New England Fishery Management Council

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MEMORANDUM

DATE: **March 25, 2016**

TO: Atlantic Herring Committee

FROM: Atlantic Herring Plan Development Team

SUBJECT: Localized depletion of Atlantic herring

In January 2016, the Herring Plan Development Team (PDT) was tasked by the Herring Committee to provide data and analyses to support the development of a problem statement and related measures in Amendment 8 regarding localized depletion of Atlantic Herring. This memo summarizes the PDT progress to date. This memo was developed during PDT meetings on January 21, February 10, and March 22. In addition to the regular PDT members, Dr. Walt Golet (University of Maine/Gulf of Maine Research Institute) contributed to this memo.

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PDT tasks

1. Clarify how much herring is currently set aside (e.g., in the stock assessment) to account for the forage needs of predators? What is the best estimate of how much herring is needed for forage?
2. Identify herring fishing locations, by season and gear type; identify any evidence of pulse fishing (i.e., multiple herring vessels in a concentrated time/area).
3. Within the 12 nm territorial sea line, identify areas (e.g., Ipswich Bay, Nantucket Shoals) where herring fishing seasonally intensifies.
    a. Determine and compare midwater trawl trip catches over time in each area, considering variation in tow-specific catches (accounting for tow time, number of tows, and trip duration).
    b. Determine if, over the time of intensified fishing, catches could only be maintained by longer tows, more tows and/or longer trips, thereby indicating local depletion (e.g., F much higher than F set for entire stock).
4. Identify predator fishery (e.g., striped bass, tuna) locations, by season and gear type.
5. Expand the PDT analysis presented to the Committee in January 2016, which examined whether there are correlations between catches of herring and predators.
    a. Examine Area 1A in years prior to 2006 (i.e., Amendment 1 implementation).
    b. Examine catch of predators in the second week after herring catches (across the full time range).
6. Examine potential impacts (biological, economic, social) to different fisheries (herring, tuna, striped bass, etc.) of closing the following 30-minute squares to midwater trawl gear year-round: 99, 100, 114, 115, and 123. Calculate the percent of the total Atlantic herring stock area that these 30-minute squares comprise.
7. Examine predator/prey relationships between cod and herring in Ipswich Bay.
8. Examine ideas for analysis identified in the public scoping comments for Amendment 8.

Introduction

Localized depletion has been a topic discussed in the herring management arena since at least the mid-2000s, at the time Amendment 1 to the Atlantic Herring FMP was developed. Through Amendment 1, midwater trawl (MWT) gears were excluded from management Area 1A from June-September. No evidence or data linking midwater trawling to localized depletion, however, was used at the time to support this action. The Council's rationale was to ensure access to herring for the purse-seine and fixed gear components of the fishery and to address concerns raised by the public and the Scientific and Statistical Committee about concentrated catch inshore and need for precaution due, in part, to lack of data on the inshore resource. There was a concern that midwater trawl gear was particularly prone to causing localized depletion (NEFMC 2006).

This memo is intended to improve understanding of herring management and the footprint in time and space of the herring fisheries as well as fisheries or businesses (e.g., whale-watching) that rely on the predators of herring. The memo also identifies limits to existing data that may hinder a full evaluation of the existence and extent of localized depletion. The work herein is not intended to be definitive and should likely be amended (e.g., applied at different spatial and temporal scales) or expanded (e.g., use different datasets) to be more definitive.

In this memo, the PDT defines localized depletion as described in the Council's public scoping document for Amendment 8:

> *"In general, localized depletion is when harvesting takes more fish than can be replaced either locally or through fish migrating into the catch area within a given time period."*

The occurrence of localized depletion suggests that the removal of prey from a given area would either leave relatively immobile predators (e.g., monkfish) with insufficient prey for some time, or that relatively mobile predators (e.g., cod, tuna) would leave the area in search of alternative prey.

To the degree that temporal and spatial fishery catch data is available, it is relatively simple to describe where and when fishing has occurred for predator fisheries. As described below, this may not be so straight forward for tuna fisheries and perhaps striped bass fisheries. It is challenging to identify if and how other fisheries have been impacted by herring catches. There are many constraints that determine where and when a fishery is prosecuted (e.g., area closures, weather windows, mobility of fish) that need to be understood in an investigation of whether there is causality to any correlations.

In Amendment 1 and more recently, much attention has been given to midwater trawls as the gear responsible for causing localized depletion. The method of removal, however, should not be relevant to the evaluation of localized depletion. If predators are responding only to herring abundance in an area, then given the same amount of catch, the same level of depletion occurs regardless of gear type and would subsequently have the same effect on predators. That said, as a relatively large and mobile gear, midwater trawls likely have different effects on predators than other gears commonly used to harvest similar amounts of herring (e.g., purse seines). Both gear types can be used to fish in a concentrated fashion. Issues of gear conflict should be kept distinct from issues of localized depletion. Are herring predators responding to depletion of herring (which should not depend on the gear used to remove herring), or are the predators responding to a trawl gear passing through an area (and would respond the same way regardless of herring depletion)? The former is localized depletion while the latter is not. These issues are also not mutually exclusive. Conducting field research would help determine if correlations indicate causality and avoid speculation.

Forage needs

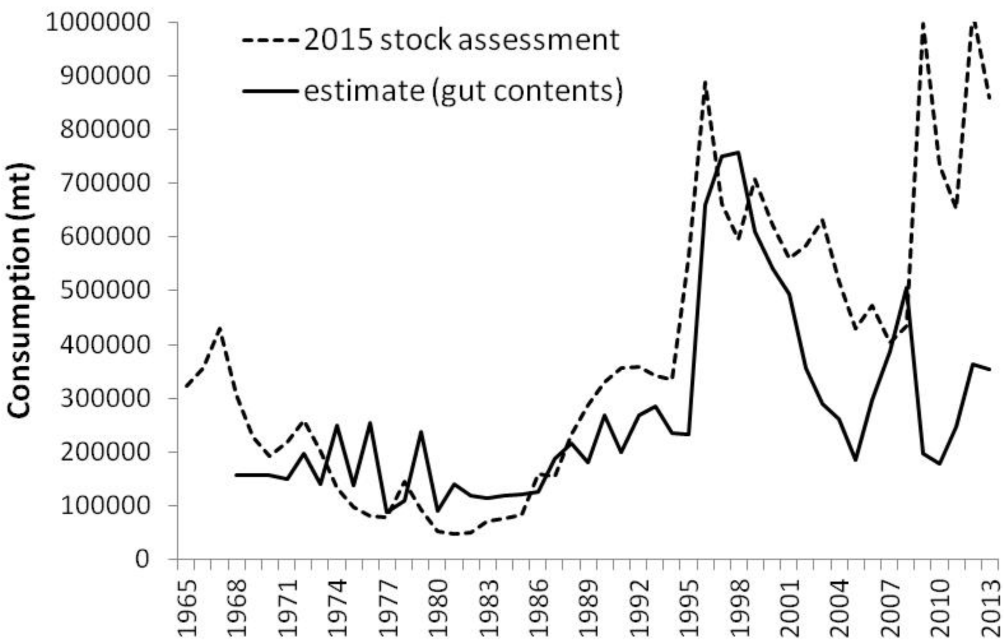
The PDT was asked to clarify how much Atlantic herring is currently set aside to account for the forage needs of predators and to provide the best estimate of how much Atlantic herring is needed for forage.

In the Atlantic herring stock assessment, the amount of herring assumed to be ***taken*** by predators (e.g., piscivorous fish, seabirds, highly migratory species, marine mammals) has varied annually (Figure 1, dashed line). The 2015 stock assessment assumed that, during 2009-2013, an annual average of 852,000 mt of Atlantic herring was eaten by predators, which equaled 44% of average total biomass (1.92 million mt) over the same period. The amount of herring assumed to be consumed by predators in the assessment is based on natural mortality rates and estimates of herring consumption largely based on gut contents data, which also vary annually (Figure 1, solid line), with an annual average of 268,000 mt during that time. The gut contents data are from NMFS surveys, and are highly imprecise and likely biased. The short-term projections used to provide catch advice (overfishing limit, acceptable biological catch) assume a similar amount of herring are consumed as assumed in the stock assessment. More information is available in the 2015 Atlantic Herring Operational Assessment report (Deroba 2015).

The Ecosystem-Based Fishery Management PDT report on scientific advice for accounting for ecosystem forage requirements (NEFMC 2015a) and assessment reports (e.g., Deroba 2015) may be referenced for sample estimates of predator consumption. In recent years, marine mammal consumption of herring is similar to commercial fishery landings, averaging 105,000 mt/year. Bluefin tuna and blue sharks have recently consumed 20-25,000 mt/year. Seabirds consume a relatively small amount of herring, conservatively estimated at about 3-5 mt/year. According to the NEFSC diet database, herring constitutes roughly 20% of the diet of cod and spiny dogfish. There is also some evidence which suggest it is not just volume of herring available, but the age structure of that forage base that is important in the energy budgets of predators (Diamond & Devlin 2003; Golet et al. 2015).

The PDT assumes that the amount of Atlantic herring ***needed*** for forage is the amount below which predators are negatively impacted. Estimates of this need do not currently exist and would vary by the abundance of predators and other prey. To summarize, consumption estimates can be generated, but that is different than what is necessary – which is a difficult question to answer definitively.

Figure 1 - Atlantic herring consumption by predators



Source: Deroba (2015).

Footprint of the Atlantic herring and predator fisheries

The PDT was asked to describe Atlantic herring fishing locations throughout the range of the fishery and within the 12 nm territorial sea line, by season and gear type. For predator fisheries, the PDT was asked to identify their location and gear types. For the herring fishery, the PDT was asked to identify any evidence of pulse fishing, defined as multiple herring vessels fishing in a concentrated time and/or area. Within the 12 nm territorial sea line, the PDT was asked to identify areas (e.g., Ipswich Bay, Nantucket Shoals) where herring fishing seasonally intensifies. Within each identified area, the PDT was asked to compare midwater trawl trip catches over time (considering variation in tow-specific catches, accounting for tow time, number of tows and trip duration) to determine if, over the time of intensified fishing, catches could only be maintained by longer tows, more tows and/or longer trips, thereby indicating local depletion (e.g., F much higher than F set for entire stock).

Due to time constraints, the PDT has partially completed these tasks as reported here, but could provide more information in subsequent memos if so directed by the Committee. Data for the bottom trawl fishery is not included here, neither is an analysis of tow-specific catches over time, or predator fisheries by gear type. Information at other time scales could be provided in future as well. Data limitations are noted.

Heat maps

To locate effort by different fisheries in recent years, the PDT developed "heat maps" of herring revenue by midwater trawl vessels from 2000 to 2014, using a method generated by the NEFSC Social Sciences Branch (DePiper 2014). These maps use a statistical model to match Vessel Trip Report (VTR) data with observer data. The model compares haul-level observer data with the VTR point location to model the probability that an observed haul is within a particular distance of a VTR point. The model results are then applied to the VTR data to construct concentric rings. The lat/lon data of the trip is used along with other data, primarily days absent.

A benefit to this approach is that it does not just take a VTR point and expand it to a stat area, but takes into account the trip length, gear used, and general area of the ocean. All subtrips with a lat/lon point are used, not just observed trips. This approach is a way to resolve the limitations of having one VTR point per trip.

This probability mapping approach is a means to use the VTR position data on a grid finer than statistical area, but there should be caution in interpreting results and ensuring appropriate time scales are used. It is not possible, however, to identify catch per tow. These maps can be generated for different gears and time intervals, and for all fisheries that are in the VTR database. Maps for revenue and effort (trips) are also readily available.

Figure 2 to Figure 13 show, by month, the estimated landings by geographic areas fished for the herring midwater trawl (MWT) and herring purse seine (PUR) fisheries, as well as the commercial fisheries for cod, pollock), and spiny dogfish.

In January, there is a bit of overlap between the midwater trawl fleet and both cod and pollock fisheries east of Cape Cod. It also overlaps with cod near Block Island. The same patterns exist from February through April, but there is a bit less fishing for herring than in January.

In May, there is a bit of overlap between the midwater trawl fleet and both cod and pollock fisheries east of Cape Cod.

In June, the midwater trawl fishery has moved mostly to Georges Bank and maybe a bit of midwater trawl fishing in the Great South Channel. There may be a bit of overlap between the trawl fishery in block 113 with both cod and pollock fisheries. Spiny dogfish are being caught east and southeast of Cape Cod (Blocks 114 and 98), but the herring fishery is not using these areas extensively in June. July is qualitatively similar.

In August, herring, cod, pollock, and spiny dogfish are all being caught in Block 114, east of Cape Cod. There is also may be a bit of overlap between the pollock and purse seine gear just northeast of the Western Gulf of Maine Area. September is similar.

By October, the midwater trawl fishery has moved back into Area 1A, so there is some overlap between midwater trawl herring vessels and the three predator fisheries. This continues into November. By December, there may be a bit of overlap again, east of Cape Cod.

Figure 2 – January landings 2010-2014 (pounds landed per quarter km² square). For reference, the 30 minute squares are shown.

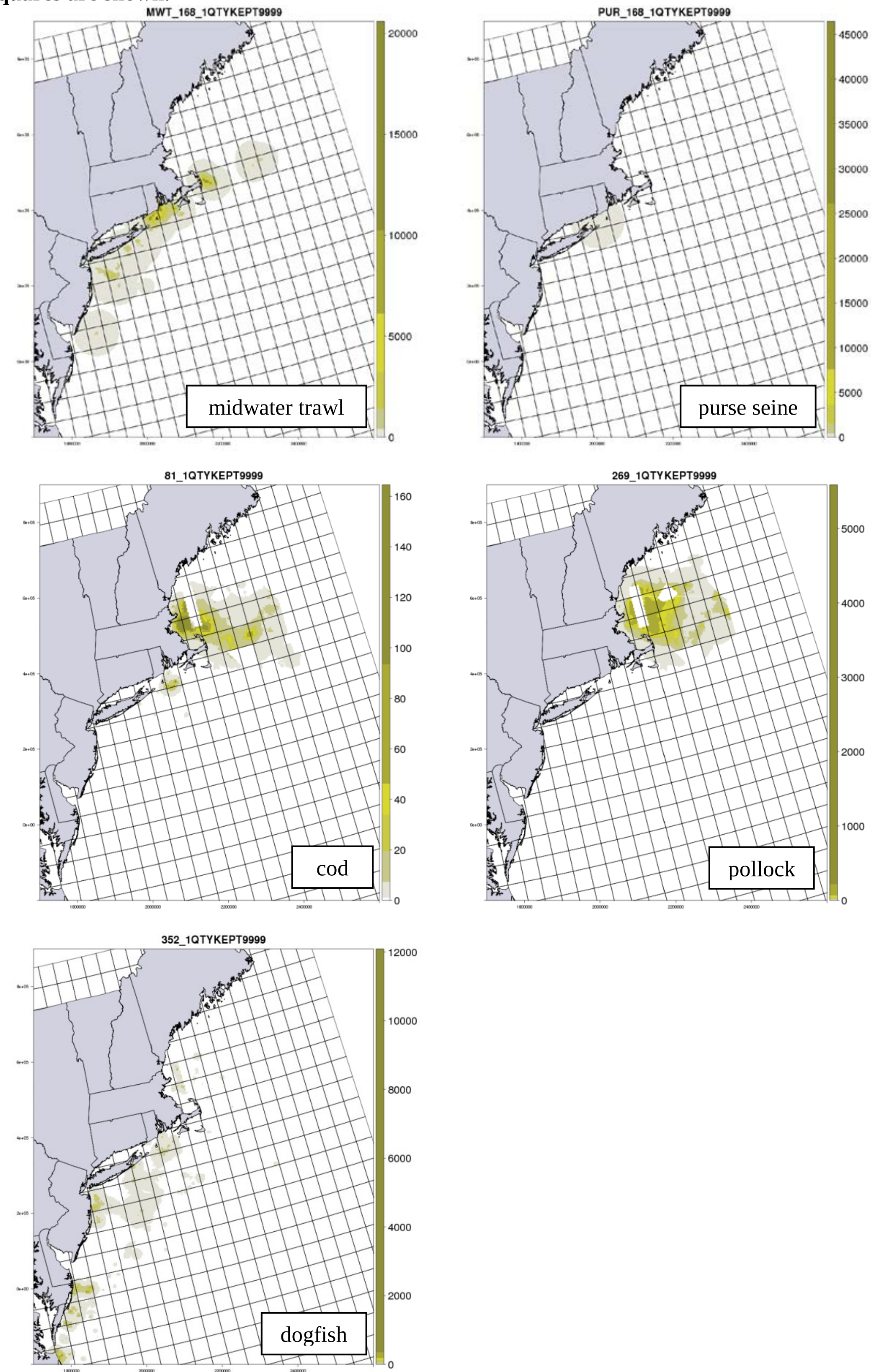


Figure 3 - February landings 2010-2014 (pounds landed per quarter km^2 square). For reference, the 30 minute squares are shown.

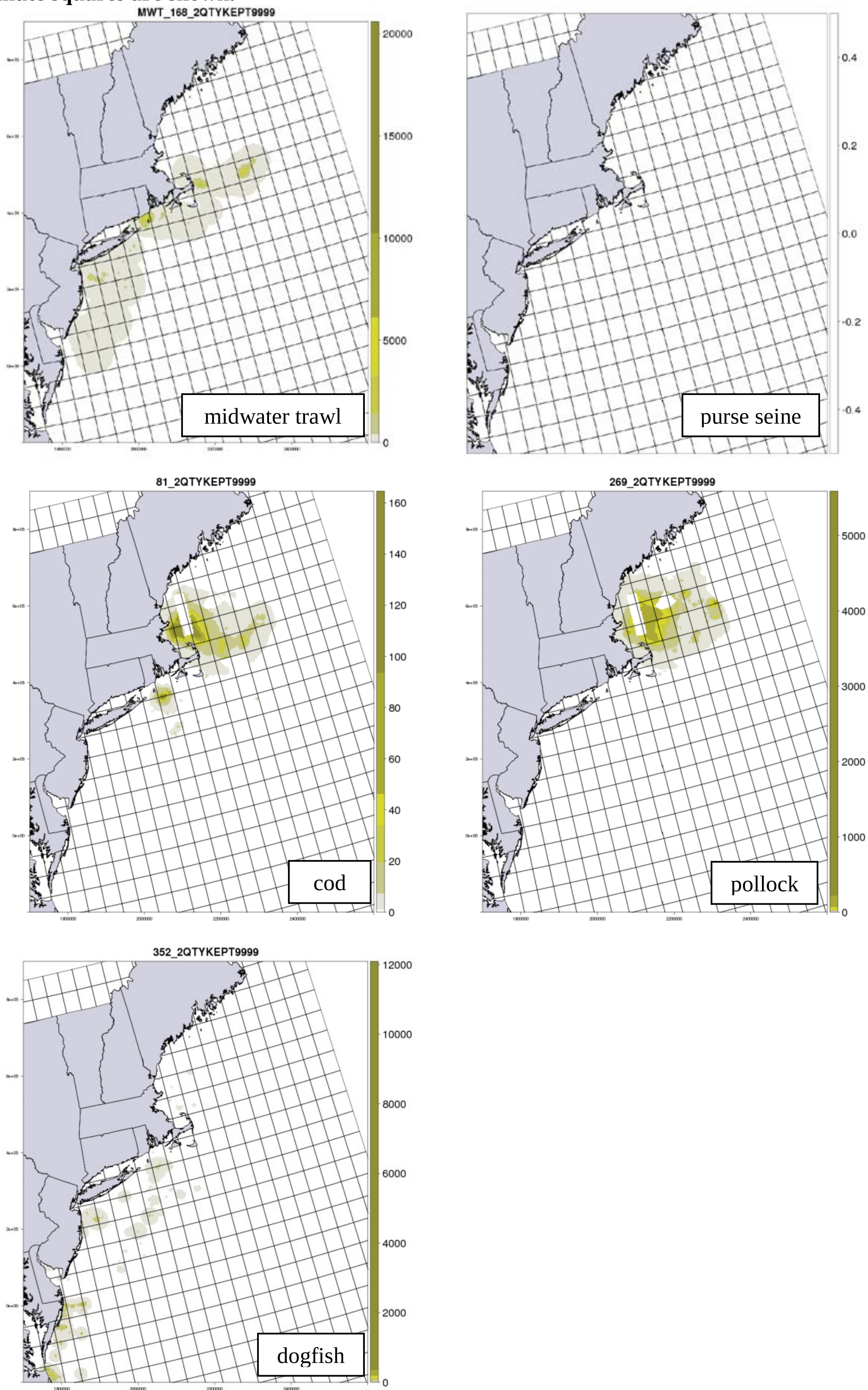


Figure 4 - March landings 2010-2014 (pounds landed per quarter km^2 square). For reference, the 30 minute squares are shown.

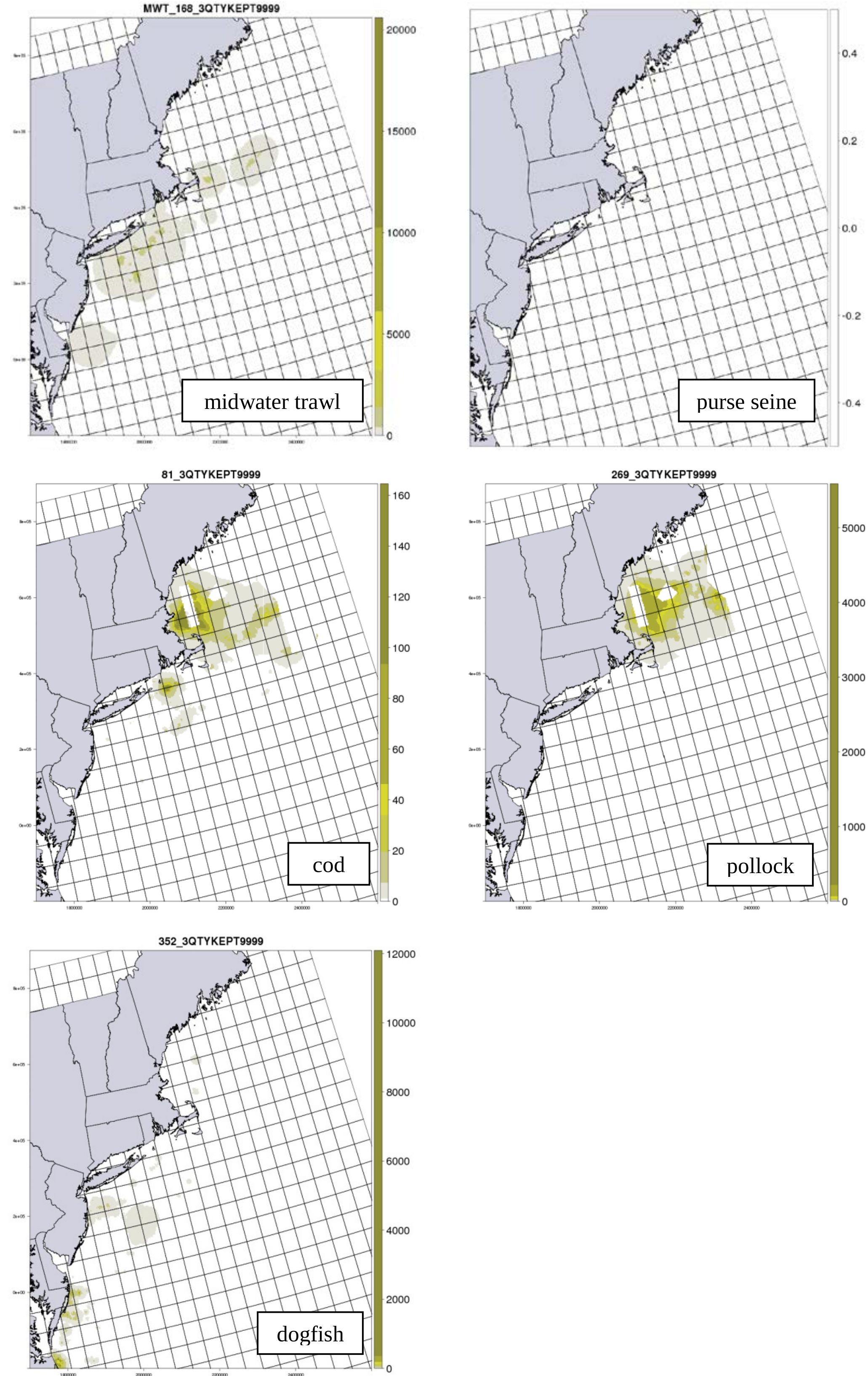


Figure 5 – April landings 2010-2014 (pounds landed per quarter km^2 square). For reference, the 30 minute squares are shown.

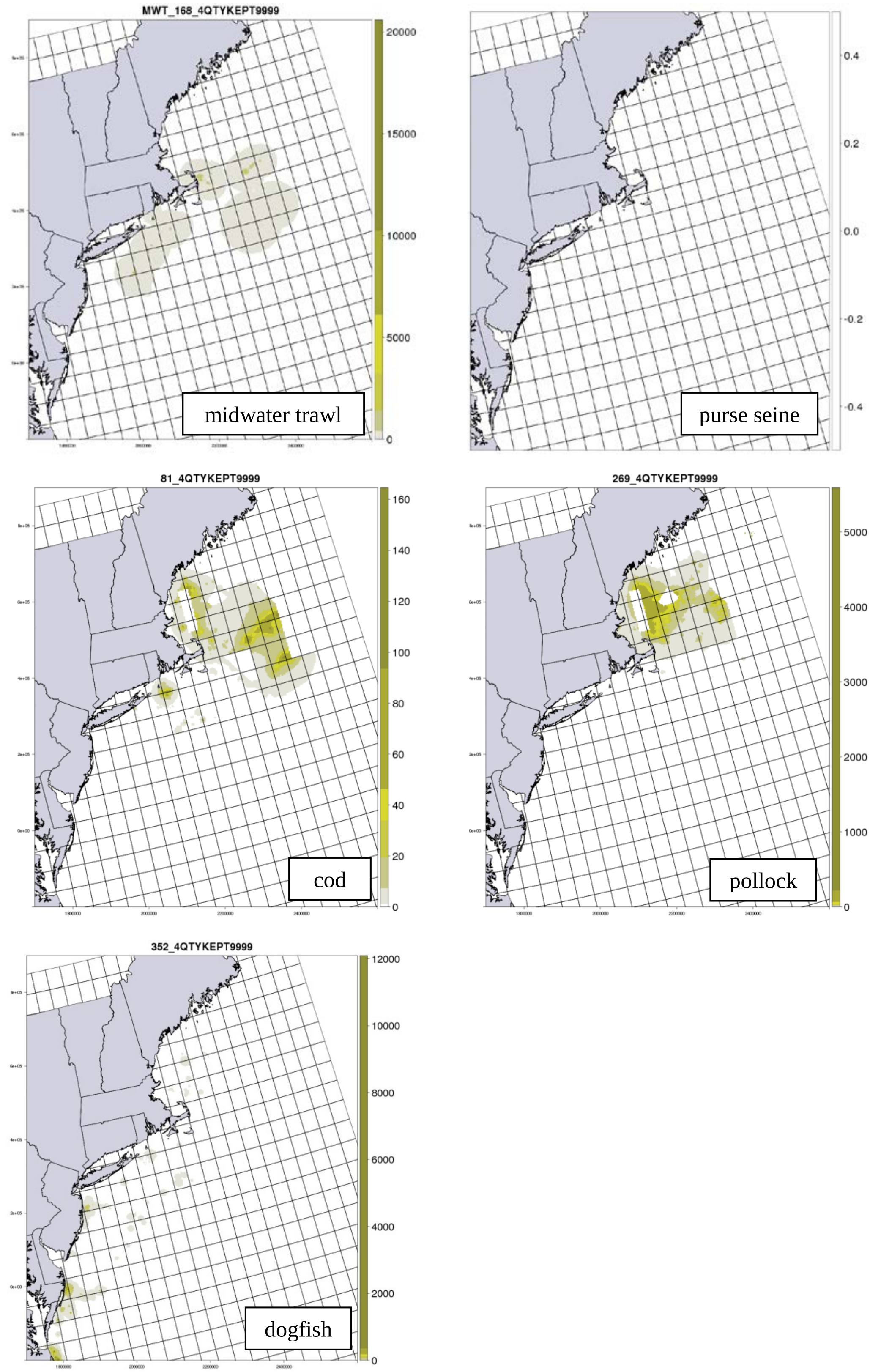


Figure 6 – May landings 2010-2014 (pounds landed per quarter km^2 square). For reference, the 30 minute squares are shown.

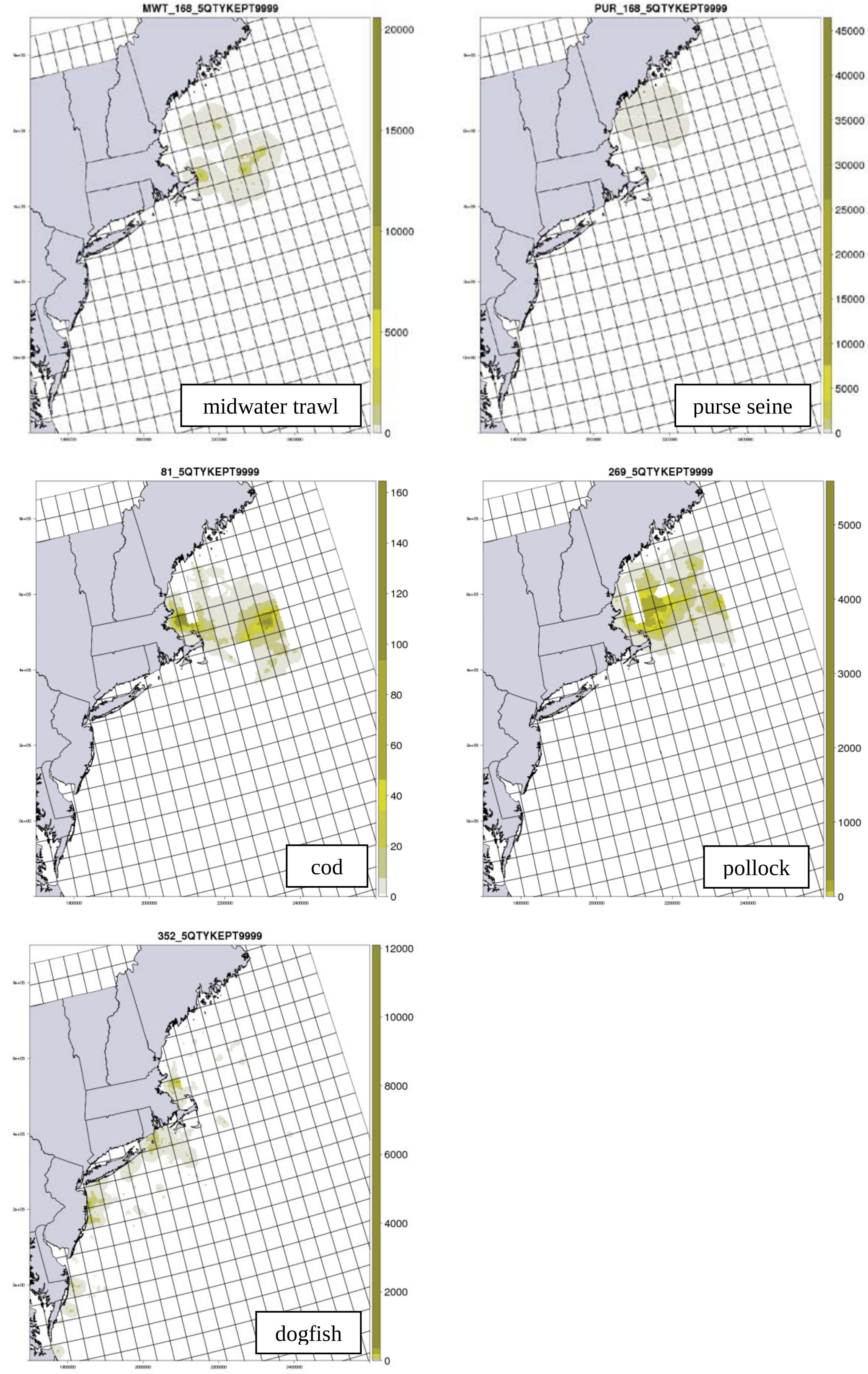


Figure 7 – June landings 2010-2014 (pounds landed per quarter km^2 square). For reference, the 30 minute squares are shown.

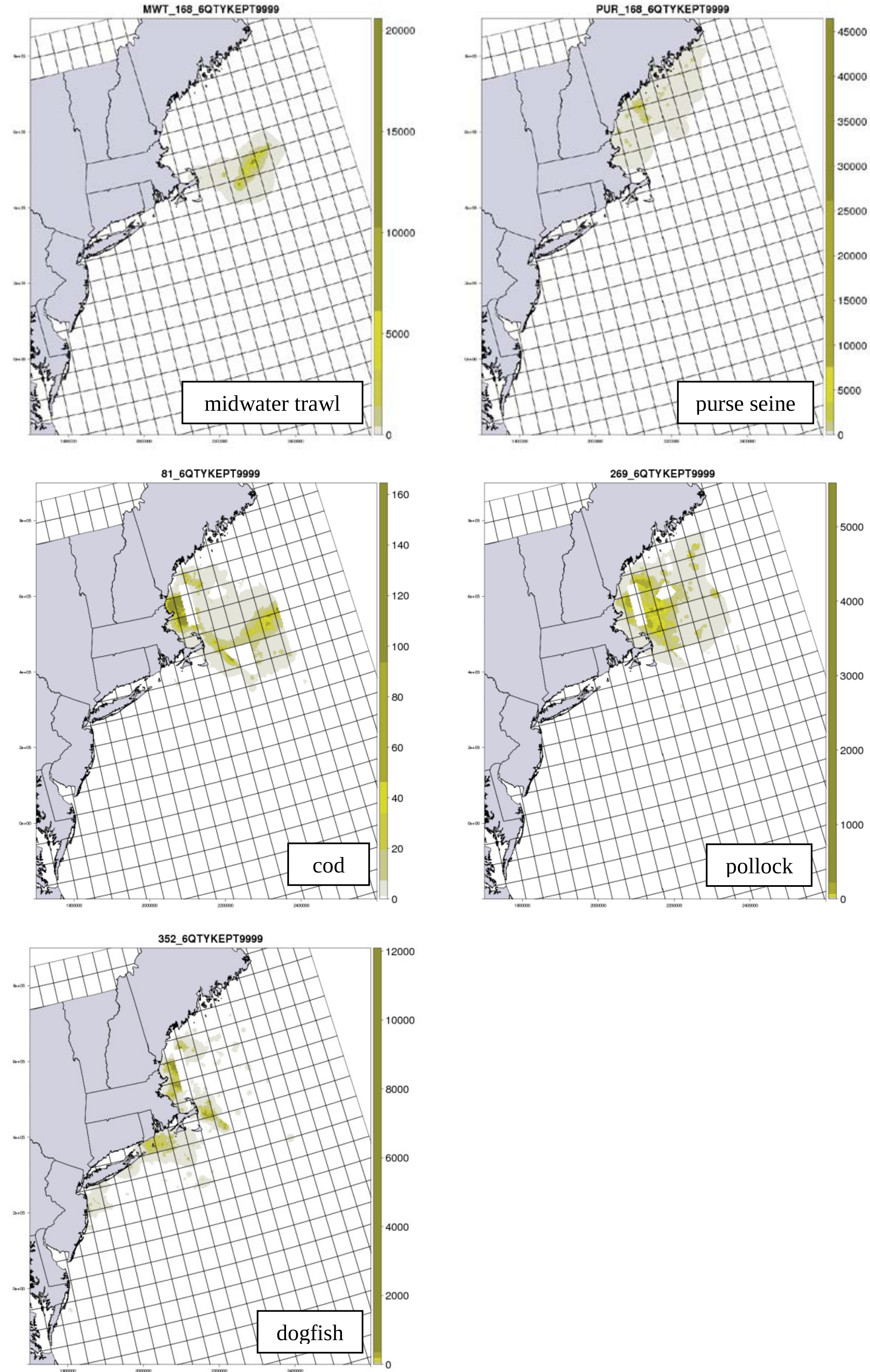


Figure 8 – July landings 2010-2014 (pounds landed per quarter km² square). For reference, the 30 minute squares are shown.

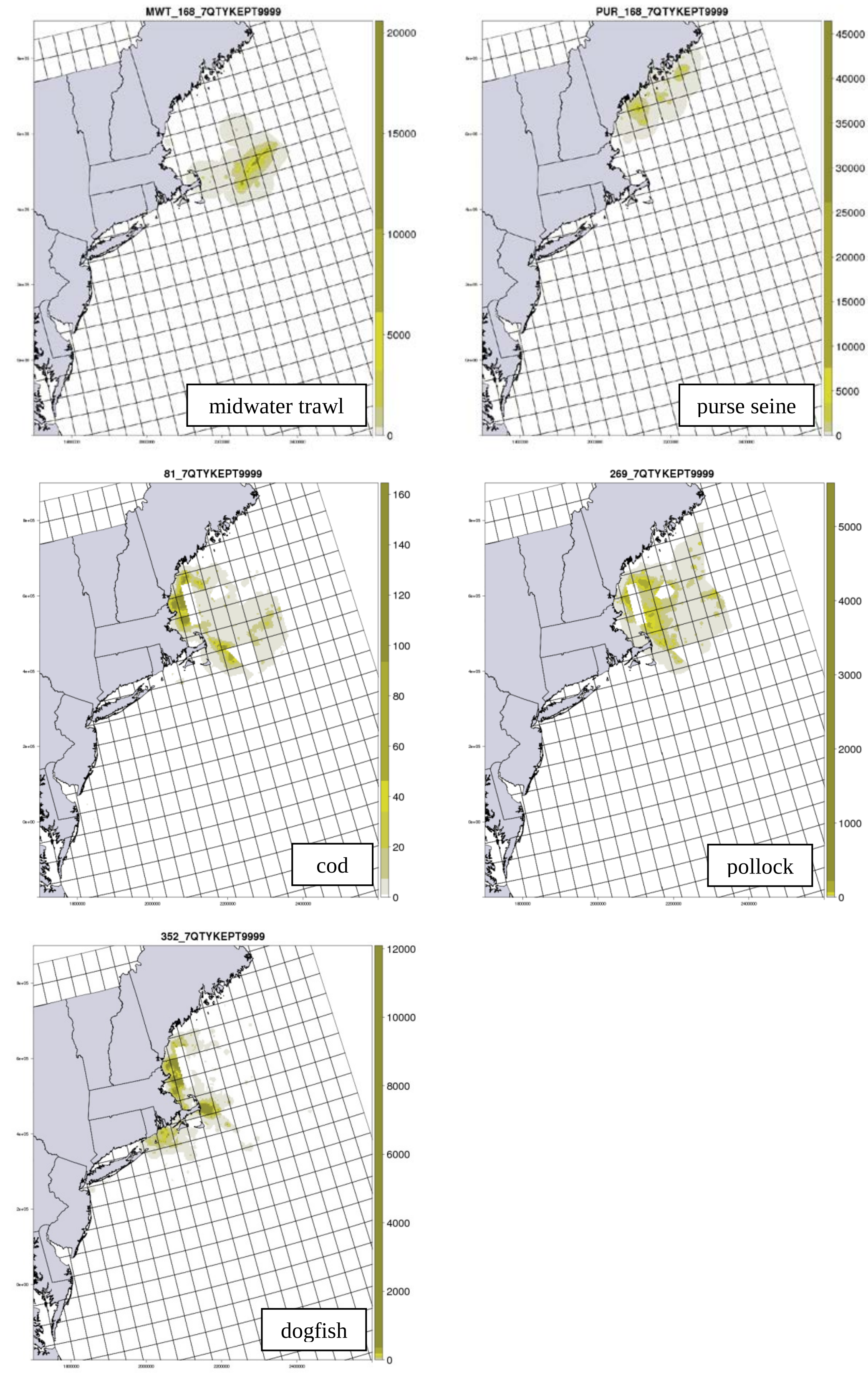


Figure 9 – August landings 2010-2014 (pounds landed per quarter km² square). For reference, the 30 minute squares are shown.

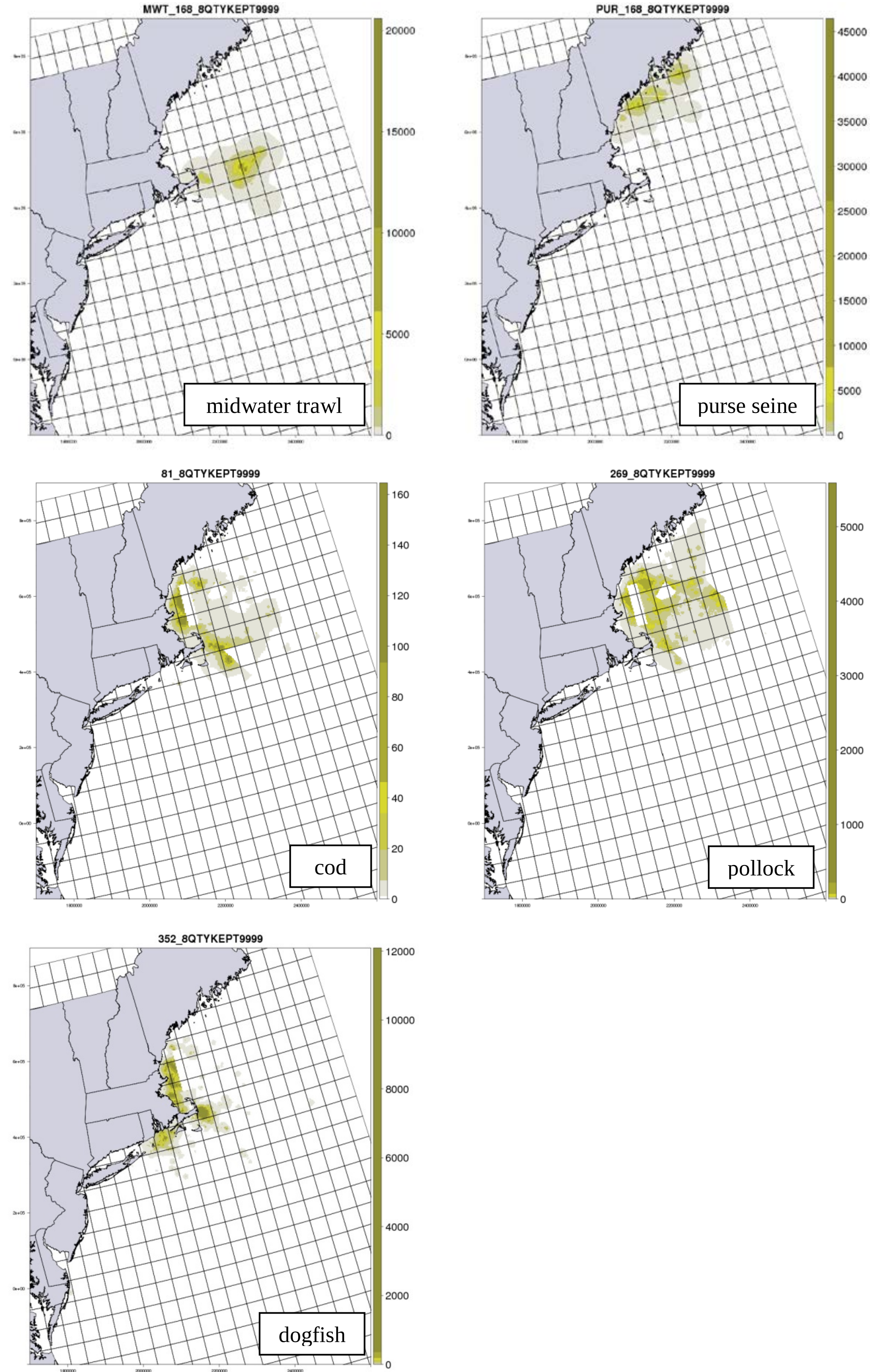


Figure 10 – September landings 2010-2014 (pounds landed per quarter km^2 square). For reference, the 30 minute squares are shown.

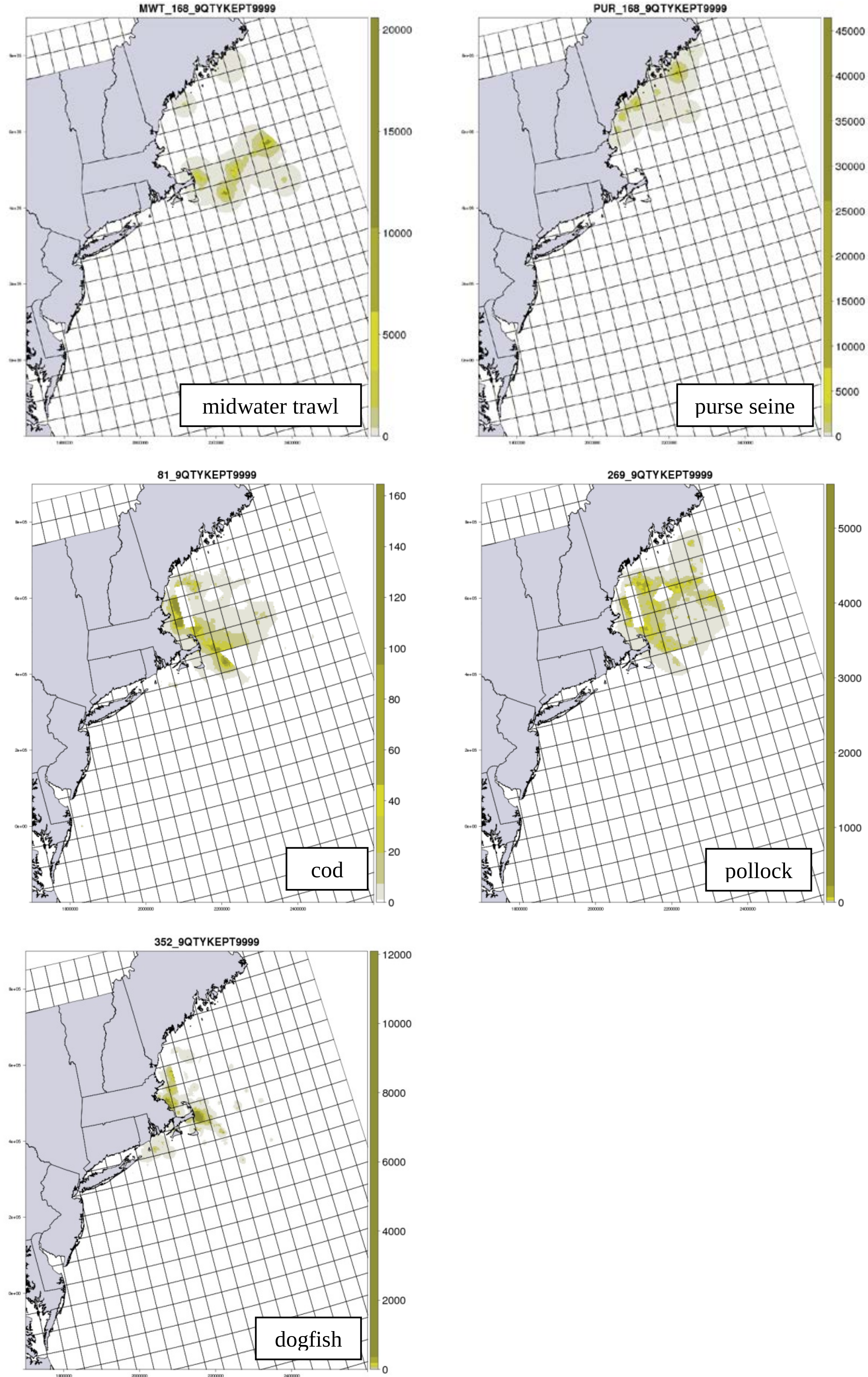


Figure 11 – October landings 2010-2014 (pounds landed per quarter km^2 square). For reference, the 30 minute squares are shown.

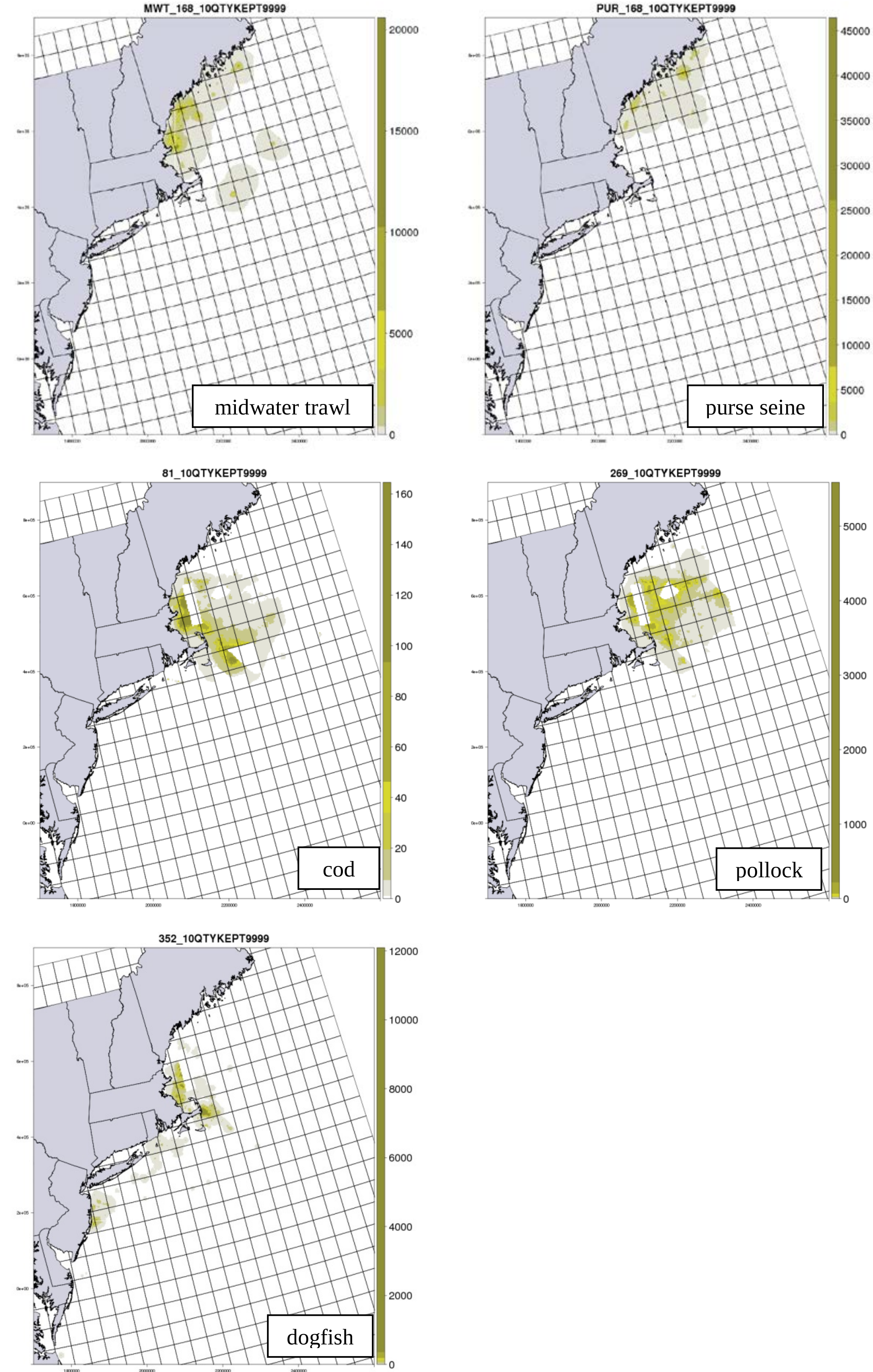


Figure 12 – November landings 2010-2014 (pounds landed per quarter km² square). For reference, the 30 minute squares are shown.

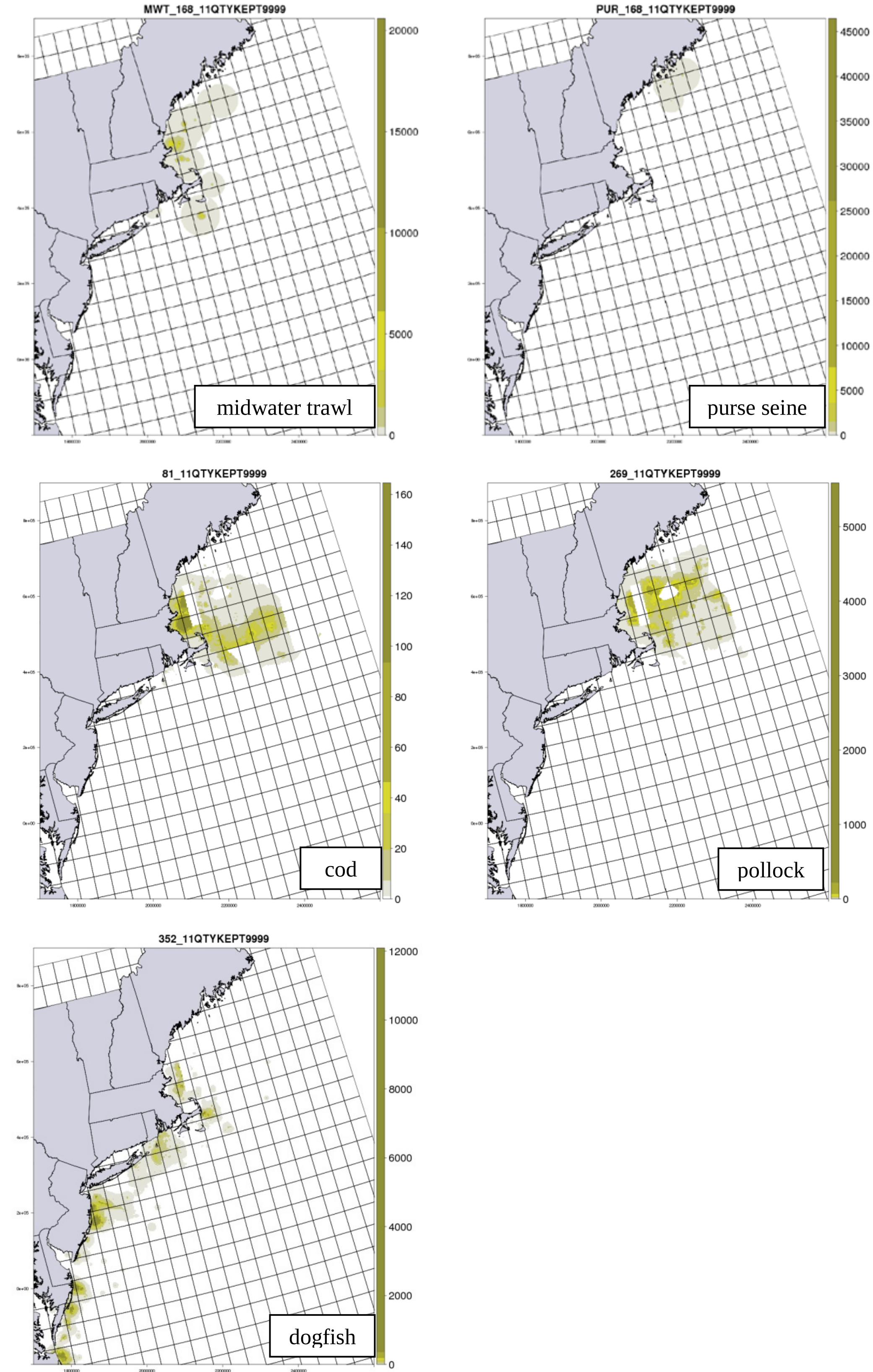
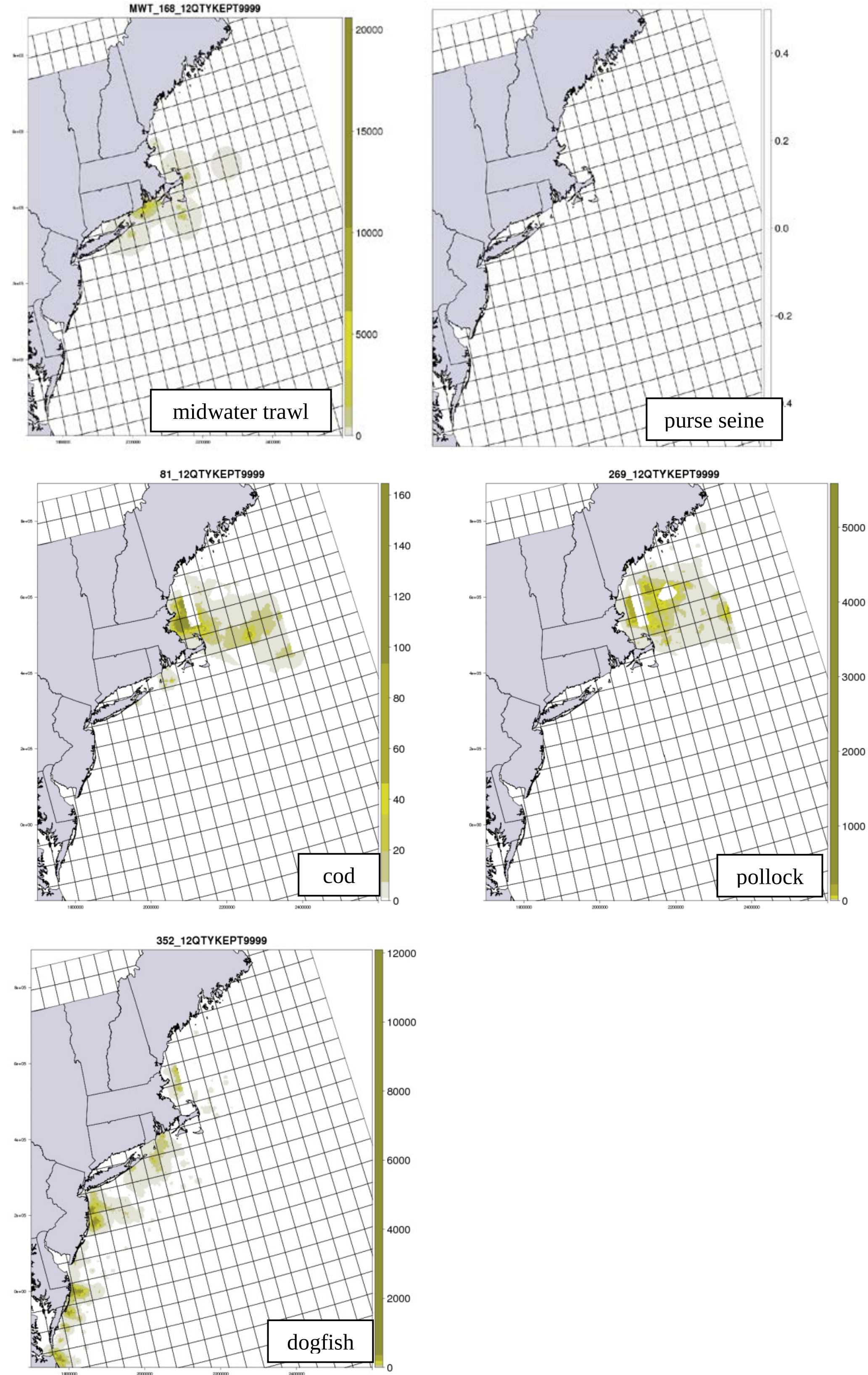


Figure 13 – December landings 2010-2014 (pounds landed per quarter km^2 square). For reference, the 30 minute squares are shown.



Area 1A

The Atlantic herring fishery has undergone multiple changes to its management structure in Area 1A and elsewhere since 2007. Chiefly, midwater trawls were excluded from Area 1A in June-September, starting in 2007. Additionally quota reduction in Area 1A and elsewhere have also impacted the fishery. To identify how catch and effort distributions have changed, a series of plots and graphs were produced. The goal was to examine catch and effort by area and season both before and after the series of management changes. The VTR (Vessel Trip Report) System was queried for catch and effort by gear type, location, and date. Data were only queried for catch >6,600 lbs to represent the directed fishery. From this data set, a series of graphs and maps were produced to examine changes in catch and effort across the fishery.

Examination of catch by area (Figure 14) suggests a marked change in removals by area. Post 2007 catches in the offshore areas (Areas 2 & 3) increased while catches inshore decreased. This is likely due to a number of factors, including the reduction in Area 1A quota from ~60,000 mt in 2005 to ~27,000 by 2010. Catches over all have decreased and then increased, due in part to changes in Optimum Yield and overall quotas fishery-wide.

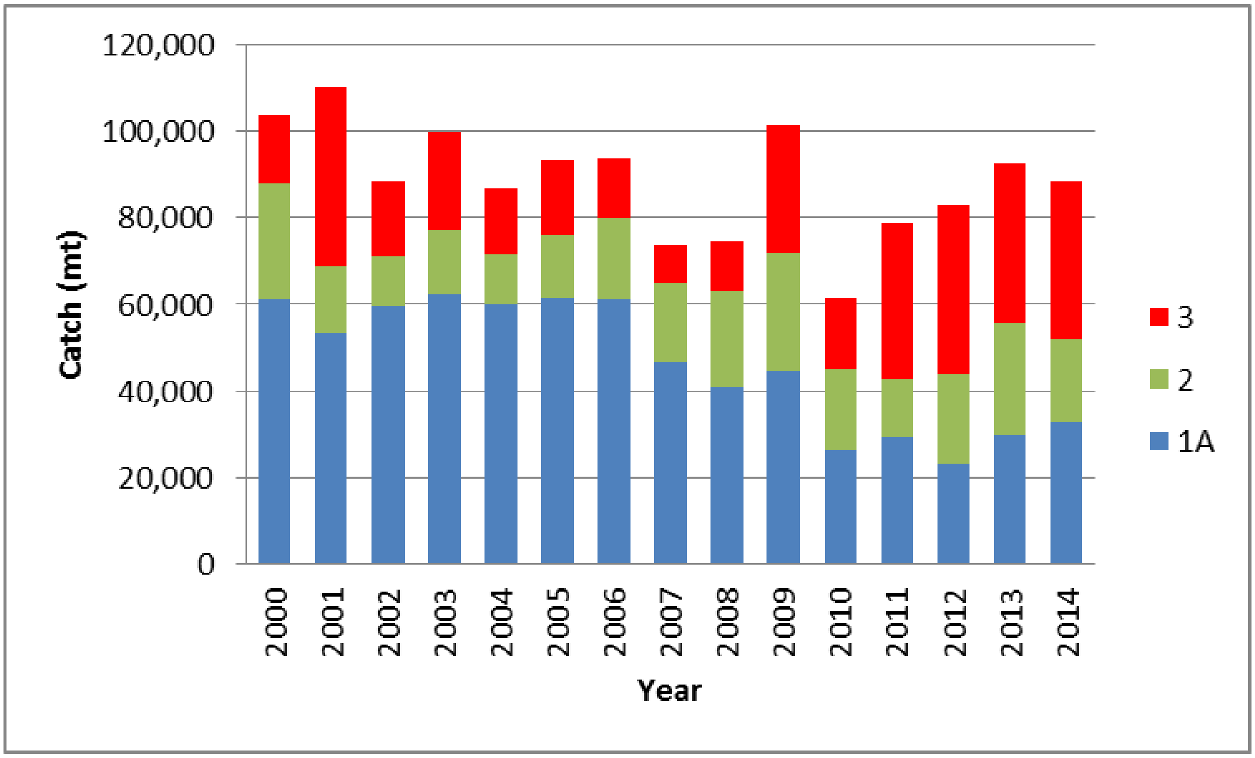
Overall catch fishery wide has declined since 2000, while price has increased from $0.05 to over $0.15 per pound, a three-fold increase (Figure 15). This increase is thought to be largely due to the reductions in overall catch, the shift to more off-shore harvest and consolidation of the fleet given management action to control access.

Within Area 1A, catch and number of active permits has declined, due in part to reductions in quota, limited access, and exclusion of midwater trawling June through September (Figure 16). Despite those reductions, catch by purse seine gear per trip has increased since 2010 (Figure 17), but is variable over the time series since 2000. This suggests that, while the number of trips by purse seiners has remained fairly stable, purse seine catch has increased overall since 2010 (Figure 18, Figure 19). However, it should be noted that catch per trip by purse seine gear in Area 1A is less than what it was prior to the seasonal removal of the mid-water fleet (Figure 17). Care should be taken to not draw conclusions on stock status from catch-per unit effort data.

In Area 1A June to September, the overall number of active permits has declined, in part due to management changes listed above. However, total removal by permits has increased (Figure 20). Given the aforementioned change in price per pound, this translates into a larger ex-vessel revenue per permit since 2010: from $100,000 per permit to over $800,000 per permit in June through September (Figure 21).

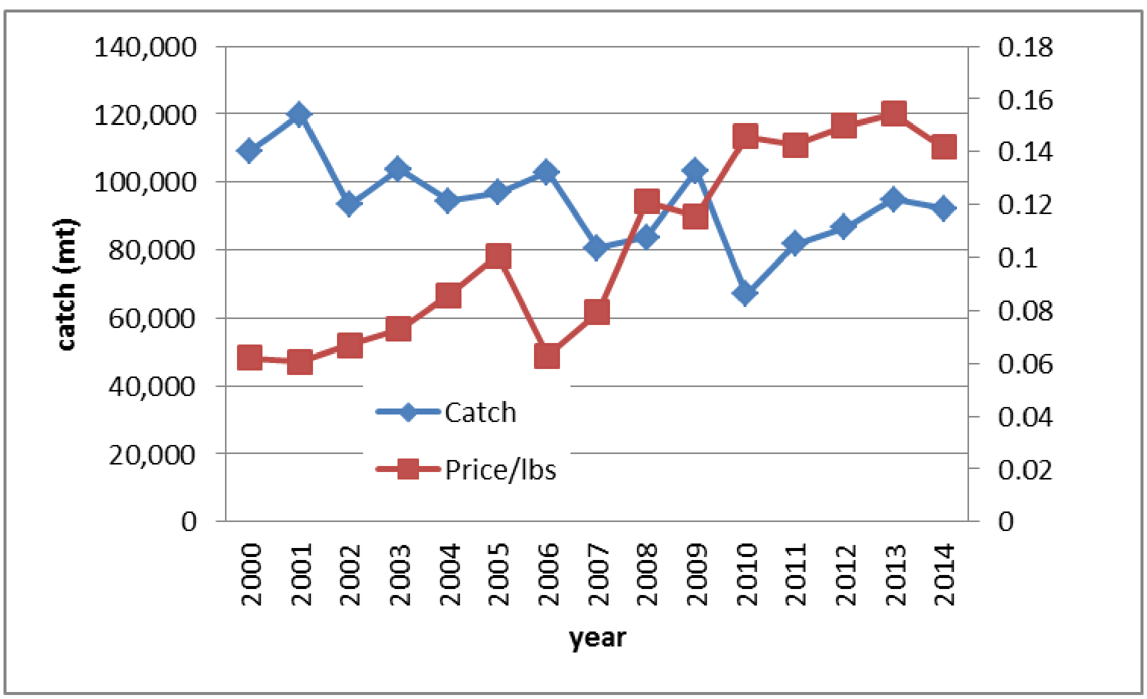
An examination of map prior to and after 2007 shows some interesting changes for the purse seine fleet. Overall, catch locations have remained the same, but there seems to be an indication of a move south and west along the Maine coast in terms of intensity (Figure 22 to Figure 24). This change appears consistent June through September.

Figure 14 – Atlantic herring catch by all gear types by herring management area by year.



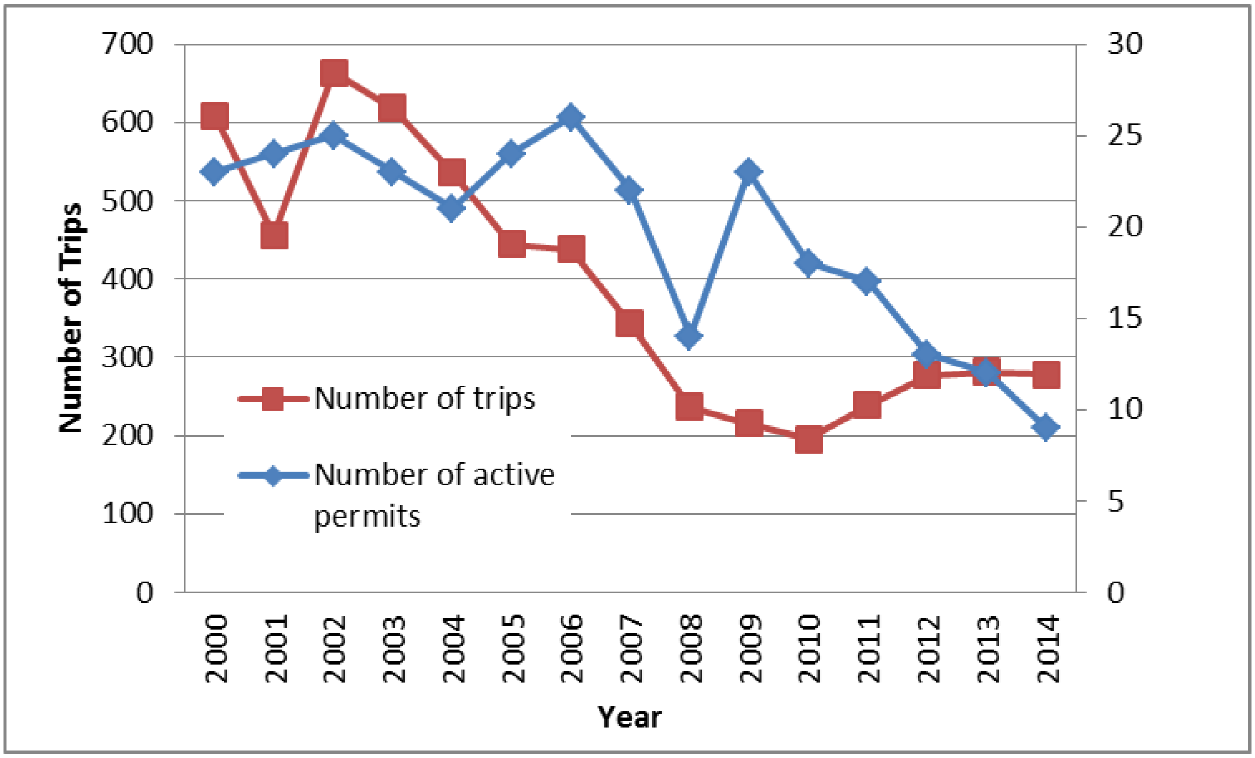
Note: Only catches >6,600 lbs are included. Area 1B excluded.

Figure 15 – Atlantic herring catch and price per lbs, all gears all areas.



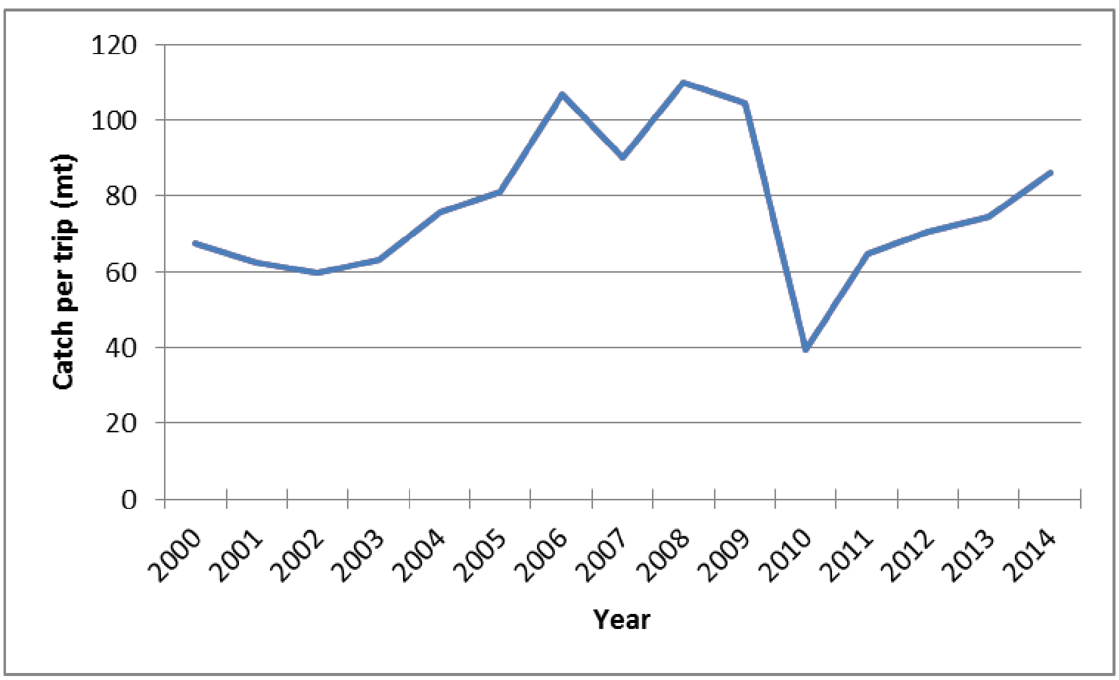
Note: Only catches >6,600 lbs are included.

Figure 16 – Atlantic herring catch and number of active permits in Area 1A by year, June-September



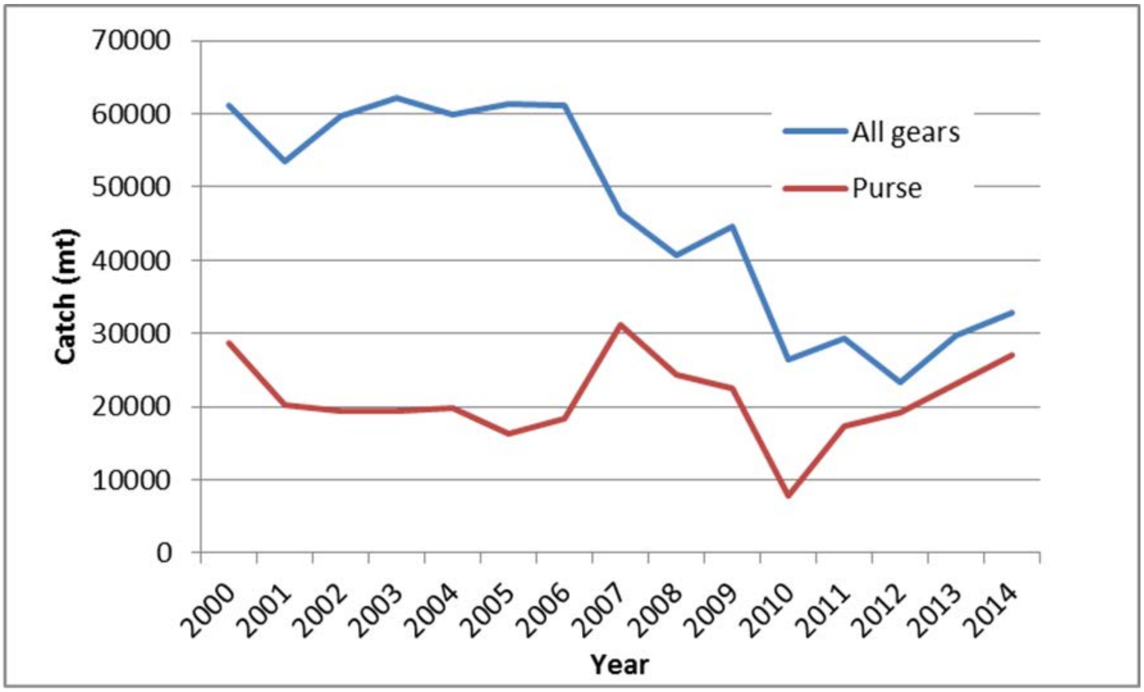
Note: Only catches >6,600 lbs are included.

Figure 17 - Average Atlantic herring catch per trip for purse seine vessels in Area 1A, June through September.



Note: Only catches >6,600 lbs are included.

Figure 18 - Annual Atlantic herring catch in Area 1A for purse seines and all gears



Note: Only catches >6,600 lbs are included.

Figure 19 - Annual number of trips in Area 1A for purse seines and all gears

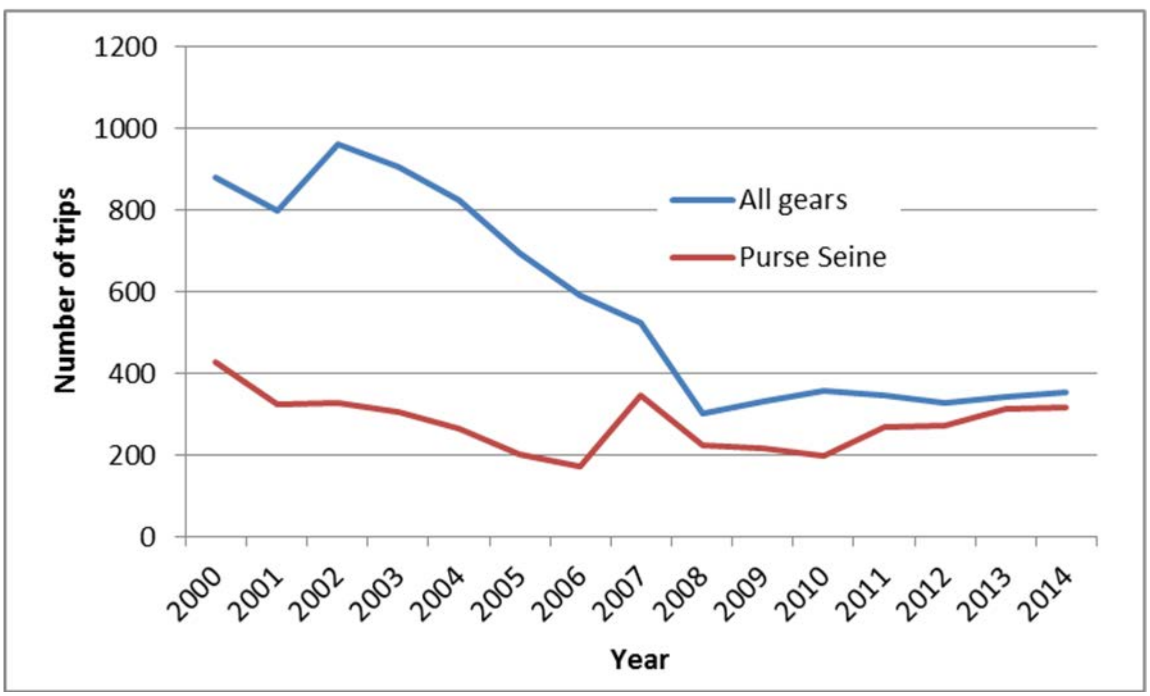


Figure 20 – Atlantic herring catch and number of active permits in Area 1A, June through September by year

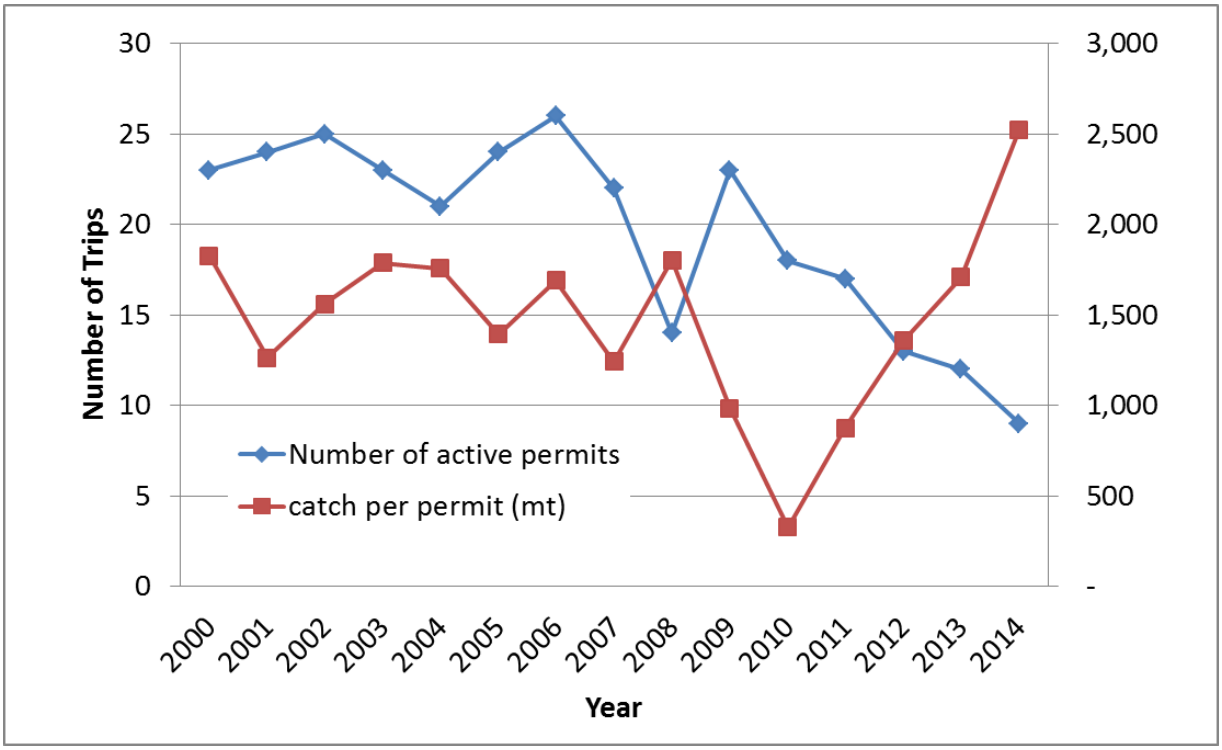


Figure 21 - Number of active permits and average total revenue (average catch times average price/lbs summed) in Area 1A, June through September by year

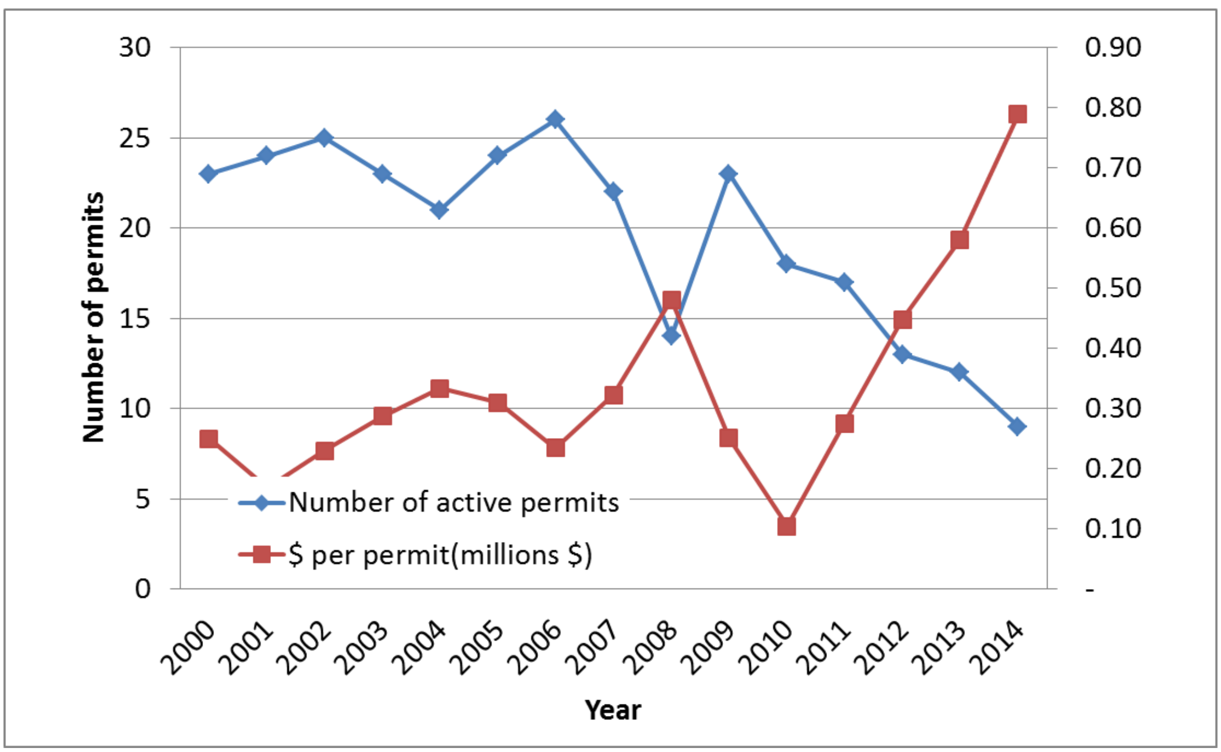


Figure 22 - Area 1A kernel density plots of herring seiner landings (>6000lbs/trip) locations for May-June, 2000-2007 and 2008-2014

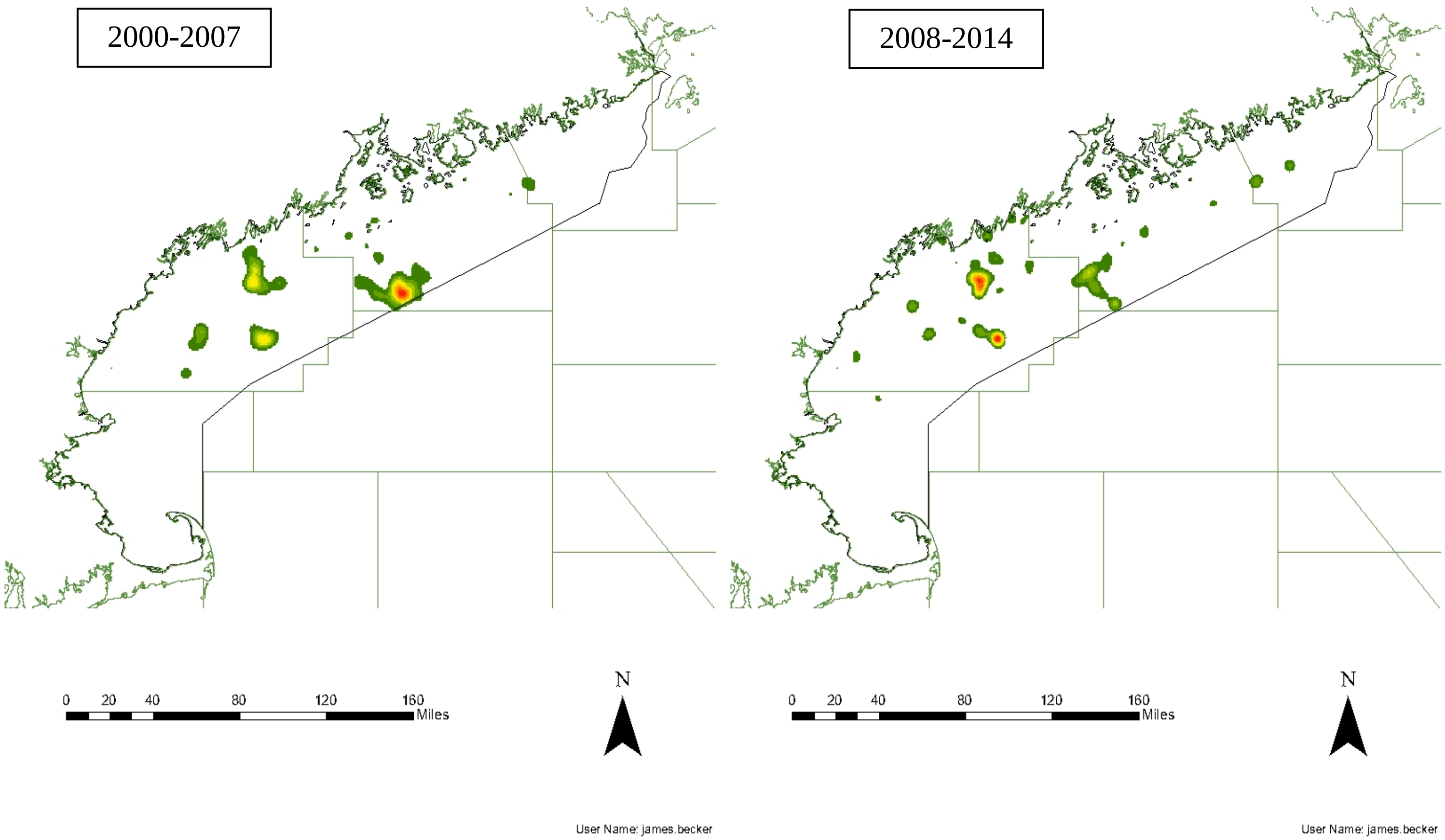


Figure 23 - Area 1A kernel density plots of herring seiner landings (>6000lbs/trip) locations for June-July, 2000-2007 and 2008-2014

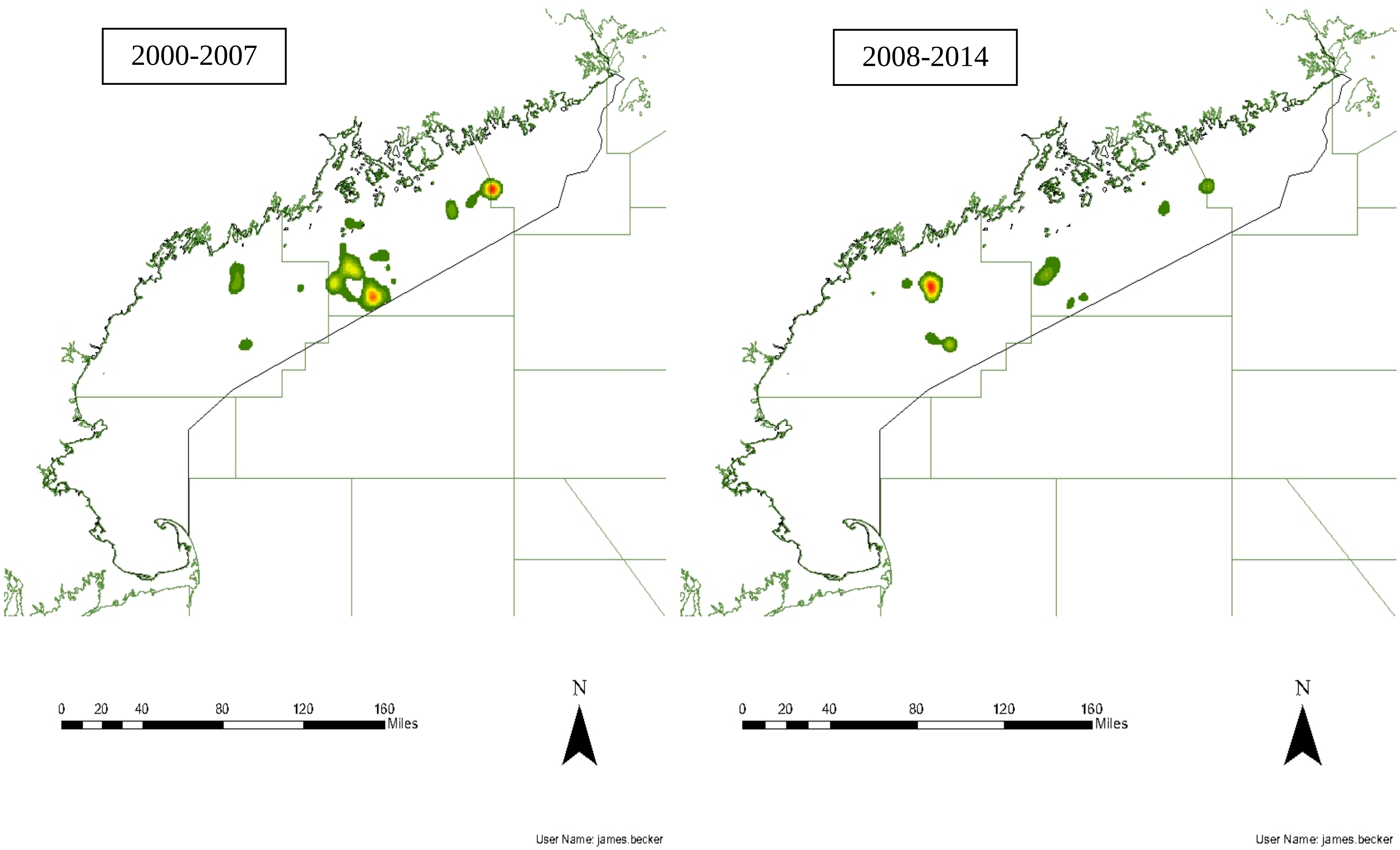
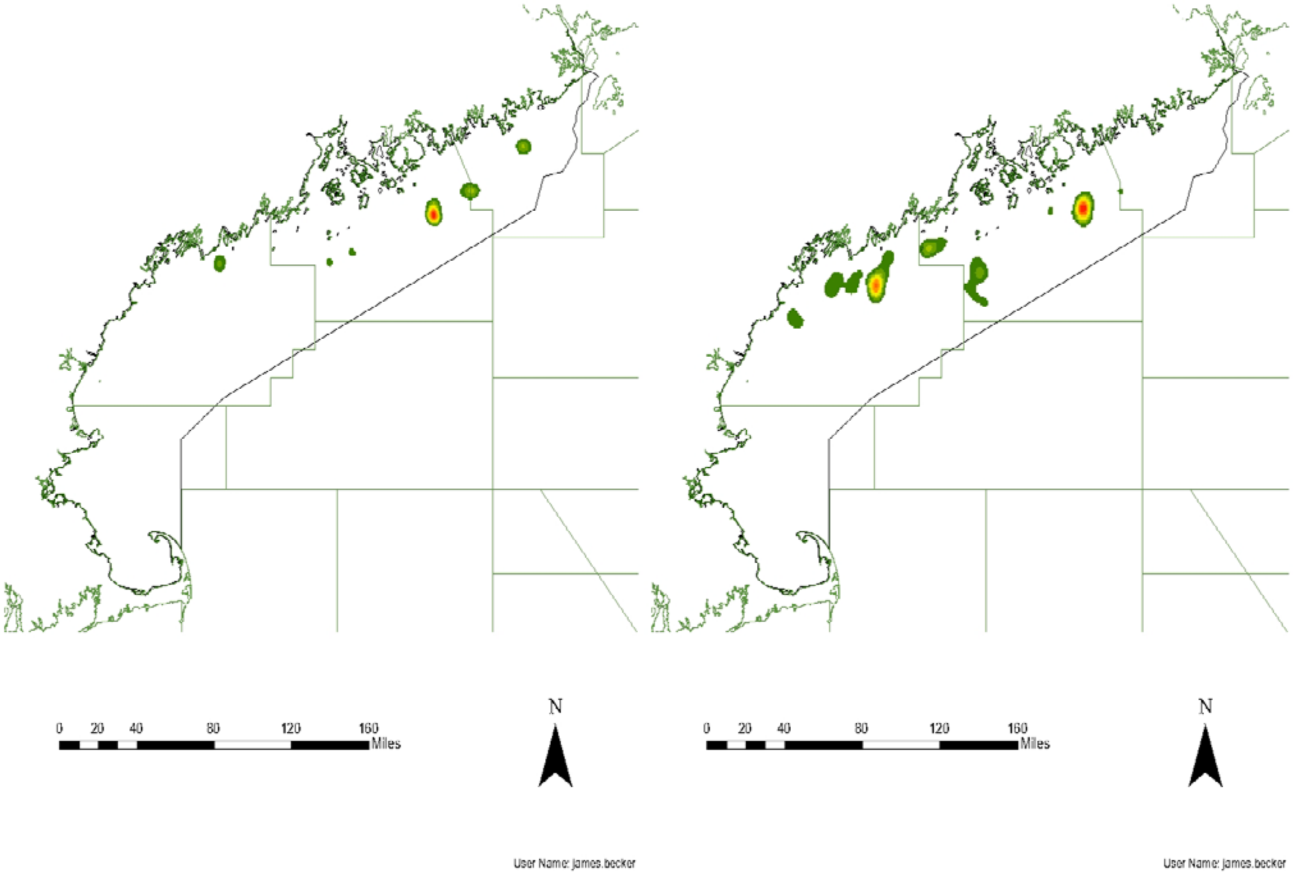


Figure 24 - Area 1A kernel density plots of herring seiner landings (>6000lbs/trip) locations for August to September, 2000-2007 and 2008-2014



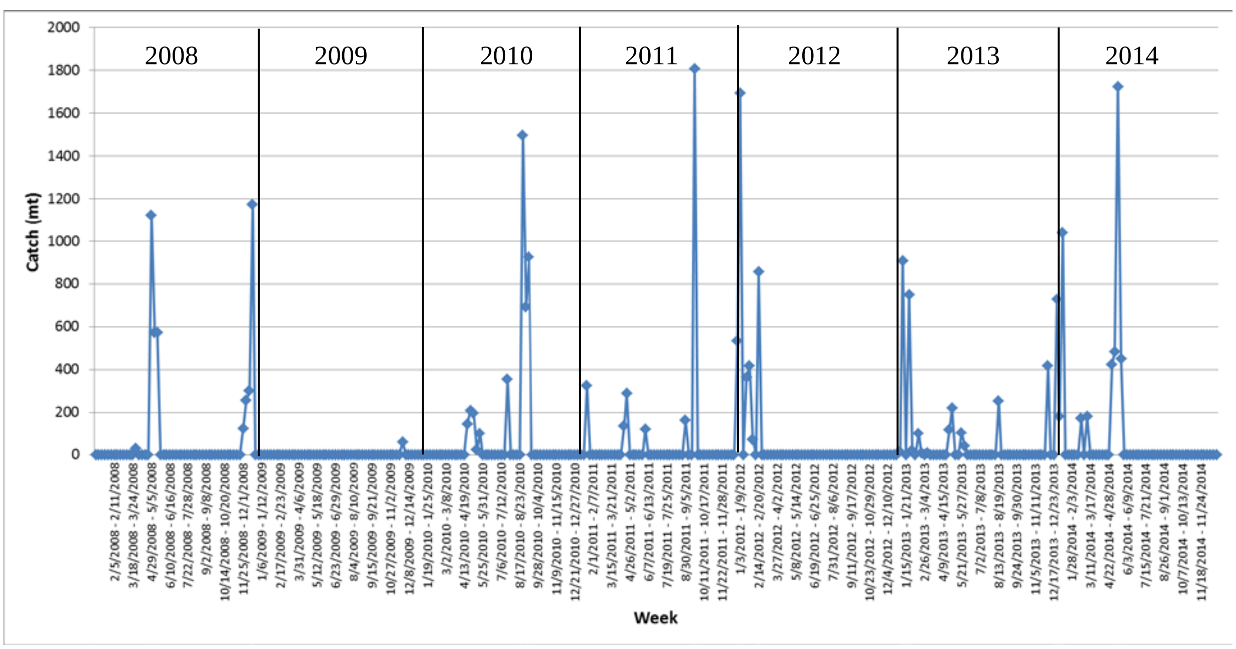
Back side of the Cape

Atlantic herring catch data from the area directly seaward of Cape Cod (Figure 25) was examined to observe the spatial-temporal distribution of effort within about 12 nautical miles of Cape Cod, to provide background to the Council for Amendment 8. For this area, Atlantic herring catches generally occur early in spring or very late in the fall to early winter. Overall, catches are episodic (Figure 11), and rarely occur more than two weeks in a row. Given that most of the catches occur during the spring and fall herring migration, it is likely that the fishery exploits herring while they are in the vicinity, but that schools of herring move too quickly through the area for sustained catches to occur; unlike the summer-time catch in the Gulf of Maine when the herring are more resident.

Figure 25 - Map showing area of inquiry (red line) to the east of Cape Cod, Massachusetts

Source: Google earth (2016).

Figure 26 – Atlantic herring catch by week for vessels catching >6,600 lbs of Atlantic herring from the area within 12 nautical miles of Cape Cod, 2008-2014



Striped bass

Information about the striped bass fishery is limited. For the recreational fishery, which occurs within the state waters of Maine, New Hampshire, and Massachusetts, the only data are collected through the Marine Recreational Information Program (MRIP). However, MRIP includes no spatial data for catch. There is no commercial fishery for striped bass in Maine, New Hampshire, Rhode Island, and Connecticut. The Massachusetts commercial fishery occurs within state waters in the summer.

The Massachusetts Division of Marine Fisheries manages the fishery using 14 statistical areas within state waters. Figure 27 and Figure 28 map the landings and CPUE (pounds per fishing hours) within each area from 2010 to 2014. Area 9, to the east of Cape Cod, has had relatively high landings throughout the time series, and areas to the east and south of Cape Cod have had relatively high CPUE. Figure 29 tracks the landings and CPUE over time each year, showing that most of the landings have occurred between mid-July and mid-August. Decreased CPUE over the length of the season could be an indicator of decreased striped bass availability, but the landings data do not show consistent increases or decreases in CPUE across seasons.

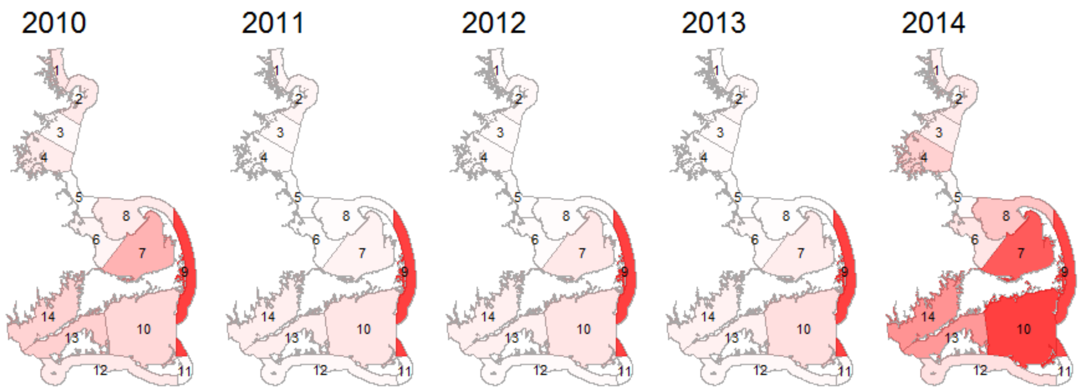
Striped bass are typically present in Massachusetts waters between May and October, yet the commercial fishery (the only source of spatial fishery-dependent data) occurs over a much narrower timeframe (Kneebone, Hoffman, Dean, Fox, et al. 2014). Prior to 2014, the commercial striped bass fishery began each year on July 11 and closed when the quota was exhausted, which was typically in 5-7 weeks. In 2013, the fishery closed after 5 weeks, and then reopened for an additional two weeks in late August, after it became evident that there was quota remaining. In 2014, regulations changed the fishery start date to June 23rd, and a reduced trip limit led to a more protracted season (11 weeks).

Neither recreational nor commercial striped bass fishing is allowed outside of state waters, per federal law. However, striped bass are abundant in federal waters and frequently cross this state/federal jurisdictional boundary (Kneebone, Hoffman, Dean & Armstrong 2014). Coastwide, the recreational fishery accounts for 60-70% of total removals in recent years. In Massachusetts, the recreational/commercial ratio is approximately 85%/15%.

As part of an effort to estimate the predation mortality of striped bass on Atlantic menhaden, all available data sources for diet composition of striped bass were assembled and summarized (SEDAR 2015). A total of 28 data sources were identified that included over 40,000 individual stomachs examined. On a coastwide and annual basis, herring species comprise <10% of striped bass diets. At specific times and regions (e.g., Gulf of Maine in summer/fall), Atlantic herring may comprise up to 30% of the diet.

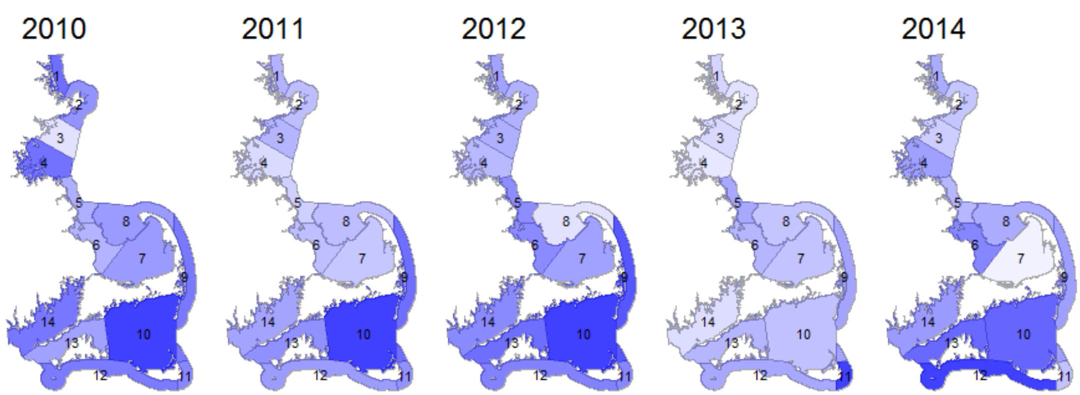
While there are no specific rules that explicitly prevent midwater trawling for herring in Massachusetts state waters, there are regulations that effectively prohibit this activity: 1) There is no exemption from the 6" minimum mesh size for herring fishing (as there is for the whiting and squid fisheries); and 2) A "coastal access permit" is required to fish with mobile gear in MA state waters, which has a maximum vessel length of 72 feet. There are very few coastal access permits (CAP), and there has been a moratorium on issuing new CAP permits since 1995.

Figure 27 - Spatial pattern in landings (pounds) for Massachusetts striped bass commercial fishery, 2010-2014



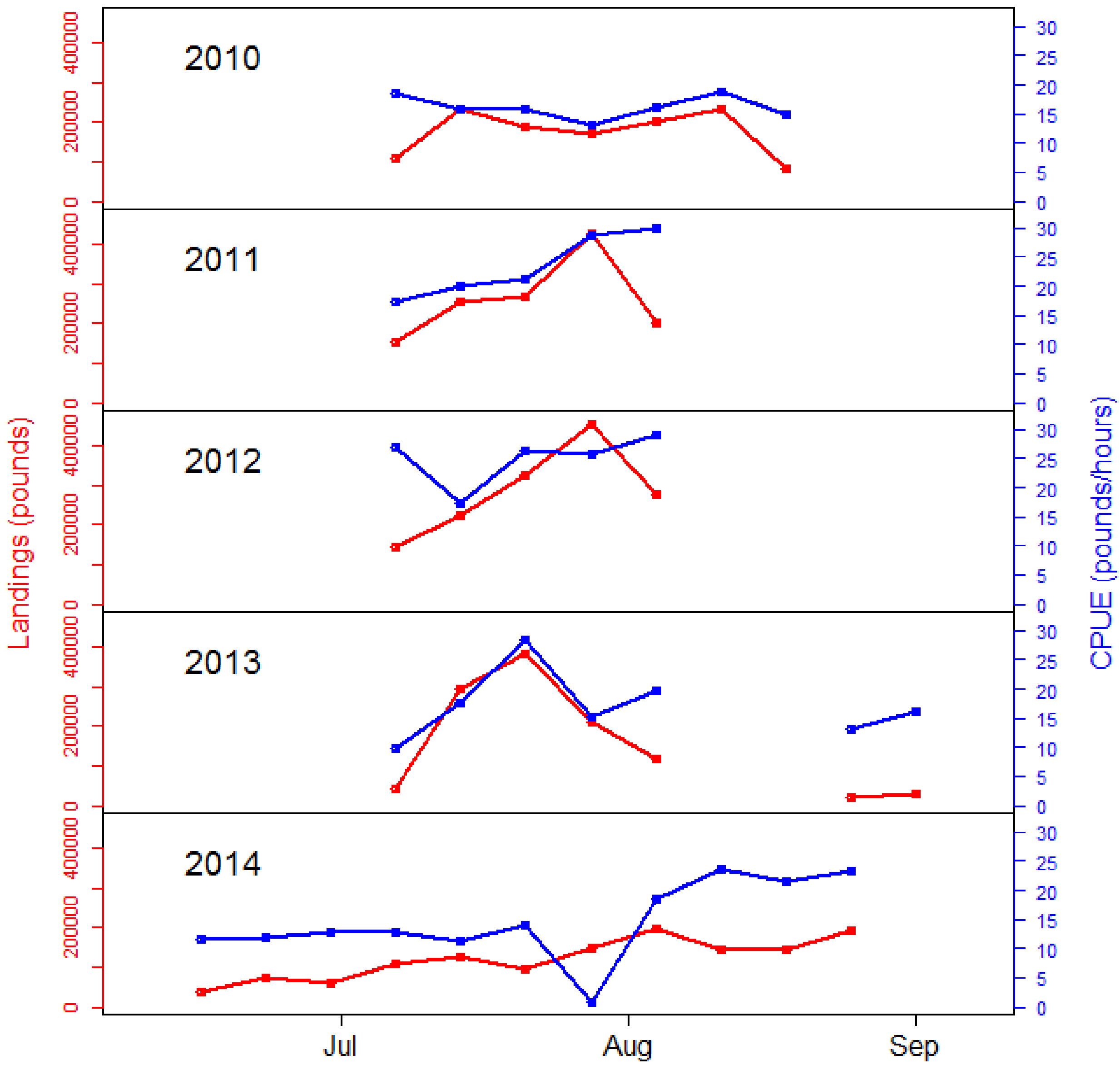
Source: MADMF (2016).

Figure 28 - Spatial pattern in CPUE (pounds / fishing-hours) for Massachusetts striped bass commercial fishery, 2010-2014



Source: MADMF (2016).

Figure 29 - Seasonal profile of Massachusetts commercial striped bass fishery, 2010-2014



Source: MADMF (2016).

Bluefin Tuna

Unless specifically stated in an exempted fishing permit, commercial bluefin tuna fisheries in the Gulf of Maine begin June 1st. There are three main gear types in the Gulf of Maine: general (rod and reel), harpoon, and purse seine. Bluefin tuna fishermen work off an annual TAC which is divided up amongst the categories. The general category receives the largest allocation and has within season allocations (e.g., X% of quota can be caught between June 1 and August 31). If the catch limit is reached before August 31, the fishery will close and reopen again in September. September has its own quota as does October, and then there is a winter allocation. The fishery has not closed due to reaching any of these within season quotas since the 1990s. Historically, the bluefin season runs from June through October, even into November and, in recent years, December. The length of the season is dependent on the catch rate in any particular year.

The bluefin tuna fishery is located throughout the entire Gulf of Maine. Historically, large catches of bluefin have been landed in the Kettle, Cape Cod Bay, Stellwagen Bank, Jeffreys Ledge, Great South Channel, Ipswich Bay, Platts Bank, Cashes Ledge, Georges Bank, Wilkinson's Basin, and the Schoodic Ridges. This is not a comprehensive list, rather a highlight of some of the areas which have yielded large landings.

The Highly Migratory Species Division has informed the PDT that high resolution spatial data for bluefin tuna catches is limited. There is some spatial data for the recreational fishery as collected by the Large Pelagic Survey. The commercial catch location is recorded in the bluefin dealer data and trip reports, but the bluefin tuna reporting areas are broader in scope and differ from GARFO Statistical areas. There is some level of overlap with vessels holding both bluefin tuna and GARFO permits thereby triggering the VTR requirement, but that overlap and consistency in reporting bluefin in the VTRs has yet to be assessed.

Dr. Walt Golet (GMRI/UMO) has not examined localized depletion questions specifically, but has done a lot of research on bluefin migration and diet, and has identified correlations between Atlantic herring and bluefin tuna schools (Golet et al. 2013). Golet has been given access by tuna fishermen and dealers to their logbooks, which has spatial catch data at a finer resolution than what is submitted to NMFS. However, these data are proprietary and not available to the PDT. The fishermen have told him that there has been some confusion over time whether they were supposed to report to NMFS the area that they fished or the area of their homeport (it's supposed to be the former). He indicated that an investigation of localized depletion would be possible, but would need to draw on many areas of expertise and involve using acoustics, vessels, and the logbook data, be a long-term project, and involve a diverse array of investigators to ensure that causality is appropriately attributed (e.g. tuna fishermen are constrained by weather windows). The biggest concern is study design; this would have to be carefully thought out and by a diverse team. Such an open process is critical for the transparency of results, the most efficient use of any funds which may be available to support this work, and for proper study design (e.g. to ensure causality is correctly identified).

Through current and prior work, Golet and colleagues have identified linkages between bluefin tuna and herring (Golet, et al. 2013; Golet, et al. 2015). Aggregations of bluefin and herring are associated with each other, though not all herring aggregations have bluefin present (Schick et al. 2004; Schick & Lutcavage 2009). Bluefin rely on herring for a substantial portion of their diet and come to the Gulf of Maine specifically to feed on herring as a lipid source (Golet, et al. 2013; Logan et al. 2015). Bluefin has declined in mean weight and lipid reserves over time, and these changes appear connected to declines in herring weight and size-at-age, despite high herring abundance (Golet, et al. 2015; Logan, et al. 2015). Golet et al (2013) have correlated herring and tuna schools, but a more thorough analysis could be completed. To date, the data have not been examined on sufficiently fine spatial and temporal scales to determine the specifics of co-location.

Whale-watching

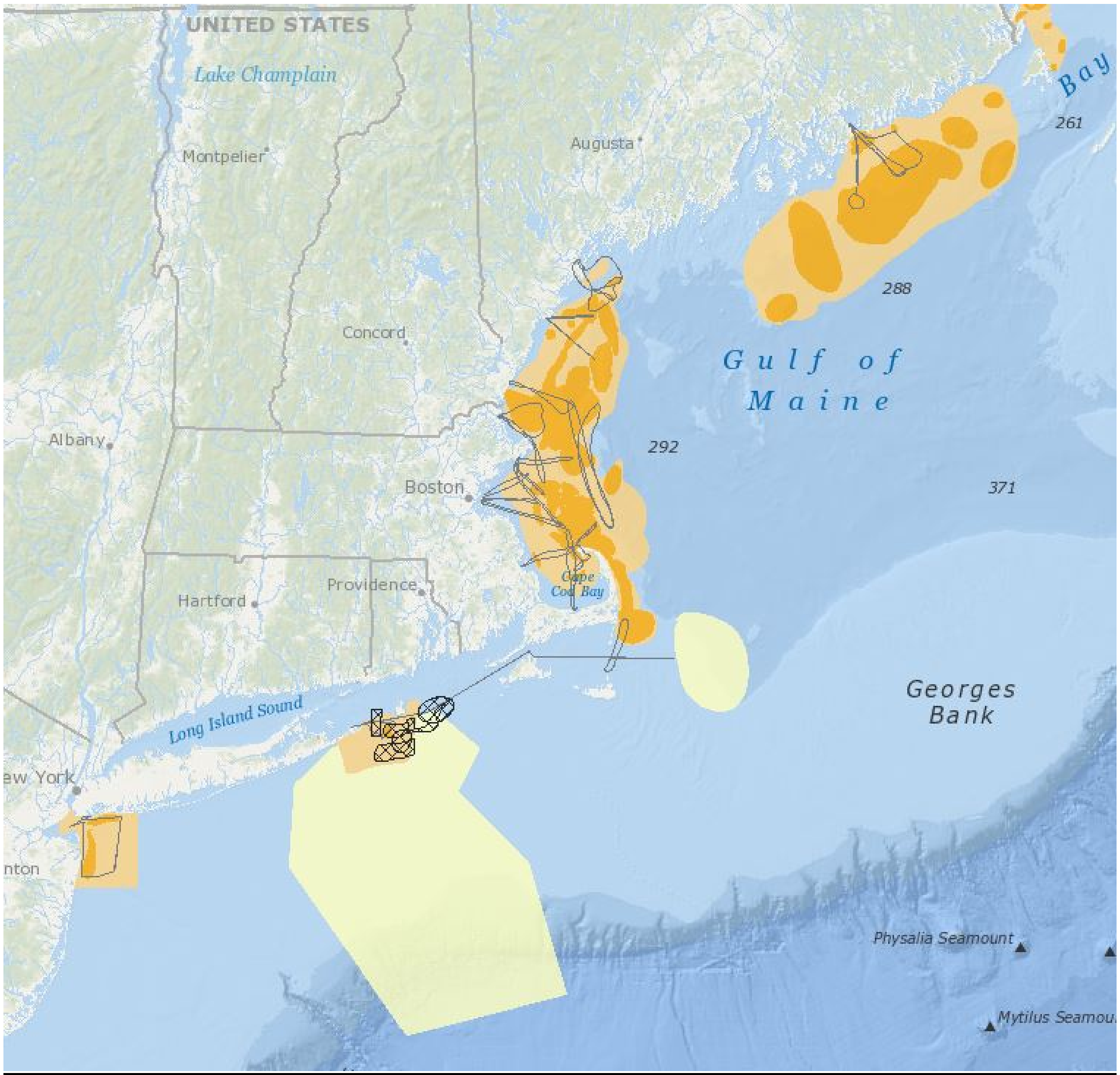
The GARFO Protected Species office has informed the PDT that whale watch companies do not report to NMFS where they go and what protected species they see. Many, if not all, whale watch vessels carry naturalists on board to collect data. The naturalists are from research or conservation organizations. The PDT contacted Mr. Zach Klyver, a current Herring Advisory Panel member and employee of Bar Harbor Whale Watch Company. This company has been collecting data (e.g., number of humpbacks and finbacks, location and date) since the 1990s, but in 2003, started carrying scientists from Allied Whale on every trip. Their data is digitized, and he has offered to help obtain the data. The Blue Ocean Society, The Whale and Dolphin Conservation, Provincetown Center for Coastal Studies, and College of the Atlantic also provide scientists for trips by other companies that do excursions to Jeffries Ledge, Stellwagen Bank, and other areas. Due to time limitations, the PDT was unable to pursue these potential data sources further.

Key whale species of interest to the whale watching industry are humpback, finback, and minke whales. Humpback whales are known to feed on herring, particularly in the Gulf of Maine. Humpbacks feed during the spring, summer and fall in the western North Atlantic (Waring et al. 2015). Their distribution in this region is largely correlated with prey species, though behavior and bathymetry are factors as well (Payne et al. 1986; Payne et al. 1990). Prey include herring, sand lance and other small fish (Waring, et al. 2015).

Figure 30 is a map showing commercial whale watching areas from the Northeast Ocean Data portal. As described on the portal, the map:

> *"depicts activity areas mapped by whale watch industry experts in the Northeast Coastal and Marine Recreational Use Characterization Study which was conducted by SeaPlan, the Surfrider Foundation, and Point 97 under the direction of the Northeast Regional Planning Body. Whale watch owners, operators, naturalists, and data managers attended participatory mapping workshops to map areas where whale watching takes place in the region, while also providing information about seasonality, species, and overall industry trends."*

Figure 30- Map showing commercial whale watching areas



Source: Northeast Ocean Data Explorer, http://www.northeastoceandata.org/data-explorer/

Notes quoted from the Data Explorer:

"The data are classified by the following categories:

- **"General use areas** [light orange] reflect the full footprint of whale watch activity in the last 3 – 5 years (2010 – 2014) regardless of frequency or intensity
- **"Dominant use areas** [dark orange] include all areas routinely used by most users most of the time, according to seasonal patterns.
- **"Transit routes** [lines] include areas used for transit to and from general or dominant use areas
- **"Supplemental areas** [yellow] depict areas used for closely-related activities and infrequent specialty trips.
- **"RI Ocean Special Area Management Plan areas** [hatched] were mapped as part of the Rhode Island Ocean Special Area Management plan and are symbolized separately to reflect different data collection methodologies."

Relationships between catches of herring and predators

The PDT was asked to expand the PDT analysis presented to the Committee in January 2016, which examined whether there are correlations between catches of herring and predators. The PDT was asked to examine Area 1A in years prior to 2006 (i.e., Amendment 1 implementation) and examine the catch of predators in the second week after herring catches (across the full time range). Here, both the original information and more recent analysis are presented.

Methods

This analysis focused on the localized depletion scenario in which relatively mobile herring predators would leave a depleted area in search of alternative prey. Vessel Trip Reporting System (VTR) data were used to compare the catch of Atlantic cod, pollock, and spiny dogfish subsequent to herring catch. Catch per trip (CPT) of these three predators were calculated during the week of reported herring catch and compared with predator CPT for the first and second weeks following herring catches:

$$D_{y,s,p,w} = \frac{C}{T}_{y,s,p,w+1} - \frac{C}{T}_{y,s,p,w};$$

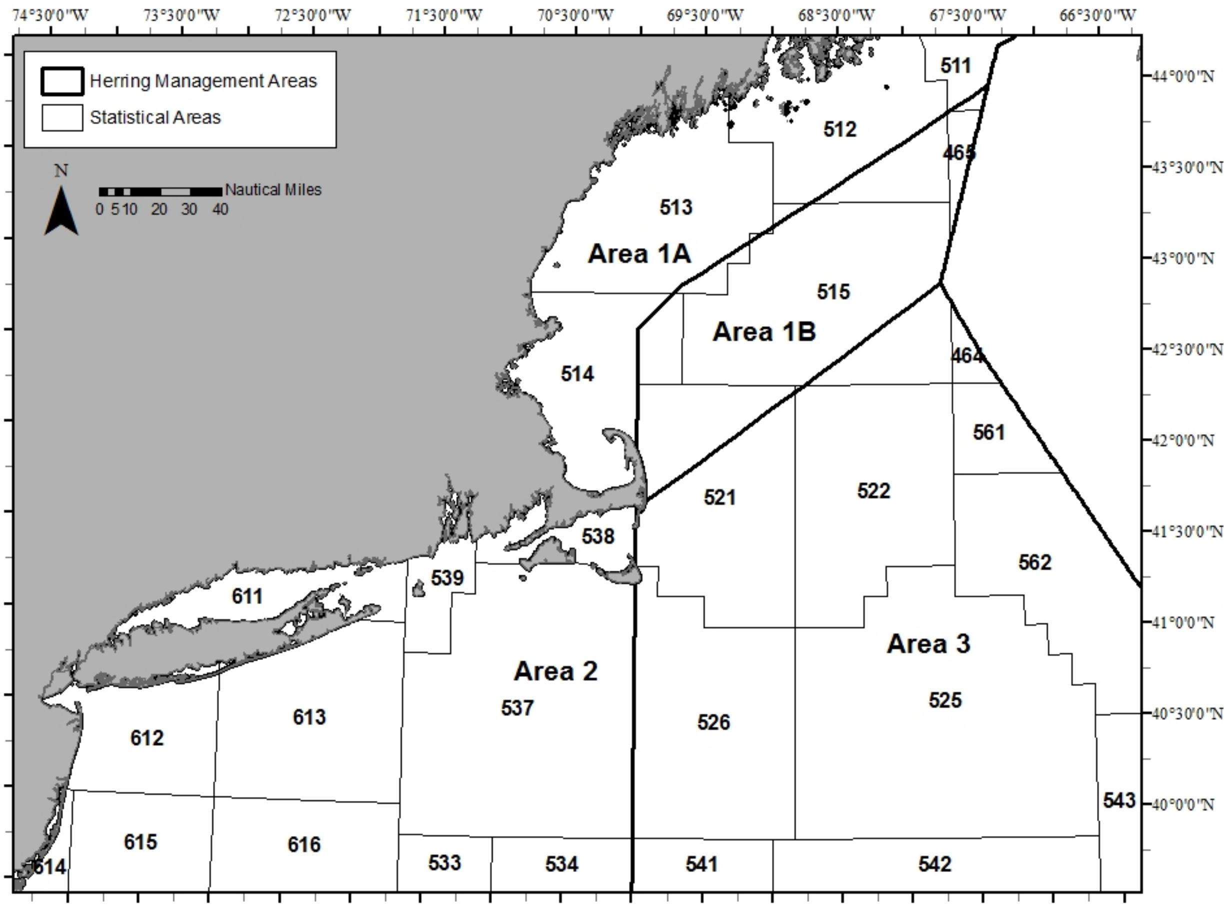
where C is the catch and T is the number of trips that caught any of the predators (p) in each year (y), statistical area (s), and week (w). x equaled either 1 or 2, depending on whether the analysis was conducted using a one week or two week lag. Figure 31 shows the herring management areas and statistical areas for reference. These three predators were included because they are of commercial interest and gut contents data from National Marine Fisheries Service bottom trawl surveys suggest that these species prey heavily on herring.

A linear regression then was conducted with $D_{y,s,p,w}$ as the dependent variable and the catch of herring (h), $C_{y,s,h,w}$, as the independent variable. A consistent negative relationship would support localized depletion, while any other relationship would provide no evidence for localized depletion.

Analyses were also restricted to the years 1997-2014 to capture a range of years before and after Amendment 1, and to keep the number of comparisons manageable, and because each of these years has an adequate number of observations for the chosen statistical areas.

The analysis described above was also repeated: 1) for only predator trawl gears with the number of trips in the CPT estimate replaced with the number of tows, 2) using predator CPT from only bottom otter trawls, 3) using predator CPT from only bottom otter trawls, 4) using predator CPT from only sink gillnets, and 5) using predator CPT from only longlines. These additional analyses were intended to serve as a test of whether the effects of herring catches on the predators may vary depending on the gear type used to catch the predators. For example, if harvesting herring serves to scatter predators over a broader area, then a mobile trawl gear may maintain CPT (or per tow) by towing longer over a broader area, whereas maintaining CPT with fixed gillnets and longlines would require the predators to reaggregate in a given location. The fixed gears might also increase soak times, but that is not accounted for here.

Figure 31 - Herring management areas and statistical areas



Results

Results among statistical areas were similar. Consequently, results from one statistical area from herring management areas 1A, 2, and 3 are provided (statistical areas 513, 521, and 537; Figure 32 to Figure 37). The gear-specific results were generally similar to those from using CPT from all predator gears combined, and so results for these sensitivities were not presented.

None of the regressions of were statistically significant except for statistical area 537 in 2012 and 2013 with a two week lag, (Figure 32 to Figure 37). The direction of the relationship between $D_{y,s,p,w}$ and $C_{y,s,h,w}$ was inconsistent (i.e., positive in some years and negative in others). These results provide no evidence of localized depletion for these predators at the scale of statistical area and one or two week time intervals.

Discussion

This analysis has several caveats. The spatial and temporal scale at which localized depletion operates has no specific definition and may depend on the predator. Here, localized depletion was examined on the scale of statistical area and week. So, if conditions within a statistical area were unchanged after one or two weeks, then no evidence of localized depletion would be found. This analysis also focused on three predators and combined them for analysis, but different predators may respond differently to the removal of herring. Conducting analysis by individual predator or groups of predators thought to react similarly to herring removals should likely be considered in the future. Likewise, varying the temporal and spatial scale of analysis by predator might also be considered, and other predators of interest could be examined. This analysis also used VTR data, which is self-reported and may contain errors (e.g., incorrect spatial assignments). Other data sources might be considered in the future. This method assumes that CPT is an index of predator abundance.

Data from all times of year were combined in this analysis, but perhaps analysis by season should be considered. Herring migrate during certain times of year, so localized depletion is unlikely to occur during these times because the herring will be in a different location in the near future regardless of catches. Analysis of a time of year when herring are likely to be confined in a single region might be more appropriate (summer feeding grounds or fall spawning). However, having included data from all times of year in this analysis would only increase the chances of finding a negative correlation, which may support the occurrence of localized depletion. Follow up analyses could include examining the data at finer time intervals than by year.

Figure 32 – Predator catches in sequential weeks, Statistical Area 513 (Area 1A)

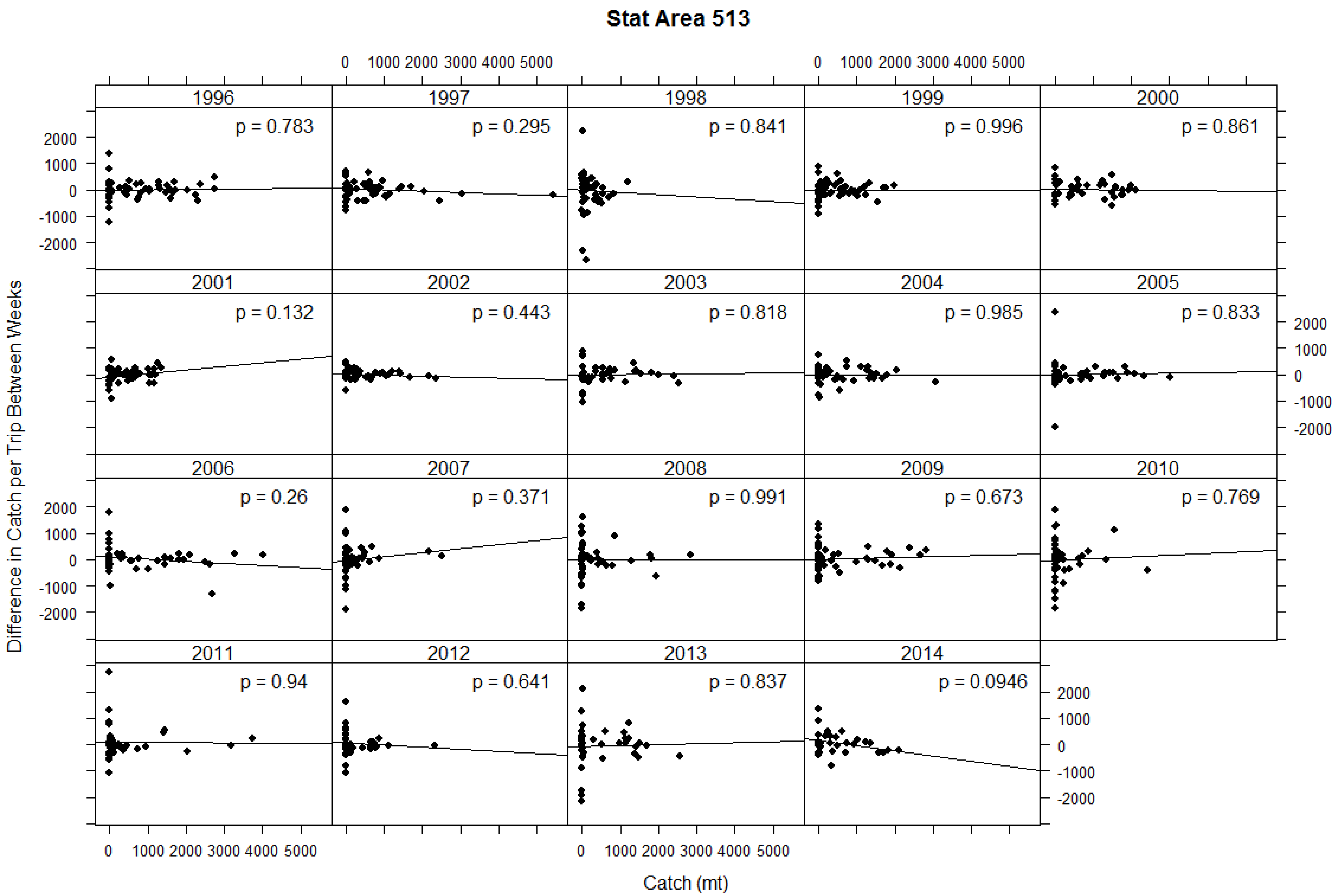


Figure 33 - Predator catches two weeks apart, Statistical Area 513 (Area 1A)

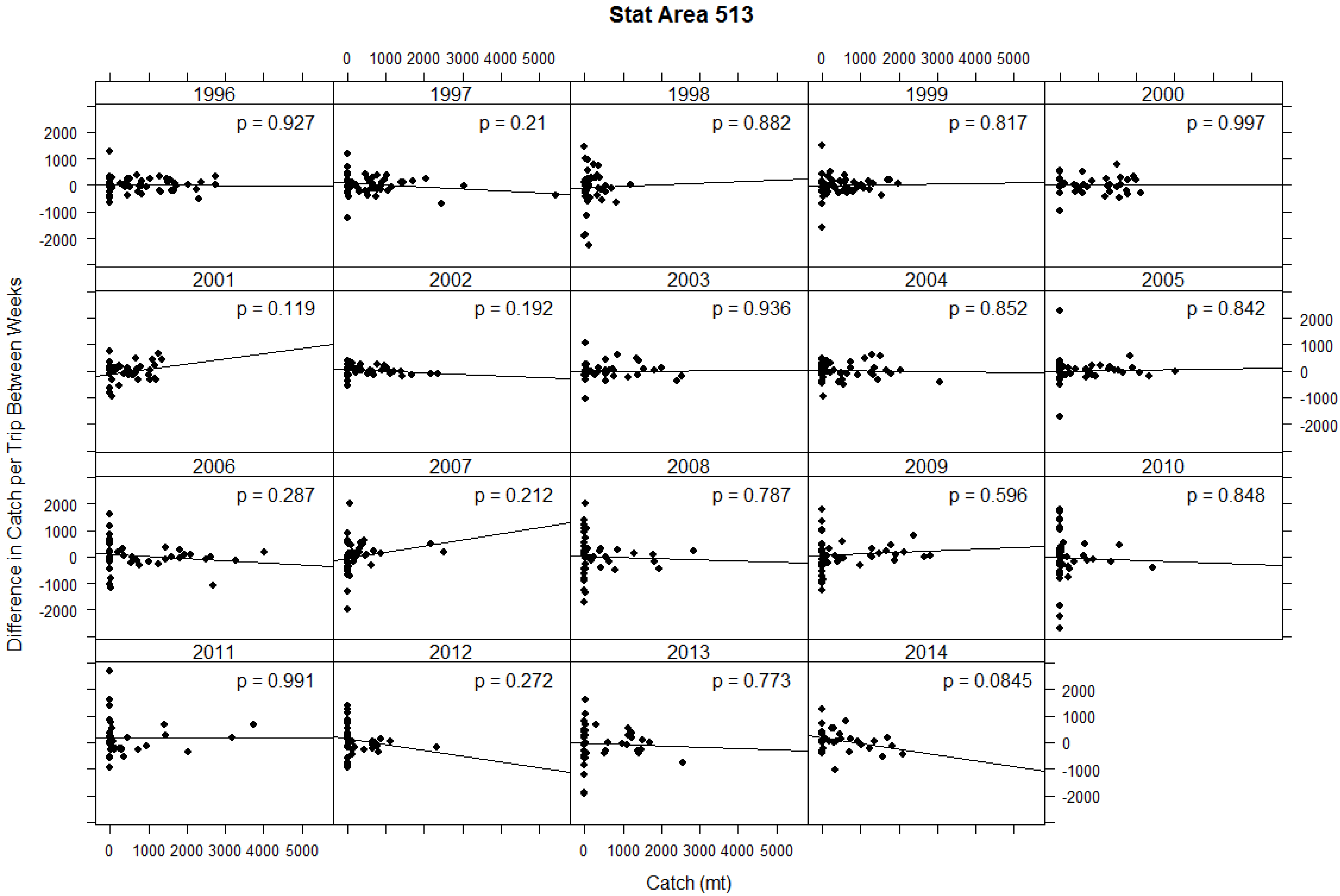


Figure 34 - Predator catches in sequential weeks, Statistical Area 521 (Area 3)

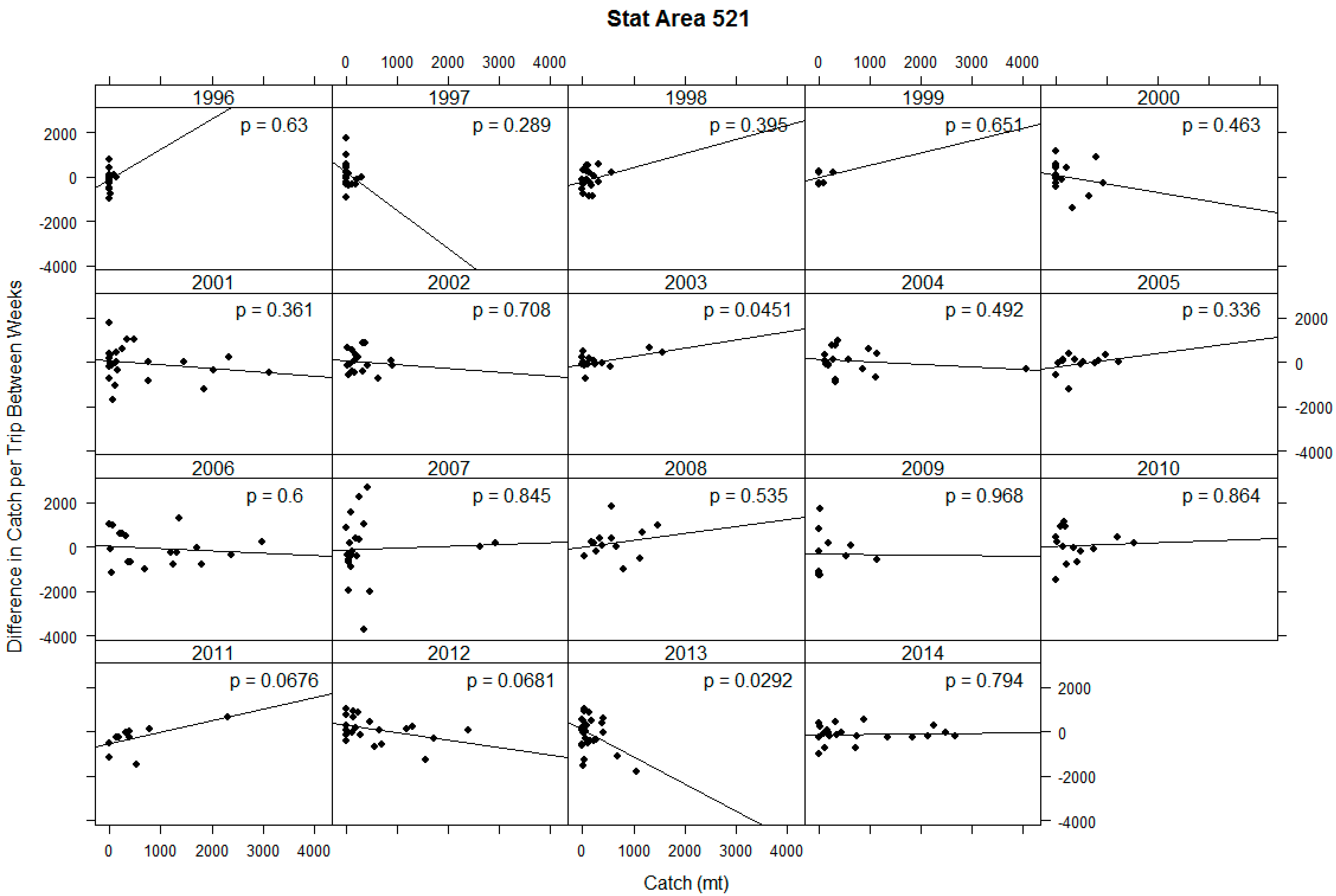


Figure 35 - Predator catches two weeks apart, Statistical Area 521 (Area 3)

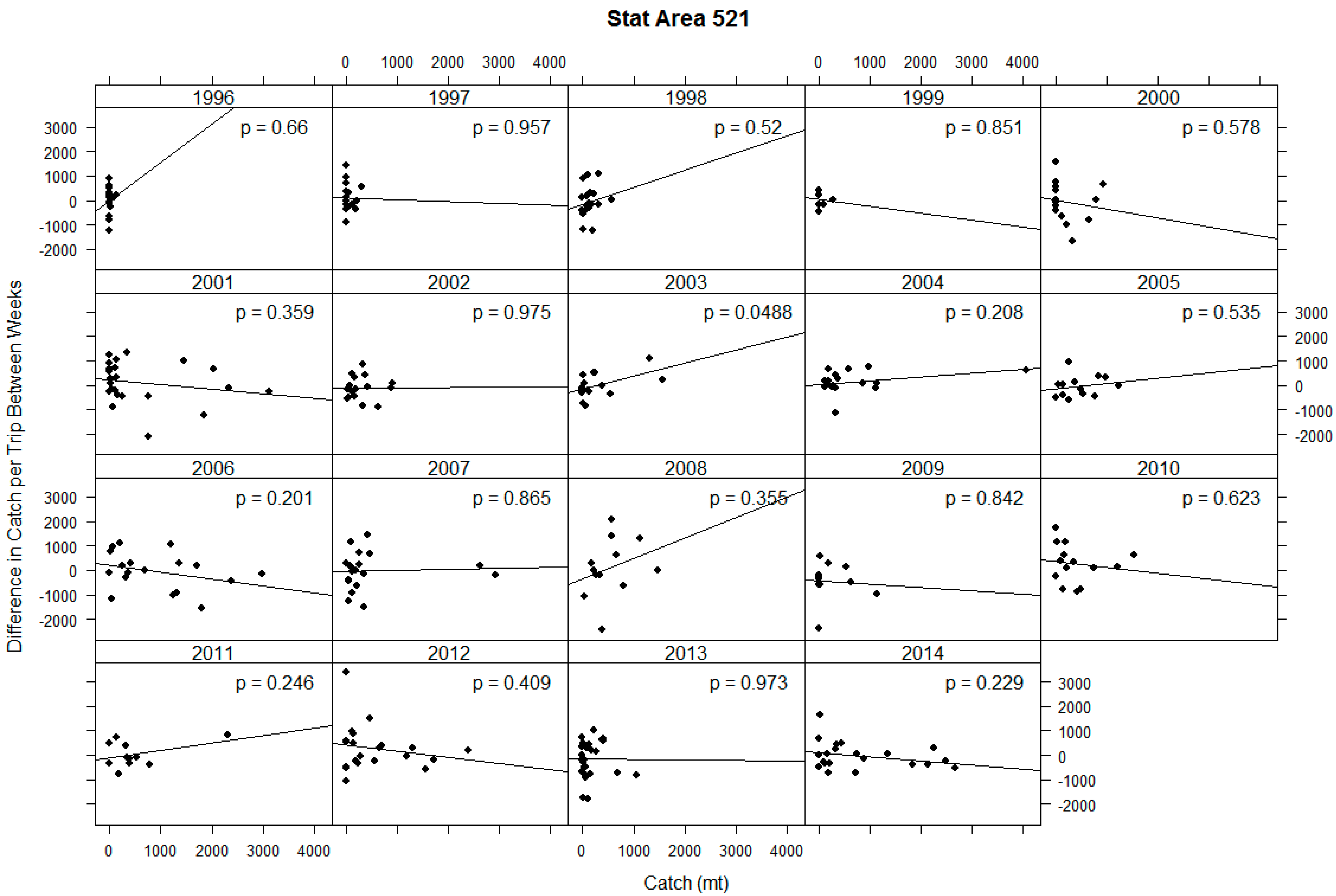


Figure 36 - Predator catches in sequential weeks, Statistical Area 537 (Area 2)

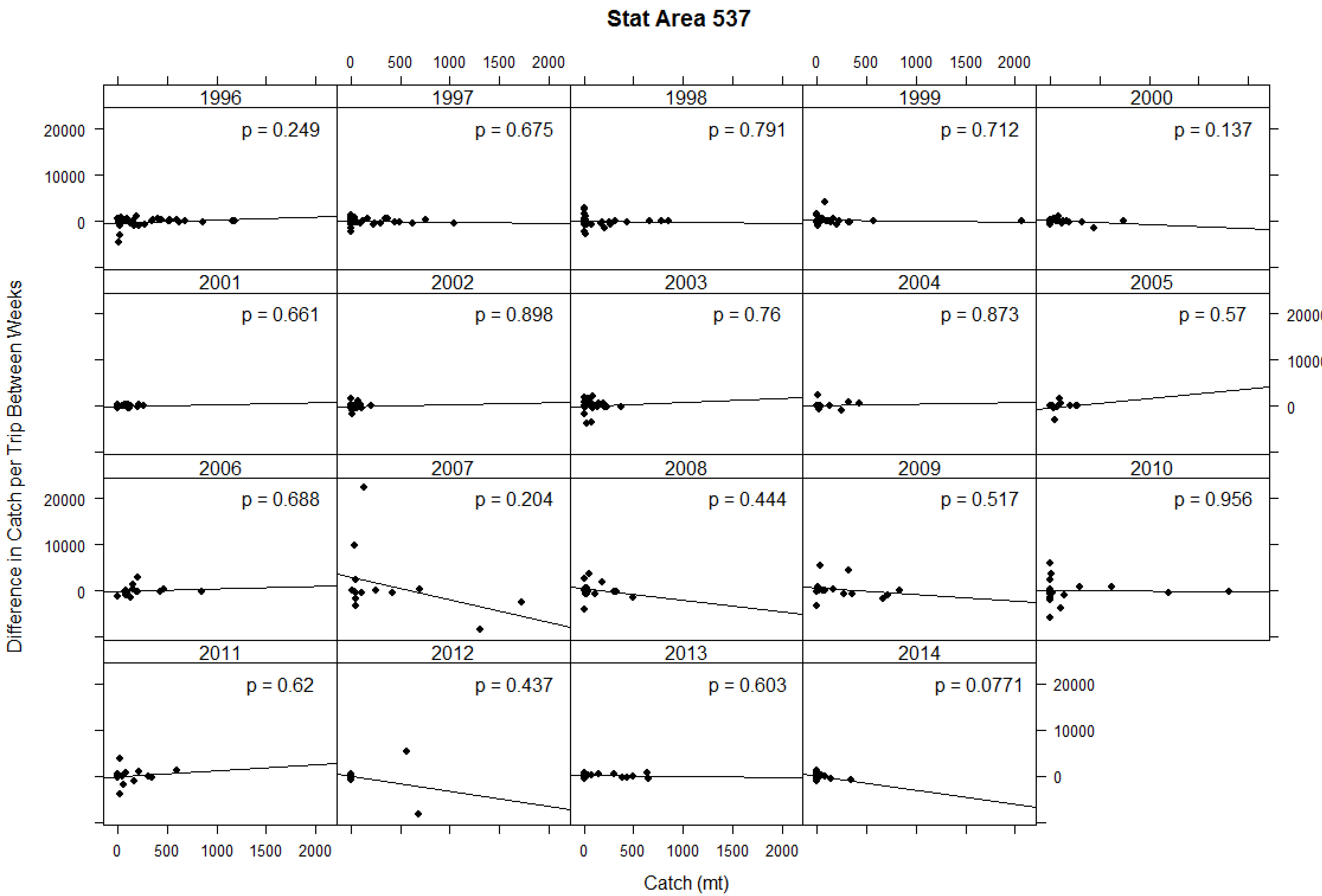
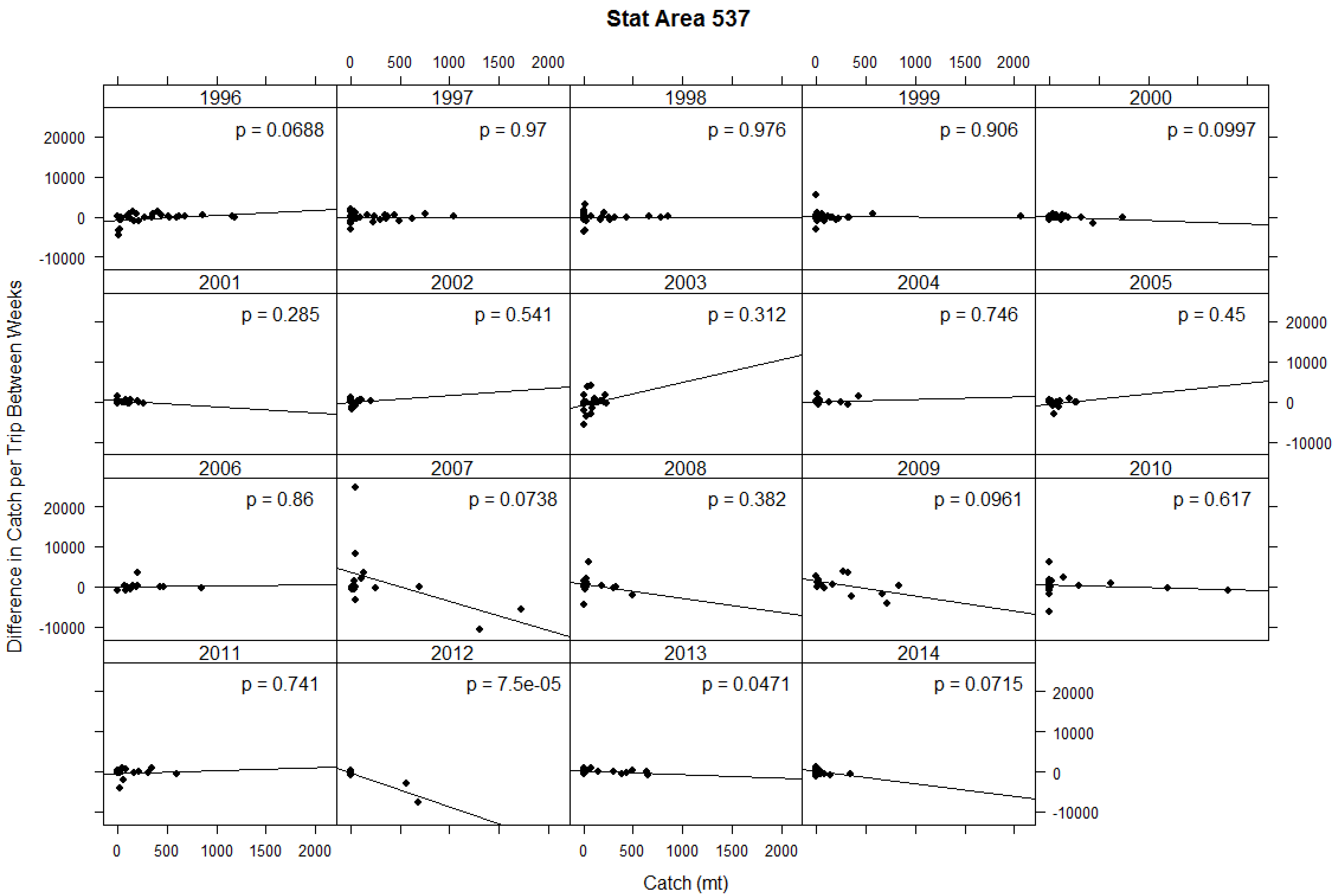


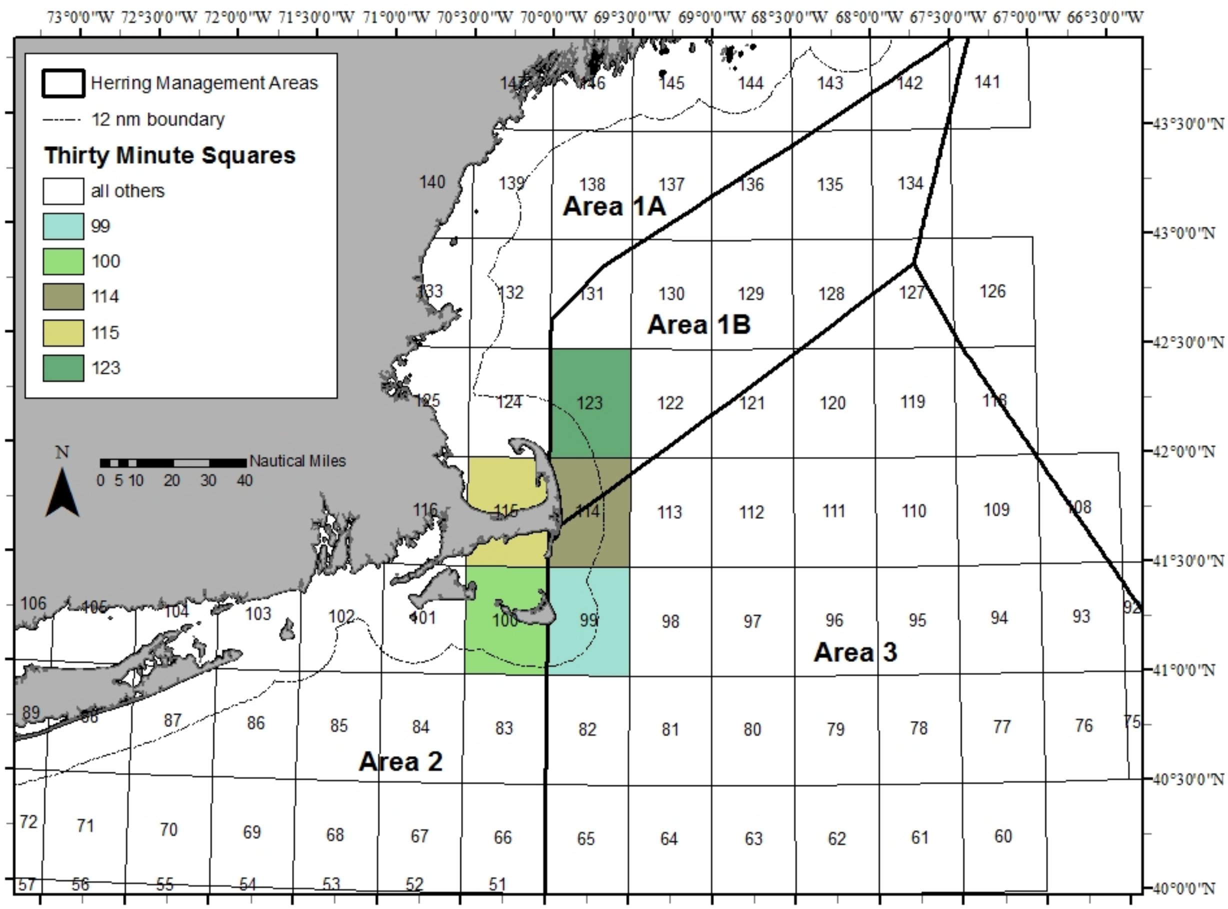
Figure 37 - Predator catches two weeks apart, Statistical Area 537 (Area 2)



Potential midwater trawl closures

The PDT was asked to examine potential impacts (biological, economic, social) to different fisheries (herring, tuna, striped bass, etc.) of closing the following 30-minute squares to midwater trawl gear year-round: 99, 100, 114, 115, and 123 (Figure 38), and to calculate the percent of the total Atlantic herring stock area that these 30-minute squares comprise.

Figure 38 - Herring management areas and 30 minutes squares



Each 30 minute square comprises <1% of the total Atlantic herring stock area. Within each herring management area, the squares of interest here (99, 100, 114, 115, and 123) comprise <2%, with the exception of Area 1B (Table 1, Table 2). These area calculations were done in ArcGIS using the UTM19N projection. Sliver portions of the squares were excluded where there were landmass intersections or artifacts from geoprocessing. The areas excluded were exceptionally small in relation to the overall areas and did not influence the percentages.

Table 1 - Percent area of Herring Management Areas of the 30-minute squares: 99, 100, 114, 115, and 123

Area	**30-Minute Square**				
	99	**100**	**114**	**115**	**123**
Herring Area 1A				3.2%	
Herring Area 1B			3.9%		10.6%
Herring Area 2		0.6%		0.2%	
Herring Area 3	1.7%		1.0%		
Source: GARFO GIS Database					

Table 2 - Percent Herring Stock Area of the 30-Minute Squares 99, 100, 114, 115, and 123

30-Minute Square	**Percent Herring Stock Area**
99	0.4%
100	0.4%
114	0.4%
115*	0.3%
123	0.4%
Source: GARFO GIS Database *115 is smaller because a large portion of the 30-minute square is overlaps Cape Cod, which was not included in the area calculation.	

No analysis was done to quantify landings from these 30 minute squares. The PDT feels that the model used to generate the "heat maps" presented earlier (starting p. 5) would be the most appropriate method to do so, and can be done.

The size of a square relative to a stock or management area has little relevance to a discussion of potential biological, economic, and social impacts of closing a particular square year round, since both fish and fishing effort are not evenly distributed throughout the stock area. The PDT is uncertain the degree to which an accurate assessment of future impacts can be made regarding area closures, as future changes in environmental conditions, and fish distribution, and fisheries would factor in.

For bluefin tuna, portions of the 30-minute squares in question have been important foraging grounds. However, much of the Bluefin fishery catches in recent years have been further north, and in some cases east, of these squares. If herring biomass increases in an area, bluefin could be attracted. However, the areas in question are known to be a migratory corridor for herring, so they only remain there for limited time periods. Foraging and spawning requirements move herring outside these areas.

Cod and herring in Ipswich Bay

The PDT was asked to examine predator/prey relationships between cod and herring in Ipswich Bay. The NMFS food habits database is sizeable, but only a small portion of the data is from Ipswich Bay. The sources for the data are the spring and fall bottom trawl surveys. Cod are known to be omnivorous, and around 10% of their diet is herring.

Analytical ideas from public scoping

The PDT was asked to examine ideas for analysis identified in the public scoping comments for Amendment 8. Using the thematic coding that the PDT previously conducted to summarize scoping comments (NEFMC 2015b), the topics listed below were identified. Some of the topics are explored or explained within this memo, some are the subject of current research, while others could be tasked to the PDT in the future.

- Stock assessment/modeling
  - Determine why there is a retrospective pattern in the stock assessment.
  - Revise modeling based on closer to real-time data (not 2-3 year lag).
- Formally explain and/or determine how much herring is used by predators.
  - Consider differences in age/size/nutritional value for different predators.
  - What other species also serve as prey to fish that eat herring? Is there a difference in their ability to fulfill prey role?
  - Role of herring in the ecosystem.
  - What is required to measure/account for scientific uncertainty?
- Look at the effects of inshore closures waters to herring fishing (Area 1A, Canada)
- Where is midwater trawling allowed world-wide; where is it banned? What has been the effect?
- Consider socio-economic impacts on businesses and communities of changes in herring regulations, considering economic value of other businesses that depend on herring (tuna, whale watch, recreational fishing).
- Devise tools to analyze localized depletion.
- Has abundance of herring declined inshore (e.g., off Nantucket)?
- Reconstruct the history of environmental factors such as ocean temperatures, salinity, shifts in oceanic and climatic regimes (here and elsewhere) to determine impacts on pelagic species.
- Better understand herring schooling behavior.
- Are the effects of herring seining different from midwater trawling? Why/How?

Summary and next steps

The PDT has focused here on characterizing the spatial and temporal footprint of the herring fishery and predator fisheries and businesses as time and data have allowed. Additional work could occur on finer scale resolutions and other fisheries or gear types not reported here (e.g., small mesh bottom trawl). Several overlaps were identified. Even if correlations are found between herring removals and a signal in a predator fishery or business (i.e., whale watching) that may suggest that localized depletion is occurring, the PDT expects it will be difficult to identify a causal link, using just the data available. It is not a trivial undertaking.

The PDT has not yet examined the Study Fleet data relative to the current tasking, but the data may be useful for estimating catch rates on a given trip, though only a subset of the fishery participates in Study Fleet. It would need to be determined how many herring trips that have participated in Study Fleet have occurred within the area of interest (e.g., 12 nm). Within 12 miles, there is very little trawl fishing for herring, except on the back side of the Cape, around Block Island, and in Area 1A (fall only). Herring fishing on the back side of the Cape is primarily done in the spring and fall and is episodic. The fishery around Block Island is primarily prosecuted in the winter, and is unlikely to have much interaction with other fisheries (e.g., tunas are only present from about May-September, primarily in the Gulf of Maine and Georges Bank).

References

DePiper GS. (2014). *Statistically Assessing the Precision of Self-reported VTR Fishing Locations*. Woods Hole (MA): U.S. Department of Commerce. NOAA Technical Memorandum NMFS-NE-229. 22 p.

Deroba J. (2015). *Atlantic Herring Operational Assessment Report*. Woods Hole, MA: U.S. Department of Commerce. NEFSC Reference Document 15-16. 30 p.

Diamond AW & Devlin CM. (2003). Seabirds as indicators of changes in marine ecosystems: Ecological monitoring on Machias Seal Island. *E#nvironmental Monitoring and Assessment. 88*: 153-175.

Golet WJ, Galuardi B, Cooper AB & Lutcavage ME. (2013). Changes in the distribution of Atlantic bluefin tuna (Thunnus thynnus) in the Gulf of Maine 1979-2005. *PLoS ONE. 8*(9): e75480.

Golet WJ, Record NR, Lehuta S, Lutcavage ME, Galuardi B, Cooper AB & Pershing AJ. (2015). The paradox of the pelagics: why bluefin tuna can go hungry in a sea of plenty. *Marine Ecology Progress Series. 527*: 181-192.

Kneebone J, Hoffman W, Dean M & Armstrong M. (2014). Movements of striped bass between the Exclusive Economic Zone and Massachusetts state waters. *North American Journal of Fisheries Management. 34*: 524-534.

Kneebone J, Hoffman WS, Dean M, Fox D & Armstrong M. (2014). Movement patterns and stock composition of adult striped bass tagged in Massachusetts coastal waters. *Transactions of the American Fisheries Society. 143*: 115-1129.

Logan JM, Golet WJ & Lutcavage ME. (2015). Diet and condition of Atlantic bluefin tuna (Thunnus thynnus) in the Gulf of Maine, 2004-2008. *Environmental Biology of Fisheries. 98*: 1411-1430.

NEFMC. (2006). *Final Amendment 1 to the Atlantic Herring Fishery Management Plan incorporating the Environmental Impact Statement Volume I and II*. Newburyport, MA: M New England Fishery Management Council in consultation with the ASMFC, and NMFS.

NEFMC. (2015a). *Scientific Advice on Herring Control Rules that Account for Forage Requirements and the Role of Atlantic Herring in the Ecosystem, provided by the Ecosystem-Based Plan Development Team*. Newburyport (MA): New England Fishery Management Council. 58 p.

NEFMC. (2015b). *Summary of Public Scoping Comments for Amendment 8 to the Atlantic Herring Fishery Management Plan*. Newburyport (MA): New England Fishery Management Council. 20 p.

Payne PM, Nicholas JR, O'Brien L & Powers KD. (1986). The distribution of the humpback whale, *Megaptera novaeangliae*, on Georges Bank and in the Gulf of Maine in relation to densities of the sand eel, *Ammodytes americanus*. *Fishery Bulletin. 84*: 271-277.

Payne PM, Wiley DN, Young SB, Pittman S, Clapham PJ & Jossi JW. (1990). Recent fluctuations in the abundance of baleen whales in the southern Gulf of Maine in relation to changes in selected prey. *Fishery Bulletin. 88*: 687-696.

Schick RS, Goldstein J & Lutcavage ME. (2004). Bluefin tuna (Thunnus thynnus) distribution in relation to sea surface temperature fronts in the Gulf of Maine. *Fisheries Oceanography. 13*: 225-238.

Schick RS & Lutcavage ME. (2009). Inclusion of prey data improves prediction of bluefin tuna (Thunnus thynnus) distribution. *Fisheries Oceanography. 18*(1): 77-81.

SEDAR. (2015). *SEDAR 50 - Atlantic Menhaden Stock Assessment Report*. Charlston (SC): U.S. Department of Commerce. SouthEast Data, Assessment, and Review. 643 p.

Waring G, Josephson E, Maze-Foley K & Rosel P. (2015). *U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments -- 2014*. Woods Hole (MA): U.S. Department of Commerce. NOAA Technical Memorandum NMFS-NE-231. 361 p.