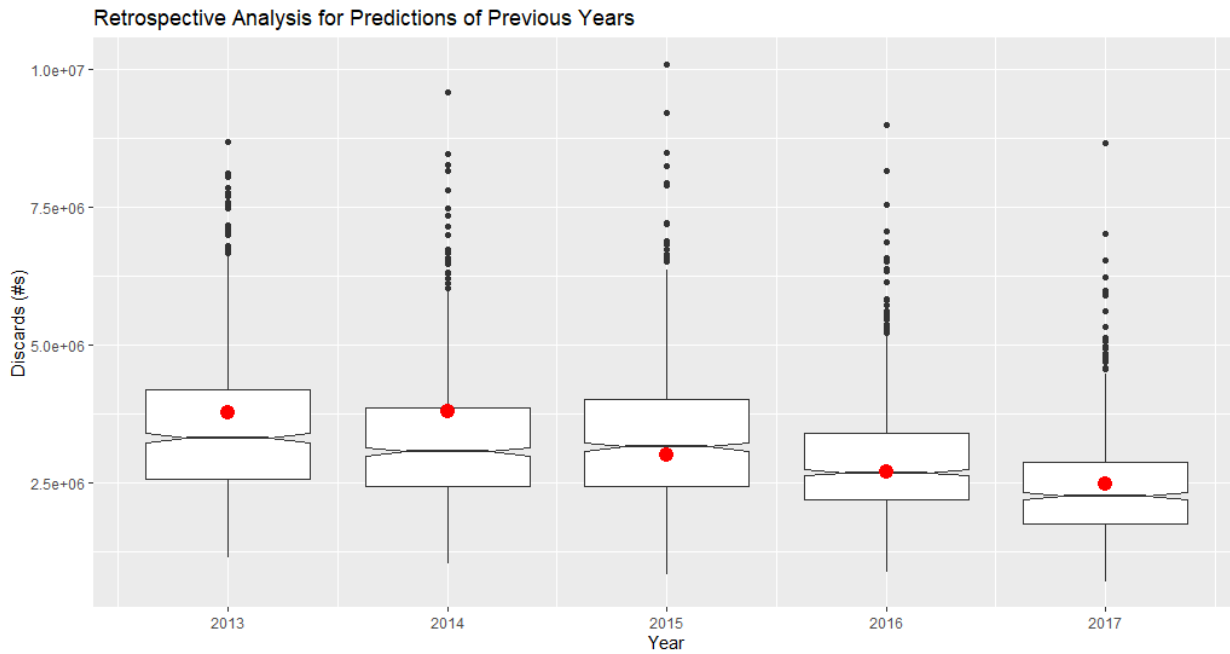

Figure 15 – Retrospective analysis using simulated data from the summer flounder GAM and comparing it to MRIP summer flounder discard estimate for years 2014 - 2018. The box and whisker plot is the model estimate with uncertainty and the red dot is the "observed" MRIP estimate.