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Ecosystem Modeling of Food Web Dynamics Explicitly Considering the Effects of Climate Change in a Macrotidal Coastal Estuary

Kylee DiMaggio

Eric Chapman

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Kylee DiMaggio
Department of Marine Sciences
University of New England
kdimaggio@une.edu

Eric Chapman, Ph.D.
Marine Science Center
University of New England
echapman3@une.edu

Advised by:
Carrie J. Byron, Ph.D.
NSF SEANET Assistant Professor
Department of Marine Sciences
University of New England
cbyron@une.edu

Abstract

Climate change is influencing ecosystem structure and function in oceans; changes such as ocean acidity levels, temperature and shifting species alter marine ecosystem food webs. Cobscook Bay is a boreal, macrotidal coastal estuary, located in Washington County, ME that is important ecologically and is threatened by climate change. As biologists consider the effects of climate change on ecosystems such as Cobscook Bay, it is a topic of interest to consider what is the most critical threat. The purpose of this study was to simulate the effects of climate change on Cobscook Bay food webs to determine the biggest impact of climate change could have on the system. We conducted primary literature searches to generate scenarios and model parameters for the Ecopath with Ecosim simulation model software. We used these scenarios in the Ecopath with Ecosim program to change species' overall biomass that were expected to be adversely affected by scenarios by percent change intervals of 15. In this study, it was found that for there to be a detrimental impact on the Cobscook Bay ecosystem there must be a biomass loss of zooplankton by 95% for ocean warming and a biomass loss of shell forming organisms by 95% for ocean acidification. In contrast, it was also found there must be a 275% increase in biomass of green crabs (*Carcinus maenas*) for species shifts to cause a detrimental change on the system. The results this study suggest that ocean warming and ocean acidification pose an equal threat to the food web of Cobscook Bay while species shifts pose a less urgent, but still serious threat in the face of climate change.

Introduction

Climate change is modifying ocean environments globally (Brennand et al. 2010). Climate change can negatively impact ecosystems such as Cobscook Bay through ocean acidification, which has a direct negative impact on bivalves and invertebrates of the ecosystem by reducing their ability to form shells (Brennand et al. 2010 and Guo 2015). Climate change has been linked to increasing ocean temperatures, which can negatively impact zooplankton due to fluctuations of spawning and other seasonal processes, ultimately decreasing overall populations (Friedland et al. 2013). In addition to ocean warming and ocean acidification, climate change can lead to changes in species ranges (Tepolt 2014). Species shifts are evident all over the world due to climate change. Examples of these species shifts include green crabs (*Carcinus maenas*), asian shore crabs (*Hemigrapsus sanguineus*), lionfish (*Pterois*), zebra mussles (*Dreissena polymorpha*), etc. Species shifts may alter the Cobscook Bay ecosystem through the increase of green crabs that have proven to be detrimental in areas where they are considered invasive species, such as the Gulf of Maine. In this study we simulated the effects of climate change on Cobscook Bay through scenario generation.

Cobscook Bay is a macrotidal coastal estuary, located in Washington County, ME. Cobscook is described as macrotidal to describe the tides, with tidal intervals of 3-7m (Larsen 2004). Cobscook Bay is a coastal estuary; it is at the edge of an intersection between the Bay of Fundy and the Atlantic Ocean. The bay is characterized as intertidal with a shallow average depth of 10m and a high tide surface area of about 110km^2 (Larson 2004). The current speeds reach a maximum of 2m/s and exhibits extreme tidal mixing that contribute to low water temperatures in the summer months (Larsen 2004 and Brooks 2004). Substrate is composed and dominated by gravel and rock; mudflats make up 60% of the intertidal regions around the bay (Kelley and Kelley 2004). The diversity of the substrate provides niches for adaptation. Unique macro intertidal wave patterns that bring in food and flush out waste also contribute to biodiversity (Beginning with Habitat 2003). Summarily, the physical characteristics of Cobscook Bay allow unusually high biodiversity in the area, making Cobscook a unique area of study. Cobscook's high biodiversity includes the highest density of nesting bald eagles in the northeastern United States and many other rare birds and plants such as Salt Marsh Sedge.

In this study, several effects of climate change were simulated on the Cobscook Bay ecosystem to show how food webs can be impacted in the system due to climate change.

Focus is on the direct impact on the ecosystem due to shifts in the food web in situations of ocean warming, ocean acidification and species shifts. Due to the clear evidence of global climate change and the adverse effects it can have on ecosystems, this study was created in an effort to identify which impact is the biggest threat to diversity hotspots such as Cobscook Bay. It was then hypothesized that ocean warming and ocean acidification would be more impactful on the simulated ecosystem than species shift due to their more widely dispersed affects.

Methods

In this study three different effects of climate change were simulated using a static mass balance food web model. This study was designed to determine what factors of climate change pose the most immediate threat to ocean ecosystems using modelling techniques. For this study it was determined that the tested scenarios of climate change would be ocean warming, ocean acidification and species shifts. To test these scenarios, overall biomass of species known to be effected by these scenarios were minimized or maximized until the model became unbalanced due to a dramatic shift in carrying capacity of a species. An unbalanced model is indicative of a collapsing food web and in this study is regarded as the highest impact a climate change scenario can have before it becomes detrimental to the food web.

In this study, ecopath was used as a modeling tool to determine changes in the Cobscook Bay food web due to major predicted effects on climate change. To simulate this effect, we used Ecopath with Ecosim to alter the model to show how food webs would shift as a result of these changes. We developed a method of increasing or decreasing a species biomass by 10% and 25% according to the scenario and the literature research that supports the simulated change. For the ocean warming scenario, a decrease in the biomass of zooplankton in the model was performed. This scenario was determined through literature research stating that an increase in ocean warming may potentially decrease the biomass of zooplankton in an area (Friedland et al. 2013 and Runge et al. 2015). For ocean acidification, a decrease in the biomass of shell forming organisms such as bivalves was performed. This scenario was based on literature research that supported the idea that an increase in ocean acidification may result in the decrease in biomass of shell forming organisms (Fitzer 2016 and Guo 2015 and Waldbusser 2015). Lastly, for species shifts, an increase the biomass of green crabs *(Carcinus maenas)* was performed with the model. This scenario was based on literature research that gave evidence of the Green Crab *(Carcinus maenas)* as a strong invasive species along the Cobscook Bay study area (Neckles 2015 and Tepolt 2014 and Large 2013).

Implemented scenarios

Three scenarios were tested in this study explicitly surrounding common effects of climate change including, ocean warming, ocean acidification, and species shifts. All of the scenarios we considered in this study were derived from literature research within each topic and how it affects the ecosystem within the model. Through literature research we developed scenarios pertaining to a change in species biomass. For example, each scenario involved either an increase or decrease of 10%, or 25% in biomass of the affected organisms depending on the scenarios. The scenarios were:

- It is previously known that ocean acidification results in reduced ocean pH and shifts in seawater carbonate chemistry. Ocean acidification is known for lowering calcium carbonate rates making corals, bivalves and other shell forming organisms unable to build their shells and exoskeletons (Doney et al. 2009). To simulate the effect of ocean acidification on the model, we will minimize overall biomass of shell forming organisms in the model.
- A former study in the Gulf of Maine shows warming along the northern shelf and that zooplankton species have shown increased seasonal growth with a decrease in absolute abundance (Friedland et al. 2013 and Runge et al. 2014). To simulate this effect of ocean warming on the model, we will minimize the overall biomass of zooplankton in the model.
- Studies of the green crab (*Carcinus maenas*) show the species thriving outside of their natural habitat in areas such as the Gulf of Maine, ultimately causing species shifts within these areas (Tepolt 2014 and Large 2013). Other studies performed within the Gulf of Maine show large impacts along the timeline that coincides with coast wide increases of green crab (*Carcinus maenas*) populations (Neckles 2015). To simulate the effect of species shifts in the event of invasive species on the model, we will increase the overall biomass of green crabs (*Carcinus maenas*).

Ecopath with Ecosim

In this study we used Ecopath with Ecosim to simulate an ecosystem model of Cobscook Bay. Ecopath with Ecosim was used to make food web models of Cobscook Bay by collecting input data for simulation through literature research. Ecopath uses a mass balance approach to calculate energy flow and biomass in ecosystems based on the input paramets. Ecopath considers basic input data (Figure 1) and diet composition (Table 2) but only what data that is supplied. and will then supply researchers with a model based on the data given. To obtain input data such as that in Table 1 and Table 2, we used primary literature to populate the model parameters.

Ecopath with Ecosim is a mass balance model software guided by two master equations:

$$\boldsymbol{Production} = \boldsymbol{Predation} + \boldsymbol{Fishery} + \boldsymbol{Biomass\ accumulation} \\ + \boldsymbol{Net\ migration} + \boldsymbol{Other\ mortality}$$

and

$$\boldsymbol{Consumption} = \boldsymbol{Predation} + \boldsymbol{Unassimilated\ food} \\ (= \boldsymbol{excretion} + \boldsymbol{egestion}) + \boldsymbol{Respiration}$$

We used these equations and Ecopath to simulate Cobscook Bay to test scenarios considering consumption divided by biomass and production divided by biomass. Based on these equations and the information provided for basic input and diet composition, Ecopath with Ecosim produces a basic estimates table and a food web model as shown in Table 3 and Figure 1.

Data acquisition for Ecopath model simulation

To estimate basic input data of trophic levels for the Cobscook Bay ecosystem, we reviewed the peer-reviewed literature; data were used from scholarly articles and other reliable sources, including government reports (Tables 1 & 2). We used published data to produce to estimate values for biomass (B), production/biomass (P/B), and consumption/biomass (Q/B). In instances of incomplete datasets, we estimated values by biomass based on trophic level position.

Diet composition

Trophic levels can be understood through energy transfer through an ecosystem from one group to the next. To determine how energy flows through an ecosystem, a diet composition must be developed to establish and observe which species feed on other trophic groups. The diet composition can also be made through the Ecopath model where each species is formatted against each other and ratios can be put into the diet table. The ratios of the table must sum up to 1 thus indicating 100% composition of each species in the ecosystem.

Prebalancing and diagnostics for model validation

In order to begin using the model we first had to make sure that the model would provide accurate and reliable information. To do this, we implement PREBAL diagnostics (Link 2010). This process will allow us to ensure there are no issues with the structure of the model and that the data is sufficient (Link 2010). After performing PREBAL procedures we must determine our input data in an effort to begin with a balanced model. Input data was retrieved from scholarly articles and other reliable sources for the common species found in Cobscook Bay. The data was then imported into the model with the species on the x axis and the parameter (biomass, production/biomass, consumption) on the y axis. To achieve a parameter estimation that could be used in our model the model must be balanced. The model is balanced when the linear regression was a value close to one, once the model is balanced the warning messages will no longer show (this can take some time).

With a balanced model of the ecosystem input data we are then able to determine the consumption and production rates. The input data found to make a balanced model for the biomass could be used to reevaluate the data for the production and consumption chart. Again, once the model is balanced warning messages will no longer appear.

Determining carrying capacity

Determining carrying capacity of a species with the Ecopath model is a guess and check process in which the biomass of a species is either increased or decreased until there is a change in the model. When carrying capacity of an organism is reached the model will become unbalanced due to excessive increase in another organism's eutrophic efficiency level. Ecopath is a complex program that is able to recognize the change of a food web in order to put out accurate results of carrying capacity and many other important factors of an ecosystem. Carrying capacity can be determined for any organism within the balanced model by adjusting the biomass until the model becomes unbalanced yet again.

Results and Discussion

In the following section, we present the outputs of the model and provide interpretation of the results. This study provided insight to which major impact of climate change is the most immediate threat to ocean ecosystems. It was found that ocean warming and ocean acidification pose are equally critical risks to the food web of Cobscook Bay and are additionally, slightly more critical than that of species shifts. This then suggests that immediate focus should be on combatting ocean warming and ocean acidification and protecting species such as zooplankton and shell forming organisms such as crustaceans and bivalves. However, we should not forget about species shift in the event of invasive species as they show to also have a very critical impact on ecosystems such as Cobscook Bay and are increasingly more common.

Effects of ocean acidification on food web structure

The biomass of bivalves in the model were decreased by percent intervals of 15 as a simulated effect of ocean acidification on the Cobscook Bay ecosystem. A dramatic change in the ecosystem represents a major impact of climate change through ocean acidification when the model becomes unbalanced. In this simulation scenario, the model did not become unbalanced until a 95% decrease in the biomass of bivalves was performed. This 95% decrease then causes the model to become unbalanced through bivalves (Table 4 and Figure 2). This suggests that ocean acidification begins to show a detrimental change in the Cobscook Bay food web when the biomass of bivalves is decreased by 95%, a large reduction in the current biomass.

Other studies modeling climate change effects on foodwebs with Ecopath have similar findings. A 2011 study focused on potential impacts of climate change on marine foodwebs in the Northeast Pacific using Ecopath as a modelling tool (ref). This study used climate change effects such as primary productivity, zooplankton community structure, range shifts, ocean acidification and ocean deoxygenation. Out of all the studied potential climate change effects, it was found that ocean acidification was one of the two effects that resulted only in a decrease of group productivity (Ainsworth 2011). This study additionally categorizes change in productivity of functional groups into three categories that are: conservative, moderate and substantial the majority of which fall into the moderate and substantial categories (Ainsworth 2011). Comparison of results found in other studies further suggests that ocean acidification is a great threat to marine ecosystems, directly effecting populations of crustaceans, bivalves and other organisms that rely on calcium carbonate and therefore threatening whole food webs.

Effects of ocean warming on food web structure

To simulate the effects of ocean warming on the Cobscook Bay food web the biomass of zooplankton in the model were decreased by percent intervals of 15.
A major ecosystem change due to ocean warming is not witnessed until the model becomes unbalanced. In this scenario, the model did not become unbalanced until a 95% decrease in overall zooplankton biomass of the model was performed. This 95% decrease then causes the model to become unbalanced through zooplankton as shown in Table 5 and Figure 3. These results suggest that ocean warming only begins to show a detrimental change in the Cobscook Bay food web when the overall biomass of zooplankton is decreased by 95%.

Additionally, other modelling studies also suggest a decrease of zooplankton in areas such as Cobscook Bay due to ocean warming. These decreases are seen as zooplankton such as the species *C. finmarchicus* migrate poleward from the Northeast Atlantic in the event of ocean warming in their current region (Chust 2014). This poleward shift was consistent during the 1959-2004 period (Chusy 2014) and will continue in the event of further seaward warming that is inevitable in the path we are currently on. Our study proves to be consistent with other studies that provide an explanation for our results and the loss of zooplankton in the model. Further proving that ocean warming is a substantial threat to food webs such as Cobscook Bay.

Effects of species shifts on food web structure

In our final simulated scenario, the biomass of the invasive green crab *(Carcinus maenas)* was increased by percent intervals of 15 as a simulated effect of species shifts on the Cobscook Bay ecosystem.A detrimental change to the Cobscook Bay ecosystem due to species shifts is not seen until the model becomes unbalanced. In this last scenario, the model did not become unbalanced until a 275% increase was made in the biomass of green crabs *(Carcinus maenas)*. This 275% increase caused the model to become unbalanced through an unsustainable decrease Eelgrass (*Zostera*) as shown in Table 6 and Figure 4, likely from increased herbivory of eelgrass from green crabs. The results of this scenario suggest that species shifts of green crabs *(Carcinus maenas)* do not cause a detrimental change in the ecosystem until their biomass is increased by 275%. These findings are consistent with that of other studies such as Neckles HA (2015). Neckles (2015) found that loss of Eelgrass (*Zostera*) was directly linked to an increase of green crab *(Carcinus maenas)* populations in Casco Bay, Maine. In this study, researchers found that in places where green crabs *(Carcinus maenas)* were excluded there was an 82% survival rate of eelgrass (*Zostera*) and in places where green crabs *(Carcinus maenas)* were present, survival rate of eelgrass was only 24% (*Zostera*).

Our results suggest that green crab disturbance in the Gulf of Maine due to species shifts directly impacts food webs through eelgrass. Therefore, through these studies it is evident that direct and indirect effects of climate change contribute to the vulnerability of the Cobscook Bay ecosystem to climate change.

Conclusion

Cobscook Bay is an important ecosystem to the Bay of Fund and the Gulf of Maine because it provides habitat for several threatened or endangered species and has unique qualities that make it important for biodiversity. As biologists consider the effects of climate change on ecosystems such as Cobscook Bay, it is interesting to consider what is the most critical threat. This study aimed to answer that question, using Ecopath as a way to simulate the effects of climate change on the Cobscook Bay ecosystem.

In this study we developed three scenarios to test the effects of climate change on the Cobscook Bay ecosystem. Our results suggest that ocean warming and ocean acidification have an equally detrimental impact on the Cobscook Bay ecosystem and from a relative magnitude are more detrimental compared to species range shifts on the Cobscook Bay ecosystem. In the simulation representing the effects of ocean acidification we showed that ocean acidification does not unbalance the Cobscook Bay ecosystem until there is a loss of bivalves by 95% (Table 4 and Figure 2). In the simulation scenario for ocean warming, we showed that ocean warming also does not unbalance the Cobscook Bay ecosystem until there is a 95% biomass loss of zooplankton (Table 5 and Figure 3). Lastly, in the simulation scenario representing species shifts, it was shown that species shifts does not unbalance

Cobscook Bay ecosystem food web until there is a 275% increase in green crabs *(Carcinus maenas)* (Table 6 and Figure 4).

The results found from this simulation of Cobscook Bay using Ecopath suggest that ocean warming and ocean acidification pose an equal magnitude risk to the food web of Cobscook Bay while species shifts pose a lower magnitude, but still significant threat. This study helps to determine which factors of climate change are the most pressing. Through this study and the comparison of others, it is shown that emphasis should be put first on ocean warming and ocean acidification and protecting both zooplankton and bivalves respectively. However, it is also shown that emphasis should also be put into efforts of combatting species shifts due to climate change and protecting ecosystems from harmful shifts such as that caused by the green crab *(Carcinus maenas)*.

Table 1: Basic input data table for the Cobscook Bay ecosystem simulation

	Group name	Habitat area (fraction)	Biomass in habitat area (t/km²)	Production / biomass (/year)
1	Bald Eagle[1]	0.667	0.0261	0.2
2	Gadidae (Cod, Haddock, Hake)[2]	0.667	1.971	0.38
3	Scombridae (Atlantic Mackerel)[2]	0.667	2	0.19
4	Pleuronectidae (Winter Flounder)[2]	0.667	12.47	1.9
5	Gasterosteidae (Stickleback)[2]	0.667	4.056	0.54
6	Clupeidae (Herring)[2]	0.667	10.72	0.6
7	Osmeridae (Smelt)[2]	0.667	2.6	0.39
8	Green Crabs[3]	0.333	13.74	1.4
9	Bivalves[4]	0.333	305	0.7
10	Littorina litorrea[5]	0.333	22.46	0.483
11	Other Invertebrates	1	50	2
12	Zooplankton	1	56.25	50
13	Eelgrass[6]	0.667	300	0.391
14	Kelp[7]	0.667	157.4	3.543
15	Rockweed[8]	0.333	1814	0.546
16	Phytoplankton	1	675	125
17	Microphytobenthos	1	6750	125
18	Red/Green Algae	0.333	4631.5	8

1 Shipp 1980, Hatcher 2011, Barefield 2012
2 Vieser 2010, *Fishbase* 2015
3 Tyrrell, 2006
4 Beal 2015, Ripley 1998
5 Ugarte, Bartlett, Perry 2010, Moore 1937
6 Beal et al. 2004
7 Vadas et al. 2004
8 Vadas, Wright, Beal 2004
9 Phinney, Yentsch, Phinney 2004

Table 2: Diet composition table for the Cobscook Bay ecosystem simulation

	Prey \ predator	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	Bald Eagle[1]	0	0	0	0	0	0	0	0	0	0	0	0
2	Gadidae (Cod, Haddock, Hake)[2]	0.4	0.0691	0	0	0	0	0	0	0	0	0	0
3	Scombridae (Atlantic Mackerel)[2]	0	0.0691	0	0	0	0	0	0	0	0	0	0
4	Pleuronectidae (Winter Flounder)[2]	0.0696	0.0691	0	0	0	0	0	0	0	0	0	0
5	Gasterosteidae (Stickleback)[2]	0	0.0691	0	0	0	0	0	0.03	0	0	0	0
6	Clupeidae (Herring)[2]	0.53036	0.0691	0	0	0	0	0	0.03	0	0	0	0
7	Osmeridae (Smelt)[2]	0	0.0691	0	0	0	0	0	0.03	0	0	0	0
8	Green Crabs[3]	0	0.006	0	0.0472	0	0	0	0	0	0	0	0
9	Bivalves	0	0.0112	0	0.0394	0	0	0	0.28	0	0	0	0
10	Littorina litorrea[4]	0	0	0	0	0	0	0	0	0	0	0	0
11	Other Invertebrates	0	0.145	0.486	0.611	0	0.0078	0	0	0	0	0	0
12	Zooplankton	0	0.349	0.503	0	1	0.93	1	0	0.15	0	0	0
13	Eelgrass	0	0	0	0	0	0	0	0.15	0	0	0.1	0
14	Kelp	0	0	0	0	0	0	0	0.1	0	0	0	0
15	Rockweed	0	0	0	0	0	0	0	0.18	0	0.15	0	0
16	Phytoplankton	0	0	0	0	0	0	0	0	0.4	0	0	1
17	Microphytobenthos	0	0	0	0	0	0.05	0	0	0.1	0.2	0.3	0
18	Red/Green Algae	0	0	0	0	0	0	0	0	0.11	0.35	0.35	0
19	Detritus	0	0.075	0.012	0.302	0	0.012	0	0.2	0.24	0.3	0.25	0
20	Import	0	0	0	0	0	0	0	0	0	0	0	0
21	Sum	1	1	1	1	1	1	1	1	1	1	1	1
22	(1 - Sum)	0	0	0	0	0	0	0	0	0	0	0	0

1 Cash et al. 1985, Todd et al. 1982
2 *Fishbase* 2015
3 Tyrrell 2006
4 Lenseth 2004

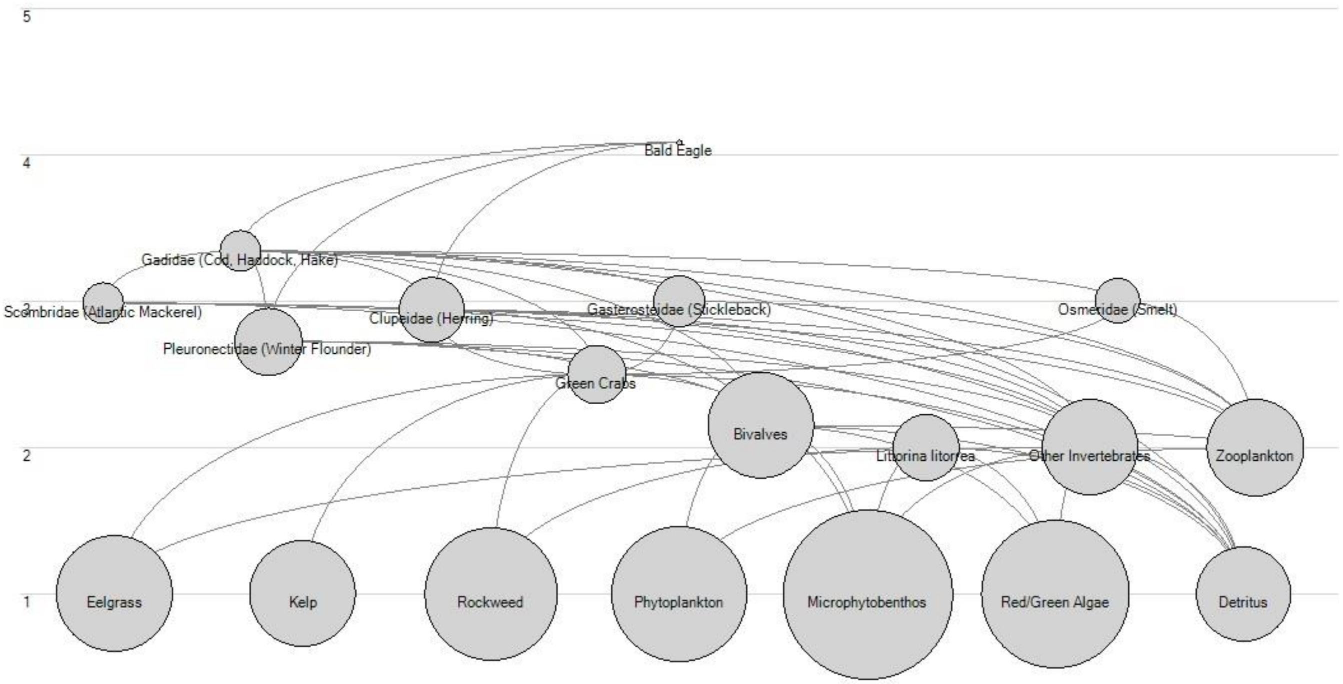

Figure 1: Food web of simulated Cobscook Bay ecosystem produced by Ecopath with Ecosim based on basic estimates in Table 1

Table 3: The balanced basic output table produced by Ecopath with Ecosim based on input data for the simulation of Cobscook Bay

	Group name	**Trophic level**	**Habitat area (fraction)**	**Biomass in habitat area (t/km²)**	**Biomass (t/km²)**	**Production / biomass (/year)**	**Consumption / biomass (/year)**	**Ecotrophic efficiency**	**Production / consumption**
1	Bald Eagle	4.085776	0.667	0.0261	0.017409	0.2	0.75	0	0.266667
2	Gadidae (Cod, Haddock, Hake)	3.34412	0.667	1.971	1.314657	0.38	2.58	0.479675	0.147287
3	Scombridae (Atlantic Mackerel)	2.988006	0.667	2	1.334	0.19	4.4	0.924834	0.043182
4	Pleuronectidae (Winter Flounder)	2.727418	0.667	12.47	8.317491	1.9	3.8	0.01489	0.5
5	Gasterosteidae (Stickleback)	3	0.667	4.056	2.705352	0.54	9.7	0.44233	0.05567
6	Clupeidae (Herring)	2.937987	0.667	10.72	7.15024	0.6	10.1	0.152238	0.059406
7	Osmeridae (Smelt)	3	0.667	2.6	1.7342	0.39	2.9	0.955434	0.134483
8	Green Crabs	2.50014	0.333	13.74	4.57542	1.4	3	0.236219	0.466667
9	Bivalves	2.15	0.333	305	101.565	0.7	4	0.072096	0.175
10	Littorina litorrea	2	0.333	22.46	7.47918	0.483	18	0	0.026833
11	Other Invertebrates	2	1	50	50	2	14	0.232173	0.142857
12	Zooplankton	2	1	56.25	56.25	50	200	0.058135	0.25
13	Eelgrass	1	0.667	300	200.1	0.391	0	0.921009	
14	Kelp	1	0.667	157.4	104.9858	3.543	0	0.00369	
15	Rockweed	1	0.333	1814	604.062	0.546	0	0.068718	
16	Phytoplankton	1	1	675	675	125	0	0.135259	
17	Microphytobenthos	1	1	6750	6750	125	0	0.000333	
18	Red/Green Algae	1	0.333	4631.5	1542.29	8	0	0.027298	
19	Detritus	1	1	46.8	46.8			0.000349	

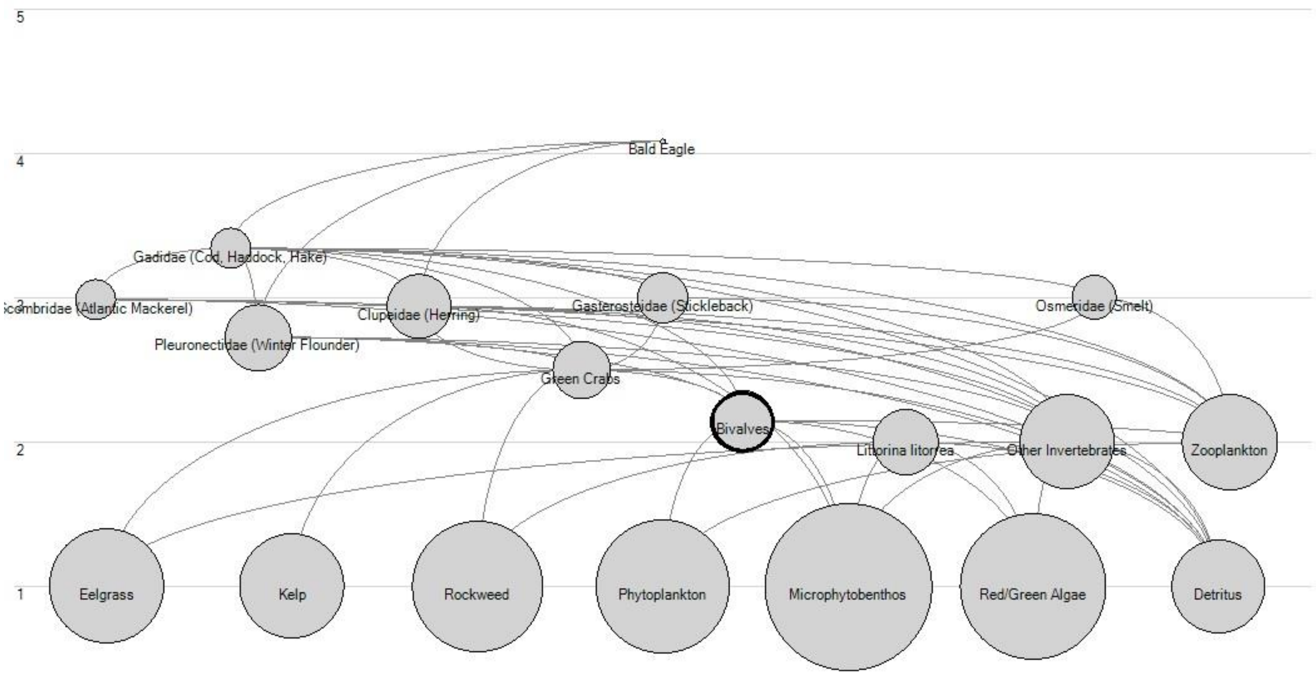

Figure 2: The food web flow diagram produced through Ecopath with Ecosim with an adjusted 95% decrease in biomass of bivalves in the system

Table 4: The adjusted and unbalanced Ecopath with Ecosim basic output table with a 95% decrease in bivalves of the system

	Group name	Trophic level	Habitat area (fraction)	Biomass in habitat area (t/km²)	Biomass (t/km²)	Production / biomass (/year)	Consumption / biomass (/year)	Ecotrophic efficiency	Production / consumption
1	Bald Eagle	4.085776	0.667	0.0261	0.017409	0.2	0.75	0	0.266667
2	Gadidae (Cod, Haddock, Hake)	3.34412	0.667	1.971	1.314657	0.38	2.58	0.479675	0.147287
3	Scombridae (Atlantic Mackerel)	2.988006	0.667	2	1.334	0.19	4.4	0.924834	0.043182
4	Pleuronectidae (Winter Flounder)	2.727418	0.667	12.47	8.317491	1.9	3.8	0.01489	0.5
5	Gasterosteidae (Stickleback)	3	0.667	4.056	2.705352	0.54	9.7	0.44233	0.05567
6	Clupeidae (Herring)	2.937987	0.667	10.72	7.15024	0.6	10.1	0.152238	0.059406
7	Osmeridae (Smelt)	3	0.667	2.6	1.7342	0.39	2.9	0.955434	0.134483
8	Green Crabs	2.50014	0.333	13.74	4.57542	1.4	3	0.236219	0.466667
9	Bivalves	2.15	0.333	15.25	5.07825	0.7	4	1.441916	0.175
10	Littorina litorrea	2	0.333	22.46	7.47918	0.483	18	0	0.026833
11	Other Invertebrates	2	1	50	50	2	14	0.232173	0.142857
12	Zooplankton	2	1	56.25	56.25	50	200	0.037552	0.25
13	Eelgrass	1	0.667	300	200.1	0.391	0	0.921009	
14	Kelp	1	0.667	157.4	104.9858	3.543	0	0.00369	
15	Rockweed	1	0.333	1814	604.062	0.546	0	0.068718	
16	Phytoplankton	1	1	675	675	125	0	0.13343	
17	Microphytobenthos	1	1	6750	6750	125	0	0.000287	
18	Red/Green Algae	1	0.333	4631.5	1542.29	8	0	0.023857	
19	Detritus	1	1	46.8	46.8			0.00025	

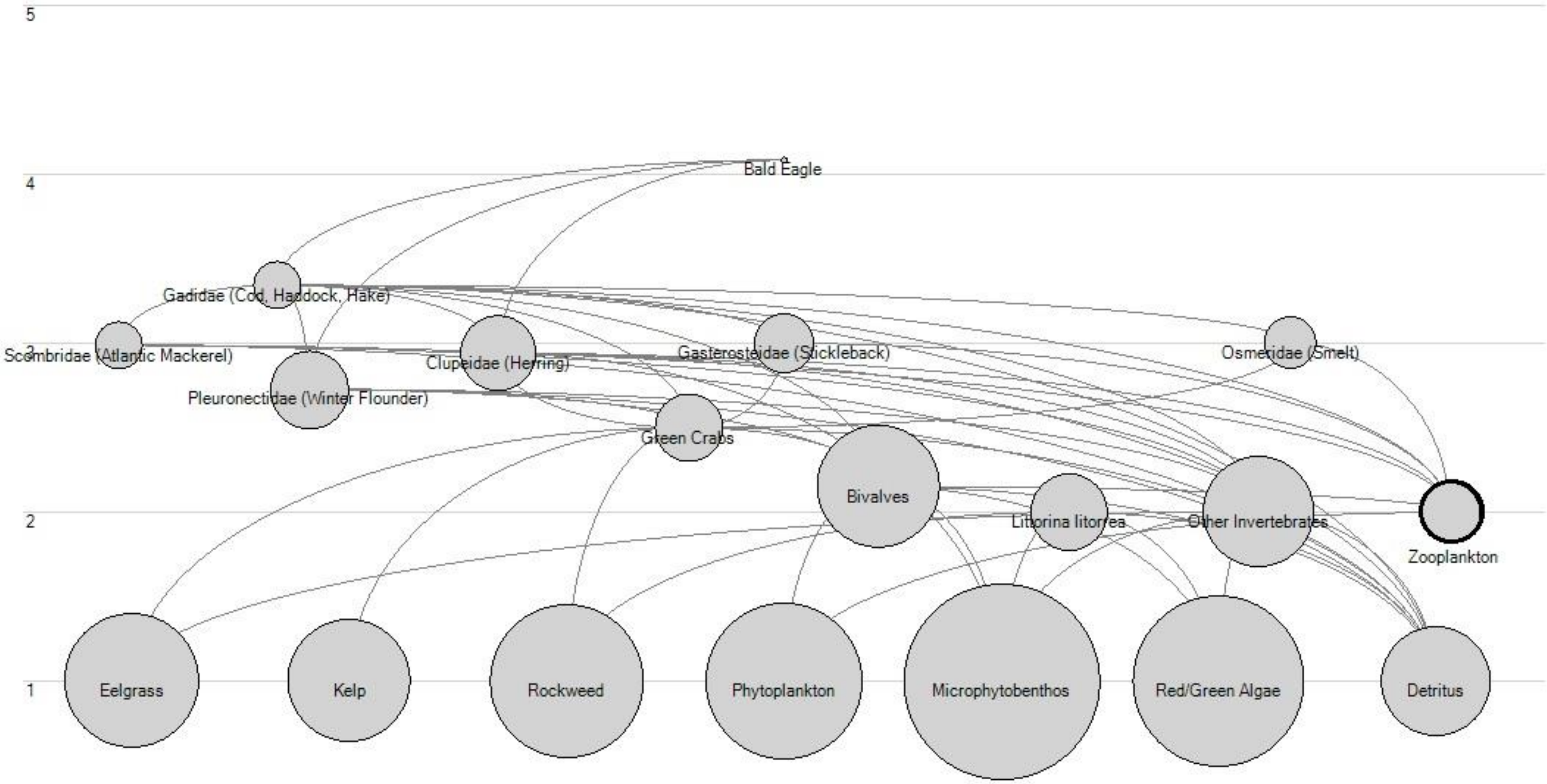

Figure 3: The food web flow diagram produced through Ecopath with Ecosim with an adjusted 95% decrease in biomass of zooplankton in the system.

Table 5: The adjusted and unbalanced Ecopath with Ecosim basic output table with a 95% decrease in zooplankton of the system.

	Group name	**Trophic level**	**Habitat area (fraction)**	**Biomass in habitat area (t/km^2)**	**Biomass (t/km^2)**	**Production / biomass (/year)**	**Consumption / biomass (/year)**	**Ecotrophic efficiency**	**Production / Consumption**
1	Bald Eagle	4.085776	0.667	0.0261	0.017409	0.2	0.75	0	0.266667
2	Gadidae (Cod, Haddock, Hake)	3.34412	0.667	1.971	1.314657	0.38	2.58	0.479675	0.147287
3	Scombridae (Atlantic Mackerel)	2.988006	0.667	2	1.334	0.19	4.4	0.924834	0.043182
4	Pleuronectidae (Winter Flounder)	2.727418	0.667	12.47	8.317491	1.9	3.8	0.01489	0.5
5	Gasterosteidae (Stickleback)	3	0.667	4.056	2.705352	0.54	9.7	0.44233	0.05567
6	Clupeidae (Herring)	2.937987	0.667	10.72	7.15024	0.6	10.1	0.152238	0.059406
7	Osmeridae (Smelt)	3	0.667	2.6	1.7342	0.39	2.9	0.955434	0.134483
8	Green Crabs	2.50014	0.333	13.74	4.57542	1.4	3	0.236219	0.466667
9	Bivalves	2.15	0.333	305	101.565	0.7	4	0.072096	0.175
10	Littorina litorrea	2	0.333	22.46	7.47918	0.483	18	0	0.026833
11	Other Invertebrates	2	1	50	50	2	14	0.232173	0.142857
12	Zooplankton	2	1	2.813	2.813	50	200	1.162503	0.25
13	Eelgrass	1	0.667	300	200.1	0.391	0	0.921009	
14	Kelp	1	0.667	157.4	104.9858	3.543	0	0.00369	
15	Rockweed	1	0.333	1814	604.062	0.546	0	0.068718	
16	Phytoplankton	1	1	675	675	125	0	0.008594	
17	Microphytobenthos	1	1	6750	6750	125	0	0.000333	
18	Red/Green Algae	1	0.333	4631.5	1542.29	8	0	0.027298	
19	Detritus	1	1	46.8	46.8			0.000347	

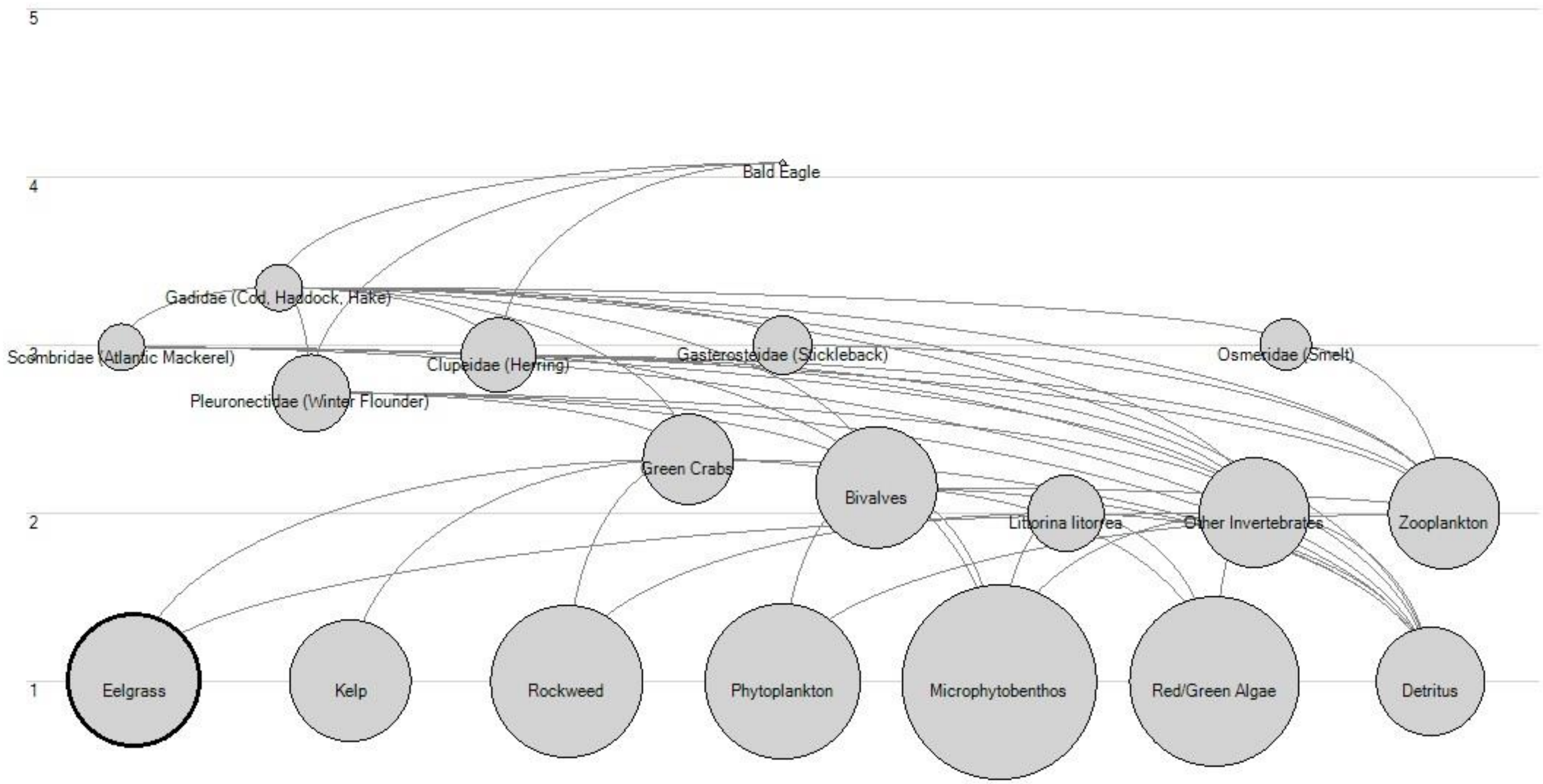

Figure 4: The food web flow diagram produced through Ecopath with Ecosim with an adjusted 275% increase in biomass of green crabs (Carcinus maenas) in the system.

Table 6: The adjusted and unbalanced Ecopath with Ecosim basic output table with a 275% increase in green crabs (<u>Carcinus maenas</u>) of the system.

	Group name	**Trophic level**	**Habitat area (fraction)**	**Biomass in habitat area (t/km²)**	**Biomass (t/km²)**	**Production / biomass (/year)**	**Consumption / biomass (/year)**	**Ecotrophic efficiency**	**Production / consumption**
1	Bald Eagle	4.085776	0.667	0.0261	0.017409	0.2	0.75	0	0.266667
2	Gadidae (Cod, Haddock, Hake)	3.34412	0.667	1.971	1.314657	0.38	2.58	0.479675	0.147287
3	Scombridae (Atlantic Mackerel)	2.988006	0.667	2	1.334	0.19	4.4	0.924834	0.043182
4	Pleuronectidae (Winter Flounder)	2.727418	0.667	12.47	8.317491	1.9	3.8	0.01489	0.5
5	Gasterosteidae (Stickleback)	3	0.667	4.056	2.705352	0.54	9.7	0.160	0.05567
6	Clupeidae (Herring)	2.937987	0.667	10.72	7.15024	0.6	10.1	0.056	0.059406
7	Osmeridae (Smelt)	3	0.667	2.6	1.7342	0.39	2.9	0.347	0.134483
8	Green Crabs	2.322	0.333	51.53	17.15949	1.4	3	0.062986	0.466667
9	Bivalves	2.15	0.333	305	101.565	0.7	4	0.220778	0.175
10	Littorina litorrea	2	0.333	22.46	7.47918	0.483	18	0	0.026833
11	Other Invertebrates	2	1	50	50	2	14	0.232173	0.142857
12	Zooplankton	2	1	56.25	56.25	50	200	0.058135	0.25
13	Eelgrass	1	0.667	300	200.1	0.391	0	1.013	
14	Kelp	1	0.667	157.4	104.9858	3.543	0	0.018	
15	Rockweed	1	0.333	1814	604.062	0.546	0	0.094	
16	Phytoplankton	1	1	675	675	125	0	0.135259	
17	Microphytobenthos	1	1	6750	6750	125	0	0.000	
18	Red/Green Algae	1	0.333	4631.5	1542.29	8	0	0.027298	
19	Detritus	1	1	46.8	46.8			0.000	

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