DEVELOPING ALTERNATIVES TO MITIGATE RIVER HERRING BYCATCH AT SEA

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Background

Problem Statement

Many river herring runs have declined along the Atlantic coast to a degree such that a collapse of the coast-wide stock is feared to be underway (Limburg and Waldman 2009). Commercial landings of river herring (alewife, *Alosa pseudoharengus*, and blueback herring, *Alosa aestivalis*) in state waters have declined dramatically in the past 50 years from approximately 70 million lbs in 1957 to 13.7 million lbs in 1985 to under a million lbs in 2007 (ASMFC). The National Oceanic and Atmospheric Administration (NOAA) declared both species as "Species of Concern" in 2006, and in 2009, the Atlantic States Marine Fisheries Commission (ASMFC) has passed a default closure of directed fisheries and has joined the Mid-Atlantic Fishery Management Council (MAFMC) in requesting emergency action from the Secretary of Commerce. The New England Fishery Management Council (NEFMC) is now joining efforts to reverse the decline of river herring by tasking the Atlantic Herring Plan Development Team (PDT) with development of alternatives to mitigate bycatch in ocean fisheries.

River herring are an important part of freshwater and oceanic ecosystems (Garmen and Macko 1998, Saunders et al. 2006). Undertaking extensive migrations, river herring, anadromous fish, spawn in fresh and brackish water then return to the ocean, where they spend the majority of their life (Colette and Klein-MacPhee 2002, Yako et al. 2002). They encounter numerous impacts in their riverine, estuarine, and oceanic habitat (Yako et al. 2002, McKenzie 2008, Cieri et al. 2008, Limburg and Waldman 2009). All of these impacts need to be monitored, managed, and ultimately mitigated in a comprehensive restoration strategy (Fig. 1).

***River Herring Bycatch in Sea Fisheries*.**

Bycatch in ocean fisheries is known to occur (Shepherd 1986, Cieri et al. 2008, Wigley et al. 2009). The magnitude of this impact likely varies among alewife and blueback herring spawning populations based on their unique at-sea migration patterns (Colette and Klein-MacPhee 2002, Haas-Castro 2006). In some places, it might be the most significant factor driving declines, whereas elsewhere it might be negligible. Several studies estimated river herring bycatch in sea fisheries along the US Eastern Continental Shelf.

Most recently using the Standardized Bycatch Reporting Methodology (SBRM), Wigley et al. 2009 determined that 106,455 pounds (149% CV) of river herring were discarded between June 2008-July 2009. Wigley et al. (2009) included data from the Northeast Fisheries Observer Program (NEFOP), Vessel Trip Reports (VTR), the Northeast Fisheries Science Center (NEFSC) commercial landings database, and the NOAA Fisheries Marine Recreational Information Program (MRIP) recreational landings. They stratified this larger dataset by geographic area (New England or Mid-Atlantic based on port of departure) and gear type (see Table 1 of Wigley et al. 2009). They found river herring discards to be the greatest in the New England small mesh otter trawl fleet, and to a lesser degree in New England shrimp trawl, New England large mesh trawl and Mid-Atlantic small mesh otter trawl fleets. However, Wigley et al. (2009) noted that the number of observed Mid-Atlantic gillnet fleet trips were relatively low. In addition, they noted that fishing practices in high volume fisheries limited observation of all discards (Wigley et al. 2009).

For 2005-2007, Cieri et al. (2008) estimated river herring bycatch using data from the NEFOP and portside sampling of the directed Atlantic herring (*Clupea harengus*) fishery. Portside sampling occurred at processing plants and bait dealers in Maine, New Hampshire, Massachusetts, Rhode Island, and New Jersey (Cieri et al. 2008). In their analysis, Cieri et al. (2008) defined directed Atlantic herring commercial fishing trips as those trips keeping or landing greater than 2,000 lbs (907.18 kg) of Atlantic herring. They estimated bycatch stratified by year (2005, 2006, and 2007), quarter (1: Jan-Mar, 2: Apr-Jun, 3: Jul-Sep, and 4: Oct-Dec), gear type (single mid-water trawl, paired mid-water trawl, purse seine, and bottom trawl), and area (western Gulf of Maine, eastern Gulf of Maine, Georges Bank/Cape cod, and southern New England (Cieri et al. 2008). Coverage of trips by stratum was highest in 2005 (26%) and lowest in 2007 (8%).

They found for 1% of trips composition of the catch was at least 10% river herring (Cieri at al. 2008). They suggested that large bycatch events might greatly impact river herring populations due to the scale of the Atlantic herring fishery (Cieri et al. 2008). Estimated bycatch was greatest in late fall and winter as the authors noted that Atlantic herring , Atlantic mackerel (*Scomber scombrus*), and river herring mix as they migrate around Cape Cod to their overwintering grounds south of Block Island (Cieri et al. 2008).

Overall, the greatest bycatch was for single and paired mid-water trawl gears. One exception was in 2007; bottom-trawl bycatch was noted as anomalously larger than 2005 and 2006 estimations for the same gear type (Cieri et al. 2008). Yearly estimates of river herring bycatch for the directed Atlantic herring fishery were 285,833 lbs (60% CV) in 2005 and 171,973 (60% CV) in 2006 and an order of magnitude higher in 2007 (50% CV) with 1,686,617 lbs (see Table 2 in Cieri et al. 2008).

We currently lack the information needed to link bycatch impacts with population trends in specific coastal areas. However, it is the one impact on river herring that is unmanaged and unmitigated. Alternatives developed in this project aim to correct that gap, acknowledging that any action taken is unlikely to fully rectify the problem in any particular watershed and certainly not on a coast-wide scale, but will add a missing piece to the multi-dimensional restoration effort nonetheless.

Goals and Objectives

This project will evaluate management alternatives to mitigate river herring bycatch at sea under a range of ecological and fishing fleet dynamics scenarios in a management strategy evaluation (MSE). Additionally, this will involve evaluating the impact of these management alternatives on fishing fleets and co-occurring pelagic species. The overarching goals are to develop alternatives to mitigate river herring bycatch at sea and to identify the management action most likely to produce the largest decrease in bycatch with the smallest impact on the affected fleets.

Three main objectives of this work to meet these goals are to:

1. Develop a detailed and dynamic model that captures spatial, seasonal, and inter-annual differences in the relative abundance of river herring and Atlantic herring.
2. Construct a fleet dynamics model for the Atlantic herring fleet to use in simulations of fleet behavior.
3. Evaluate management strategies to mitigate river herring bycatch by linking the ecological model with the fleet model.

Methodology

Study Area

The study area for this project includes the Eastern US Continental Shelf, which overlaps with NEFMC Atlantic herring fishery management plan areas (Figure 3). This inlcudes the Gulf of Maine, Georges Bank, and Mid-Atlantic Bight. Detailed oceanography can be found in the extensive studies of the region (e.g. Townsend et al. 2006).

Datasets

Table 1 provides a summary of the datasets to be used in this project. These include fisheries independent (NMFS and MA bottom-trawl surveys) and dependent data sources (NEFOP, VTRs, and Dealer Reports).

Management Strategy Evaluation

Management Strategy Evaluation (MSE), uses models (derived from fisheries-independent and dependent data) to test management prior to implementation and can be used can address concerns for fish stocks at critical population levels (Sainsbury et al. 2000, Kell et al. 2007). Computer simulations track how the ecological and human system responds to these management actions. MSEs have been used to study many fisheries including:

- South African multi-species pelagic fisheries (De Oliveira and Butterworth 2004),
- Icelandic cod (*Gadus morhua*) fishery (Stefánsson and Rosenberg 2005),
- North Sea haddock (*Melanogrammus aeglefinus*) fishery (Needle 2008),
- Western British Isles herring fishery (Kell et al. 2009), and
- Gulf of Alaska walleye pollock (*Theragra chalcogramma*) fishery (A'mar et al. 2010).

The model comprises of two components an operating model and management model (Figure 2). The operating model includes the full dynamics of the exploited population, fisher behavior in response to management actions, and environmental conditions (Kell et al. 2007). The management model includes the analysis methods (stock assessment) and management strategies (Kell et al. 2007). The main components of the management model are a simulated observation model, a simulated assessment model, and potential management actions (Kell et al. 2007).

Here, models will be developed and management options will be evaluated using R, open-source statistical software, and the R library FLR (R Development Core Team 2010, Kell et al. 2007). Objective one (to develop a detailed and dynamic model that captures spatial, seasonal, and inter-annual differences in the relative abundance of river herring and Atlantic herring) and objective two (to construct a fleet dynamics model for the Atlantic herring fleet to use in simulations of fleet behavior) comprise the operating model. Objective three (to evaluate management strategies to mitigate river herring bycatch by linking the ecological model with the fleet model) develops and evaluates the management model.

Management Options

There are a range of management options to be tested within this management strategy evaluation framework. These may include:

- Time-area closures (fixed or responsive)
- Bycatch quotas (fleet-wide or individual)
- ‘Move-along’ rules
- Some combination.

For example, the Alaskan pollock fleet and the North Pacific Fishery Management Council (NPFMC) have addressed salmon bycatch using different combinations of fixed spatial closures (Salmon Savings Areas), rolling hotspot closures, and bycatch quotas. The initial approach using fixed spatial closures proved limiting because oceanic aggregations of Chinook salmon (*Oncorhynchus tshawytscha*) where not consistent year-to-year. Therefore, the closures only contained salmon aggregations in some years, and in fact increased effort on salmon in other years when they were outside the closure area.

The Commission for the Conservation of Antarctic Living Marine Resources (CCALMR) has addressed bycatch of a range of species using so-called “move along rules”, whereby vessels are required to move fishing operations a minimum distance if a bycatch threshold is exceeded. This work will examine these and other strategies to determine the approach that is most effective at reducing river herring bycatch while considering the impact on the Atlantic herring fleet.

Preliminary Analysis

Much of the work to date has focused on accomplishing objective one and compiling datasets to address the other objectives. Preliminary analyses revealed that multiple datasets could be used for modeling river herring populations and bycatch in sea fisheries. Observations of river herring from NMFS bottom-trawl surveys and NEFOP data were explored in a Geographic Information System (GIS) mapping analysis using ArcGIS 9.3.1. (Tables 2-3, Fig. 4-11).

Maps of 2004-2008 relative weights of alewife and blueback herring, from NMFS bottom-trawl surveys, suggested important seasonal differences in fish distribution and aggregations between species (Table 2, Figs. 4-6). In particular, both species aggregated in the Gulf of Maine in the fall (Fig. 4) and spread throughout the region in the spring (Fig. 5). The winter survey did not sample in the Gulf of Maine, but rather focused on Southern New England and the Mid Atlantic Bight (Fig. 5). Aggregations of both species occurred in the northern portion of the winter survey in Southern New England and the Northern Mid-Atlantic Bight (Fig. 5).

To explore river herring bycatch in multiple fisheries and gear types, NEFOP data was selected for by target species (identified as first, second, third, fourth, or fifth target species) (Tables 1). These fishing targets included pelagic fish - Atlantic herring, Atlantic mackerel, Atlantic menhaden (*Brevoortia tyrannus*), whiting/silver hake (*Merluccius bilinearis*), and butterfish (*Peprilus triacanthus*) - and invertebrate - Atlantic long-fin squid (*Loligo pealei*), and boreal short-fin squid (*Illex illecebrosus*) - species. Maps of bycatch events of alewife, blueback herring, and unclassified herring in were constructed for combined gear types and target species (Table 3, Fig. 7-9). The unclassified herring category likely included Atlantic herring and Alosine species. Patterns of unclassified herring bycatch appeared similar to those for alewife and blueback herring bycatch (Figs. 7-9). Upon visual inspection, maps overlapping NMFS survey and NEFOP data revealed that areas of high relative weight of alewife and blueback herring in surveys correlated with high relative weight of alewife and blueback bycatch (Fig. 10-11).

Next Steps

The next steps involve developing biological and fleet dynamic models. River herring catch weight will be used as the response variable since it is common in all fishery independent and dependent datasets. First, spatially and temporally explicit statistical models of river herring aggregations and distributions will be developed using spatial and temporal factors from bottom-trawl surveys (NMFS and MA) as model predictors. This will then involve modeling river herring bycatch events and the magnitude of those events using spatial, temporal, and fisheries factors (in NEFOP and VTR datasets) as predictors. Regression trees will be used to identify and determine the contribution of the important factors in each dataset that can be used to predict river herring aggregations and bycatch (Prasad et al. 2006). Generalized linear models (GLMs) will then be used to model the catch event (presence/ absence) with a Bernoulli error structure and to model the non-zero catches with a gamma-log link error structure using variables identified with regression tree analysis (Stefánsson 1996).

Then, a model of seasonal and spatial fishing effort distribution in the Atlantic herring fleet will be developed. This will be accomplished by using NEFOP data, VTRs, and Dealer data stratified by fishery statistical area (Fig. 1). The fleet model will then be refined using Atlantic herring aggregations and distribution from NMFS bottom-trawl surveys. Potential models for examining fleet dynamics include those based on behavior and decision making such as ideal free distribution models (Gillis 2003, Branch et al. 2006) and discrete choice models (Haynie and Layton 2010).

Lastly, MSE will involve running simulations using these models to compare between management options. Metrics to evaluate and compare option performance will include both ecological and economic indicators.

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Tables

Dataset	Fisheries	Sampling design	Years	Seasons	Coverage	Vessels	Targets
NMFS bottom-trawl surveys	Independent	Stratified random sampling	1963-2009	Winter* Spring Summer** Fall	Offshore	FR/V Delaware II, FR/V Albatross II, FR/V Bigelow***	Fish
MA bottom-trawl surveys	Independent	Stratified random sampling	1978-2009	Spring Fall	Inshore MA	R/V Gloria Michelle	Fish
Observer Program	Dependent	Unbiased trip observation	1989-2009	All	10% trips	Commercial vessels	Atlantic herring, Atlantic mackerel, menhaden,whiting, butterfish, and squids
Vessel Trip Reports	Dependent	All trips	2000-2009	All	All trips	Commercial vessels	Atlantic herring
Dealer Reports	Dependent	All trips	2000-2009	All	All trips	Commercial vessels	Atlantic herring

Table 1: Summary of the main characteristics by dataset from NMFS bottom-trawl surveys, MA bottom-trawl surveys, NEFOP data, VTRs, and dealer reports. NMFS does not currently operate the *winter and **summer bottom-trawl surveys. ***FR/V Bigelow is the only vessel used for bottom-trawl surveys starting in 2009.

2004-2008 NMFS Bottom-Trawl Surveys	
Season	**Observations**
Fall	1464
Winter	421
Spring	1451

Table 2: Number of observations (tows) in 2004-2008 NMFS bottom-trawl surveys separated by season.

2004-2008 NEFOP Data for Specified Target Species	
Gear Types	**Observations**
Purse Seine	61
Gillnet	65
Twin Trawl	80
Pair Trawl	232
Otter Trawl	2278

Table 3: Number of observations (tows) in 2004-2008 NEFOP data for specified target species separated by gear types.

Figures

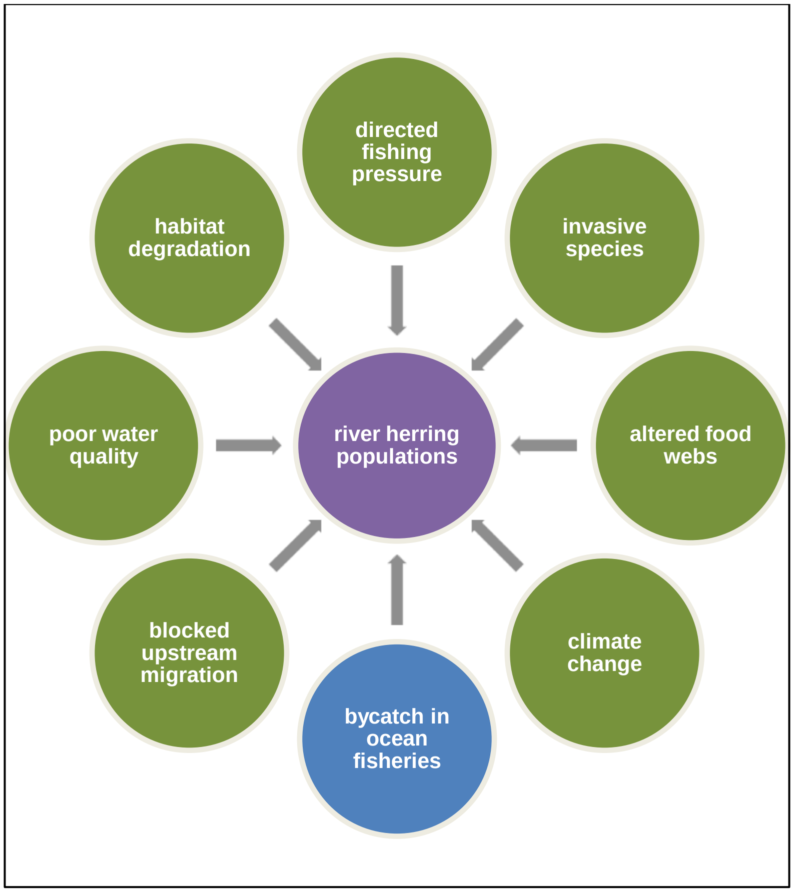

Figure 1: River populations are affected by numerous impacts, inlcuding bycatch in ocean fisheries.

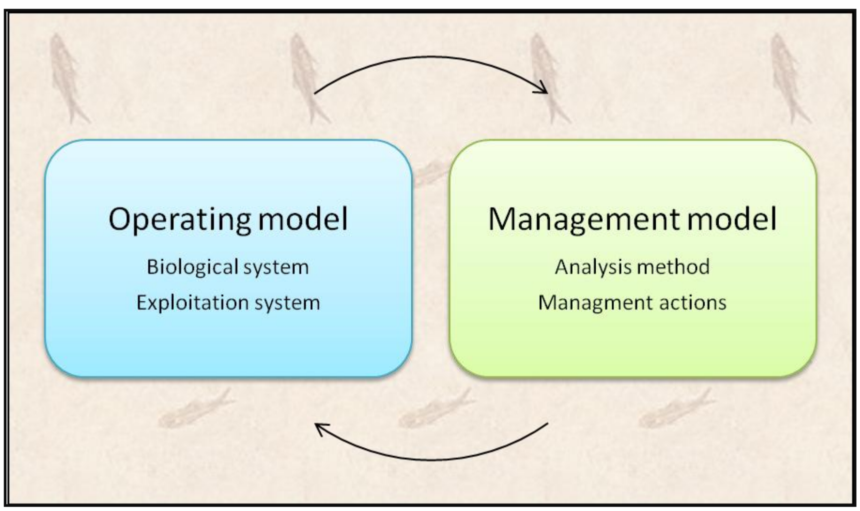

Figure 2: Conceptual framework for Management Strategy Evaluation.

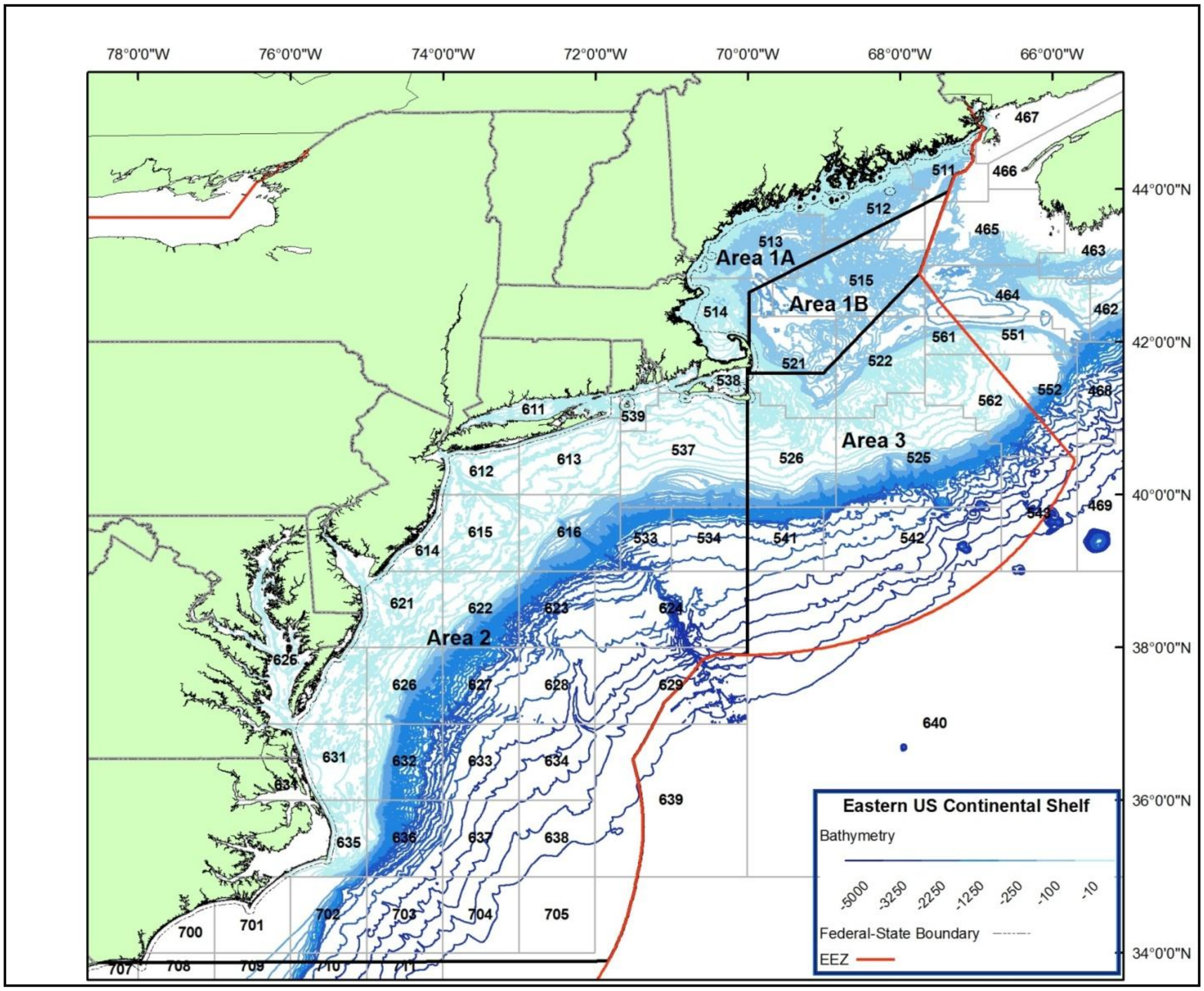

Figure 3: Study area of the Eastern US Continental Shelf. Overlapping Atlantic herring fishery management plan areas (Area 1A, 1B, 2, and 3) and fisheries management statistical areas (400-700s) indicated.

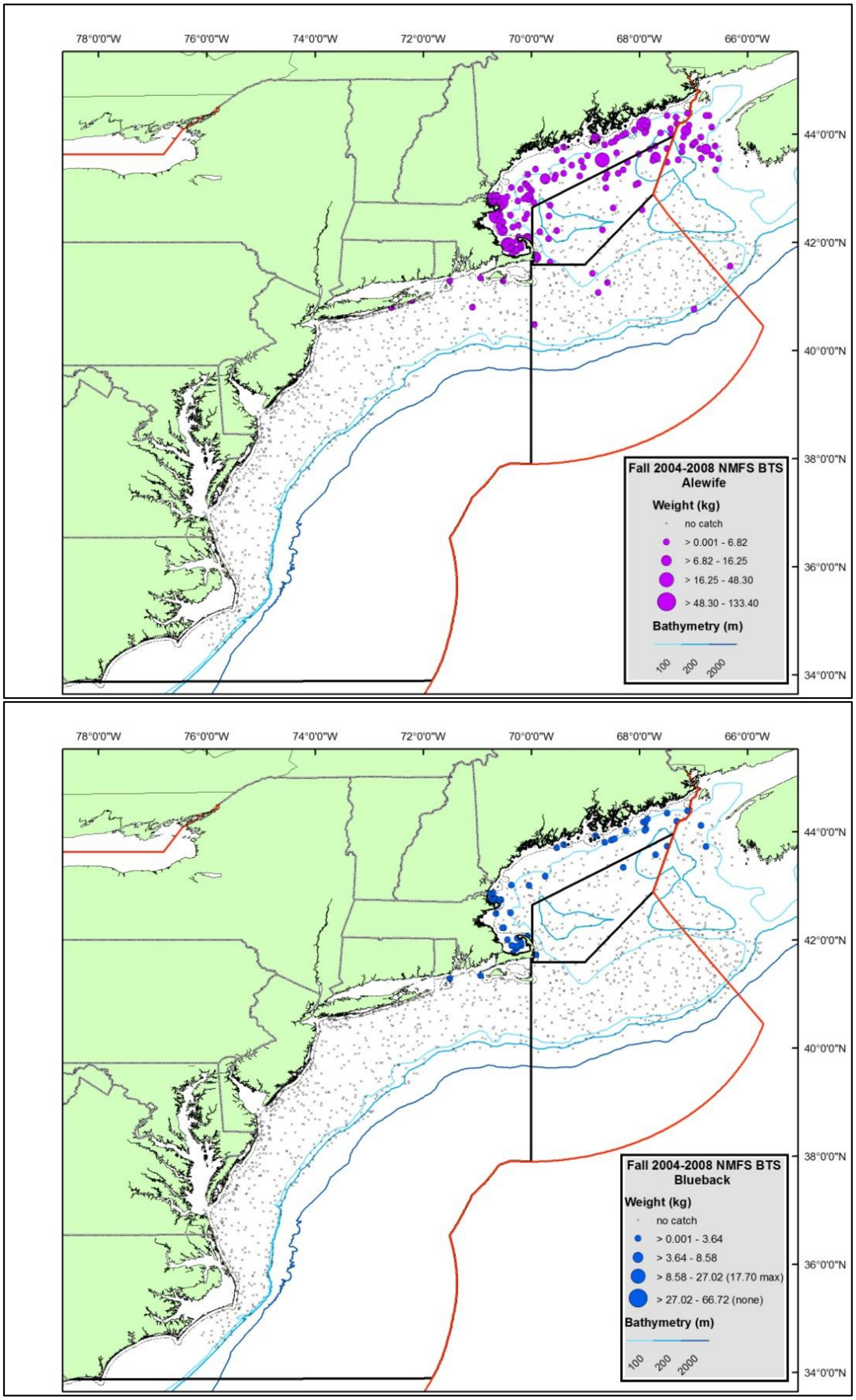

Figure 4: Alewife (top - purple circles) and blueback herring (bottom - blue circles) relative weights (kg) from 2004-2008 fall NMFS bottom-trawl surveys. Catches without river herring indicated (black x's).

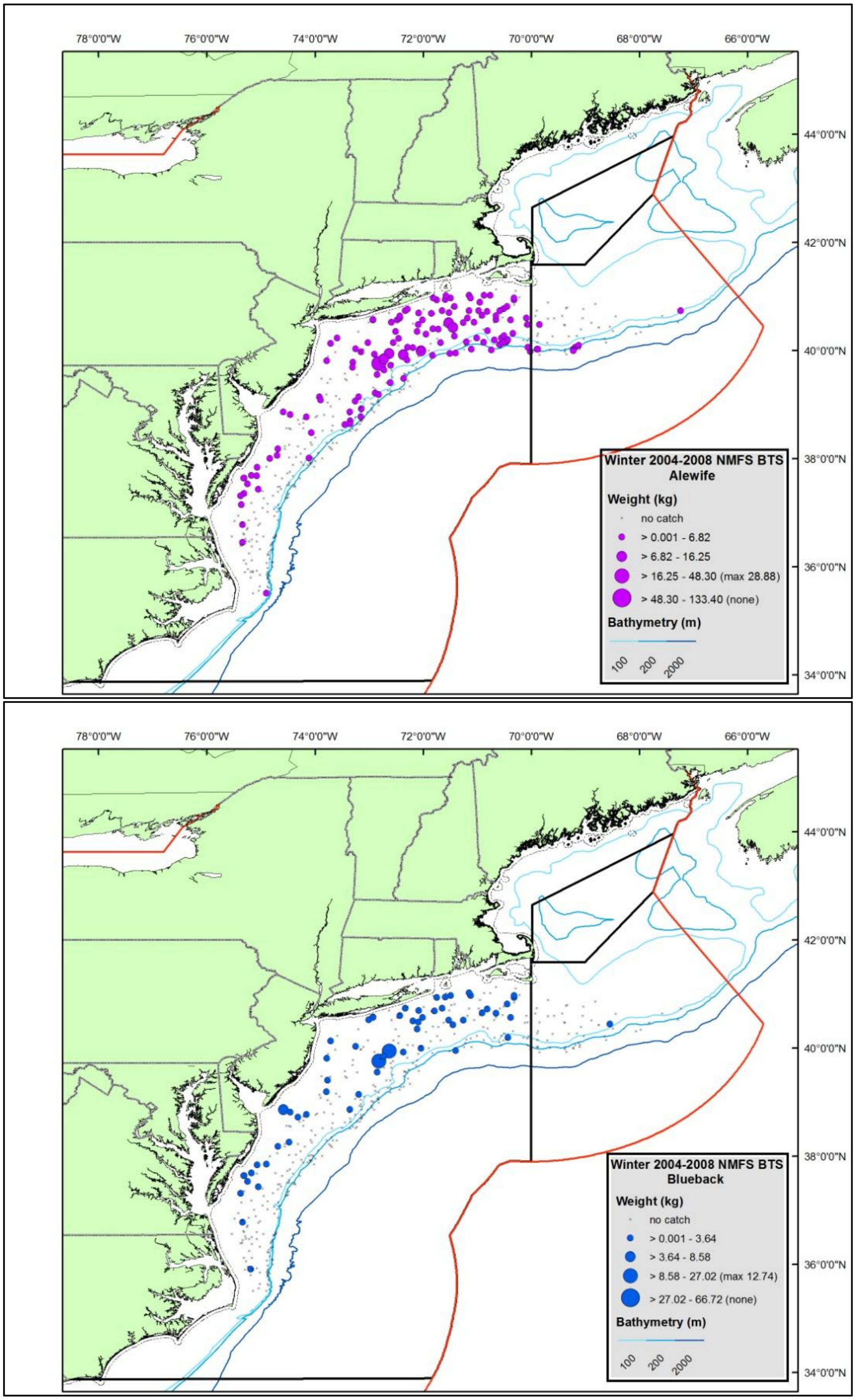

Figure 5: Alewife (top - purple circles) and blueback herring (bottom - blue circles) relative weights (kg) from 2004-2008 winter NMFS bottom-trawl surveys. Catches without respective species indicated (black x's).

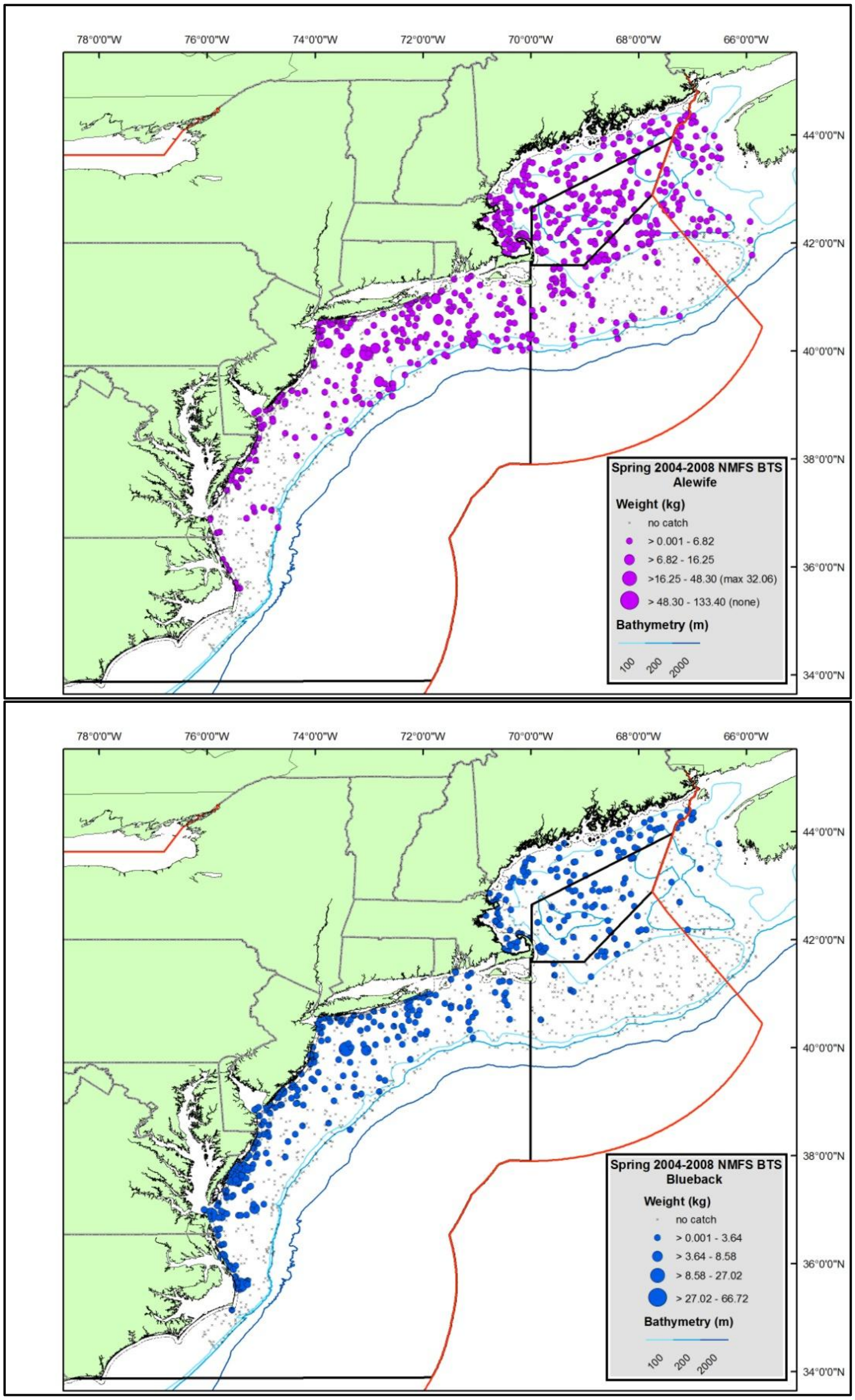

Figure 6: Alewife (top - purple circles) and blueback herring (bottom - blue circles) relative weights (kg) from 2004-2008 spring NMFS bottom-trawl surveys. Catches without respective species indicated (black x's).

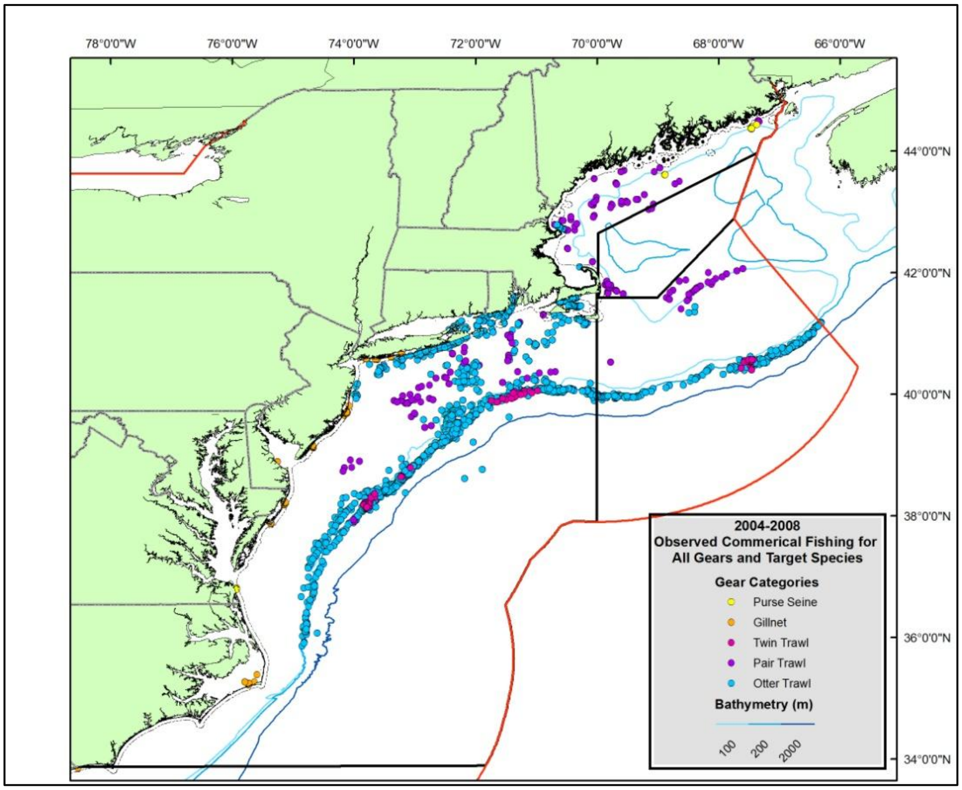

Figure 7: 2004- NEFOP data for all seasons and specified target species (Atlantic herring, Atlantic mackerel, whiting, butterfish, long-fin squid, and short-fin squid) seperated by gear categories (purse seine, gillnet, twin trawl, pair trawl, and otter trawl).

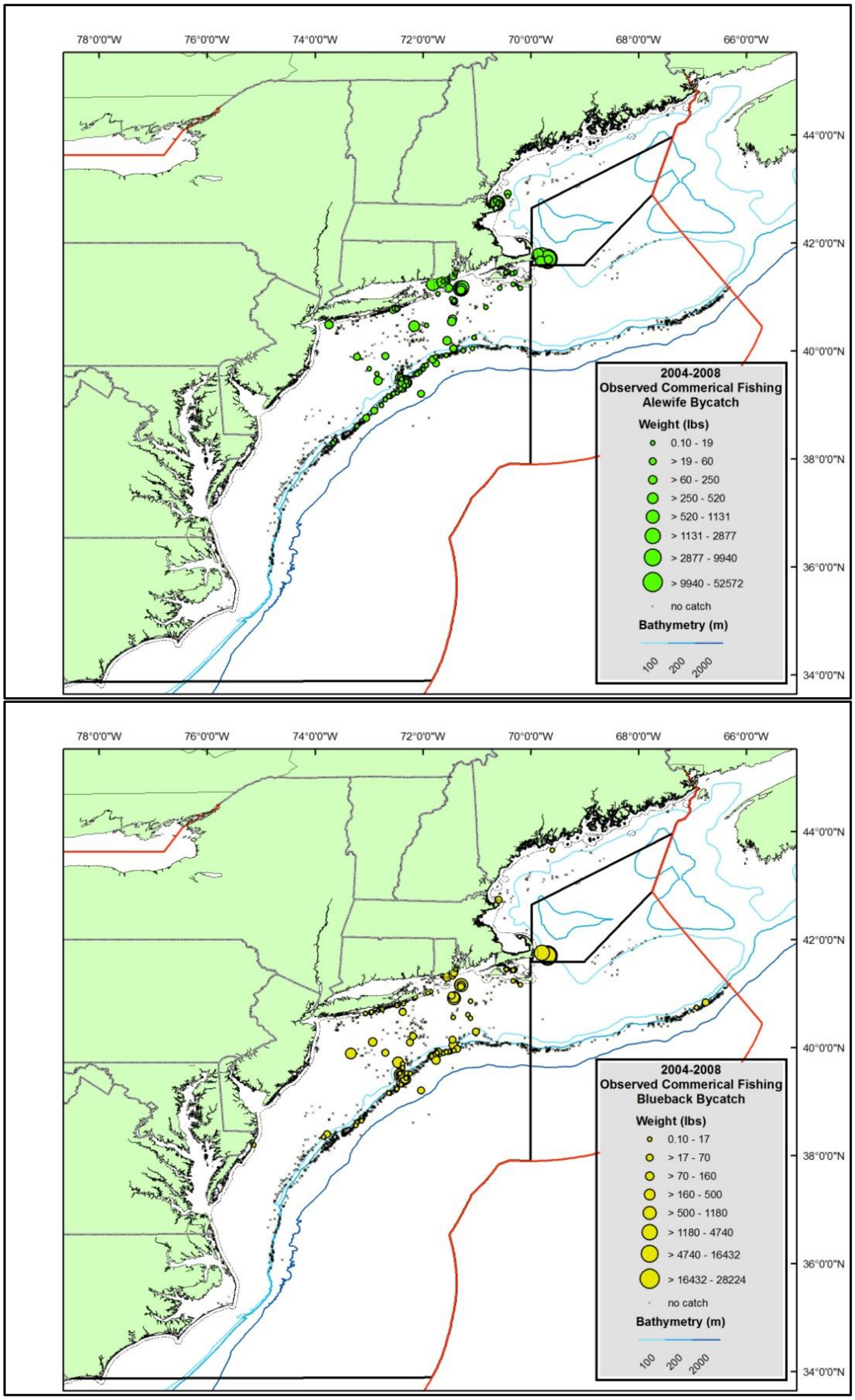

Figure 8: Relative weights (lbs) of alewife (top-green circles) and blueback herring (bottom-yellow circles) bycatch from 2004-2008 NEFOP data for all seasons and specified target species used in this analysis and combined gear categories. Catches without respective species bycatch indicated (black x's).

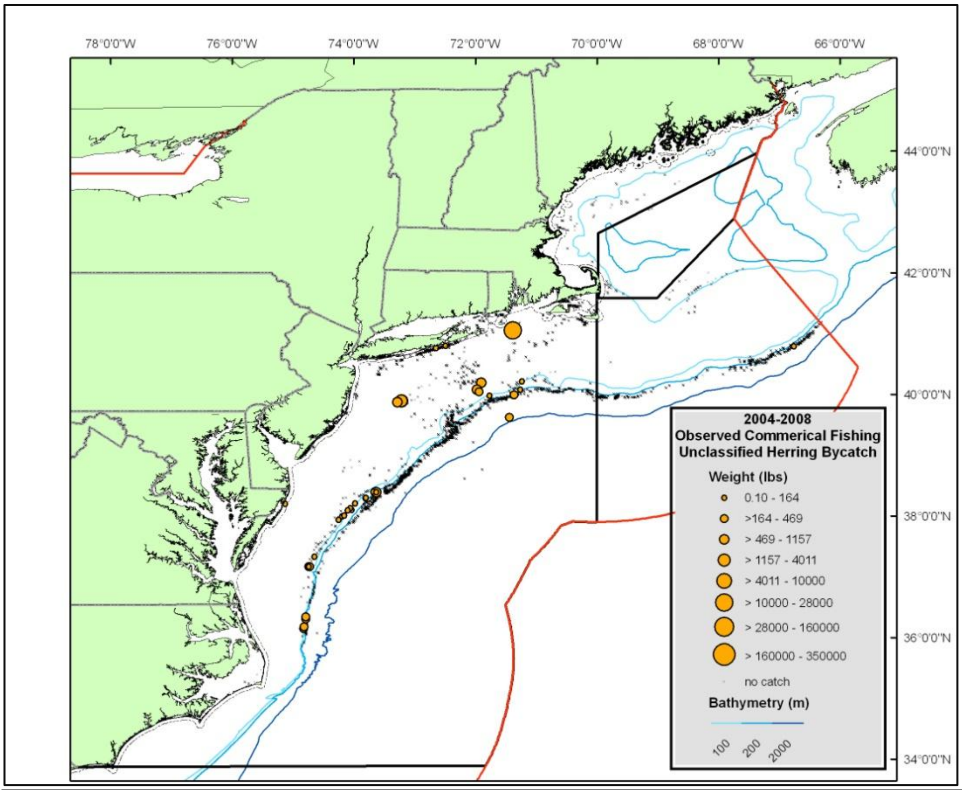

Figure 9: Relative weights (lbs) of unclassified herring (orange circles) bycatch from 2004-2008 NEFOP data for all seasons and specified target species used in this analysis and combined gear categories. Catches without unclassified herring bycatch indicated (black x's).

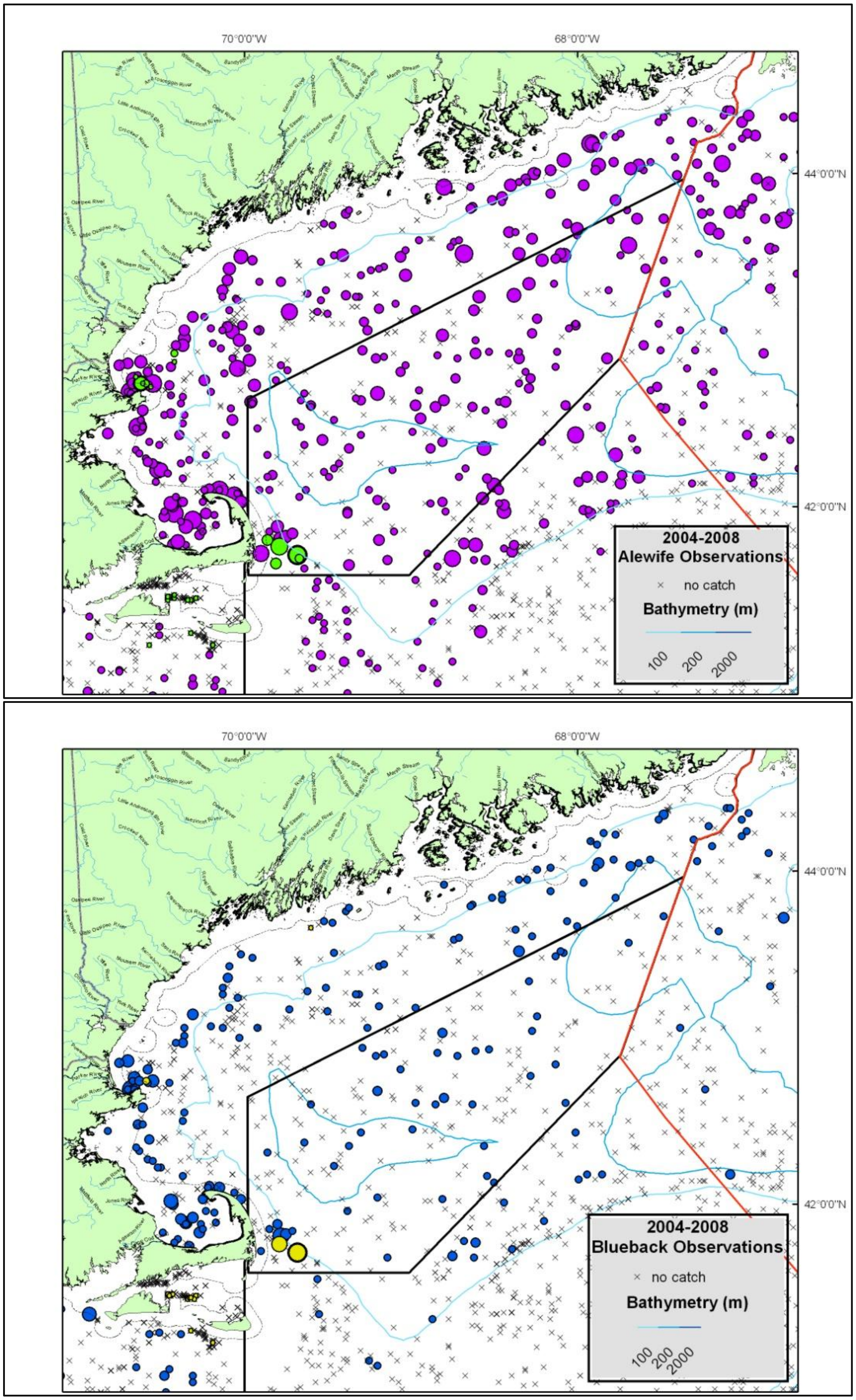

Figure 10: Patterns of river herring from fisheries datasets in the Gulf of Maine and Georges Bank. Relative weights (lbs) of alewife (top) and blueback herring (bottom) from 2004-2008 combined seasonal NMFS bottom-trawl surveys (top-purple, bottom-blue) and NEFOP data (top-green, bottom-yellow) for all specified target species and gears. Catches without respective species indicated (black x's).

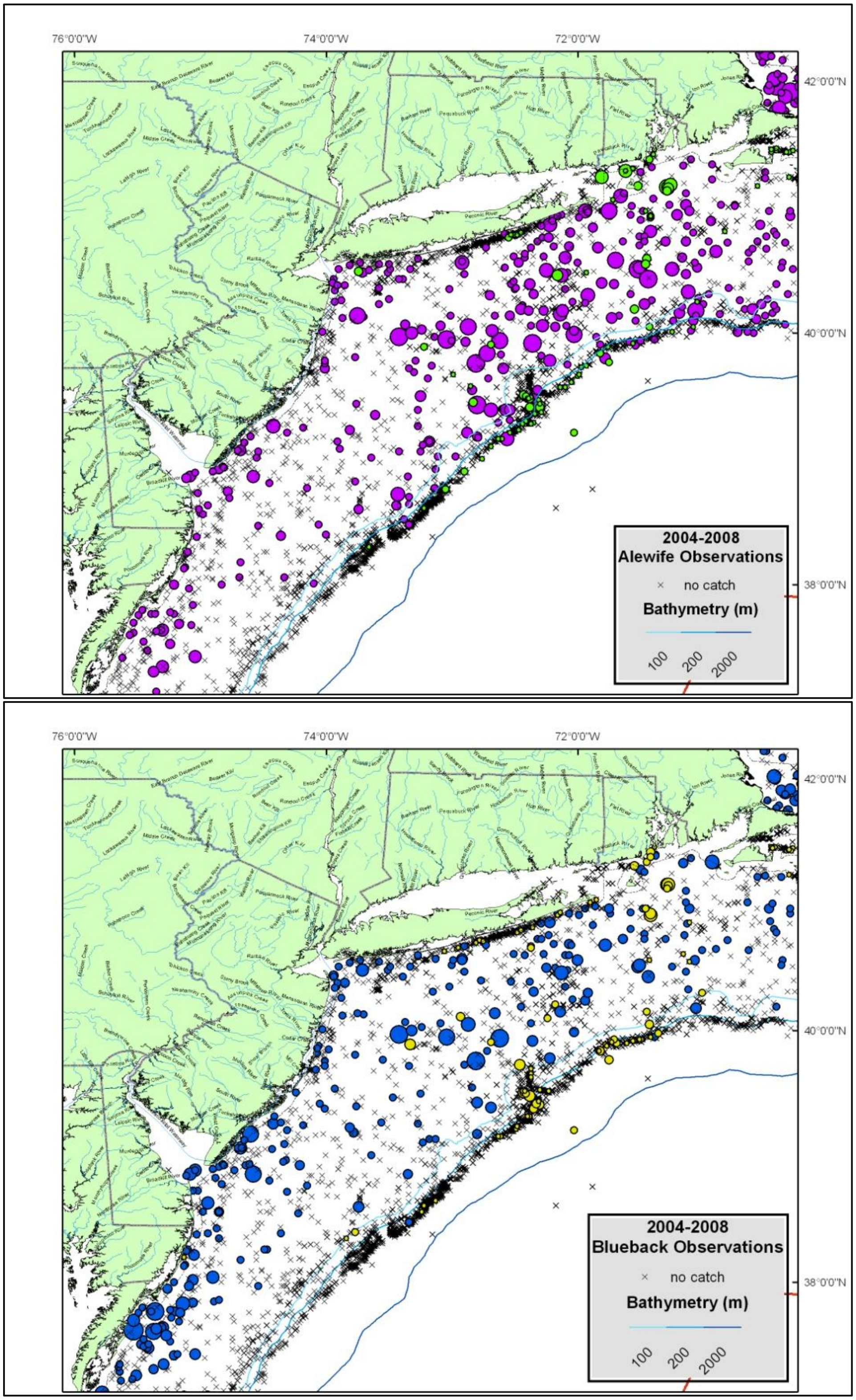

Figure 11: Patterns of river herring from fisheries datasets in the Mid-Atlantic Bight. Relative weights (lbs) of alewife (top) and blueback herring (bottom) from 2004-2008 combined seasonal NMFS bottom-trawl surveys (top-purple, bottom-blue) and NEFOP data (top-green, bottom-yellow) for all specified target species and gears. Catches without respective species indicated (black x's).