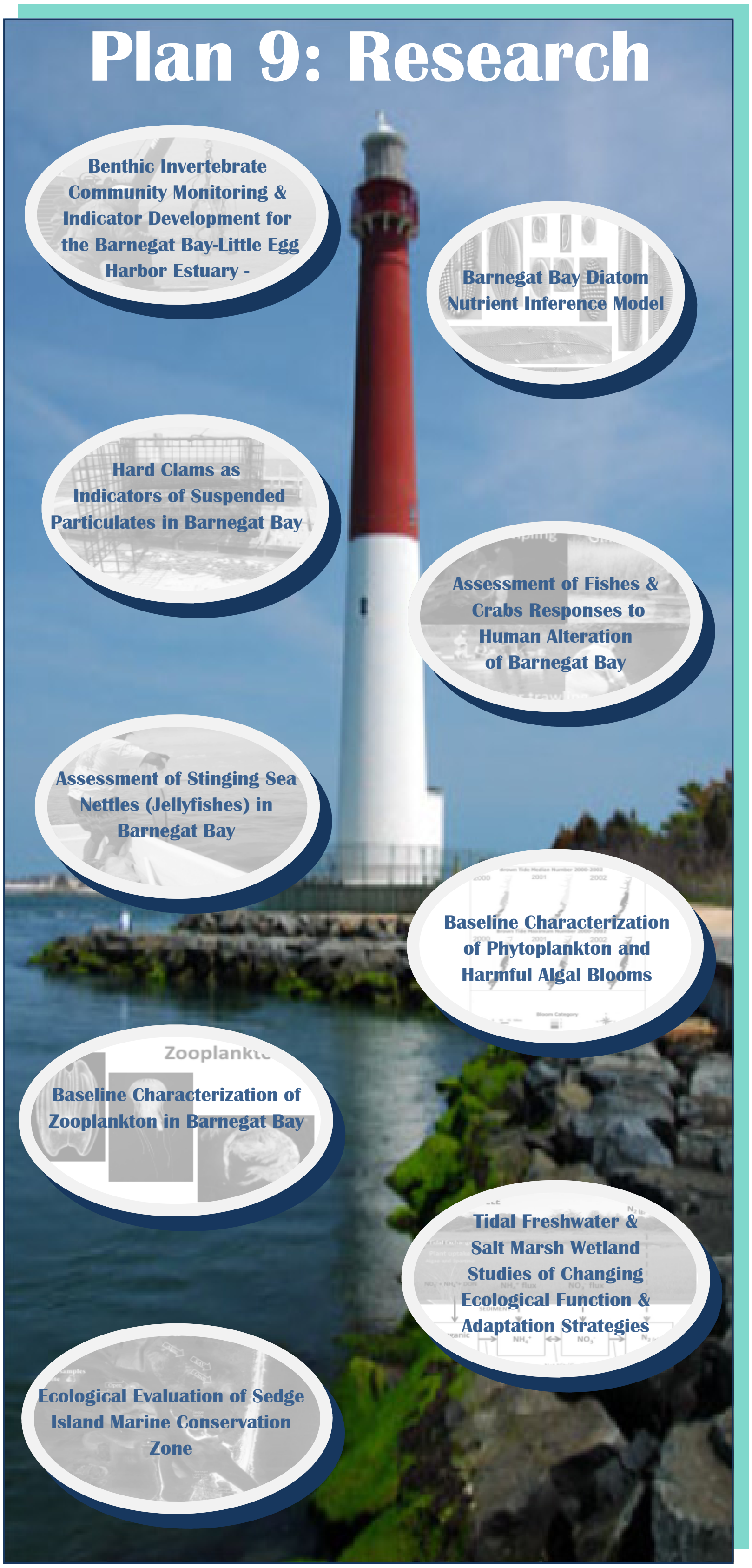
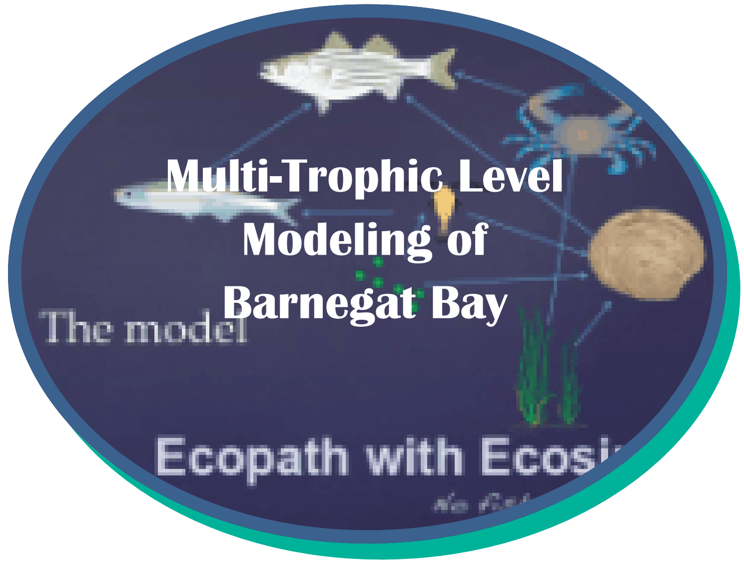


Barnegat Bay—Year 1



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Year 1 Project Report for "Multi-Trophic Level Modeling of Barnegat Bay"

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Objective 1: Develop Conceptual Model of Barnegat Bay Social-Ecological System

Methodology

Fuzzy Logic Cognitive Mapping

To elucidate the ways in which individuals conceptualize the function and operation of the Barnegat Bay social ecological system we collected a series of Fuzzy Logic Cognitive Maps (FCMs) from interested stakeholders. FCM are a simplified way of mathematically modeling a complex system (Ozesmi and Ozesmi 2004), and have been used to represent both individual and group knowledge (Gray et al. 2011). It has been used to understand processes and decisions in human social systems, the operation of electronic networks, and in the ecological realm to identify the interactions between social systems, biotic, and abiotic factors in lakes (Ozesmi 2003, Hobbs et al. 2002) and the summer flounder fishery (Gray et al. 2011).

FCM are a model of a how a system operates based on key components and the causal relationships between them. The components can be tangible aspects of the environment (a biotic feature such as fish or an abiotic factor such as salinity) or an abstract concept such as aesthetic value. The individual participants identify the components of the system that are important to them, and then link them with weighted, directional arrows. The weighting can range from -1 to +1, and represents the amount of influence (positive or negative), that one component has on another.

Data collection

In order to collect FCM from a wide variety of stakeholders with knowledge of the Barnegat Bay ecosystem we contacted the Barnegat Bay Partnership, an Environmental Protection Agency National Estuary Program, to obtain a list of their management and science committee members, as well as a list of public citizens who have expressed long-term interest in the ecosystem. These individuals were then divided into four groups that were determined *a priori*; scientists, managers, environmental non-governmental organizations, and local stakeholders. These groups were selected as they represent the major categories of stakeholders present in ongoing efforts to manage and improve the bay’s natural resources. While the map of an individual stakeholder provides information regarding that particular individual's conception of the important components and linkages within the system, it can be combined with other individuals within the group to produce a more robust picture of the group's understanding of the system (Ozesmi and Ozesmi 2004). In addition, all of the individual stakeholder maps can be combined into a community level map depicting the collective understanding of the system.

In accordance with the procedures used in prior FCM's (Carley and Palmquist 1992, Ozesmi and Ozesmi 2004, Gray et al. 2011) individuals were interviewed separately, and each interview began with an overview of the project, a promise of anonymity, and an example of a simple FCM related to an issue outside of the realm of ecology, namely traffic flow. Interviewee's were then asked to describe what they considered to be the key components of the Barnegat Bay social-ecological system, and how those components relate to one another. They were then asked to score the strength and direction of the relationship using positive or negative high, medium, or low. The discussion continued until the interviewee was satisfied that the map as drawn accurately depicted their understanding of the system. This ranged anywhere from 45 minutes to 180 minutes, with the typical session lasting 90 minutes.

Data Analysis

There are a number of different methods that can be used to analyze the data contained within an FCM, many of which are based upon graph theory (Harary et al. 1965, Ozesmi and Ozesmi 2004, Kosko 1991). In order to better understand the structure of an individual FCM we translated each map into a square adjacency matrix, with the variables v_i on the vertical axis and v_j on the horizontal axis. The interactions strengths between variables were then scored, with high interactions scored as 0.75, medium as 0.5, and low as 0.25. A list of all individual variables mentioned throughout the process was compiled and redundant variables (plurals, different names for the same species, *etc.*) were eliminated. When two variables represented opposite directions of the same concept the more prevalent variable was retained and the other variable was renamed, with the polarity of the interaction reversed, in keeping with accepted practices (Kim and Lee, 1998).

In addition to calculating the number of variables and connections within an individual map, the type of variables, and number of each, where identified to provide additional insight into the overall structure of the map and how these components relate to each other (Bougon et al. 1977, Eden et al. 1992, Harary et al. 1965). Variables were classified as transmitters (influencing other variables), receivers (influenced by other variables), or ordinary (both influenced by and influencing other variables), based on its indegree and/or outdegree. Indegree is the cumulative strength of the connections entering the variable (sum of the absolute values within a column in the matrix), while outdegree is the cumulative strength of the connections exiting the variable (sum of the absolute values within a row in the matrix) (Ozesmi and Ozesmi 2004). A transmitter variable has positive outdegree and no indegree, a receiver variable has no outdegree and a positive indegree, and an ordinary variable has positive indegrees and outdegrees (Bougon et al. 1977). Finally, the centrality, or a measure of a variable's connectedness to other variables within the map, as well as the overall strength of those connections, was calculated as the sum of the indegree and outdegree of a given variable (Harary et al. 1965).

Indices of complexity and density were also determined for each stakeholder map. The complexity of a map is calculated as the ratio of receiver variables to transmitter values (R/T). A large number of receiver variables in a map suggests a system where there are multiple outcomes (Eden et al. 1992), while a large number of transmitter variables suggest that a system is hierarchical in nature, and driven by "top down" thinking (Ozesmi and Ozesmi 2004). Density describes how well connected variables are within the map, and is determined by dividing the number of connections present by the maximum number of connections possible (Hage and Harary, 1983). A dense map suggests that an interviewee (or stakeholder group) perceives a number of possible pathways to influence a variable in their map (Ozesmi and Ozesmi 2004).

In order to more easily understand the components and patterns within an individual FCM it is often helpful to simplify the map by reducing the number of variables (Harary et al. 1965). After all of the maps were completed we listed the full set of variables and identified those most often mentioned. We then subjectively combined less frequently mentioned variables into larger categories based on shared characteristics, a process known as qualitative aggregation. For example, “homes”, “urban development”, “housing”, and “overdevelopment”, were combined, with a number of other similar variables, into a category called “development”.

In addition to calculating the variables for each map, maps were combined 1) within stakeholder groups to produce four group maps and 2) across all individuals to produce a community map. To combine maps the connection values between two given variables are added, so connections represented in multiple maps are reinforced (given similar signs) while less common connections are not reinforced, but are still included in the map (Ozesmi and Ozesmi 2004). In order to compare connection values across group maps, the summed values are averaged, which provides for equal weighting between all individual maps.

Results and Discussion

We created fuzzy cognitive maps for 42 individuals from the four targeted stakeholder groups (Table 1). The number of individuals interviewed from each group is unequal. While the uneven distribution of interviewees can have an effect on the overall community map, it does not affect the intragroup comparisons. The importance of the variables in the community map will be slightly weighted by the scientist’s input, but the important variables in the map were broadly shared across groups. In addition, a number of managers and NGOs could also have been classified as scientists and individuals in all categories may be local residents. However, individuals were assigned to a group based on their interactions with the system rather than their particular background or level of training. For example, a scientist for an NGO is likely to perceive an issue associated with Barnegat Bay differently than a state/federal/local manager responsible for a particular suite of resources in the bay, even though the manager has an advanced science degree also.

The stakeholders identified 349 unique concepts as important to understanding the Barnegat Bay social – ecological system, which were then aggregated into 84 categories for further analysis. Individual maps contained an average of 25 concepts, which when aggregated led to an average of approximately 20 categories per map. The average number of categories in an individual map was consistent across all groups, with the exception of NGOs, who had an average of nearly 30 categories per map (Table 2).

Several of the key structural indices were similar between stakeholder groups (Table 2), though the importance of particular categories differed both within and between groups (Table 3). There were no significant differences between the groups in the complexity (df=38, p=0.492) of their maps, though the environmental NGOs and local people tended to have more receiver variables than the other two groups, suggesting they think more broadly in terms of potential outcomes. Conversely, the managers and scientists saw more potential interconnections between their variables as evidenced by their slightly higher (though not significantly different; df= 38, p=.129) density indices compared to the local people and environmental NGOs. All stakeholder groups found development to be either the most central, or second most central, category in the system. In all four maps development had the largest outdegree score, indicating it exerts its influence throughout the maps, in this case through high interaction strengths on many other categories. Of note is that while the indegree score for nutrients tended to be higher than its outdegree score, for both NGOs and Scientists it was still the second largest outdegree score, only behind that of development.

When all of the individual stakeholder maps were aggregated into a community based map (Figure 1) the density of the map was greater than any of the individual group maps (Table 2), suggesting that combining knowledge bases led to connections that a single group may have not considered. This idea of enhanced connections is further supported by the fact that all but one of the 84 categories in the map is an "ordinary variable", or those with both incoming and outgoing influences. The categories with the highest centrality scores, and thus of key importance in the community map, are shown in Table .4 As expected, development and nutrients are the two most central categories, followed closely by pollution, bay water quality, and human population. In addition to having the highest centrality scores, these five categories also have the five highest outdegree scores, suggesting that they are major drivers of the system.

Table 1: Information on stakeholders who completed fuzzy cognitive maps on the Barnegat Bay social-ecological system			
Stakeholder group	Maps (N)	People (N)	Occupation/organization/social group
Scientists	19	19	Academic scientists, federal and state agency research scientist
Managers	11	11	Federal, state, county, and local resource managers
Environmental NGOs	6	6	Regional, statewide, and local environmental non-profits
Local people	6	6	Baymen, commercial fisherman, local fisherman, longtime (+40 year) residents

Table 2: Graph indices by stakeholder group. All values, except for number of maps, are mean and standard deviation.					
	Scientists	Managers	Environmental NGOs	Local people	Community
Maps	19	11	6	6	42
Number of variables (N)	20.6 (4.3)	21.2 (5.3)	29.8 (13.4)	19.3 (3.6)	84
Number of transmitter variables (*T*)	5.1 (2.7)	4.4 (2.7)	5.8 (3.3)	4.7 (2.5)	0
Number of receivers variables (*R*)	3.2 (2.8)	2.3 (1.9)	4.5 (2.9)	4.3 (1.8)	1
Number of ordinary variables	12.3 (4.3)	14.5 (4.0)	19.5 (10.8)	10.3 (2.7)	83
Number of connections (C)	38.3 (13.3)	49 (17.8)	64 (40.7)	29.5 (9.3)	1071
C/N	1.9 (0.5)	2.3 (0.6)	2.1 (0.5)	1.5 (0.4)	12.75
Complexity (*R/T*)	0.7 (0.8)	0.6 (0.5)	0.9 (0.5)	1.1 (0.6)	
Density	0.09 (0.03)	0.11 (0.04)	0.08 (0.03)	0.08 (0.02)	0.15

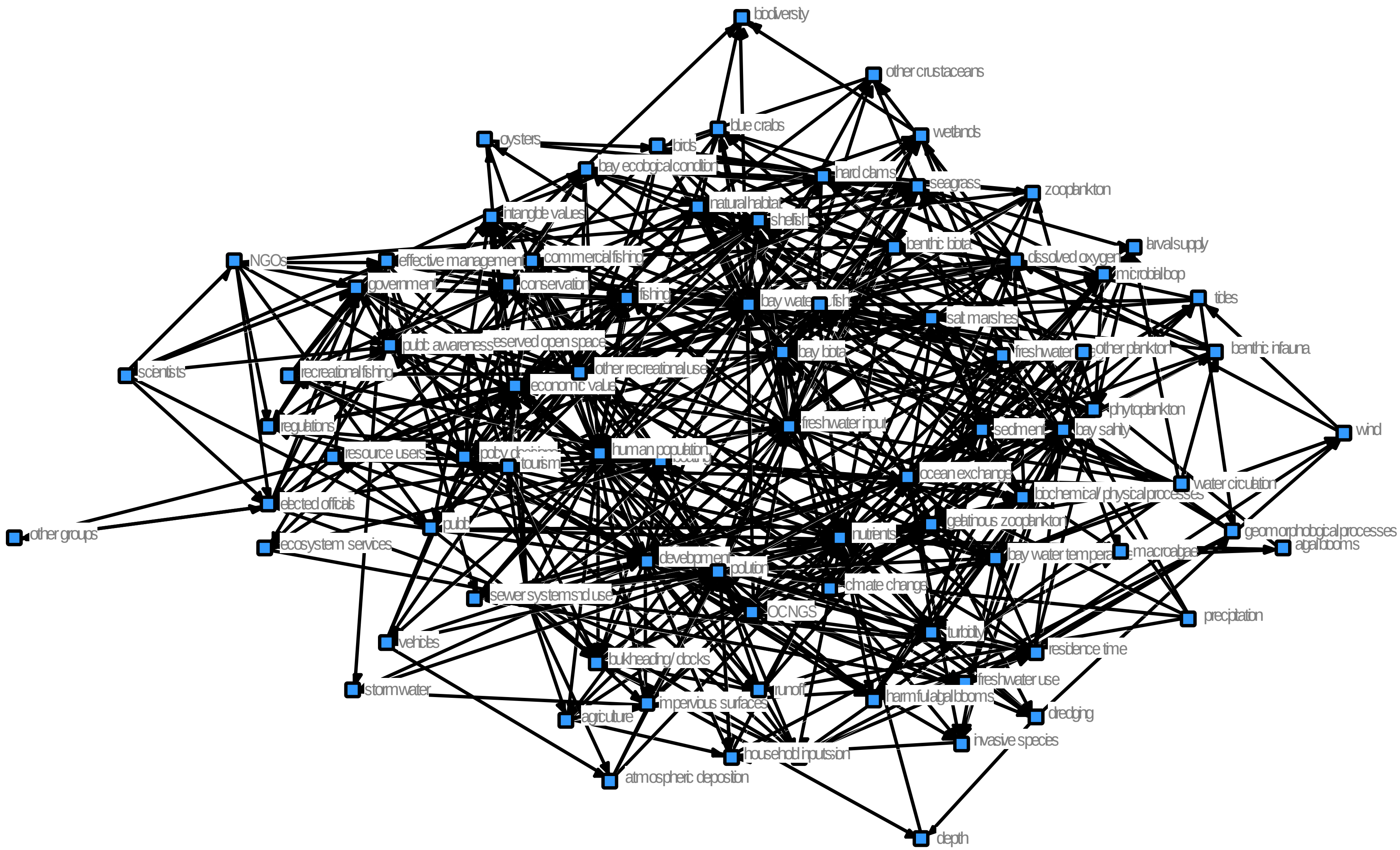
Table 3: The ten categories with the highest centrality scores for each stakeholder group, in rank order. These categories all had centrality scores >1. Categories in italics are those where the absolute value of the outdegree was larger than the absolute value of the indegree.

Scientists	Managers	Environmental NGOs	Local people
nutrients	*development*	nutrients	*development*
development	bay water quality	*development*	*human population*
seagrass	*human population*	pollution	bay ecological condition
fish	pollution	bay water quality	*seagrass*
pollution	*freshwater input*	bay biota	bay water quality
ocean exchange	nutrients	*effective management*	*other recreational use*
phytoplankton	natural habitat	freshwater input	pollution
other recreational use	other recreational uses	*impervious surfaces*	*public awareness*
freshwater input	*policy decisions*	bay water temperature	fish
gelatinous zooplankton	economic value	resource users	boating

Table 4: Categories in the community cognitive map of the Barnegat Bay social-ecological system.

Category	Centrality	Outdegree	Indegree
development	2.75	2.08	0.67
nutrients	2.48	1.01	1.47
pollution	2.00	0.95	1.05
bay water quality	1.96	0.86	1.10
human population	1.74	1.26	0.49
seagrass	1.46	0.54	0.92
freshwater input	1.34	0.75	0.60
fish	1.33	0.24	1.09
other recreational use	1.32	0.57	0.74
natural habitat	1.08	0.27	0.80
bay biota	1.04	0.29	0.76
ocean exchange	1.00	0.79	0.21

Figure 1: Community cognitive map of the Barnegat Bay social-ecological system



Objective 2 - Gather time series data and model parameters for NPZ and EwE models

EwE model parameters

Ecopath with Ecosim (EwE) is a software modeling tool used to quantitatively evaluate trophic interactions within an ecosystem in order to assess options for ecosystem-based management of fisheries. The first step in the process is to develop a mass-balance model (Ecopath), which requires four groups of basic input parameters to be entered into the model for each of the species (or groups) of interest: diet composition, biomass accumulation, net migration, and catch (for fished species). Three of the following four additional input parameters must also be input: biomass, production/biomass (Z), consumption/biomass, and ecotrophic efficiency. The model uses the input data along with algorithms and a routine for matrix inversion to estimate any missing basic parameters so that mass balance is achieved.

For the purposes of the initial Barnegat Bay model we have set biomass accumulation and net migration to zero for all of our species groups. This is equivalent to the assumption that biomass of all species groups was at equilibrium. This is a typical assumption in the absence of information to the contrary. The biomass, production/biomass, consumption/biomass, and Ecotrophic efficiency initial estimates for the model can be found in Table 5 below. These parameters were estimated from a variety of sources, the details of which can be found in Appendix 1. The initial diet composition matrix can be found in Appendix 2, with the source data also listed in Appendix 1. Harvest data for recreationally and commercially important species can also be incorporated into the EcoPath model as the landings ($t/km^2/year$) for the year in which the model is initiated. Landings data specific to Barnegat Bay, and statewide if longer time series are available, are summarized in Table 6.

One of the concerns in the current model is the "lumping" of age/size classes of certain fish and invertebrate species. While we may have diet data for a number of age/size classes of a given species, we lack specific information for a number of the other parameters. As identified in Appendix 1, many of the initial parameters utilized in the model at this time were not developed specifically for Barnegat Bay. This is particularly true for the biomass estimates, where with the exceptions of SAV and hard clams, the other values were taken from the Chesapeake Bay or Delaware Bay, or estimated by the software. We will endeavor to find alternate methods to obtain Barnegat Bay specific estimates (*e.g.*, simple stock assessment models to estimate biomass or estimation of fishing and natural mortality as a proxy for P/B). As information becomes available from the NJDEP Barnegat Bay field research projects, we will incorporate it into the model.

Table 5: Basic parameters for the Barnegat bay Ecosystem Model. Values estimated by Ecopath are shown in *italics*. Estimated from a variety of sources as described in Appendix 1.

Group name	Biomass (t/km^2)	Prod./biomass ($year^{-1}$)	Cons./biomass ($year^{-1}$)	Ecotrophic Efficiency	Prod./Cons.
Piscivorous seabirds	0.250	0.163	120	*0.0*	*0.001*
Non-piscivorous seabirds	0.121	0.511	120	*0.0*	*0.004*
Weakfish	*18.610*	0.260	3	0.9	*0.087*
Striped bass	2.1	0.4	2.4	*0.593*	*0.167*
Summer flounder	*1.217*	0.52	2.6	*0.95*	*.20*
Bluefish	*1.722*	0.434	3.1	0.95	*.140*
Winter flounder	*3.070*	0.46	3.4	0.95	*0.135*
Atlantic silversides	*2.635*	0.8	*4*	0.95	0.2
Atlantic croaker	*0.03*	0.63	4.2	0.037	*0.15*
Spot	*0.108*	0.9	6.2	0.9	*0.145*
Atlantic menhaden	*6.670*	0.69	31.42	0.95	*0.022*
River herring	*1.179*	0.75	8.4	0.95	*0.089*
Mummichog	*24.562*	1.2	3.65	0.95	*0.329*
Bay anchovy	*17.506*	3	9.7	0.99	*0.309*
Benthic infauna/epifauna	*228.975*	1	*5*	0.9	0.2
Amphipods	*44.455*	1	*5*	0.9	0.2
Blue crabs	7.2	1.21	4	*0.669*	*0.303*
Hard clams	169.9	1.02	5.1	*0.044*	*0.2*
Oyster	0.001	0.15	2	*0*	*0.075*
Copepods	10.3	25	*83.333*	*0.771*	0.3
Microzooplankton	*5.566*	140	*350*	0.95	0.4
Sea nettles	0.583	5	6.5	*0.0*	*0.769*
Ctenophores	3.4	8.8	11.38	*0.066*	*0.773*
Benthic algae	*11.734*	80		*0.900*	
Phytoplantkon	27	160		*0.704*	
SAV	58.2	5.11		*0.011*	
Detritus	1			*0.153*	

Table 6: Harvest information available for Barnegat Bay.				
Species	Years	Type	Source	Notes
Alewife	1950-1997	Commercial landings	Kennish 2001.	** for all of New Jersey**
Blue crab	1989-1997	Commercial landings	Kennish 2001	Barnegat Bay specific landings
Blue crab	1996-2008	Commercial landings	NJDEP Bureau of Marine Fisheries Dealer reports	Barnegat Bay specific landings
Blue crab	2007	Recreational estimates	Macro International, 2008	Estimated recreational landings as 80% of commercial
Bluefish	1997	Commercial	Kennish 2001	Barnegat Bay specific landings
Bluefish	1950-1997	Commercial landings	Kennish 2001	** for all of New Jersey**
Hard clam	1929-1977	Commercial landings	Carriker 1971, Kraueter, 1996	Landings at Parson's seafood. 10% of baywide
Hard clam	1960-2005	Commercial landings	Bricelj et al, 2013	G. Calvo figure for Ocean County, sporadic through time
Hard clam	1989-1997	Commercial landings	Kennish 2001	Barnegat Bay specific landings
Striped bass	1950-1997	Commercial landings	Kennish 2011	** for all of New Jersey** We have estimate of BB % of total catch for 2000s
Summer flounder	1967-1976	Recreational creel census	Kennish 2001	Conducted in Great Bay – likely a DEP report (Festa)
Summer flounder	1950-1997	Commercial landings	Kennish 2001	** for all of New Jersey**
Winter flounder	1978- 2006	Commercial fyke landings	NJDEP Bureau of Marine Fisheries Dealer reports	Barnegat Bay specific; 2001-2005 has 0 landings
Winter flounder	1989-1994	Commercial	Kennish 2001	Barnegat Bay specific landings
Winter flounder	1950-1997	Commercial landings	Kennish 2001	** for all of New Jersey**
Weakfish	1993	Commercial	Kennish 2001	Barnegat Bay specific landings
Weakfish	1989-1997	Commercial landings	Kennish 2001	** for all of New Jersey**

EwE time series data

Once the Ecopath model has been balanced the mass-balanced linear equations are then re-expressed as coupled differential equations so that they can be used by the Ecosim module to simulate what happens to the species groups over time (Christensen and Walters, 2004). Model runs are compared with time-series data and the closest fit is chosen to represent the system. Time-series data for model calibration are thus essential for developing and validating an Ecosim model (Christensen *et al*. 2009). Therefore, time-series data depicting trends in relative and absolute biomass, fishing effort by gear type, fishing and total mortality rates, and catches for as long a period as possible should be viewed as additional data requirements.

In addition to the commercial landings information in Table 6 there are few other time-series data available specific to Barnegat Bay. Many other ecosystem models glean data from formal stock assessments, which utilize similar time series data for single species management plans. While many of the fish species in our model have been the subject of stock assessment, these are generally coastwide assessments, and it will therefore be necessary to develop assumptions and correction factors so that these stock assessments for the larger population can be used in our model.

We have acquired a long-term (1988-2011, except 1991-1995) otter trawl data set from the Rutgers Marine Field Station that includes 6 regularly sampled sites located in Little Egg Harbor. The NJDEP has hard clam surveys from 1986/1987 in Barnegat Bay and Little Egg Harbor, 2001 in Little Egg Harbor, 2011 in Little Egg Harbor, and 2012 in Barnegat Bay. The 1986/1987 and 2001, and 2011 data are currently available and the 2012 data by 2013.

The final source of time series data will be the other projects currently funded by the NJDEP, assuming they receive multiple years of funding. We will continue to search for datasets that complement the ongoing projects in order to lengthen the time series as the model progresses.

Nutrient-Phytoplankton-Zooplankton model

Our working NPZ model is a size-spectrum model detailed in Fuchs and Franks (2010). This model captures many aspects of ecosystem dynamics using only a few parameters. Model inputs are the total nitrogen in the system and parameters that define fundamental rates (mortality, nutrient uptake by phytoplankton, and feeding by zooplankton) and size dependence in nutrient uptake and feeding. Most of these rate parameters are rarely measured directly, so we use standard values where available and educated guesses elsewhere (Table 7).

As described under Objective 3, our efforts for Barnegat Bay focus on understanding how the prevalence of jellyfish might affect community dynamics under changing nutrient scenarios. We define distinct zooplankton assemblages by varying the average feeding parameters. Feeding parameters are available for schyphomedusae (*Chrysaora quinquecirrha*) and several copepod species (Table 7). Average feeding parameters for schyphomedusae and copepods can be used to represent the extremes of gelatinous and non-gelatinous communities, with intermediate values for mixed communities.

The NPZ model outputs have different units than data measured in Barnegat Bay (Table 8), but some qualitative comparisons are possible. The NPZ outputs the size-resolved biomass of phytoplankton and zooplankton in units of nitrogen concentration, as well as the free nitrogen. The Barnegat By measurements of total nitrogen (NJDEP continuous monitoring) include dissolved, particulate, and cellular nitrogen and are comparable to combined free nutrients and phytoplankton biomass in the NPZ model. Chlorophyll a measurements (e.g., NJDEP, USGS) can be compared to modeled phytoplankton biomass using some assumptions about carbon:chlorophyll ratios and Redfield ratios in phytoplankton. Size-fractionated phytoplankton data (Ling Ren) can be used to construct coarse size spectra, and the spectral slopes can be compared to those in the NPZ model. Zooplankton data are less translatable to model outputs but can be used to estimate the relative abundances or biomasses of gelatinous vs. non-gelatinous zooplankton. Data on phytoplankton size structure and zooplankton are still being collected and processed, but we will incorporate them into our analysis as they become available.

Table 7: Data sources for NPZ model parameters.		
Parameters	Source	Notes
Allometric scaling parameters	Tang (1995), Moloney & Field (1989).	Values relate nutrient uptake rate to phytoplankton size
Half-saturation constant	Moloney & Field (1991)	Suggested value for microphytoplankton
Phytoplankton mortality rate	Fuchs and Franks (2010)	Estimate based on assumption that most mortality is due to grazing
Zooplankton mortality rate	Edwards et al. (2000), Franks et al. (1986)	Estimate based on reasonableness of size spectrum shape
Base feeding rate	Fuchs and Franks (2010)	Estimate based on reasonableness of estimated ingestion rates
Assimilation coefficient	Edwards et al. (2000)	Suggested value for microzooplankton
Feeding distribution parameters (*C. quinquecirrha*)	Cowan and Houde (1993)	Size distributions of jellies and ingested prey
Feeding distribution parameters (*C. quinquecirrha*)	Purcell and Cowan (1995)	Size distributions of jellies and ingested prey
Feeding distribution parameters (*C. quinquecirrha*)	Suchman and Sullivan (1998)	Size distributions of jellies and ingested prey
Feeding distribution parameters (copepods)	Fuchs and Franks (2010)	Size distributions of copepods and prey, summary for multiple species

Table 8: Data sources from Barnegat Bay-Little Egg Harbor that can be compared to NPZ model outputs. Includes only data sets that are or will be made publicly available.			
Data	Years	Source	Notes
Total Nitrogen	2011-2012	NJDEP[a], Monmouth University, USEPA	14 sites, surface and bottom data, shipboard measurements, ~4 samples per month
Chlorophyll-a	2011-2012	NJDEP[a], Monmouth University, USEPA	14 sites, surface and bottom data, shipboard measurements, ~4 samples per month
Chlorophyll-a	2012-2013	NJDEP[a], USGS	5 sites, continuous monitoring
Phytoplankton[b]	2012-2013	ANSP (Ling Ren)	count data, 3 size fractions
Zooplankton[b]	2012-2013	Monmouth University (Ursula Howson)	biovolume CPUE, 2 size fractions, 1-2 samples per month
Gelatinous Zooplankton[b]	2012-2013	Monmouth University (Ursula Howson)	abundance and size, 1-2 samples per month
Gelatinous Zooplankton[b]	2012-2013	Rutgers University (Ken Able/Talia Young)	biovolume CPUE, 49 sites, bimonthly sampling in Spring-early Fall and 1 site with weekly sampling

[a]publicly available at http://www.state.nj.us/dep/barnegatbay/bbmapviewer.htm

[b]anticipated to become available

Objective 3 - Develop initial NPZ and EwE models and evaluate historical predictions of the models

EwE model

The Ecopath model shown in Figure 2 represents a possible configuration of Barnegat Bay for 1980, with the groups arranged by trophic level. There are no surprises in the trophic level of any of the groups, though striped bass in our system do occupy a slightly higher level than those in the Chesapeake Bay. The fact that this model output is parsimonious with other models of similar systems lends additional support to its interpretation. The model is balanced, in that there is sufficient food for the consumers and enough production to meet consumptive demands.

A sensitivity analysis was undertaken to investigate the influence of each group on the behavior of the model. A base simulation was run for a period of 50 years, where no changes were made to the variables (Figure 3, top left panel). As expected, the model remains in equilibrium, and thus a straight line. An individual parameter perturbation analysis was then conducted by applying an additional mortality of 0.2 to each group after 15 years to assess the impact of changes in abundance of the modified group on other groups in the model (Figures 3-6). This step was repeated for each group. A variety of responses were identified. In some cases the increased mortality on one group (weakfish, striped bass, menhaden, bay anchovy, benthic infauna) had far ranging effects on most of the other groups in the model (Figure 3). In other cases the increased mortality lead to small changes to other groups, or larger changes to only a few groups (Figures 4 and 5). The final response type occurred when the applied mortality was not large enough to cause any real decrease in the relative biomass of the target group (Figure 6). The model is most sensitive to the groups identified in Figure 3 and thus additional care should be taken when reviewing their input values.

When the time series data currently available is incorporated into the model, the fit of the model prediction to the available data is reasonable (Figure 7, Sum of Squares = 468.6). The model fits most of the groups well, with changes in relative biomass from the time series data reflected in the model (Figure 8). The model fit to the hard clam data, however, is not as robust as we would like. We are currently investigating ways to bring the model more in line with the available data.

This EcoSim run includes forcing functions for phytoplankton, benthic algae, and submerged aquatic vegetation (SAV) in an effort to replicate changes in primary producers over time (Figure 9). The chlorophyll a (phytoplankton) and benthic algae forcing functions are nearly linear increases over the 32 year of the model run, with a 3x increase from the beginning to the end of the time series. The SAV function is a nearly linear decrease over the time series. These rates are an estimate of forcing based on the historic decline in SAV and the anecdotal increase in benthic macroalgae. We are awaiting time series data on chlorophyll *a* measurements for the bay, which will be incorporated into the model. Furthermore, the dynamic linking of the EwE model to the NPZ model will provide additional resolution to the lower trophic level interactions.

Nutrient-Phytoplankton-Zooplankton Model

Phytoplankton and zooplankton dynamics in Barnegat Bay are expected to reflect variation of environmental conditions in space and over time. As of the last quarterly report, we intended to use the NPZ model to investigate whether spatial variation in plankton communities is better explained by gradients in eutrophication or salinity. After reviewing recent data collected in Barnegat Bay, however, we concluded that spatial patterns in phytoplankton biomass and size structure are consistent with spatial variation in nutrient inputs: the northern end of the Bay generally has higher chlorophyll concentrations and higher abundance of larger phytoplankton than the southern end of the bay (NJDEP continuous monitoring data , Olsen and Mahoney 2001), as would be expected given the higher nutrient concentrations in the north. Given that observations can be explained by bottom-up forcing (nutrient availability), there is little reason to expect that phytoplankton production is strongly affected by salinity. Moreover, we have found no documentation of salinity dependence in rate parameters for estuarine plankton. Thus there is little justification for modifying the NPZ model to account for salinity dependence in rate parameters.

Salinity may have more significant impacts on the composition of zooplankton communities, particularly the abundance of jellyfish. Although ctenophores (*Mnemiopsis leidyi*) thrive at a wide range of salinities (Purcell et al. 2001), there is evidence that scyphomedusae (*Chrysaora quinquecirrha*) are most abundant at a salinity of around 15 (Decker et al. 2007). Mean salinities in Barnegat Bay range from ~18ppt in the north to ~25ppt in the south (Moser 1997), although salinity can be <15ppt at the mouth of the Tom's River and >30ppt near the inlets (Kennish 2001a). Recent data indicate that these patterns have remained consistent over time (NJDEP continuous monitoring data). If Barnegat Bay jellyfish follow similar salinity preferences, then zooplankton communities should be more gelatinous in the north end of the Bay and more copepod-dominated in the south end of the Bay.

This difference in community composition can be accounted for in our working NPZ model by changing the feeding parameters. Jellyfish consume a wider size range of prey than crustacean zooplankton (e.g., copepods), and these different feeding dynamics lead to dichotomous results in the

NPZ model (Fuchs and Franks 2010). The ratio of phytoplankton biomass to free nutrients is higher in a jelly-dominated model than in a copepod-dominated model (Fig. 10). We calculated a similar ratio (chl a to nitrate+nitrite concentrations) using data from the continuous monitoring program in Barnegat Bay. Sites from the north end of the bay have higher phytoplankton-to-free-nutrient ratios than sites in the south end of the bay, consistent with the hypothesis of a more gelatinous community in the north.

Because zooplankton composition affects community feeding dynamics, the abundance of jellyfish is relevant to understanding how phytoplankton biomass varies with nutrient inputs. In a copepod-dominated model a decrease in nutrients always leads to a reduction in phytoplankton biomass, whereas in a jelly-dominated model, a decrease in nutrients sometimes leads to an unexpected increase in phytoplankton biomass. This counter-intuitive result may be particularly relevant for management actions the Tom's River area of Barnegat Bay, where one potential scenario is a mandated reduction of nutrient inputs. In year two we will explore nutrient-reduction scenarios in the model to better understand how these management actions would affect copepod-dominated vs. jelly-dominated plankton communities.

Figure 2: Barnegat Bay 1980 model. Numbered horizontal lines indicate trophic level.

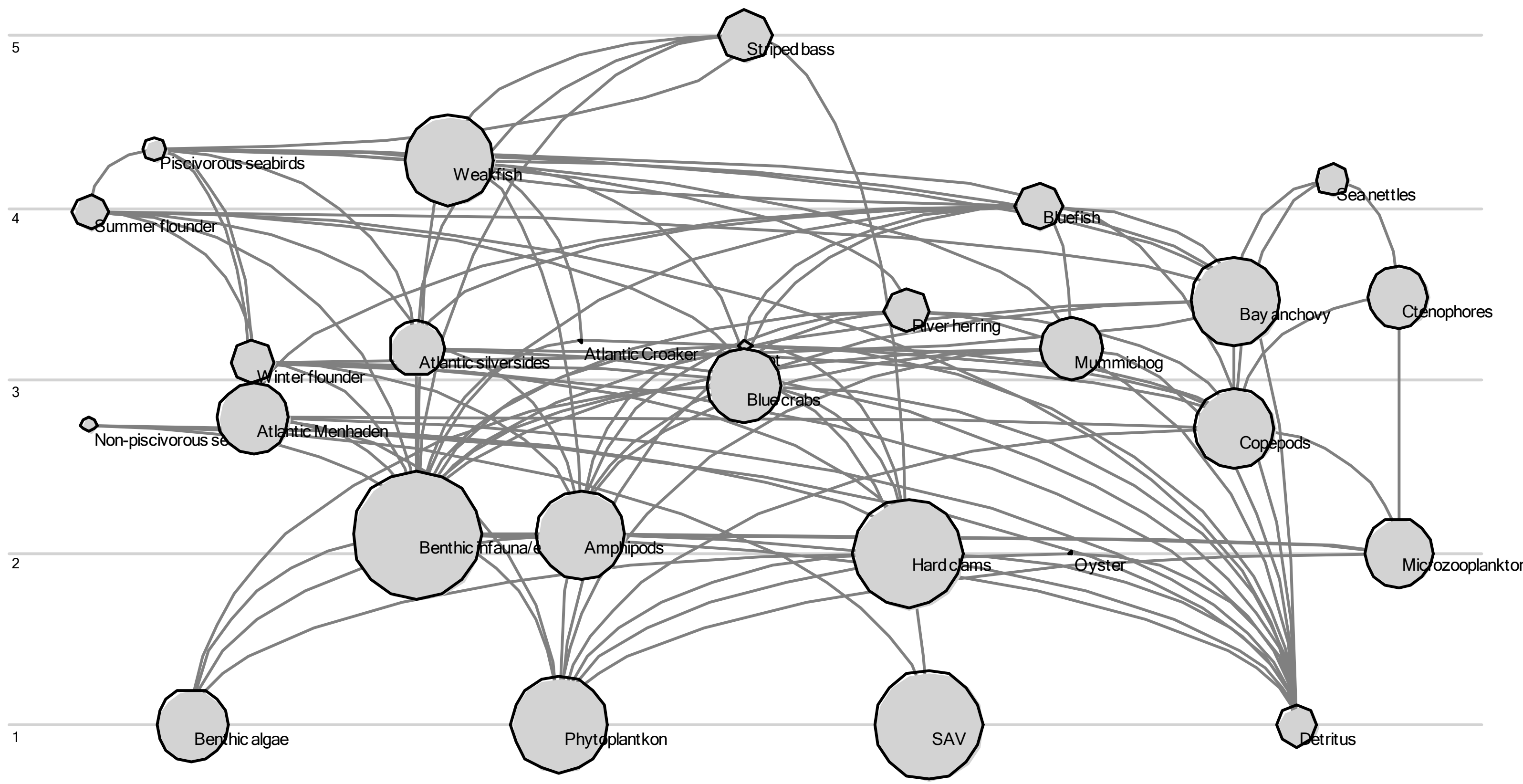


Figure 3 : Ecosim model simulations with additional mortality equal to 0.2 for a group

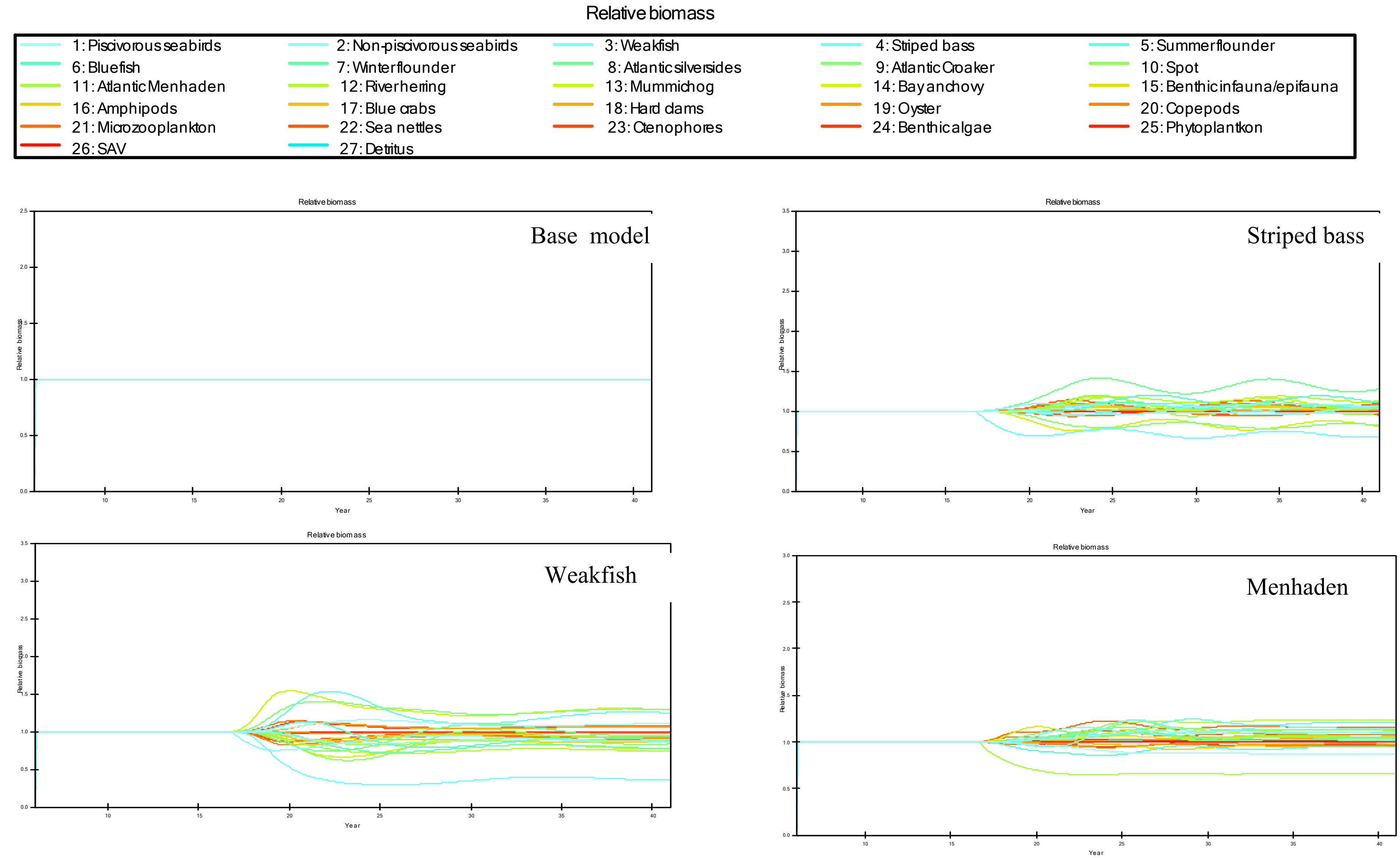


Figure 3 con't : Ecosim model simulations with additional mortality equal to 0.2 for a group.

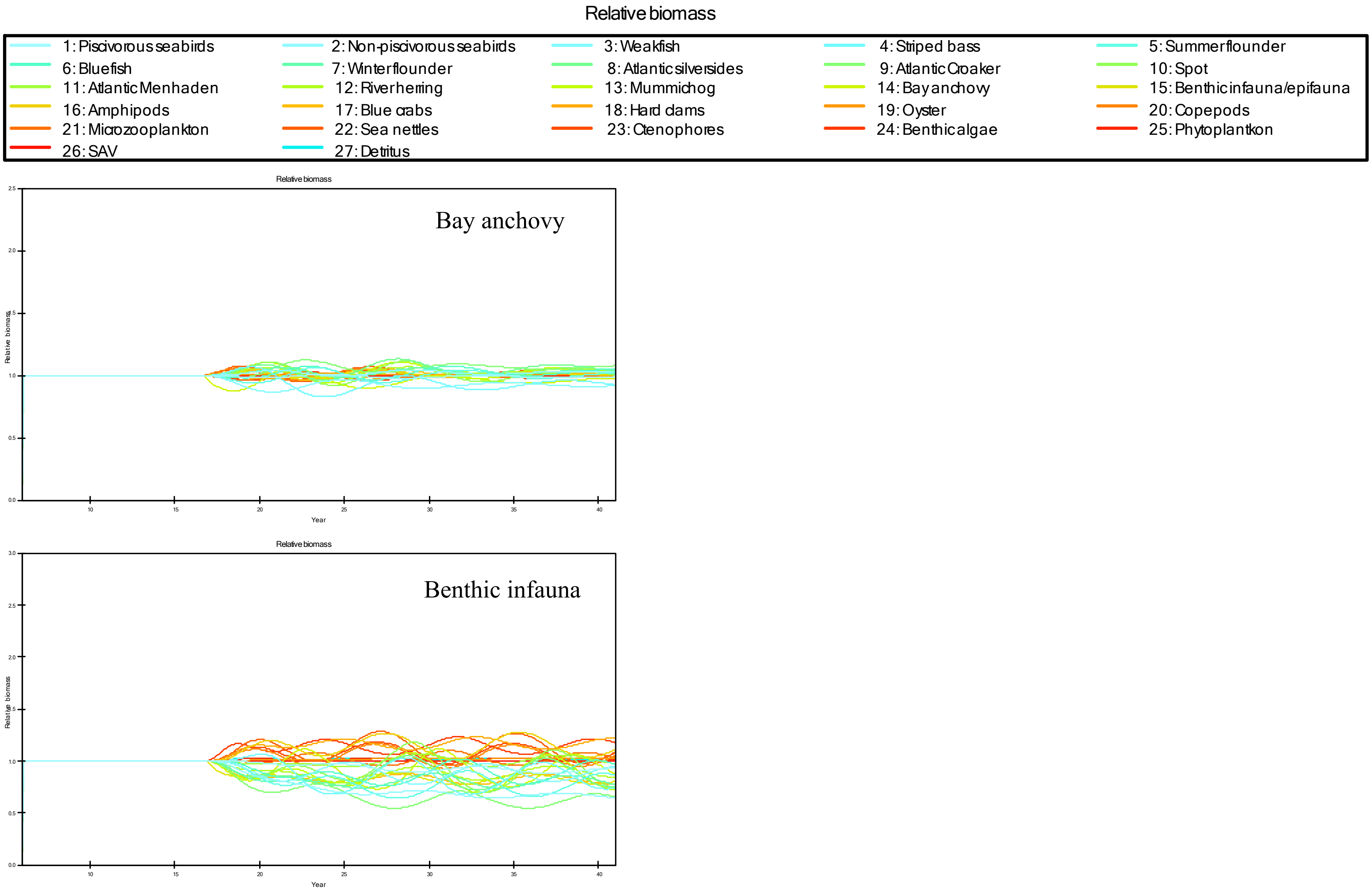


Figure 4 : Ecosim model simulations with fishing mortality equal to 0.2 for a group.

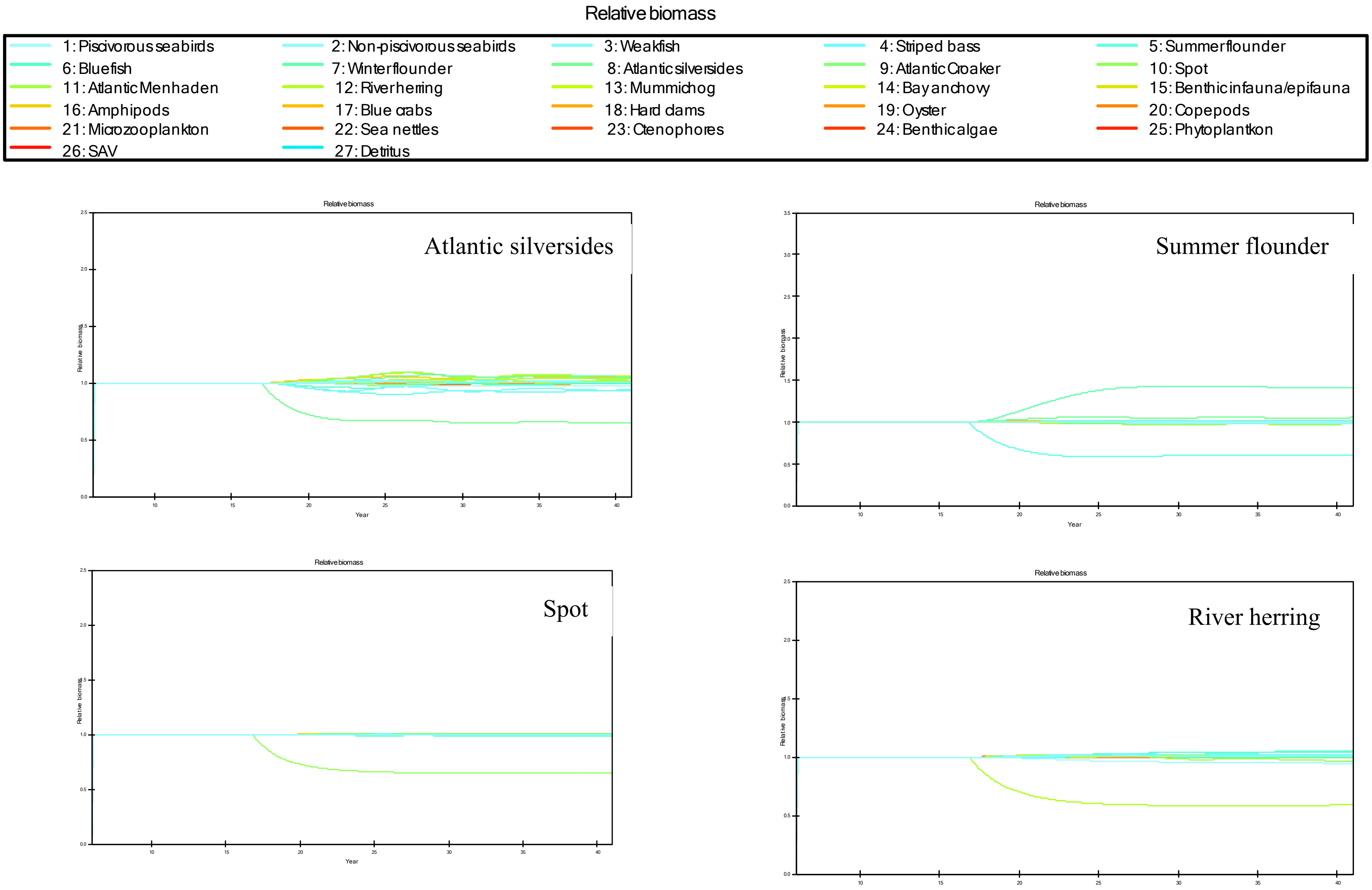


Figure 4 con't : Ecosim model simulations with fishing mortality equal to 0.2 for a group.

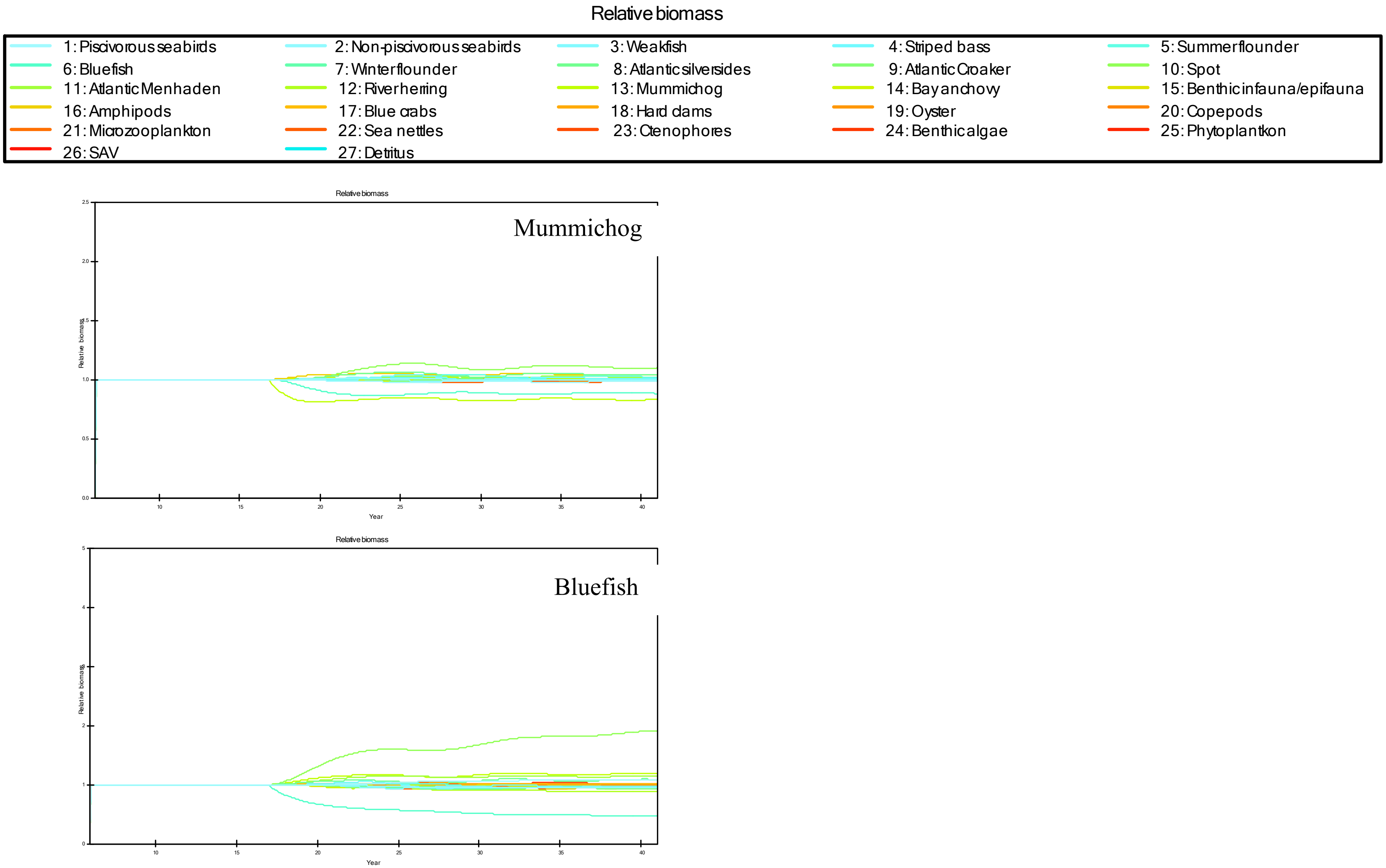


Figure 5 : Ecosim model simulations with fishing mortality equal to 0.2 for a group.

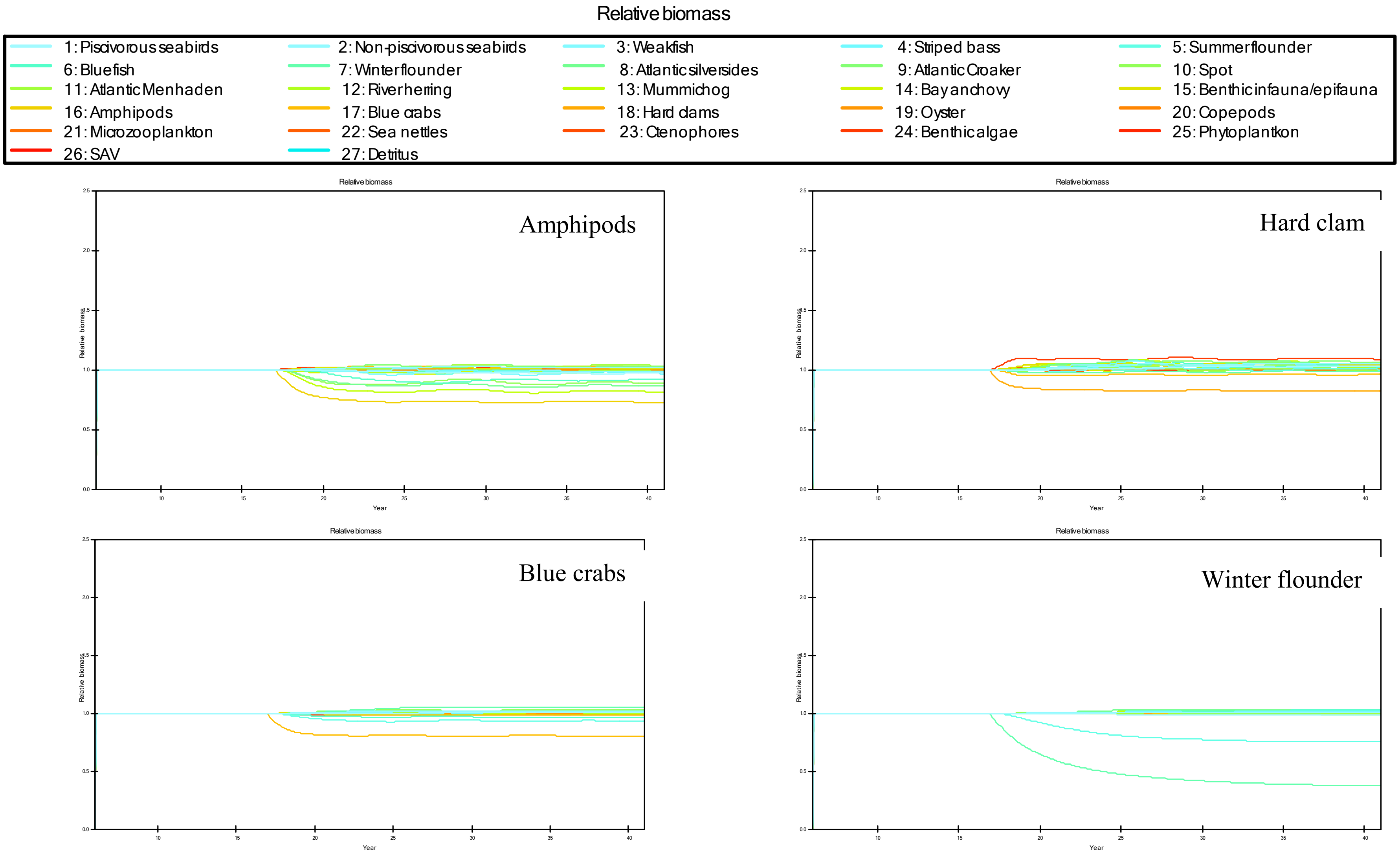


Figure 6: Ecosim model simulations with fishing mortality equal to 0.2 for a group.

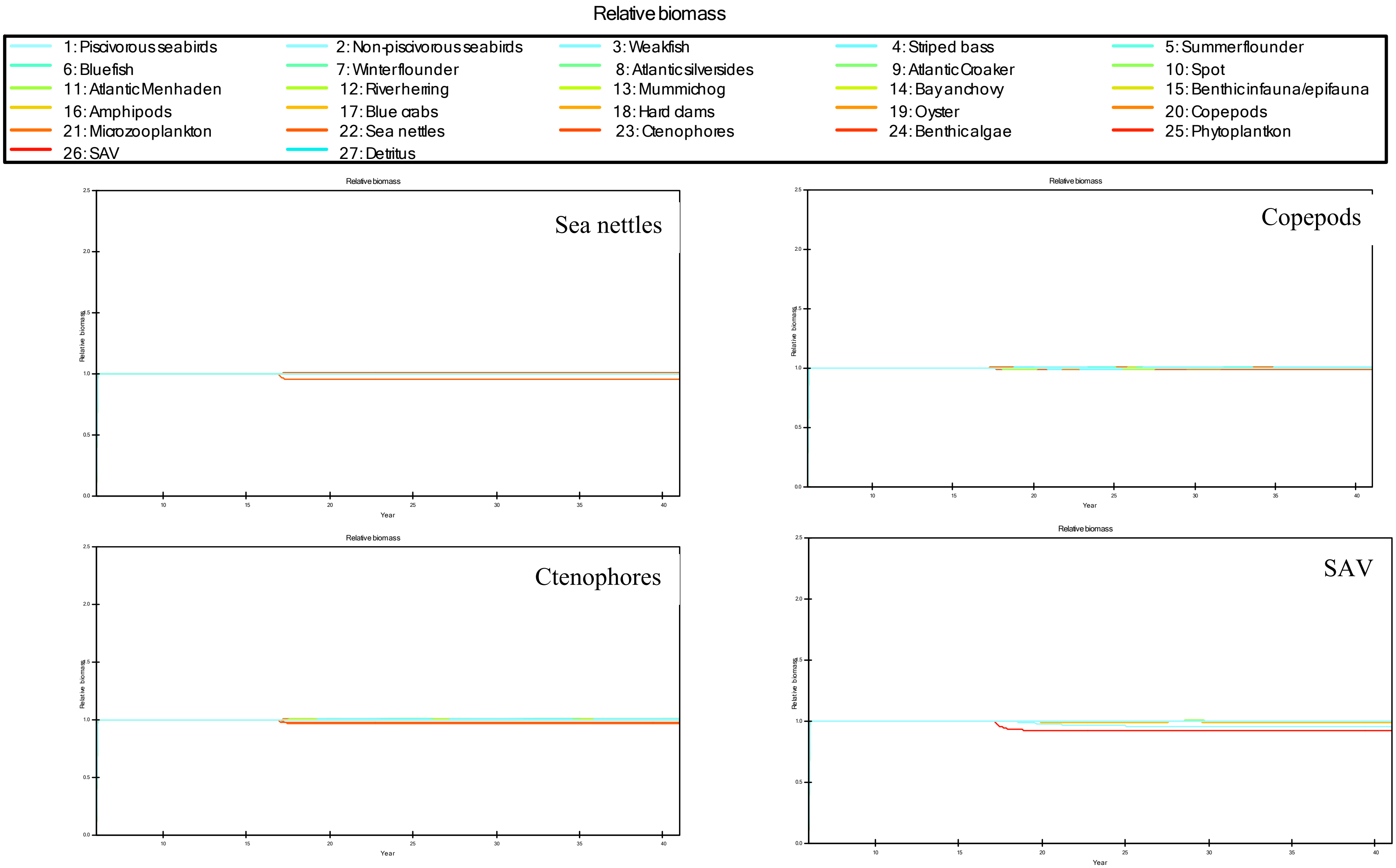


Figure 6: Ecosim model simulations with fishing mortality equal to 0.2 for a group.

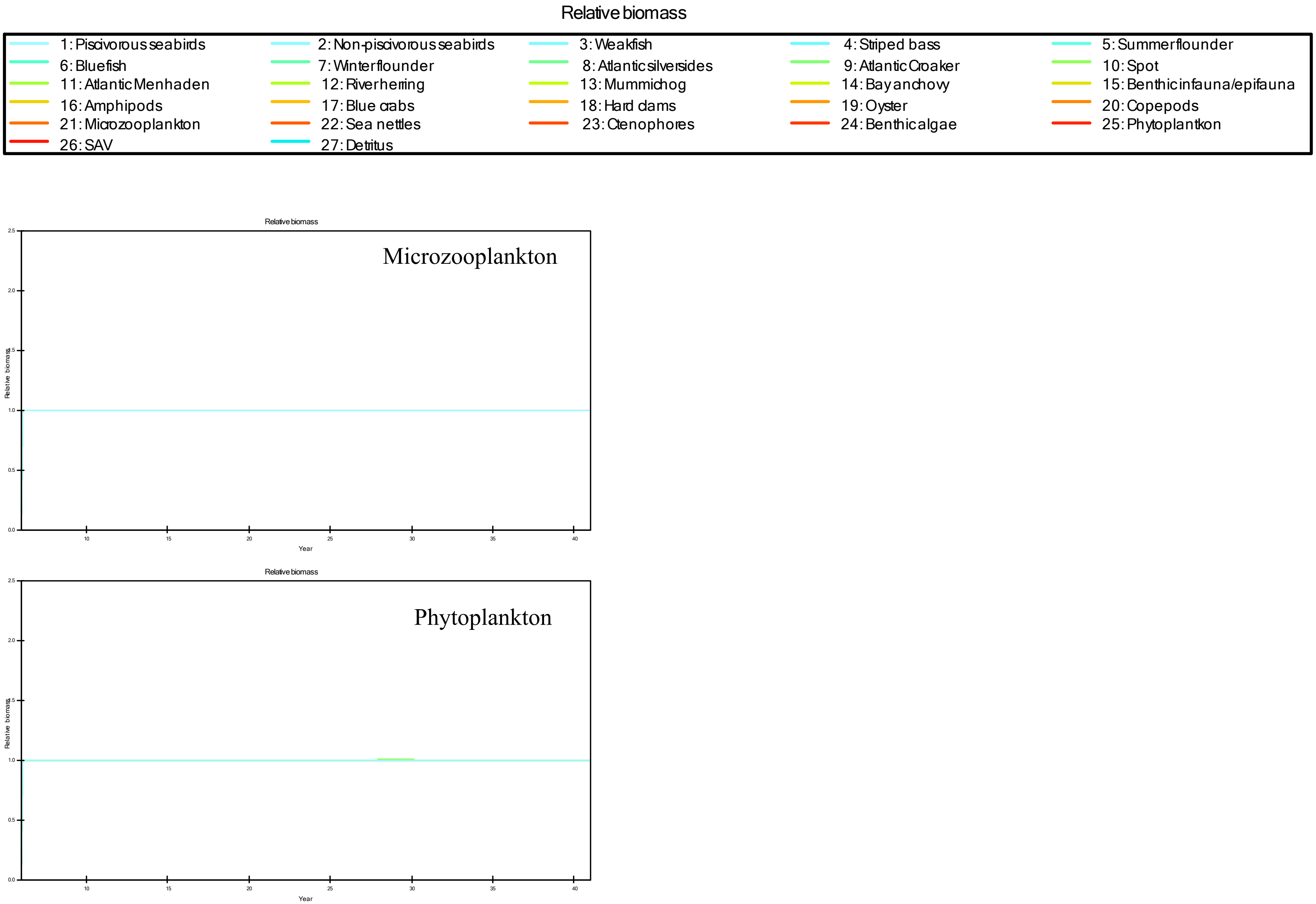


Figure 7: Model predictions versus time series data for 1980 through 2012.

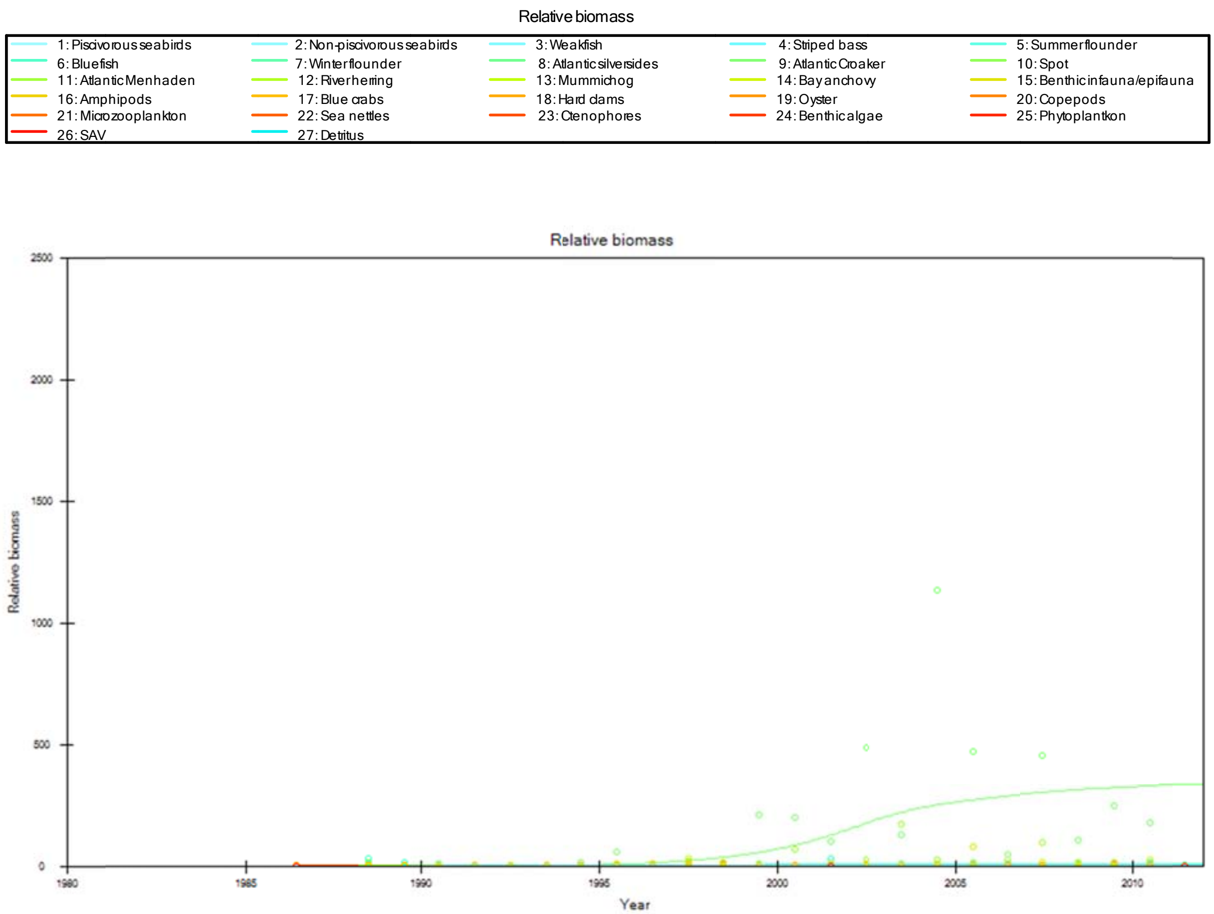


Figure 8: Graphs of the model fit to the currently available time series data for each of the groups in the EwE model.

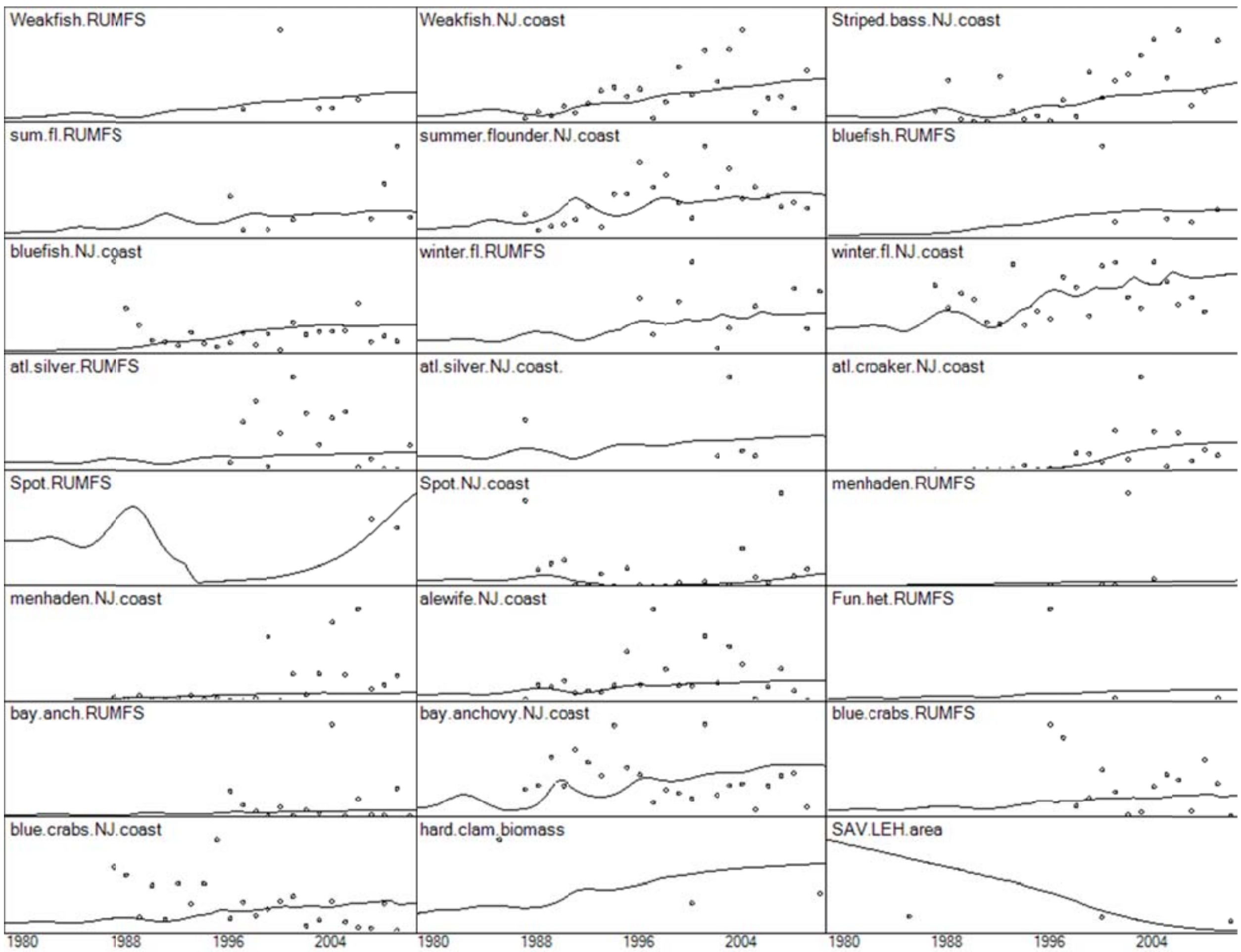
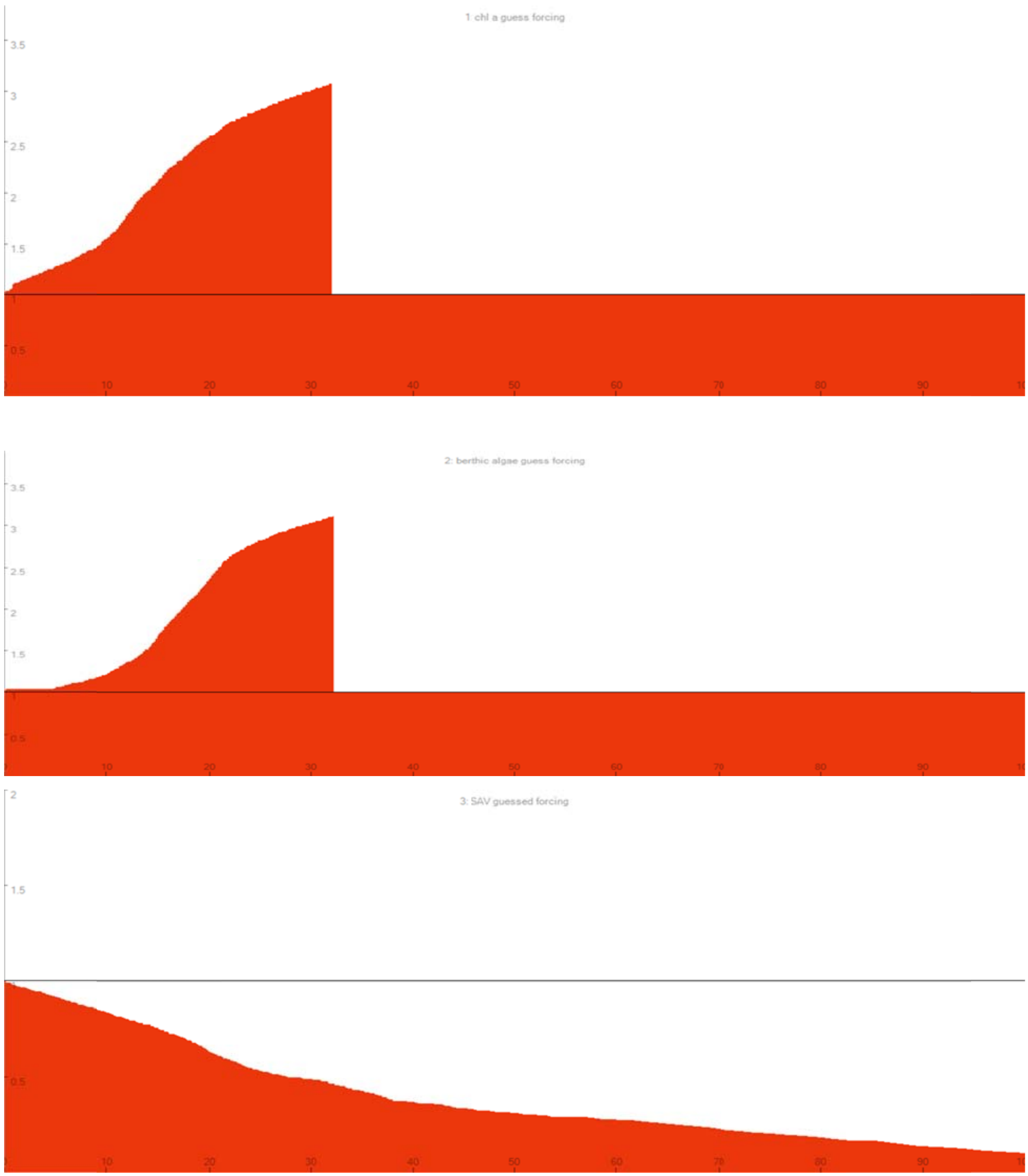
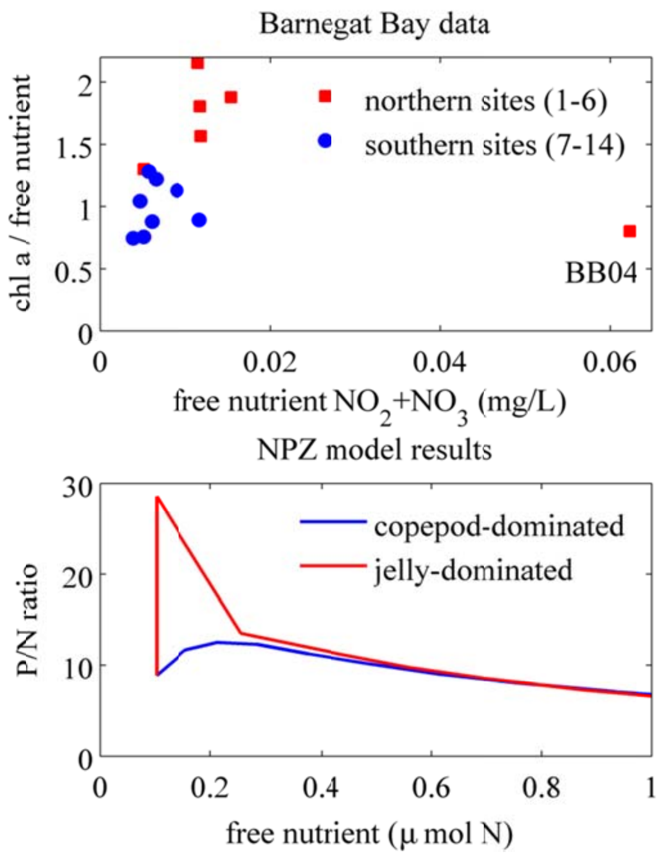


Figure 9: Forcing functions for the EcoSim model run; chlorophyll a (top), benthic algae (middle), and SAV (bottom).





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Objective 4 - Write and test the program to dynamically link the NPZ and EwE models

This proved to be more technically challenging than anticipated and we have budgeted funds in Year 2 for a contract programmer at the EwE consortium to complete this task. EwE runs on an annual time step, which is suitable for capturing the dynamics of longer-lived species such as fish and corresponds well with the annual reporting of fisheries data. The dynamics of phytoplankton and zooplankton, however, occur on much finer temporal scales (days to weeks). Meshing these two time scales will require modification of the EwE model such that the dynamics of some groups can occur on shorter time scales. We have identified a suitable programmer within the EwE consortium (Jeroen Steenbeek) and will initiate a contract with him as soon as Year 2 funds are available.

Objective 5 and 6- Develop and run quantitative change scenarios

During the conceptual model development interviews we asked individuals to tell us what variables in their cognitive maps they would increase or decrease the values of in order to effect "positive" change on the bay ecosystem. The responses included changes to both social and ecological components of the system, the impacts of some of which we can model in the EwE, and to a lesser extent in the NPZ, models.

Scenario 1 – Oyster Creek Nuclear Generating Station (OCNGS) closure

As America's oldest continuously operating nuclear plant, the facility uses a once-through cooling water system, where water is drawn from Forked River, used to cool the plant, and is then returned to Oyster Creek to flow into the bay. The impingement and entrainment of fish, crab, and hard clam larvae, as well as other zooplankters, is well documented. OCNGS functions as a *de facto* fishery, and the removal of biomass from the system is accounted for through catch data used in the EwE model. As part of the Governor's 10-point Plan, the Oyster Creek Nuclear Generating Station (OCNGS) will cease power generation by 2020. To model this scenario we reduced the "catch" of the plant from the "catch" at full operating capacity to 4% of the full operating capacity beginning in 2020, based on the percent reduction in intake water that is planned. The time series data was amended so that the 2011 values for the forced catches and effort series were used for 2012-2030, with the previously noted exception of OCNGS effort. The chlorophyll a, benthic macroalage, and SAV forcing was set to the 2011 level for the remainder of the simulation. Under those model parameters the relative biomass of the fish and other secondary consumers remains stable, while the primary consumers show a slight increase (Figure 11). If the forced catches and effort data for 2012-2030 are the average of the 1980-2011 data, the results are similar.

The closure of the plant is not expected to have an effect on NPZ model parameters, which are independent of temperature. Temperature dependence is rarely included in NPZ models and would be a major modification, therefore this scenario will be run in EwE only.

Scenario 2 – Changes to blue crab management strategy

Blue crabs are Barnegat Bay's largest commercial fishery, and are currently managed based on a mix of sex and size limits and seasonal closures (NJAC7E:25 and 25A). We modeled the effects of increasing the commercial dredge harvest to 92 metric tons. (twice the 1996-2006 average of 46 MT.) and of decreasing the commercial dredge harvest to 23 MT (one-half the ten year average) from 2012 to 2030, while keeping the commercial pot fishery and recreation fishery at the 1996-2006 average. Doubling or halving the commercial dredge had little effect on crab biomass (Figure 12). We also modeled the effects of doubling the commercial pot fishery over the 1996-2006 average of 218 MT to 436 MT and of halving it to 109 MT. Reducing or increasing the landings in the commercial pot fishery had little effect on crab biomass (Figure 13). The results are not unexpected given that the largest landings modeled (436 MT) is only 4% of the available modeled biomass (38MT/km^2).

Scenario 3 – Changes to hard clam management strategy

Hard clams were historically one of the most important commercial fisheries in the Bay, but landings have declined dramatically over the past several decades. We will model the effects of limiting the commercial harvest to 25,000 lbs. (approximate 2005 landings) and of closing the fishery entirely for a period of ten years. Because of the trouble we are having with fitting the model to the existing hard clam data we have not modeled this scenario at this time. Once the model fit for hard clams has been improved we will run this analysis.

Scenario 4 – Nutrient input reduction

The Barnegat Bay has been described as a moderately eutrophic estuarine system, and the focus of recent legislation (NJ Fertilizer Act, P.L. 2010 Chapter 112; NJ Soil Restoration Act, P.L. 2010 Chapter 113) and restoration efforts (NJ Stormwater Act, P.L. 2010 Chapter 114; Clean Water Act Section 319 projects) in New Jersey has been to reduce the amount of nitrogen being delivered into the system. As no target reductions have been set at this time, we propose to model the effects of reducing nitrogen inputs by 5% and 15%. The effects of these reductions on phytoplankton and zooplankton biomass and/or production in the NPZ model will then be translated to changes in the EwE model for the same groups. Furthermore, we will adjust the P/B ratio for the seagrass group in the EwE model based on the relationship found in Tomasko *et al.* (1996) on seagrass productivity and nitrogen loading. Dynamic linking of the two models for the nutrient change scenario will be accomplished in Year 2, after the code linking the NPZ and EwE models is written.

Figure 11: Relative biomass of all groups assuming a reduction in OCNGS effort to 4% of the 1980 level following decommissioning in 2020.

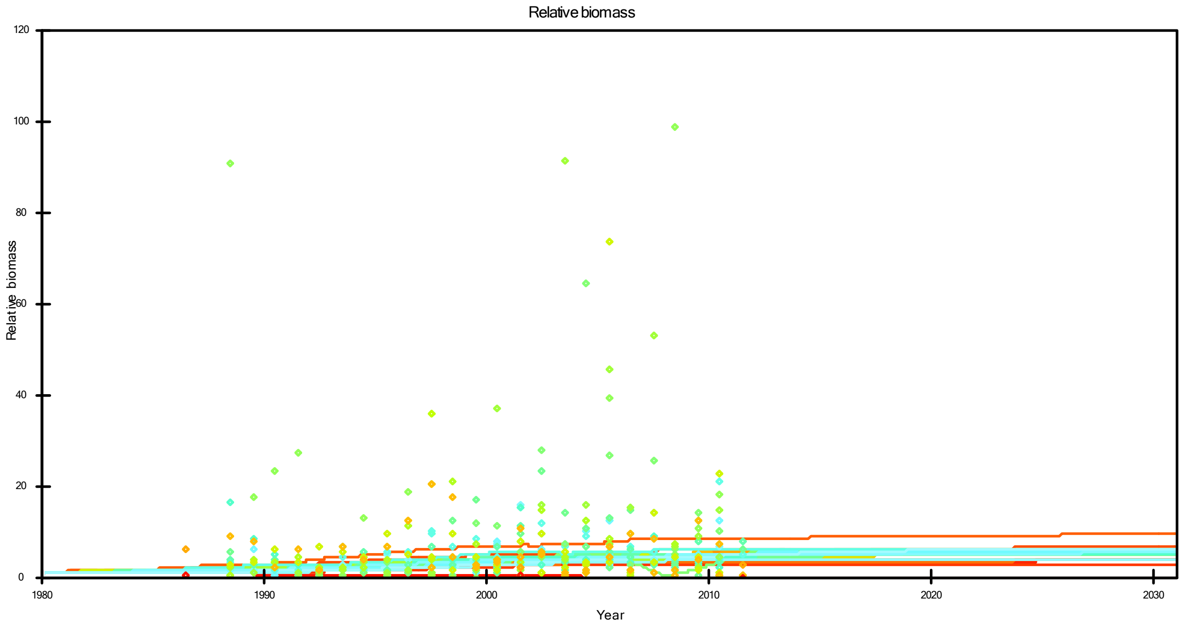
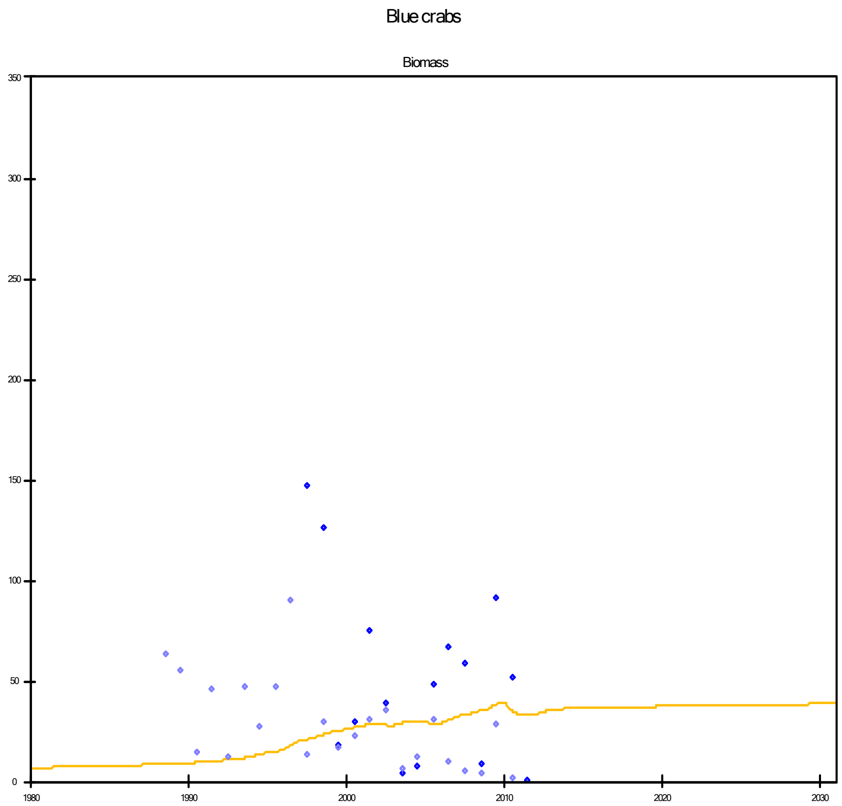


Figure 12: Changes to the biomass (t/km^2) of blue crab (*Callinectes sapidus*) post 2012 following a doubling of the average dredge fishery effort from 1996-2006 (left panel) and a halving of the effort (right panel).



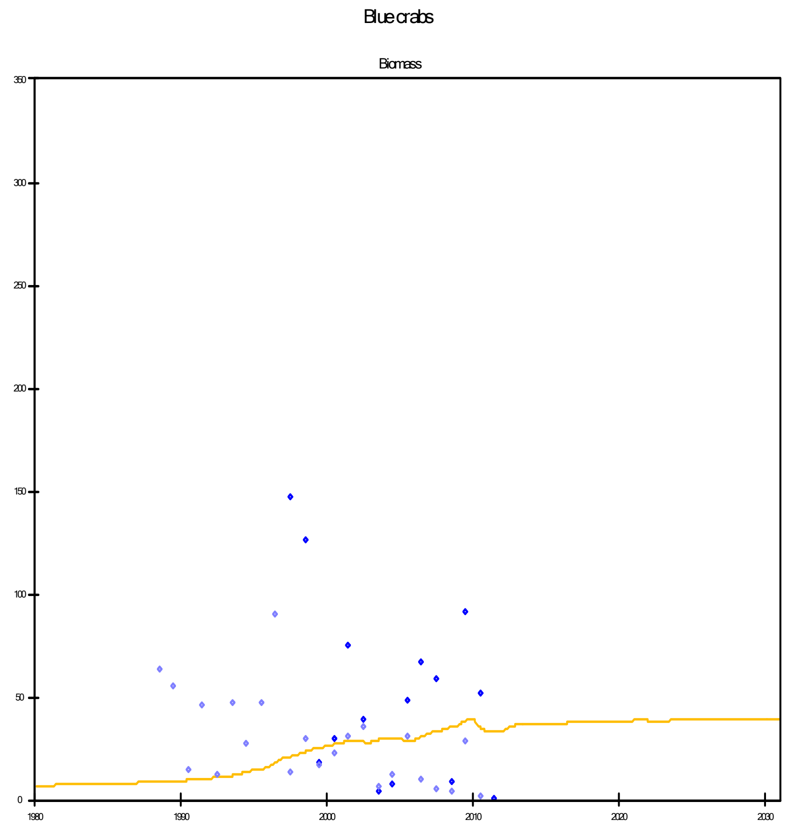
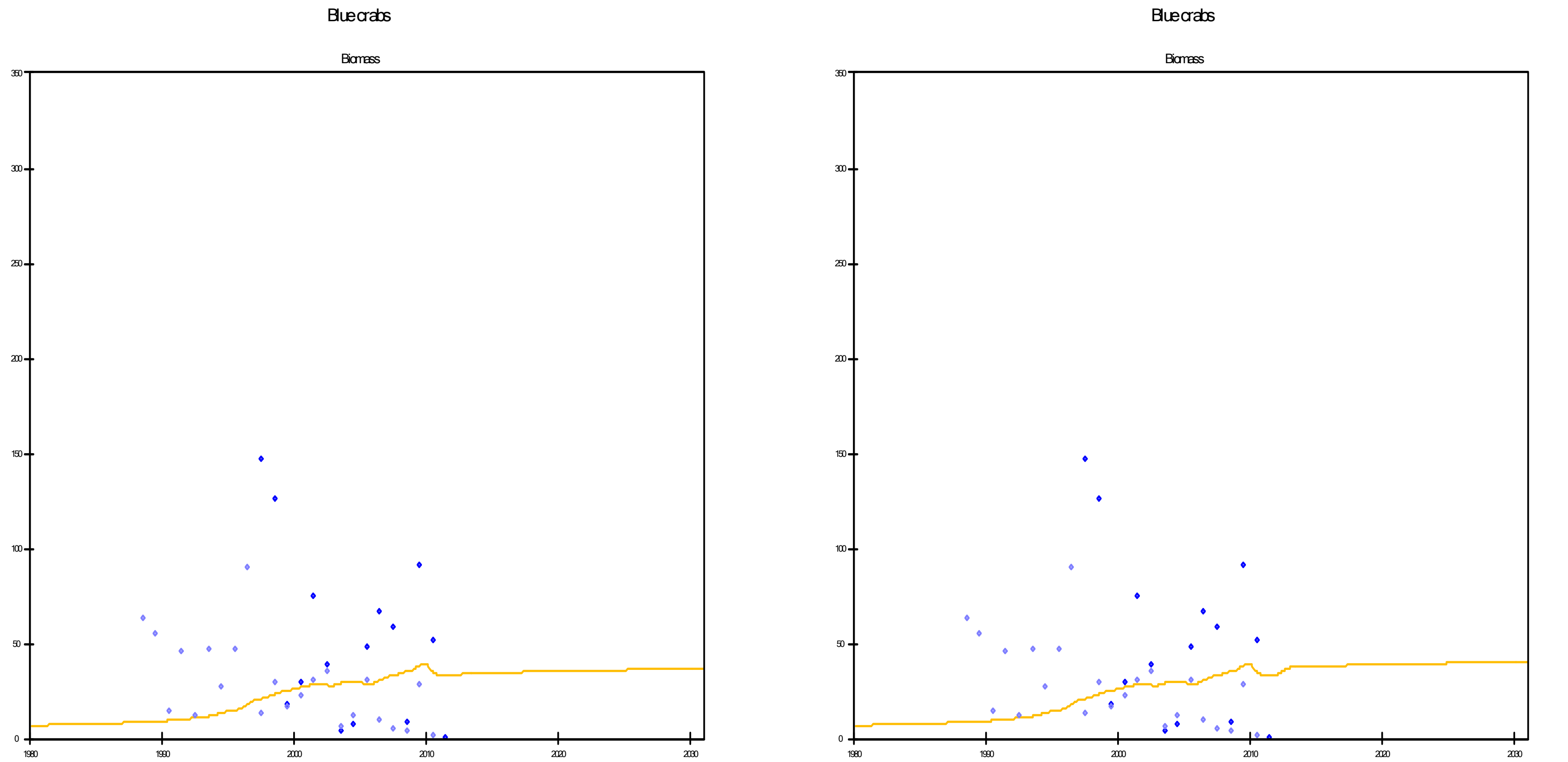


Figure 13: Changes to the biomass (t/km^2) of blue crab (*Callinectes sapidus*) post 2012 following a doubling of the average commercial pot fishery effort from 1996-2006 (left panel) and a halving of the effort (right panel).



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Appendix 1: Initial parameter values for the Ecopath model

Fish

Atlantic Croaker

Q/B - Estimates of consumption to biomass ratio was calculated in FishBase (Froese and Pauly, 2004) as 4.2 (year-1), assuming an annual temperature of the Barnegat Bay of T = 15 oC, aspect ratio = 1.32, W*inf* = 815.3, and carnivorous feeding.

P/B - Ross (1988) reported Z = 0.63 (year-1) for the species in Virginia waters (Ross, 1988).

Biomass – An Ecotrophic Efficiency value of 0.95 used and the program estimated the biomass. Croaker were rarely identified in the Sugihara *et al.* (1979) study and thus the Delaware Bay and Chesapeake models likely overestimate the biomass present here.

Diet – The diet data is based on the general diet found in the Delaware Bay model, which is a composite of the Nemerson and Able (1994) study.

Atlantic Menhaden

Q/B – A value of 31.42 was used (Palomares and Pauly, 1998).

P/B – We utilized a P/B value of 0.55, which is the M (natural mortality) from 2003 FMP. For initial parameterization we are assuming a fishing mortality rate (F) of 0 as there was no directed fishery for menhaden in the bay in 1979.

Biomass – Biomass was calculated by EwE setting the EE to 0.95.

Diet – Diet data is modified from the Sugihara *et al.* (1979) study of Manahawkin Bay.

Atlantic Silverside

Q/B – The consumption ratio for littoral forage fish of 4.0 year-1 was determined by setting a production/consumption ratio of 0.2 (Christensen *et al.*, 2009).

P/B – Total mortality for littoral forage fish was estimated by local experts at a Chesapeake Bay Ecopath Workshop (Sellner *et al.*, 2001) to be 0.8 year-1 and was assumed to be similar to other forage fish groups.

Biomass - The biomass for the group was estimated by setting Ecotrophic Efficiency to 0.95

Diet – Diet data is modified from the Sugihara *et al.* (1979) study of Manahawkin Bay.

Bay Anchovy

Q/B - Assuming habitat temperature of 15^{o}C, W∞ = 20 (g), an aspect ratio of 1.32 and carnivorous diet, the consumption to biomass ratio was calculated in Fishbase (Froese and Pauly, 2004) as 9.7 (year-1). (Values from Christensen *et al.*, 2009, except temperature).

P/B –Houde and Zastrow (1991) reported bay anchovy adult mortality rates ranging between 89% and 95% annually, while Luo and Brandt (1993) suggested that a 95% mortality rate was appropriate for the species. The P/B ratio was calculated based on the 95% mortality rate, *i.e.*, P/B ≈ 3.0 year-1.

Biomass – The biomass for the group was estimated by setting Ecotrophic Efficiency to 0.990 following Frisk *et al.* (2006).

Diet - Diet data is modified from the Sugihara *et al.* (1979) study of Manahawkin Bay.

Bluefish

Q/B - Assuming habitat temperature of 15 ^{o}C, Wmax = 16,962.1 (g), carnivorous feeding, and an aspect ratio of 2.55, the resulting consumption to biomass ratio is 3.1 (year-1) as calculated in Fishbase (Froese and Pauly, 2004).

P/B – Production/biomass was determined as 0.434 (year-1) based on an natural mortality rate (M) = 0.25 (year-1) (Christensen *et al.* 2009) and an estimate of fishing mortality (F) = 0.184 (year-1) from the ASMFC assessment (2003(b)).

Biomass – Biomass was calculated by setting the Ecotrophic Efficiency to 0.95.

Diet – Diet data is modified from the Sugihara *et al.* (1979) study of Manahawkin Bay, averaged for all size classes.

Mummichog

Q/B – A value of 3.65 was taken from Pauly (1989).

P/B – A value of 1.2 was used, following the best professional judgement value of Frisk *et al.* (2006).

Biomass- The biomass for the group was estimated by setting Ecotrophic Efficiency to 0.95 as taken from Christensen *et al.* (2009).

Diet – Diet data is modified from the Sugihara *et al.* (1979) study of Manahawkin Bay.

River herring

Q/B – A value of 8.4 was used, which is the average of Pauly (1989; 8.63 at temp = 10^{o}C) and Palomares (1991; 8.23 at temp=20^{0}C).

P/B - Total mortality for this group was based on the P/B of 0.75 year-1 for alewife in Randall and Minns (2000).

Biomass – Biomass was estimated by EcoPath assuming that the Ecotrophic Efficiency of these species in the Bay was 0.95, following Christensen *et al.* (2009).

Diet – Diet data is modified from the Sugihara *et al.*(1979) study of Manahawkin Bay.

Spot

Q/B – The consumption to biomass ratio was estimated as 6.2 (year-1) using the model in Fishbase (Froese and Pauly, 2004) assuming a habitat temperature of 15 ^{0}C, W∞ = 190g (Piner and Jones, 2004) and an aspect ratio of 1.39 (Christensen *et al.*, 2009).

P/B - Hoenig's method estimated an M = 0.9 (year-1) given a maximum age of 5 (Piner and Jones, 2004). This is consistent with the total mortality (Z) used in the Frisk *et al.*(2006) model.

Biomass – Biomass was estimated by EcoPath assuming that the Ecotrophic Efficiency of these species in the Bay was 0.90, following Christensen *et al.*(2009).

Diet – Diet data is modified from the Sugihara *et al.* (1979) study of Manahawkin Bay.

Striped bass

Q/B - An estimated consumption to biomass ratio of 2.4 (year-1) was based on the empirical relationship provided by Fishbase (Froese and Pauly, 2004), assuming an aspect ratio of 2.31 (Christensen *et al.*2009), temperature T = 15 ^{0}C, and W∞ = 46.6 (kg).

P/B – We utilized a value of 0.40, taken from Christensen *et al.* (2009). This value assumes an M=.15 (ASMFC from Smith et al 2000), and an F= 0.25 (best professional judgment) for resident bass (1-7 years old).

Biomass – A biomass value of 2.1 t/km^2 was taken from Christensen *et al.* (2009) for resident striped bass.

Diet – Diet data is modified from the Sugihara *et al.* (1979) study of Manahawkin Bay averaged across all size classes.

Summer Flounder

Q/B- The consumption to biomass ratio of = 2.6 (year-1) was calculated from Froese and Pauly (2004) assuming an aspect ratio of 1.32, Wmax = 12,000 (g) carnivorous feeding, and habitat temperature of 15 ^{o}C.

P/B- Following the Christensen *et al.* (2009) and Frisk *et al.* (2006) models, we utilized a P/B=0.52 based on the 2002 NFSC determination of M=0.2 and F ranging between 0.24 and 0.32.

Biomass – Biomass was estimated by EcoPath using an Ecotrophic Efficiency of 0.95, following Christensen *et al.* (2009).

Diet – Diet data is modified from the Sugihara *et al.* (1979) study of Manahawkin Bay.

Weakfish

Q/B - The Q/B ratio of 3.0 (year-1) was estimated using Fishbase (Froese and Pauly, 2004) assuming average habitat temperature of 15 ^{0}C, aspect ratio of 1.32, maximum weight $W\infty$ = 6,190 (g) (Lowerre-Barbieri *et al.*, 1995) and carnivorous feeding habitats.

P/B – Total mortality of Z = 0.26 (year-1) was estimated using Hoenig's method (1983) assuming a longevity of 17 years (Lowerre-Barbieri *et al.*, 1995), *sensu* Frisk *et al.* (2006).

Biomass – Biomass was estimated by EcoPath using an Ecotrophic Efficiency of 0.90.

Diet – Diet data is modified from the Sugihara *et al.* (1979) study of Manahawkin Bay, averaged across all size classes.

Winter Flounder

Q/B - The estimated consumption ratio of 3.4 year-1 was derived using the empirical equation in FishBase (Froese and Pauly, 2004), and was calculated assuming that T = 15 °C, Winf = 3,600 g, an aspect ratio of 1.32, and carnivorous diet.

P/B - The P/B estimate for this group of 0.460 year-1 is based on a value given for flatfish off the Atlantic seaboard in Sissenwine (1987).

Biomass – Biomass was estimated by EcoPath using an Ecotrophic Efficiency of 0.95.

Diet – Diet data is modified from the Sugihara *et al.* (1979) study of Manahawkin Bay.

Avifauna

Piscivorous seabirds

Q/B - The consumption ratio estimate of 120 year-1 was from data for the piscivorous seabirds group in Preikshot (2007).

P/B - A total mortality estimate for piscivorous seabirds of 0.163 year-1 was based on survival rate values of 85-90% for cormorants and 80-93% for alcids in the northeast Atlantic (ICES, 2000).

Biomass - The biomass estimate for piscivorous seabirds of 0.250 t/km^2 was modified from Christensen et al. (2009), which was based on advice provided in a Chesapeake Ecopath Workshop (Sellner *et al.*, 2001).

Diet compositions - The diet composition for piscivorous seabirds was modified from Christensen et al. (2009), modified to reduce predation on menhaden and increase the percentage of imported diet items.

Non-Piscivorous seabirds

Q/B - The consumption ratio estimate of 120 year-1 was from data for the non-piscivorous seabirds group in Preikshot (2007).

P/B - A total mortality estimate for piscivorous seabirds of 0.51 year-1 was taken from the Chesapeake model and was based on annual mortality rate of 37% for mallard males and 44% females (Anderson, 1975).

Biomass - The biomass estimate for piscivorous seabirds of 0.121 t/km^2 was taken from Christensen et al. (2009) and was based on advice provided in a Chesapeake Ecopath Workshop (Sellner *et al.*, 2001).

Diet compositions - The diet composition for non-piscivorous seabirds was taken from Christensen et al. (2009).

INVERTEBRATES

Blue crabs

Q/B- The consumption ratio of 4.0 was taken from the Chesapeake Bay model.

P/B – We utilized a P/B= 1.21 (year-1) as taken from Frisk *et al.*(2006). This was based on a stock assessment for Delaware Bay that used a natural morality of M = 0.8 (year-1) assuming a lifespan of 4 years (Kahn, 2003) and fishing mortality on total stock (recruits and post recruits) of F = 0.41 (year-1) (2000-2002).

Biomass – We utilized an estimate of 7.2 t/km^2, which was the biomass developed for the Delaware Bay stock assessment (Kahn and Helser, 2005)

Diet – The diet was taken from Frisk *et al.* (2006), averaged across stanzas.

Hard Clams

Q/B - The consumption ratio was estimated to be 5.1 year-1 assuming a P/Q = 0.20 as taken from Christensen *et al.* (2009).

P/B - A total production/biomass ratio of 1.02 year-1 was estimated from an empirical equation of Thomas Brey, AWI, included in the Ecopath software (see Christensen *et al.* (2000)] for a description of the algorithm), assuming an average mass of 20 g, water T = 17 °C, non-motile behavior, and an average water depth of 6.5 m.

Biomass – A biomass of 62.2 t/km^2 was calculated for Barnegat Bay based on a average density of 0.28 $clams/ft^2$ (1986/1987 hard clam survey, B Muffley presentation) and an average mass of 20 g (Christensen *et al.* (2009) P/B calculation).

Diet – Diet taken from Frisk *et al.* (2006).

Oyster

Q/B - The consumption to biomass ratio of 2.0 was taken from Christensen *et al.* (2009).

P/B – A P/B ration of 0.15 $year^{-1}$ was used based on Christensen *et al.* (2009).

Biomass – As there has not been a reported natural set of oysters in many years a *de minimus* biomass of 0.001 t/km^2 was entered.

Diet – Diet data taken from Christensen *et al.* (2009).

Sea Nettles

Q/B – Matishov and Denisov (1999) found a diurnal consumption rate of 7% of biomass for *Aurelia aurita* medusa in the Black Sea. This would equate to an annual consumption per unit biomass of 365 x 0.07 = 25.55 $year^{-1}$. Assuming sea nettle medusa are present in Barnegat Bay during June through September, Q/B can be derived to ≈ 6.5 $year^{-1}$.

P/B – A P/B of 5.0 $year^{-1}$ was used here based on the rational found in Christensen *et al.* (2009).

Biomass – A biomass of 0.583t/km^2 was taken from Christensen *et al.* (2009). This was derived from an average of the Baird and Ulanowicz (1989) seasonal models multiplied by a conversion factor of carbon to wet weight of 0.3% for jellies (Shushkina *et al*., 2000).

Diet – The sea nettle diet data was taken from Christensen *et al.* (2009).

Ctenophores

Q/B and P/B – Shushkina *et al.* (1989) found that ctenophores in their study had growth rates 1.5 to 2 times greater than jellies. Therefore, the P/B and Q/B values for ctenophores were the values for sea nettles multiplied by 1.75; P/B was 8.800 $year^{-1}$ and Q/B was 11.38 $year^{-1}$.

Biomass – A biomass of 3.4 t/km^2 was used based on an estimate from data obtained from the VIMS ChesMMAP survey (Sellner *et al*., 2001).

Diet - The ctenophore diet data was taken from Christensen *et al.* (2009).

Benthic infauna/epifauna

Q/B – A consumption ration of 5.0 year -1 was estimated by Ecopath after designating a P/Q ration of 0.2, following Christensen *et al.*(2009).

P/B – A P/B of 1.0 year-1 was taken from Christensen *et al.*(2009) based on the value for annelids given in Jorgensen *et al*. (2000).

Biomass – Biomass was estimated by Ecopath based on a group Ecotrophic Efficiency of 0.90, following Christensen *et al.* (2009).

Diet – Diet data taken from Chesapeake Bay model.

Amphipods

Q/B – The values for this group is currently based on the same information as benthic infauna/epifauna.

P/B – The values for this group is currently based on the same information as benthic infauna/epifauna.

Biomass – The values for this group is currently based on the same information as benthic infauna/epifauna.

Diet – The values for this group is currently based on the same information as benthic infauna/epifauna.

Copepods (Mesozooplankton)

Q/B – A consumption ration of 83.333 year -1 was estimated by Ecopath after designating a P/Q ration of 0.3, following Christensen *et al.* (2009).

P/B – A mortality rate of 25 $year^{-1}$ was taken from Christensen *et al.* (2009), as estimated during the Chesapeake Bay Ecopath Workshop.

Biomass – A biomass of 10.3 t/km^2 was estimated for the Chesapeake Bay based on field sampling as reported in Christensen *et al.* (2009).

Diet – The diet ratio, 72% microzooplankton, 28% phytoplankton is from the Chesapeake Bay model.

Microzooplankton

Q/B – A consumption ration of 350 year -1 was estimated by Ecopath after designating a P/Q ration of 0.4, as taken from the Chesapeake Bay Model.

P/B – Total mortality rate for microzooplankton was estimated to be 140 year-1 by local experts at a Chesapeake Bay Ecopath workshops (Park and Marshall, 2000).

Biomass – Biomass was estimated based on an assumed EE of 0.95.

Diet – The 100% phytoplankton diet is from the Chesapeake Bay model.

Phytoplankton

P/B – We elected to use a value of 160 year^{-1} as reported in Christensen *et al.* (2009) compared to a value of 60 as reported in Frisk *et al.* (2006) as the Chesapeake is a highly eutrophic system more similar to the conditions found in Barnegat Bay.

Biomass – 27t/km^2 taken from Christensen *et al.* (2009).

Benthic algae

P/B – A production to biomass value of 80 year^{-1} was taken from Christensen *et al.* (2009).

Biomass – Biomass of benthic algae was estimated by Ecopath based on an assumed Ecotrophic Efficiency of 0.9, following Christensen *et al.* (2009).

SAV

P/B – Mortality for *Z. marina* was estimated in the Chesapeake as Z = P/B =5.11 year-1, which was taken from a similar system in Japan (Oshima *et al.*, 1999).

Biomass – In 1979 there was approximately 8,053 ha of mapped submerged aquatic vegetation (Northern segment: 767, Central segment: 5,126, Southern segment: 2,160) out of the 27,900 hectares of Barnegat Bay (Lathrop et al 2001). The highest recorded annual eelgrass maximum biomass in the southern and central portions of the bay occurred in 2004 and was 219.7 g dry wt /m^2, while the highest Ruppia biomass recorded in the northern segment occurred in 2011 and was 32.8 g dry wt/ m^2 (Kennish et al 2013). Expanding the biomass estimates over the 1979 SAV acreage yields a baywide total biomass of 16,258.918t, or 58.2t/km^2

Appendix 2 – Initial Diet Composition

	Piscivorous seabirds	Non-piscivorous	weakfish	striped bass	summer flounder	bluefish	winter flounder	Atlantic silversides	Atlantic croaker	spot	Atlantic menhaden
Piscivorous seabirds											
Non-piscivorous											
weakfish	0.0056			0.816		0.013					
striped bass	0.0166										
summer flounder	0.011										
bluefish	0.02										
winter flounder	0.0058				0.2						
Atlantic silversides	0.017			0.121	0.132	0.087					
Atlantic croaker			0.0001								
spot						0.016					
Atlantic menhaden	0.1					0.255					
river herring	0.028										
mummichog	0.03					0.36					
bay anchovy	0.074		0.86		0.273	0.094	0.018				
benthic infauna/epifauna		0.276	0.133	0.06	0.186	0.066	0.742	0.59	0.8	0.509	0.18
amphipods			0.004				0.07	0.244		0.25	
blue crabs			0.003		0.2	0.103	0.002				
hard clams		0.01		0.003			0.157			0.057	
oysters											
copepods								0.154	0.2	0.18	0.338
Microzooplankton											
sea nettles											
ctenophores											
benthic algae											
phytoplankton											0.421
SAV		0.128									
detritus		0.011			0.009	0.006	0.011	0.012		0.004	0.061
import	0.692	0.575									

	river herring	mummichog	bay anchovy	benthic infauna	amphipods	blue crabs	hard clams	oysters	copepods	Micro zoo	sea nettles	ctenophores
Piscivorous seabirds												
Non-piscivorous												
weakfish												
striped bass												
summer flounder												
bluefish												
winter flounder												
Atlantic silversides												
Atlantic croaker												
spot												
Atlantic menhaden												
river herring												
mummichog		0.564										
bay anchovy											0.054	
benthic infauna/epifauna	0.435	0.256	0.37	0.02	0.02	0.5						
amphipods	0.055	0.157	0.044									
blue crabs						0.125						
hard clams						0.175						
oysters												
copepods	0.5		0.582								0.421	0.666
Microzooplankton				0.08	0.08				0.72			0.334
sea nettles												
ctenophores											0.525	
benthic algae				0.3	0.3	0.05	0.5					
phytoplankton	0.005	0.017		0.4	0.4		0.25	0.99	0.28	1		
SAV						0.05						
detritus	0.005	0.006	0.004	0.2	0.2	0.1	0.25	0.01				
import												