Ecological and economic tradeoffs between herring fisheries and whale watching in New England

by

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Table of Contents

Introduction **2**

Background **3**
The whale-watching industry 3
The herring fisheries 4

Data and method **5**
Marine food web model 5
Single whale value estimation 8
Herring value estimation 10

Results **11**

Discussion **12**

Reference **17**

Introduction

In the traditional view, management of marine commercial pelagic fish stocks targeting single species is regarded as insufficient in practical application. Marine ecosystems contain multiple species that have complex biological interactions. Fisheries management of only single species may cause unpredictable effect on the other species, the constancy of whole ecosystem and services to humans. Therefore ecosystem-based fisheries management (EBFM) now is being fostered by the community as a possible solution to these defects (Halpern 2008; CEEF 2006).

Although EBFM strategies have potentially great benefits, practical management can still be difficult for the lack of ideal eco-trophic models to evaluate ecological effects. (Pikitch et al. 2004). In addition, models of economic benefit-cost analysis are also necessary to assess the effect of EBFM arrangement, which can be provided to policy makers. These requirements indicate the importance of integrated economic-ecological analysis, which can be utilized to investigate the economic gains and losses led by ecological changes (Jin 2012).

This research investigates the economic benefits and losses of the ban on the harvesting for herring in the New England area. This policy is based on the theory that the heavy trawling for herring will result in the reduction of whale abundance. Research has proven that herring depletion will cause the increased search times for whales (Lee 2010).

I will compare the revenue of herring fisheries and whale-watching under different herring harvest levels through integrated economic-ecological analysis. The marine ecosystem side will be modeled through EMAX food web developed by Link et al (2008). The socio-economical analysis will focus on the herring fisheries and whale watching market price and quantity. By comparing the two-sided benefits, this research evaluates if herring should be left in the marine ecosystem or harvested.

Background

The whale-watching industry

The whale-watching industry is an important component of the New England regional economy with about one million tourism visitors (Hoyt et al. 2001). For every commercial trip, the consumer plus p in the Stellwagen Bank National Marine Sanctuary are estimated at about $29 per trip (Hoagland et al. 2008), which is the most popular location in New England area and accounts for 80% of whale watching in the region. For one whale-watching trips to Stellwagen Bank, the ticket prices are about $40 for adults and $30 for kids. One trip usually lasts about 4 hours, with about 2 hours of watching. The commercial whale-watching business operators are located along the docks of the Gulf of Maine, from Provincetown to Maine. The whale-watching season is from April to October and overlap with a significant part of the herring harvest season which is during the summer months.

Humpback whales are the most popular whale-watching targets. They are the most active and often jump out of the sea. Meanwhile fin, right, and minke whales are also seen. In Gulf of Maine areas, the major activity of humpback whales is feeding, whose distribution is largely associated to abundance of herring, although bottom geographic conditions also influence foraging distribution (Payne et al. 1990). Commercial harvest causing the reduction of herrings led to a simultaneous dramatic depletion in humpback whales richness in the area of northern Gulf of Maine in the mid-1970s (Payne et al. 1986).

The herring fisheries

In the Gulf of Maine, herrings are the major prey for a lot of predators including tuna, marine mammals and man. New England fishermen have been harvesting herring for more than 100 years. Historically, along the coast of Gulf of Maine herring were usually harvested with fixed-gear weirs. Today, fishermen usually use mid-water trawlers to harvest the herrings (NOAA Fishwatch site). According to National Marine Fisheries Service, Fisheries Statistic Division, the value of herring fishery is more than $20M annually. Herring is the major supply for canneries and lobster bait.

The Fishery peaked at 470,000 metric tons in 1968. This unsustainable harvest led to a population crash in the 1970s. Then Congress passed the Magnuson-Stevens Act. It directs the fishery management to regulate the domestic fishery in this region. The herring stock recovered substantially and now is harvested sustainably with the zonal total allowable catch (TAC). In addition, the inshore fisheries are restricted by the seasonal closures to ensure reproductive success. The close period ranged from mid-September to mid-October in southern Gulf of Maine. According to the recent stock assessment report in 2012 by NOAA's Northeast Fisheries Science Center, the population of Atlantic herring is at 517,930 metric tons, which is far above the limit of 157,000 metric tons that we could assume the stock is not over harvested.

Data and method

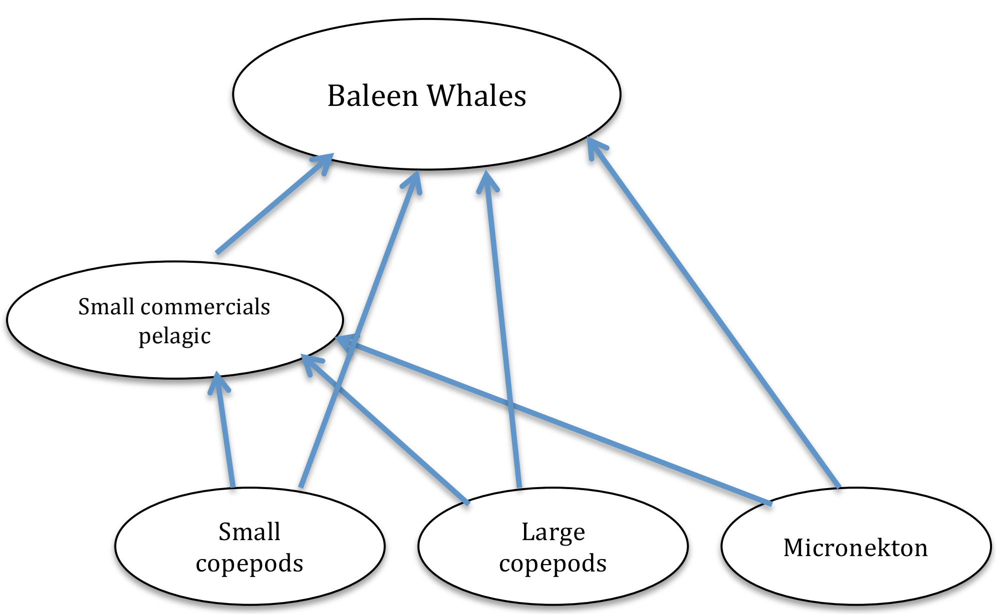
Marine food web model

Different biological food web models with multiple species combined in one compartment and linked to other compartments exist for the marine ecosystem in Georges Bank (Link et al., 2008). These models were developed for the understanding that how nutrition, stock and energy flows in the regional marine ecosystem.

In this research I will focus on the relationship of herring and humpback whales, or small commercial pelagic fish and baleen whales. To reach this objective, part of the model described by Link et al. (2008) is extracted with the compartments involving solid relationship with both targeted groups. Though we focus on the baleen whales, which are the main target of whale watching, we also want to set up a partial food web model targeting the relationship between small commercial fish and odontocetes, or toothed whales, for comparison.

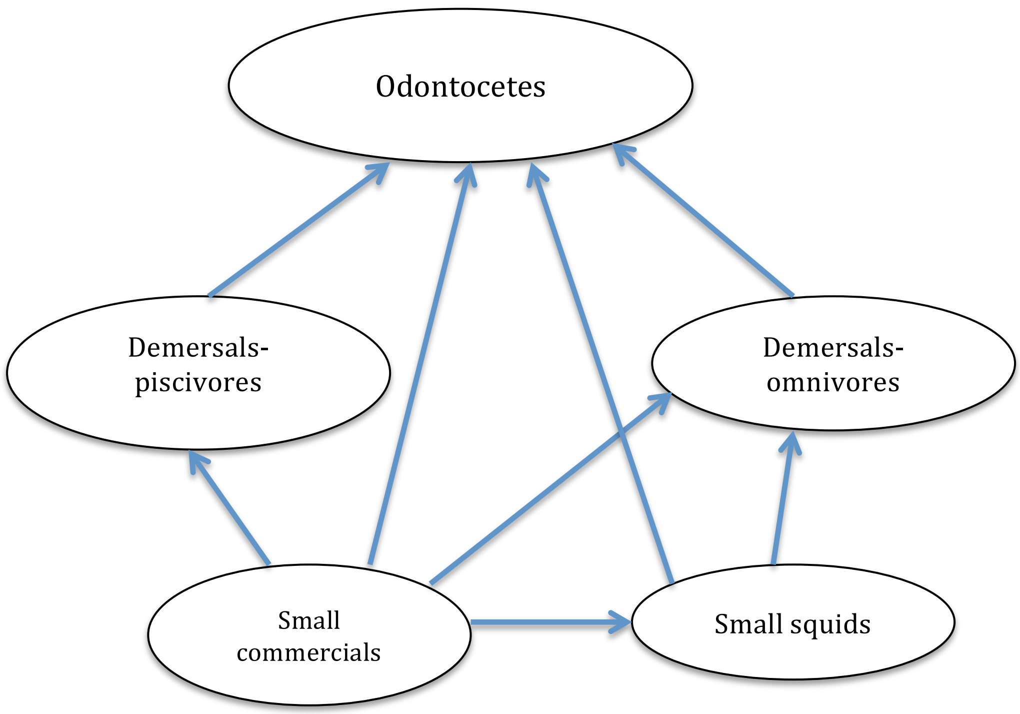
Figure 1 and 2 shows the food web relationship of different whales and small commercial fish group. For the baleen whale model, we observe small commercial fish are not only direct prey species and also competitors. Both feed on small marine organisms, mainly copepods groups and micronekton, which imply that the increase of herring stock may also lead to decrease of other prey species of baleen whales.

Figure 1 The food web model of baleen whales and small commercial fish subtracted from Link et al. (2008) EMAX model



Otherwise, Figure 2 shows that unlike the baleen whale small fish situation above, small commercial fish and odontocetes have a simple predator-prey relation. However, there are trophic levels which are mainly demersal fish groups acting as predator of small fish and prey of odontocetes.

Figure 2 The food web model of odontocetes and small commercial fish subtracted from Link et al. (2008) EMAX model



To investigate how the change of herring stock would affect the whale population, I will to apply Hannesson et al.'s (2009) formula with the ecological parameters from the EMAX model of Georges Bank. Hannesson's research introduces the method to analyze the ecological and economic trade-offs with different management strategies using Pacific sardine as the case study.

I set species *j* as the prey species, in our cases the small commercial fish like herring, and species *i* as the predator. The relationship between the change in biomass of prey species j and that of the predator species i is:

$$\Delta B_i = \frac{a_i}{C_i/P_i}\Delta B_j = s_i\Delta B_j$$

In this equation, ΔB is the change in biomass, a_i is the share of j eaten by i, C is consumption, and P is production. To calculate a, we have equation (Jin 2012):

$$a_i = \frac{B_i(P_i/B_i)D_{ij}(C_i/P_i)}{m_j B_j}$$

In this equation, D_{ij} is the share of species j in predator i's diet and m_j represents predation mortality.

All the ecological parameters using in the model are shown in table 1 to 3.

Table 1. Ecological parameters from EMAX model. Units for biomass are in g/m^2, units for production and consumption are in $g*m^{-2}*year^{-1}$

	B	P/B	C/P	m
Small copepods	9.989	41.67	3.07	0.714
Large copepods	14.25	54.64	3.07	0.776
Micronekton	7.6103	14.25	2.56	0.834
Small pelagic-commercial	9.947	0.35	5.79	0.444
Small pelagic-squid	0.962	0.95	2.89	0.787
Demersals-omnivores	3.779	0.45	1.84	0.085
Demersals-piscivores	4.254	0.45	5.42	0.461
Baleen whales	0.4167	0.04	118.36	0
Odontocetes	0.122	0.04	360	0

Table 2. Estimates of percentage diet composition in baleen whale model

Taxa	Small pelagic-commercial	Baleen whales
Small copepods	14.7	5.8
Large copepods	42.6	46.2
Micronekton	16.1	28.9
Small pelagic-commercial	0	5.8

Table 3. Estimates of percentage diet composition in odontocetes model

Taxa	Small pelagic-squid	Demersals-omnivores	Demersals-piscivores	Odontocetes
Small pelagic-commercial	1.4	12	24.3	35.2
Small pelagic-squid	15.1	2.2	1.1	25.4

Demersals-omnivores	0	0.4	0.5	6.3
Demersals-piscivores	0	3.1	15.3	6.3

Coefficient s_i represents the change when transferring from prey biomass to predator biomass. One important feature of this model is that there is not only direct conversion between small commercial fish and whales, but also an indirect effect due to. For baleen whale, we need to consider that the increase of herring will lead to decrease in copepods then in turn reduce the whale population. For the total s_i, we need to subtract these factors from the direct transformation. For the odontocetes, we need to add the expansion of whale population caused by demersals or squids increase, which is transferred from herrings.

In addition, we notice that the biomass in Table. 1 is in unit weight. In this research , we assume that the study area is identical for all species, which can be used to change of total biomass in this area.

Single whale value estimation

Since commercial whaling banned in most regions including New England, the economic value of whales is from the whale-watching industry. In this research, I will assume that whale stock is proportional to the revenues from whale watching,

Table 4 (IFAW 2009) shows the basic statistic of whale watching industry in this area. The revenues were separated into two categories: direct expenditure and indirect expenditure. Direct expenditure includes the ticket purchase, which is determined by detailed modeling of operator survey results. In this part, a distinction is made between “dedicated”, which trips are advertised explicitly as whale watching experience, and “opportunistic” referring to events whereby the whale watch is not the primary target, which may be a nature cruise that visits seal colonies. Or the whale watching could be only one activity during the multi-day cruise. In this report, 100% of the ticket’s price revenue is accounted for the “dedicated” whale watching participants and 50% of the ticket revenue is accounted for the opportunistic whale watching participants. The indirect expenditure refers to the expenditure into the local economy that can be attributed to the person participating in the whale watch activity. The other costs the whale watchers make on the day they undertake the whale watching activity can in part be attributed to that activity, including foods, hotel, etc. For the indirect expenditure, an suitable percentage to the whale watching industry is set according to the average daily inbound tourist expenditure figures country published.

Table 4 The economic statistic of New England whale watching industry

Number of vistors	Number of operators	Direct expenditure($)	Indirect expenditure($)	Total expenditure($)	Employment numbers
910,071	31	35,000,000	91,000,000	126,000,000	730

To investigate how the biological change impacts economic benefits, I will link the whale population and economics. Here I make the assumption that the whale stock is proportion to revenue from the whale watching. I divide the total expenditure by the estimated stock of humpback whales to get the value of a single whale. Table 5 shows the estimated population of humpback whale in Gulf of Maine area.

Table. 5 Humpback whale population estimation in Gulf of Maine. Nbest represents the estimation from mark-recapture statistic inference

Month/Year	Type	Nbest	Average Weight (mt)
Jun-Oct 2008	Gulf of Maine and Bay of Fundy	823	25-40

From the information above we can get that the value of single humpback whale is about $153,098.42, or 6,123.94 to 3,827.46 $/mt.

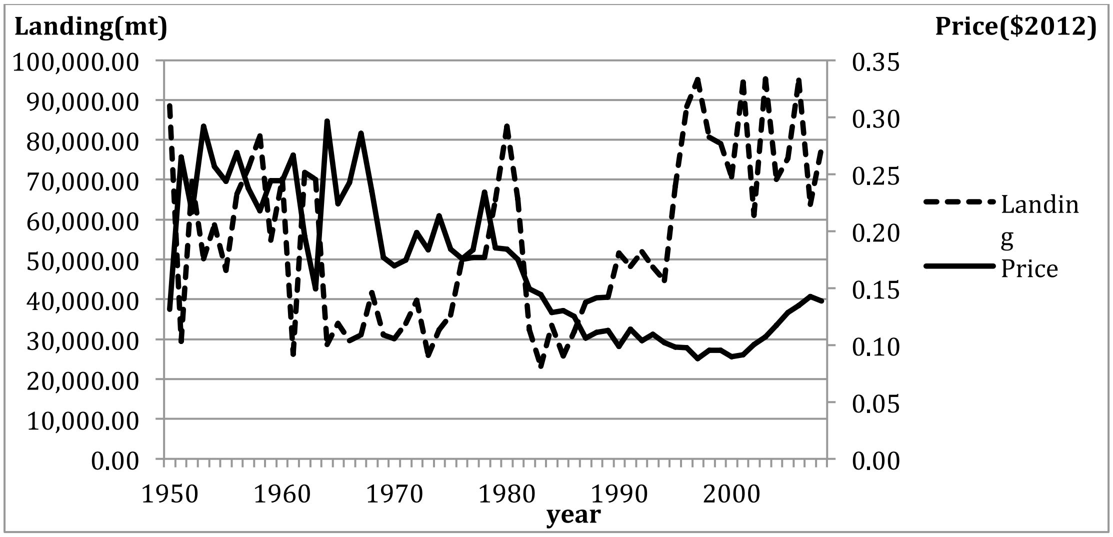
Herring value estimation

The landing quantity and value data of herring are from National Marine Fisheries Services, NOAA. To match the whale watching expenditure data, I to selected the data from the same period to conduct the benefit-cost analysis.

I selected data from 2008 to conduct the benefit-cost analysis in this case. In fact the price and landing quantity are pretty stable in recent years as shown in Figure 3.

In 2008, the annual landing quantity is 75,397.70 metric tons, or 166,221,711 pounds. The total value is $20,477,929. Then we can get the price 271.60 $/mt.

Fig. 3 Landing quantity and price of herring data since 1950 to 2011. The unit of landing is metric tons and of the prices is dollars per pound. The prices are adjusted to 2012 real dollars using Producer Price Index (PPI)



Results

From the food web model of baleen whales and small commercial fish, we get four energy flows and their s_i:

Small commercial fish – Baleen whales (0.00022)

Small copepods - Small commercial fish - Baleen whales (9.74E-06)

Large copepods - Small commercial fish - Baleen whales (1.97E-07)

Micronekton - Small commercial fish - Baleen whales (6.71E-05)

The first coefficient is positive and the latter three are negative. We can add all of them then obtain the accumulative s_i, or the total coefficient is 0.000142.

For the odontocetes model, we also get the energy flows and the s_i:

Small commercial fish – Odontocetes (0.00040)

Small commercial fish – Small squids - Odontocetes (4.74E-06)

Small commercial fish – Small squids – Demersals piscivores-Odontocetes(1.26E-08)

Small commercial fish – Small squids – Demersals omnivores-Odontocetes(1.36E-07)

Small commercial fish – Demersals piscivores - Odontocetes (1.65E-05)

Small commercial fish – Demersals omnivores - Odontocetes (4.40E-05)

All the coefficients will be positive because the small commercial group is always on the lowest level. Then we get the accumulative s_i to be 0.00045.

We then apply the conversion coefficient in baleen whale model to calculate the economic change between the two ends. We assume that the landing quantity in 2008 would reduce 10% with the price stable. The ΔB_i in this case would be 7539.77 metric tons. Using the coefficient that equals to 0.000142, we then reach the estimation of whale biomass will increase 1.07 metric tons. In other words, for the ecological side, though there is a dramatic decrease of herring harvest, the whale stock has almost no development. For the economic side, we get that the loss on the herring fishery side would be $2,047,801.53. Meanwhile, the gain from the whale side would be up to $6552.62.

Discussion

As we see above, the economic benefits analysis shows a gap between whale watching and herring fisheries is way too significant. Based on our analysis, we can conclude that under the current herring harvest level, the decline of herring landing would not significantly or equally increase the revenue from the whale watching tourism. I do not deny the fact that whale watching tourism is an important economic sector in New England area, which has similar size of herring fisheries. However, the potential growth cannot be simply attributed to the decrease of fisheries. The development of publicity and service quality would be more effective to stimulate the industry.

When it turns to the ecological side, the decrease of herring harvest would not cause dramatic increase of the whale stock, at least in the short tem. This result strongly undermines the traditional management theory that if we leave more herring in the ocean, we could have more whale stock recovered, which would generate more revenue.

This giant difference may result from the internal drawbacks in our model or the misunderstanding in the previous management plan. In this part we would discuss the possible reasons for the gap.

In our model, we made the assumption that the value and stocks of whales have a linear relationship, which is debatable. The revenue from whale watching is in fact from the sighting of the whale crowed. In other words, one or two individual change would not make observable profits decrease. The obvious loss from economic side only occurs when entire bulk is missing. It may be more sensible to suggest a "step function" between the stock and the revenue, which lacks the adequate historical data.

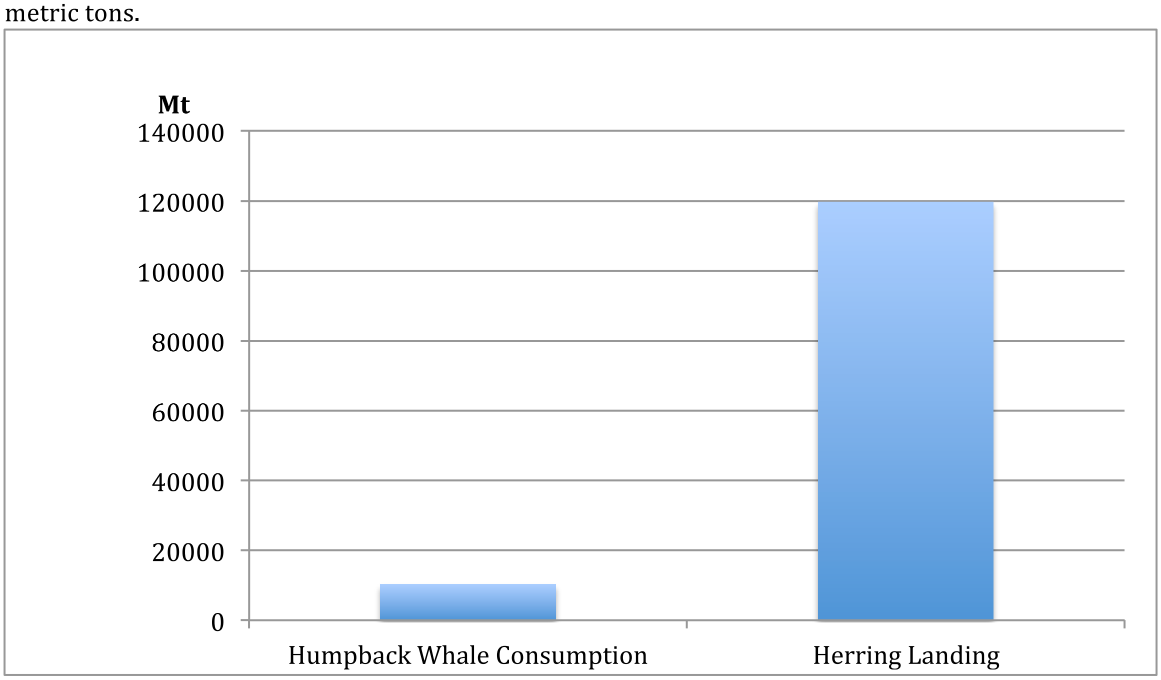
In the whale estimation, we used the data from IFAW report, which includes the direct revenue, mainly the tickets, and the indirect value, including the associated revenue along with the cruise trip. Another report (Hogland and Meeks, 2000) uses the zonal travel cost model to estimate the contribution from whale-watching tourism to the regional economy, in which a similar result is obtained. However, these two method either include the non-market value, which can be a huge portion concerning the real economic value of the whale. One of the important features of the baleen whales is their adorable look and behavior, which bring the ability to raise the awareness of wild life protection and encourage public to put more attention and efforts. However, at this stage, there is no existing reliable valuation research, such as contingent valuation or choice experiment, in the whale-watching field. The reality led to the fact we have to eliminate a significant portion of the revenue, which may result in giant bias in our model.

In the model we use the static food web model to simulate the ecological tradeoffs between herring and baleen whales. In other words, the underlying assumption is that with a stock change the parameters among the groups will not transform significantly. This can be true in the short term. However, in the long run, the transfer coefficients, including direct and indirect effect, may alter dramatically and the trophic and energy flows may arrive at a different stable point. For example, with increase of the herring stock, the humpback whales would take more of them in the diet composition, which would cause a stronger correspondence between the two groups in the future. In that case, we may observe a stronger increase of whales if the harvest of herring is reduced. To solve this concern, a more advanced dynamic food web model may be developed. At this point, no such work exists.

Another potential development of the research can be attributed to include more marine resource economic sectors in our estimation. For example, herring is also an important prey of tuna, which also generates a lot of economic revenues in the New England region. In addition, most of the harvested herring will be used as the bait for lobster. Every year there is tens of report regarding to the whale injured by the lobster entanglement, which also cause serious ecological and economic loss. If we taken into account other compartments in our model, the management suggestion may need to be modified.

In traditional fisheries management theory, the decrease of herrings stock would impact the whales significantly. However some studies shows that the herring may only comprise only 17% of the humpback whales diet, (Read 2003). This fact leads us to consider we may overestimate the effect caused by herring fisheries on the whales' population.

Fig. 4 Annual herring landing and consumption by humpback whales comparison. The unit is in metric tons.



Alternatively, since we are utilizing the current food web model, the up-to-date herring stock situation is important. According to the estimation from the NOAA Fisheries Service, the herring stock in the New England area is in healthy situation and under harvested. This implies that the current herring fisheries landing might not have a significant impact on the whale population. From figure 4, we can conclude that only small portion of the herring was consumed by the humpback whales. In other words, based on the current stock, it seems not reasonable to suggest that a landing decline would ultimately lead to greater whale stock size.

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