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OMNIBUS ESSENTIAL FISH HABITAT AMENDMENT 2 FINAL ENVIRONMENTAL IMPACT STATEMENT

Appendix H: Prey vulnerability to fishing impacts and maps of major prey types

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2.0 Introduction

The Magnuson Stevens Fishery Conservation and Management Act (MSA) has included provisions requiring fishery management plans (FMPs) to minimize the adverse effects of fishing on Essential Fish Habitat (EFH) since the 1996 reauthorization. As compared to previous plan-by-plan approaches to evaluating and minimizing adverse effects, which were somewhat ad hoc, major goal of the New England Fishery Management Council (NEFMC)'s EFH Omnibus Amendment 2 is to optimize the minimization of adverse effects on EFH across FMPs.

To this end, the NEFMC Habitat Plan Development Team (PDT) developed the Swept Area Seabed Impact (SASI) approach between fall 2007 and spring 2010. Specifically, the SASI approach was developed to estimate the magnitude, location, and duration of adverse effects across gears types and FMPs, and to evaluate the cumulative impacts of alternatives to minimize those effects. Because all fishing effort is converted into area swept units, regardless of whether trawl, dredge, or fixed gears are being evaluated, SASI allows for comparisons between gear types in terms of the magnitude of adverse effects they generate.

SASI was reviewed by the NEFMC Scientific and Statistical Committee (SSC) and also by an independent review panel, and both groups have acknowledged its utility as a decisionmaking tool. However, these groups, as well as the Habitat PDT and Habitat Committee, have acknowledged limitations of the data sets used in the current interation of SASI analyses and that there are other sources of information that may help the Committee and the Council during development of management alternatives.

Ideally, the SASI model would spatially resolve fishing effects across all components of habitat. In particular, the prey of managed fish species is an important component of fish habitat that is potentially affected by fishing gears. While the PDT recognized the importance of incorporating prey vulnerability into the assessment of the adverse effects of fishing on EFH, including prey as another habitat component in SASI would have further decoupled the model results from local spatial empirics because prey features, like biological habitat features, would need to be inferred to substrate/energy regimes. When the spatial distributions of all feature classes (geological, biological, and prey) are better known, it may be appropriate to include prey in the vulnerability assessment and make SASI regionally specific, thereby reducing errors in vulnerability estimates at the local level. As an interim step, this document describes prey species found in the region, and their vulnerability to fishing gear impacts.

3.0 Important benthic prey types

Prey features were identified using data provided by the Northeast Fisheries Science Center food web dynamics program.[1] To identify significant prey items for each managed species, the average percentage by weight of each prey item was estimated from the stomach contents data for the years 1973-2005. Table 1 shows the relative importance, by weight, of various prey types to various fish species. Important benthic invertebrate prey features for regional managed species include the following groups: amphipods, decapod shrimp and crabs, echinoderms, polychaetes, and infaunal bivalve mollusks. Many managed species of fish also feed on benthic and pelagic fish and pelagic invertebrates such as krill and squid.

Table 1 – Contribution in average percentage total weight of prey items to the diets of managed species

Managed species	*Amphipods*	*Decapod crabs*	*Decapod shrimp*	*Bivalves*	*Polychaetes*	*Echinoderms*	*Total benthic inverts*	*Fish*	*Total Benthic*	*Total pelagic*	*Total*
Acadian redfish	1	0	45	0	0	0	46	0	46	38	84
American plaice	0	0	3	3	4	70	80	0	80	1	81
Atlantic cod	0	14	5	7	1	1	28	6	34	25	59
Atlantic halibut	0	15	8	0	0	0	23	40	63	21	84
Atlantic herring	14	0	13	0	0	0	27	0	27	20	47
Barndoor skate	0	41	12	0	0	0	53	13	66	16	82
Clearnose skate	0	33	2	1	1	0	37	20	57	16	73
Haddock	13	2	3	2	9	23	52	1	53	4	57
Little skate	19	24	10	8	12	0	73	1	74	2	76
Monkfish	0	0	0	0	0	0	0	19	19	30	49
Ocean pout	4	12	0	8	3	67	94	0	94	0	94
Offshore hake	0	2	3	0	0	0	5	0	5	71	76
Pollock	1	0	21	0	0	0	22	9	31	47	78
Red hake	4	7	24	1	2	0	38	2	40	23	63
Rosette skate	7	25	17	0	14	0	63	3	66	4	70
Silver hake	1	0	15	0	0	0	16	5	21	50	71
Smooth skate	1	7	45	0	1	0	54	2	56	19	75

[1] The dataset contains gut content information for various fish species collected during the NEFSC trawl surveys. Sampling protocols, summarized in Link and Almeida 2000, have changed slightly over time, and stomach contents of some managed species have been better sampled. Despite these limitations, the data set is believed to be more than adequate for identifying broadly important prey types across the range of species managed by the NEFMC.

Managed species	Amphipods	Decapod crabs	Decapod shrimp	Bivalves	Polychaetes	Echinoderms	Total benthic inverts	Fish	Total Benthic	Total pelagic	Total
Thorny skate	1	7	8	0	24	0	40	11	51	16	67
White hake	0	0	8	0	0	0	8	3	11	44	55
Windowpane flounder	15	14	27	0	0	0	56	12	68	6	74
Winter flounder	8	0	0	3	40	0	51	0	51	0	51
Winter skate	8	6	3	15	12	0	44	20	64	7	71
Witch flounder	2	0	0	1	71	0	74	0	74	1	75
Yellowtail flounder	25	1	0	3	38	0	69	0	69	0	69

Information is for juveniles and adults – based on stomach contents, with totals for all benthic invertebrates, all benthic prey, all pelagic prey, and all prey. Unidentified prey items, and prey items that made up less than 1% of the diet of any individual fish species, were included when calculating percentages, but are not shown in the table. Prey features that were evaluated for susceptibility and recovery are shaded. Benthic plus pelagic totals do not add up to 100 because of 'other' category in food habits database. Prey information for Atlantic sea scallop, Atlantic wolffish, deep-sea red crab, and Atlantic salmon are not shown.

3.1 Amphipods

Amphipods, an order of crustaceans, make up greater than 10% by weight of the diets of Atlantic herring, haddock, little skate, windowpane flounder, and yellowtail flounder (Table 1). There are four suborders, but the primary one is the Gammaridea. Most gammarids are marine and benthic, and some are commensal with other invertebrates (e.g. *Dulichia* on the sea scallop) (Gosner 1971). The suborder Caprellidea has fewer species, and contains amphipods that are modified for attachment to other benthos, such as hydroids or algae. Generally, amphipods are found on all substrates and at all depths (Gosner 1971). Some species inhabit tubes while others are free-living. In the northeast region, amphipods range in length from 2-40 mm in (Gosner 1971). A few species commonly identified in the food habits data include *Ericthonius rubricornis*, *Leptocheirus pinguis*, *Gammarus* spp., *Monoculodes* spp., *Unciola* spp., and *Ampelisca* spp. Species like *Ampelisca* spp. also create dense "mats" of short tubes in sand and mud habitats that provide some cover for juvenile fish. Amphipods have a short life cycle: *L. pinguis*, for example, has a spring and fall cohort each year in the near shore Gulf of Maine, both of which die out by the following summer (Theil 1997).

3.2 Decapod crabs and shrimp

Decapods are another order of crustaceans that includes the shrimps, crabs, lobsters, and crayfish. Decapods are found at a range of depths and salinities, and many species are benthic. Crabs make up greater than 10% by weight of the diets of cod, halibut, barndoor skate, clearnose skate, little skate, ocean pout, rosette skate, and windowpane flounder (Table 1). Most crabs are easily recognized by large carapaces and flattened bodies. Hermit crabs, which have twisted, soft abdomens, and typically occupy empty snail shells, are a notable exception. Regional species include the jonah crabs *Cancer borealis* and rock crabs, *C. irroratus*, hermit crabs

(*Pagurus* spp.), spider crabs such as *Libinia emarginata*, and swimming crabs such as *Ovalipes ocellatus* and *Callinectes sapidus*.

Crabs occur on a wide variety of substrates. *C. irroratus* is found from Labrador to South Carolina in intertidal habitats north of Cape Cod and is mostly subtidal and in progressively deeper water southward, occurring as deep as 780 meters on all types of bottom (Gosner 1978). Jonah crabs have a slightly different range (Nova Scotia to Florida) and usually occur in deeper water than rock crabs (Gosner 1978). The common spider crab (*L. emarginata*) ranges from Nova Scotia to the Gulf of Mexico and is common all types of bottom from the shoreline to depths of 48 meters or more. Lady crabs (belonging to the family Portunidae, the swimming crabs) are common in the summer south of Cape Cod in shallow water on sandy bottoms. Another common portunid crab south of Cape Cod, the blue crab (*Callinectes sapidus*), occurs offshore to at least 36 meters, but is most common in estuaries like Chesapeake Bay. Blue crabs are also sometimes found in Massachusetts Bay and in coastal waters further north in the Gulf of Maine.

Shrimp make up greater than 10% by weight of the diets of redfish, barndoor skate, little skate, pollock, red hake, rosette skate, silver hake, and smooth skate (Table 1). Shrimp species commonly identified in the food habits data include the sand shrimp, *Crangon septemspinosa*, and northern, or pink, shrimp, *Dichelopandalus leptoceros*, and *Pandalus* spp. As its name implies, the sand shrimp occupies sandy bottom, whereas the pandalids occur on mud. Sand shrimp range along the entire east coast from the lower intertidal zone to depths of 90 meters or more (Gosner 1978). Sand shrimp and mysids are the only common shallow-water shrimp between Cape Ann and the Bay of Fundy. The pandalids are circumpolar. The largest species in the Northeast region, *Pandalus borealis*, is common in the Gulf of Maine in deep water, but its range does not extend south of Cape Cod (Gosner 1978). The species is the target of a trawl fishery, managed by the Atlantic States Marine Fisheries Commission.

Pandalus montagui is found as far south as Rhode Island, *Pandalus propinquus* is found as far south as Delaware, and *D. leptoceros* inhabits deep water down to North Carolina. In New England waters, *P. propinquus* is generally restricted to deeper water (165-330 m) while *D. leptocerus* occurs over a broader depth range (33-340 m) (Wigley 1960). *D. leptocerus* appears to have less restricted habitat requirements than either *P. montagui* or *P. borealis*, since it has been collected in areas where sediments contained low, medium, and high quantities of organic matter, whereas *P. montagui* was more associated sediments with relatively low organic matter content (Wigley 1960). The crustacean order Mysidacea also includes some benthic shrimps. Unlike crabs, crustacean shrimps are generally restricted to mud and sand bottom habitats.

3.3 Echinoderms

There are several classes of echinoderms with fairly distinct substrate associations. Sea stars are found on all types of substrate, whereas sea urchins are restricted to rocky bottom areas, sand dollars occupy sandy bottom habitats, and brittle stars are found on mud and sand. Echinoderms are important components of the diets of only three managed species of fish (Table 1): American plaice feed on brittle stars, sea urchins, sand dollars, and starfish, ocean pout feed on brittle stars, sea urchins, and sand dollars, and haddock feed on brittle stars. Species commonly identified in the diets of these three species are the brittle stars *Ophiura sarsi* and *Ophiopholis aculeata*, the sand dollar, *Echinarachnius parma*, the sea urchin *Strongylocentrotus droebachiensis*, and the sea star *Asterias vulgarias*.

3.4 Infaunal bivalve mollusks

Bivalve mollusks make up approximately 15% of the winter skate's diet and 7-8% of the diets of ocean pout, cod, and little skate (Table 1). Infaunal bivalves burrow into mud and sand, but not into gravel. Species commonly identified in the food habitats data include *Astarte* spp., *Cyclocardia borealis*, *Chlamys islandica*, *Ensis directus*, and *Sphenia sincera*.

3.5 Polychaetes

The polychaete worms are a large and diverse group that includes both sessile and mobile forms living both in and on all types of substrates. Some species create and occupy tubes, which may be hard (calcareous) or soft. Many are associated with other invertebrate fauna. Polychaetes comprise greater than 70% by weight of the diet of witch flounder, about 40% of the diets of winter flounder and yellowtail flounder, 24% for thorny skate, and 12-14% for little skate, rosette skate, and winter skate (Table 1). Families commonly identified in the food habits data include the Nephtyidae, Glyceridae, Lumbrineridae, Terebellidae, Maldanidae, Ampharetidae, Flabelligeridae, and Nereidae.

3.6 Benthic fish

Benthic species of fish account for 40% of the diet of Atlantic halibut and 10-20% of diets of barndoor skate, clearnose skate, monkfish, thorny skate, windowpane flounder, and winter skate (Table 1). A large variety of benthic fish species are eaten by larger fish. Fish that are preyed upon by larger fish tend to be small, either young-of-the-year or slightly older juveniles.

4.0 Vulnerability of benthic prey features to fishing gear impacts

The table below summarizes the prey impacts studies that were reviewed. The sections that follow discuss the results by gear type.

Table 2 – Summary of literature relating to impacts of otter trawls (OT), scallop dredges (SD), and hydraulic clam dredges (HD) on benthic invertebrate prey types, experimental studies only. S in results column indicates statistically significant results.

Citation	*Gear and fishing intensity*	*Substtrate and energy*	*Prey types evaluated*	*Summary of results*
Hansson et al 2000	Otter trawl, 2/wk for 1 yr, est 24 tows per unit area	Mud, low	Amphipods, polychaetes, iInfaunal bivalves, brittlestars	Brittlestars highly affected by trawling (31% fewer after 7-12 mos); little or no effect on polychaetes, amphipods, mollusks; for 61% infaunal species sampled, abundance was negatively affected by trawling
Sanchez et al 2000	Otter trawl, 1 or 2 in a day (2 sites)	Mud, low	Amphipods, polychaetes, infaunal bivalves	No changes due to trawling in community structure, or infaunal species or taxa present; abundance of a number of species decreased S on unfished line compared to fished line 150 h after fishing
Sparks-McConkey and Watling 2001	Otter trawl, 4 in 1 day (in same area of bottom)	Mud, low	Polychaetes, infaunal bivalves	Immediate, S impacts on infauna (30% fewer individuals 5d after trawling), esp 4 polychaetes/2 bivalves, also fewer species/species diversity); NS differences between trawled and control areas after 3.5mo following recruitment of mobile species.
Tuck et al 1998	Otter trawl, Multiple tows once a month for 16 mos, est 1.5/unit area each month	Mud, low	Polychaetes, infaunal bivalves	More infaunal species after 16 mos of disturbance (but not after 10) and throughout recovery period, but fewer individuals during 16 mos disturbance and 12 mos of recovery, no differences between control and treatment sites 18 mos after trawling ended.
De Biasi 2004	Otter trawl, 14 parallel tows 160 m apart in one day	Mud, ?	Polychaetes, infaunal bivalves, sea urchins	For 35 major taxa, NS differences prior to or 1 mo after fishing, but small S differences after 48 hrs; some taxa more abundant at treatment sites after 48 hrs, some less so.
Bergman and VanSantbrink 2000	Otter trawl, Average 1.5 tows per unit area	Sand, muddy sand, high	Decapod crabs, polychaetes, infaunal bivalves, brittlestars, sea urchins, seastars	Percent reductions <0.5-52% for 9 bivalves, 16-26% for a sea urchin, 12% brittle stars, 3-30% for crabs, and 2-33% for polychaetes, no effect on sea stars; some reductions significant (see paper); fragile species more vulnerable

Citation	***Gear and fishing intensity***	***Substtrate and energy***	***Prey types evaluated***	***Summary of results***
Boat Mirarchi and CR Environmental 2005	Otter trawl, 6 tows in same trawl lane in 1 day	Sand, muddy sand, high	Amphipods, decapod crabs, decapod shrimp, polychaetes, infaunal bivalves, sand dollars, seastars	No difference in infaunal density, richness, or species composition between treatment and control lanes after experimental tows
Brown et al 2005a	Otter trawl, 10 single tows in 30 hrs, no overlap	Sand, muddy sand, high	Amphipod, polychaetes, infaunal bivalves	Immediate responses to experimental trawling were subtle (reduced richness, absence of rare taxa such as brittle stars and several bivalve families), large, mobile polychaetes and amphipods increased in abundance
Burridge et al 2003	Otter trawl, Depletion study	Sand, high	Decapod crabs, infaunal bivalves, brittlestars, sea urchins, seastars	Study limited to epifauna that were caught in trawl, some of which are prey for some species: mean 13-14% reduction per tow for crustaceans and echinoids, 9% brittle stars and all bivalves.
Kenchington et al 2001	Otter trawl, 12 tows in ca 36 hrs once a year for 3 yrs, est 3-6 tows per unit area/yr	Sand, low	Polychaetes, infaunal bivalves, sand dollars	No effects on biomass or taxonomic diversity; full recovery of species affected by end of first year (when sampling resumed)
Drabsch et al 2001	Otter trawl, 2 series of 10 adjacent tows in one trawl lane in 1 day	Mud, sand, low	Amphipods, polychaetes, infaunal bivalves, brittlestars, sea urchins	No effect on total infaunal abundance in sand, but S reduction in mud; some taxa increased, some decreased; inconsistent results perhaps due to different disturbance regimes in each location tested plus high natural disturbance.
Freese et al 1999	Otter trawl, 8 single tows, no overlap	Granule-pebble, cobble, boulder, low	Decapod shrimp, infaunal bivalves, brittlestars, sea urchins, seastars	23% NS reduction in density of non-structure forming motile epifauna, 43% fewer brittle stars with 23% damage to those remaining in trawl transects

Citation	***Gear and fishing intensity***	***Substtrate and energy***	***Prey types evaluated***	***Summary of results***
Kenchington et al 2005	Otter trawl, 12-14 tows in 1 day on same line each yr for 3 yrs	Sand, granule-pebble, cobble, high	Amphipods, decapod crabs, decapod shrimp, polychaetes, infaunal bivalves, brittlestars, sea urchins, seastars	S changes in abundance of prey consumed (esp between first two tows and subsequent tows) and diet composition of cod, plaice, haddock, winter flounder, and yellowtail flounder, opportunistic feeding on prey made more available by trawling (infauna and spp living on or near the sediment surface (below or above)
Kenchington et al 2006	Otter trawl, 12-14 tows in 1 day on same line each yr for 3 yrs	Sand, granule-pebble, cobble, boulder, high	Amphipods, polychaetes, infaunal bivalves, brittlestars,sea urchins, seastars	15 taxa (eg polychaetes/amphipods) S reduced after trawling when results of 3 yrs of experimental tows were combined, some consumed by predators, organisms living in or just below sediment surface most affected; most impacts <1 yr and minor compared to annual changes in control lines.
Sullivan et al 2003	Scallop dredge, Multiple tows in short time period at 3 sites	Mud, muddy sand, high	Amphipods, isopods, decapod crabs, sand dollars	Prey items failed to exhibit a positive or negative change consistent with a dredging impact - but did reflect S seasonal variability
Watling et al 2001	Scallop dredge, 23 tows in 1 day	Muddy sand, high	Amphipods, polychaetes	Large, S reductions in numbers of individuals, esp one family of amphipods (Photidae) and one of polychaetes (Nephtyidae); little difference between control and treatment plots for some taxa the day after dredging
Gilkinson et al 2005a	Hydraulic dredge, 12 overlapping tows in 12 hrs	Sand, low	Amphipods, isopods, polychaetes, infaunal bivalves, brittlestars, sand dollars	Most species (esp polychaetes/amphipods) less abundant (average 40%) immediately after dredging, esp inside dredge furrows; marked increase in polychaetes and amphipods after 1 yr, densities generally elevated by >>100% after 2 yrs relative to pre-dredging levels
Pranovi and Giovanardi 1994	Hydraulic dredge, Single tows	Sand, low	Isopods, infaunal bivalves	Immediately S decrease in total abundance (45% fewer individuals in experimental vs control plot), biomass, diversity of macrofauna in fishing ground, NS effects outside (but still 26% fewer individuals); recovery in abundance, but not biomass, after 2 mos.
Hall et al 1990	Hydraulic dredge, Repeated tows for 5 hrs	Sand, high	Amphipods, polychaetes, infaunal bivalves	S reductions in numbers of infauna, NS effect on abundance of any individual species, but mean abundances of 10 most common species all lower 1 day after dredging (S reduction for whole group); recovery of total abundance and 6 of 10 species within 40 days.

Citation	*Gear and fishing intensity*	*Substtrate and energy*	*Prey types evaluated*	*Summary of results*
Morello et al 2005	Hydraulic dredge, Repeated tows in 1 day	Sand, high	Decapod crabs, decapod shrimp, polychaetes, infaunal bivalves	No impacts of experimental tows on entire sampled macrobenthic community or on polychaetes, crustaceans, detritivores, or suspensivores, but abundance/biomass of non-target mollusks S reduced by dredging; no recovery after 18 days (end of experiment).
Thorarinsdottir et al 2008	Hydraulic dredge, 3 discrete tows	Sand, high	Amphipods, polychaetes, infaunal bivalves	Immediate NS 45% reduction in density of all infauna, still 36% fewer 3 mos later; only immediate effects on crustaceans and bivalves, no effects on hydrozoa, effects on polychaetes, other taxa lasted 3 mos; full recovery after 1 yr.
Tuck et al 2000	Hydraulic dredge, Single tows	Sand, high	Amphipods, polychaetes, infaunal bivalves	S decrease in number of infaunal individuals a day after dredging, but no difference after 5 days, fewer polychaetes and more amphipods after 5 days,but not after 11 wks; some species less abundant, some more after 5 days, full recovery after 11 weeks.

4.1 Otter trawls

In **<u>mud habitats</u>**, three of the short-term studies showed that 1-2 tows had very little or no impact on infaunal communities in mud. The results of Sanchez et al (2000) indicate that trawling may, in fact, have positive effects on infaunal abundance. Species richness and diversity did not change during the first 102 hours after a single pass of the trawl, and, after 150 hours, the abundance of a number of species actually decreased significantly in the control area compared with the trawled line. Furthermore, no differences were detected after 72 hours in another line that was trawled twice. Results of the Australian study (Drabsch et al 2001) showed a significant reduction in total infaunal abundance a week after trawling (two tows per unit area), with some taxa increasing and some decreasing. One family of polychaetes (Ctenodrilidae) decreased significantly, but there were no significant differences between treatment and control samples for any other taxon. In De Biasi (2004), for each of 35 major taxa, there were no significant differences in densities between treatment and control sites prior to trawling and one month after trawling. There were small significant differences after 48 hours, with some taxa more abundant at treatment sites and some more abundant at control sites.

In the fourth short-term experiment (Sparks-McConkey and Watling 2001), there was an immediate, significant effect of four tows on infaunal abundance and species diversity, with 30% fewer individuals five days after trawling. The reduction in abundance was especially noticeable for polychaetes and infaunal bivalves. Three and-a-half months after the initial disturbance, after mobile invertebrates recruited to the benthic community, there were no longer any significant differences between the numbers of individuals and species at the treatment and control sites, although one bivalve still had not recovered. This study also showed that bottom trawling affected the sedimentary habitat for infaunal invertebrates, significantly reducing the porosity of the mud (so that it retained less water), increasing the food value (organic matter) of the upper 2 cm of sediment, and stimulating benthic chlorophyll production. All geochemical sediment properties returned to pre-trawling conditions within 3.5 months, thus the impacts on infaunal prey and their habitat were temporary.

The two long-term, multiple tow studies produced completely contradictory results. In one of them (Hansson et al 2000), brittle stars were highly affected by trawling, with 31% fewer in treatment sites 7-12 months after the experiment began, but little or no effect on polychaetes, amphipods, or mollusks. For 61% of the species sampled, abundances tended to be negatively affected by trawling (i.e., abundances decreased more or increased less in the trawled sites compared to the control sites during the experiment). Total biomass decreased significantly at all three trawled sites, and the total number of individuals decreased significantly at two trawled sites, but in both cases significant reductions were also observed at one of the control sites; thus, these changes could not be attributed solely to trawling. Total abundance and biomass at trawled sites were reduced by 25% and 60%, respectively, after a year of continuous trawling, compared to 6% and 32% in control sites.

In the other long-term, multiple tow study (Tuck et al 1998), there were significantly more individuals in trawled sites before trawling began and after 6 and 12 months of recovery. After 18 months of recovery, there was no difference between the two sites. There were no significant differences in the number of infaunal species in the experimental and reference sites during the first 10 months of disturbance, but there were more species in the trawled site after 16 months of disturbance and throughout the recovery period. Biomass was significantly higher in the trawled site before trawling started, but not during the rest of the experiment. Some species, primarily opportunistic polychaetes, increased significantly in abundance in the trawled plot in response to the disturbance, while others (a bivalve and some other polychaete species) declined significantly. Community structure became significantly different after only five months of the experiment and remained so until the end of the recovery period, or beyond (two different measures of community structure were applied). Brittle stars were also significantly more (not less, as in Hansson et al (2000)) abundant in the trawled plot at the end of the disturbance period.

In **sand habitats**, three of the five short-term experiments reported either no effect or very subtle effects on benthic prey organisms. Responses of benthic macrofauna to experimental trawling in the Gulf of Alaska (Brown et al 2005) were limited to a reduction in the total number of taxa - with an absence of rare taxa such as brittle stars, cumaceans, and isopods – but large, mobile amphipods and polychaetes increased in abundance after trawling. In the Gulf of St. Vincent, Australia (Drabsch et al 2001), there was no effect on total infaunal abundance. The only significant change that could be attributed to the two experimental tows was a reduction in the density of one order of crustaceans (Tanaidaceae) one week later; there were no significant differences in infaunal abundance between treatment and control samples at a second sandy site three months after trawling. In the Gulf of Maine study (Boat Mirarchi and CR Environmental 2003) there were no significant differences in infaunal density or species composition between treatment and control areas; the only noticeable change in epifaunal invertebrates was a reduction in rock crabs in the trawled lanes immediately after trawling, but not 4-18 hours later.

Two of the short-term experiments conducted in sandy benthic habitats estimated removal rates of benthic macrofauna by bottom trawls. These two studies have limited application to an evaluation of trawling impacts on prey species because many of the types of organisms caught and retained in trawls are not consumed by fish. Larger benthic organisms that are caught in bottom trawls and which make up a portion of the diets of NEFMC-managed fish species include crabs, bivalves, and various kinds of echinoderms (see Table 1). Densities for nine species of infaunal bivalves in the North Sea (Bergman and VanSantbrink 2000) were reduced, on average, by 0.5-52%, by 16-26% for a sea urchin, 12% for brittle stars, 3-30% for crabs, and 2-33% for polychaetes within 24-48 hours after towing a unit area of bottom 1.5 times. Fragile species were more vulnerable. Estimates of the mean percent biomass removed per tow (after 13 tows) in the depletion study (Burridge et al 2003) were 13-14% for crustaceans and echinoids and 9% for brittle stars and all bivalves. These values would obviously be higher – probably considerably so – for the first tow.

There were significant short-term reductions in total abundance and the abundance of 15 individual infaunal and epifaunal taxa (mostly polychaetes) within several hours or days after trawling in the Grand Banks study (Kenchington et al 2001), but only in one of the three years of the experiment; benthic organisms that were reduced in abundance in that year had recovered a year later. There were no short-term effects on biomass or taxonomic diversity.

Results of three experimental trawl impact studies done on **“hard bottom”** substrates were evaluated. In the short-term study (Freese et al 1999), mean densities of brittle stars were 43% lower in trawled transects than in reference transects and 23% of them were damaged, compared to 2% in the reference transects. Similar effects were observed for sea urchins (49% fewer in the trawled transects), but other prey organisms such as pandalid shrimp were more abundant in the trawled transects, and none of the differences were statistically significant.

On the Scotian shelf (Kenchington et al 2006), multiple tows had few detectable immediate effects on the abundance or biomass of individual taxa and none on community composition; a few taxa, primarily polychaetes and amphipods, decreased significantly after trawling, some because of scavenging by demersal fish. Fifteen taxa showed significant decreases 1-5 days after trawling when the data for all three years of the experiment were combined; the species affected were primarily high turn-over species, such as polychaetes and amphipods, and mussels. Organisms that were most affected were those living on or just below the sediment surface. Apart from a long-term decrease in the abundance of horse mussels, all of the detectable impacts were short-term, apparently persisting for less than a year, and minor, at least in comparison with the natural inter-annual variation seen in the control lines.

The other Scotian Shelf study (Kenchington et al 2005) is especially relevant since it found that there were significant quantitative and qualitative changes in the diets of five demersal fish species that were caught during successive experimental tows. All five species are managed by the NEFMC. Large increases in consumption of a number of prey taxa were observed between the first two and the next three to 10 or 12 experimental tows, especially for a tube-dwelling polychaete and horse mussels. Consumption of infauna and species living on or near the bottom (above or below) increased markedly. The results clearly show that the disturbance of benthic habitats by trawling causes short-term increases in prey availability for bottom-feeding fish and that the fish can easily shift their feeding habits in response to changes in the availability of prey items.

Overall, there was very little evidence of significant long-term impacts of bottom trawling on prey organisms in any substrate. In cases where there were negative impacts of sustained trawling for a year or more on total infaunal abundance or the abundance of certain taxa, recovery occurred within a year to 18 months after the disturbance ended. Recovery from the effects of 1-4 tows was faster, occurring within a few months or even days. Some opportunistic species were more abundant soon after trawling. Total abundance was reduced more often than biomass or species diversity. Trawling clearly "stirs up" infaunal organisms and organisms that live on or near the bottom, providing more for fish to eat in the first few hours after the passage of the gear (this was evident even in rocky habitats). Trawling impacts on prey were hard to detect in many cases because they are subtle, and because they take place against a background of considerable spatial and temporal variability in benthic community structure.

4.2 Scallop Dredges

Watling et al (2001) examined the effects of 23 tows in one day in a small, shallow-water, unfished area of silty sand adjacent to a commercially exploitable population of scallops in the Damariscotta River. Impacts on macrofauna (mostly infauna) were evaluated one day, four months, and six months after dredging. The total number of individuals was significantly reduced one day and four months after dredging, but not after six months. Some taxa (families) were nearly as abundant in treatment and control plots the day after dredging, while others were less abundant and there were no discernible changes in the number of taxa. Dredging affected the habitat for infaunal prey by removing the top few centimeters of fine sediment, thereby reducing the food value of the surficial sediments (by reducing amino acid content, chlorophyll a, and microbial biomass). Food value was restored within six months. **Thus, this study indicated the potential for significant, but temporary, impacts.** It should be noted that this type of environment is not typical of that fished commercially by federally-managed scallop vessels.

Sullivan et al (2003) experimentally dredged three sites at depths of 45, 67, and 88 meters in sand in order to assess the effects on habitat structure for young-of-the-year yellowtail flounder. Note that the shallower of the three continental shelf study sites may have been commercially dredged in the months leading up to the experiment; the two deeper sites were located in an area closed to scallop dredging (but not otter trawling). Benthic cores were collected during pre-dredge and post-dredge surveys with a submersible two days, three months, and one year after dredging. **Prey organisms sampled did not exhibit any change in abundance, positive or negative, that was consistent with a dredging impact, but did reflect seasonal variability.** However, compared with control plots, dredging "vigorously reworked" the top 2-6 cm of sediment and reduced the frequency of amphipod tube mats, and mobile epifauna such as sand dollars were typically dislodged or buried under a thin layer of silt.

4.3 Hydraulic dredges

In the three **single tow** hydraulic dredge experiments, there were marked immediate reductions in the density of sampled organisms, but few significant long-term effects. Tuck et al (2000) found a significant reduction in the number of infaunal organisms a day after dredging. After five days, some species were less abundant, some more abundant. At the end of the experiment (11 weeks), the infaunal community had completely recovered. Similar results were obtained in

Pranovi and Giovanardi (1994): there was an immediate and significant decrease in total abundance, biomass, and species diversity (infauna and epifauna) in the experimental versus the control plot in the fishing ground. The same downward trend in total abundance was observed outside the fishing ground, but the difference between the experimental plot and the control plot was not as dramatic (26% versus 45%) and was not significant. After two months, abundance had recovered in both sites, but not biomass. The third single tow study (Thorarinsdottir et al 2008) also reported large reductions in infaunal density (45% immediately after dredging and 36% three months later), but the results were not significant due in part to low sample sizes. Reductions in crustacean and bivalve densities were only observed immediately after dredging, whereas effects on polychaetes, cumaceans, and other taxa lasted for three months, and hydrozoa were not impacted at all. Full recovery occurred at some point between the three month and one year sampling times.

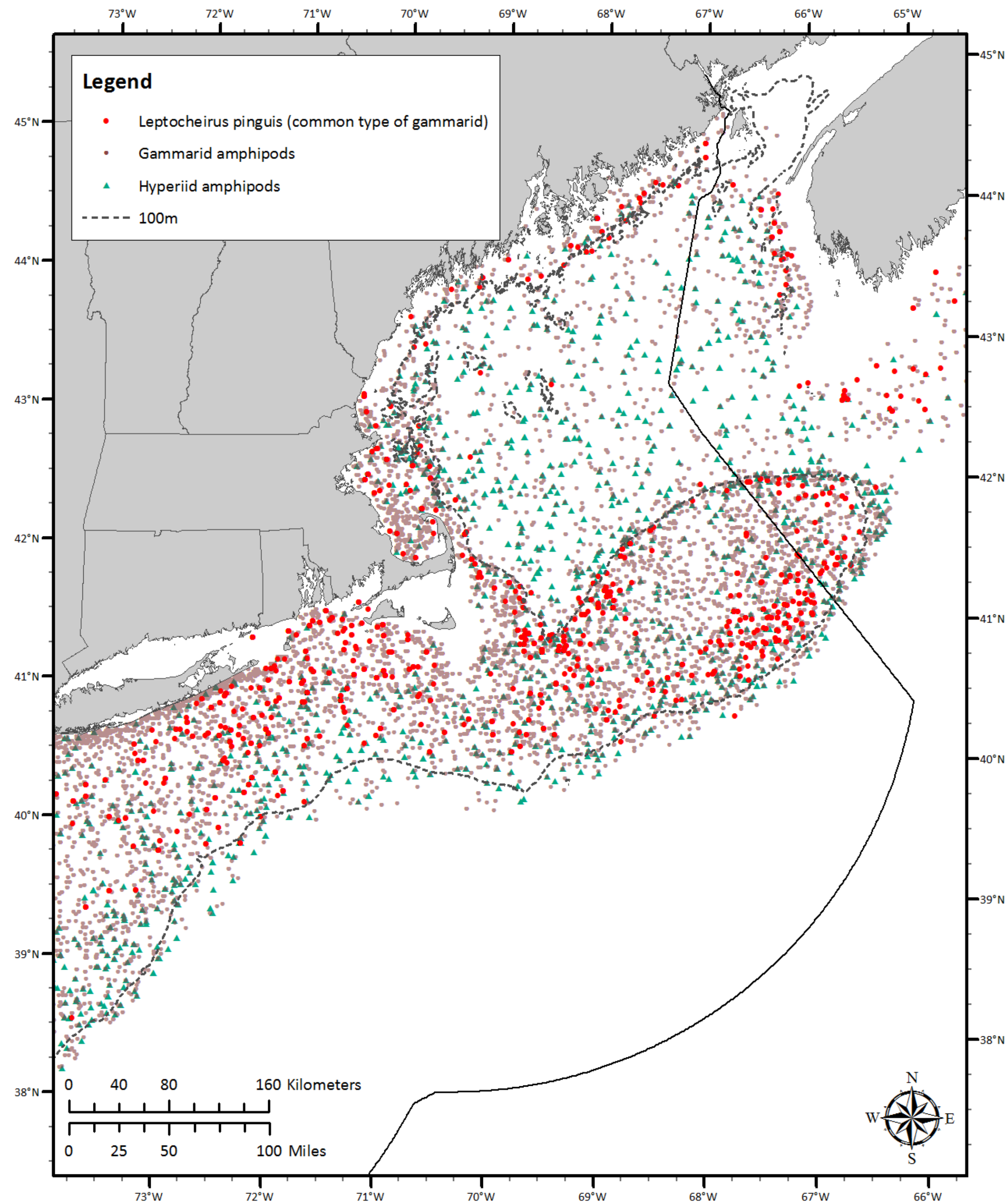
The three **repeated tow** experiments were meant to simulate the effects of commercial clam dredging operations in which multiple tows are made in a small area until most of the clams are harvested. Experimental dredging in previously undredged areas (Gilkinson et al 2005a and Hall et al 1990) had broad scale effects on the benthic fauna, but the impacts in a heavily dredged area (Morello et al 2005) were limited to infaunal bivalves. On the Scotian Shelf (Gilkinson et al 2005), most species were less abundant (numbers and biomass typically by more than 40%) immediately after dredging, especially polychaetes and amphipods, and especially inside vs outside dredge furrows. Recovery times could not really be evaluated because the study area was not re-sampled for an entire year, but none of the impacts lasted more than a year. One year after dredging, there were marked increases in abundance of opportunistic species (e.g., amphipods and polychaetes) that were even more dramatic two years after dredging. In Scotland (Hall et al 1990), there was a significant, immediate, reduction in total infaunal abundance, but no significant effect on any individual species. The mean densities of the ten most common species were all lower, however, and for the whole group, the reduction was significant. Infaunal abundance fully recovered within 40 days, but densities of four of the ten most common species were still lower in the treatment plots than in the reference plots after 40 days. In the heavily dredged study area in the Adriatic Sea (Morello et al 2005), repeated dredge tows had no impact on infaunal abundance or on the abundance of polychaetes, crustaceans, detritivores, or suspension-feeders. Only non-target bivalves (those not retained in the dredge) were affected: abundance and biomass was significantly reduced, with no recovery after 18 days.

In summary, hydraulic dredging had a greater impact on benthic prey organisms than bottom trawls or scallop dredges, causing significant and immediate reductions in the densities of infaunal organisms in dredge paths, but at the same time making them readily available to foraging fish and scavengers for a short time. In some cases, *in situ* biomass and species diversity were also reduced. Different types of infaunal (and epifaunal) organisms responded differently to dredging: polychaetes and amphipods were more likely to be affected by the excavating action of the gear on sandy bottom sediments. Recovery times varied, but were generally fairly rapid, at least in shallow-water, highly energetic environments. In the five experimental studies that were conducted in shallow water (<10 meters), total infaunal abundance recovered within five days to over three months, but in less than a year. Some individual taxa recovered from disturbance within 40 days, but others took longer, perhaps as long as 11 weeks. In deeper water (70-80 m), there were marked increases in abundance of opportunistic polychaete and amphipod species within one year and even more dramatic increases after two years, but recovery times were not evaluated at any higher temporal resolution (e.g., months).

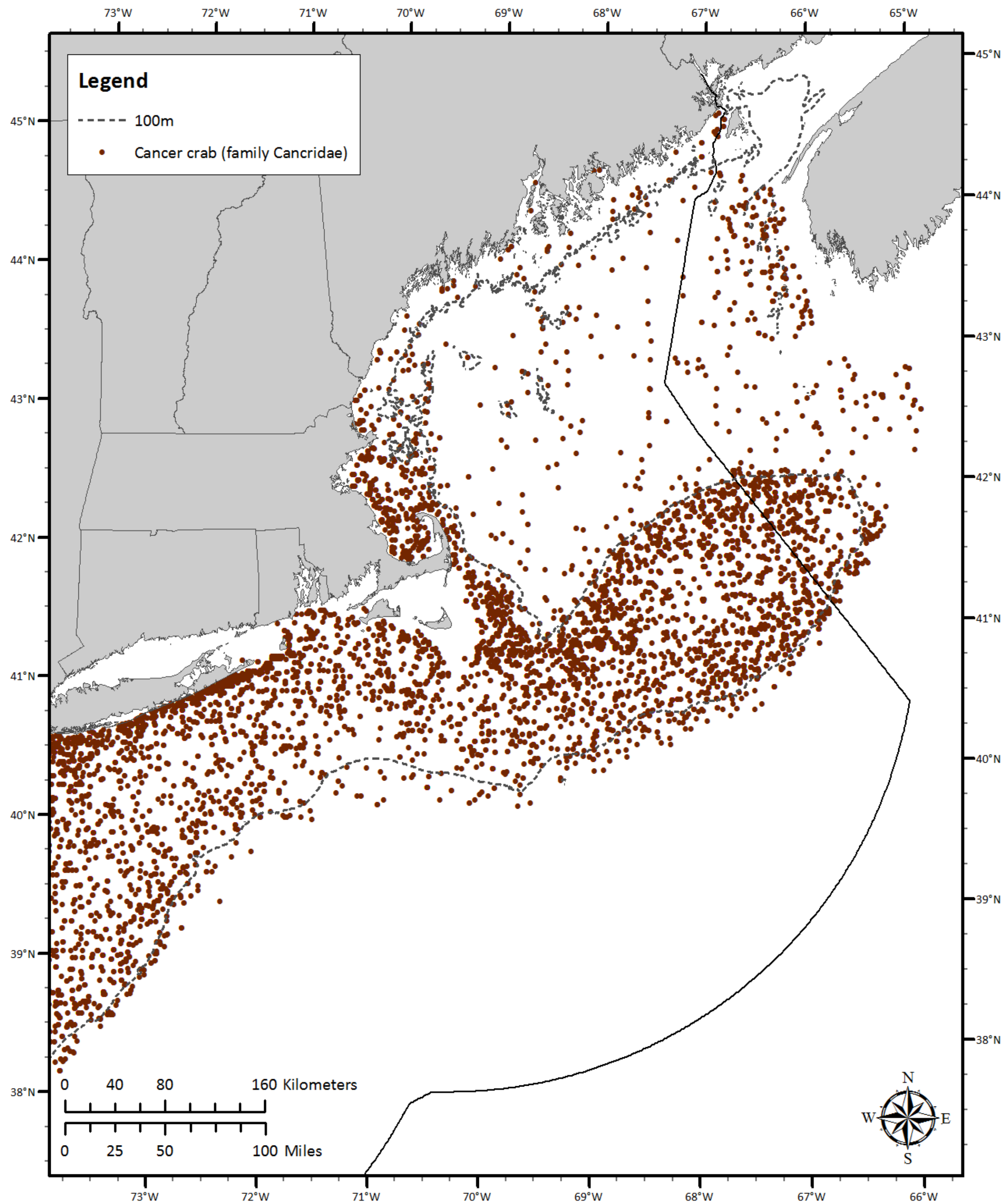
5.0 Spatial distribution of major prey groups

5.1 Benthic invertebrates

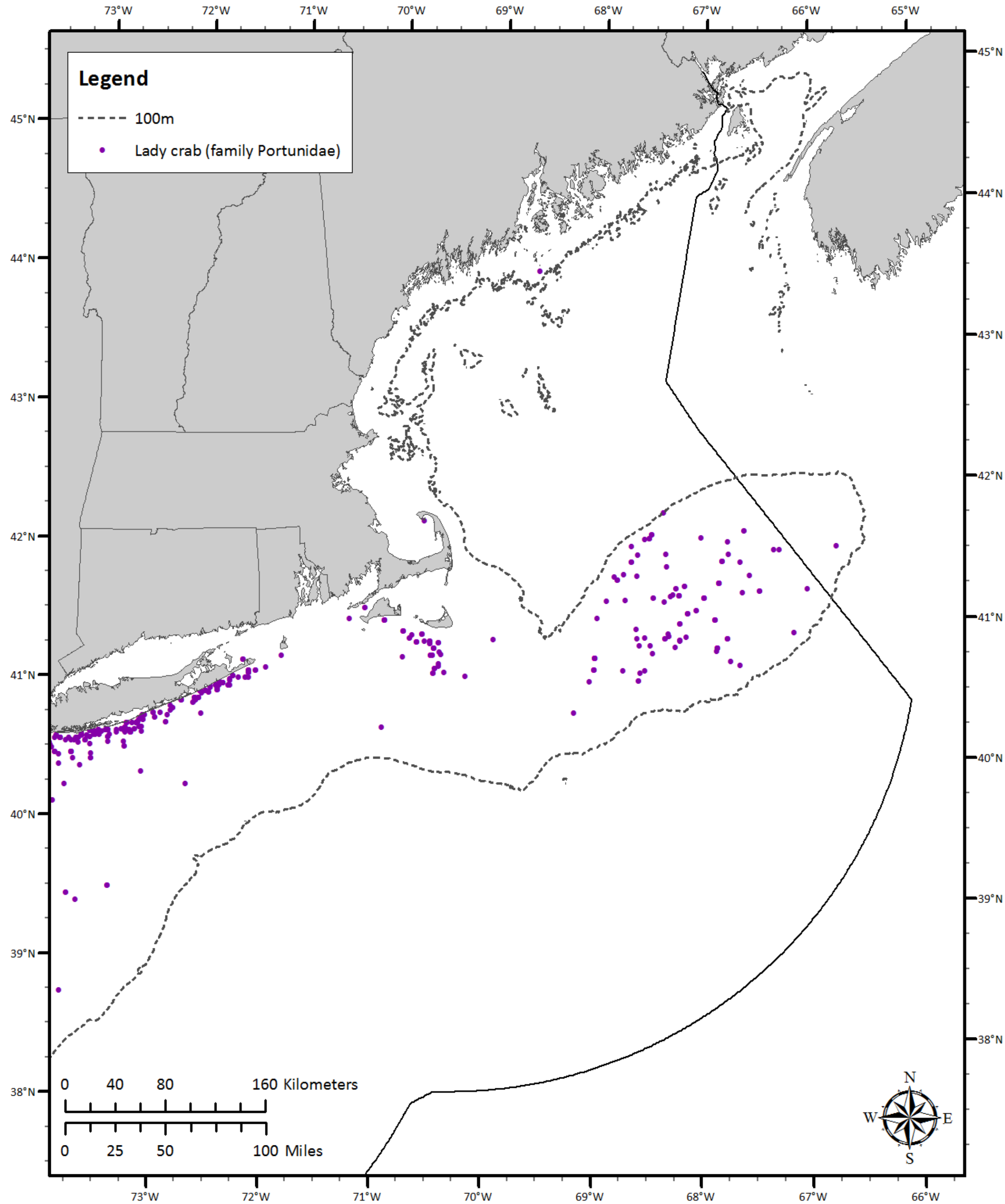
Map 1 – Amphipods



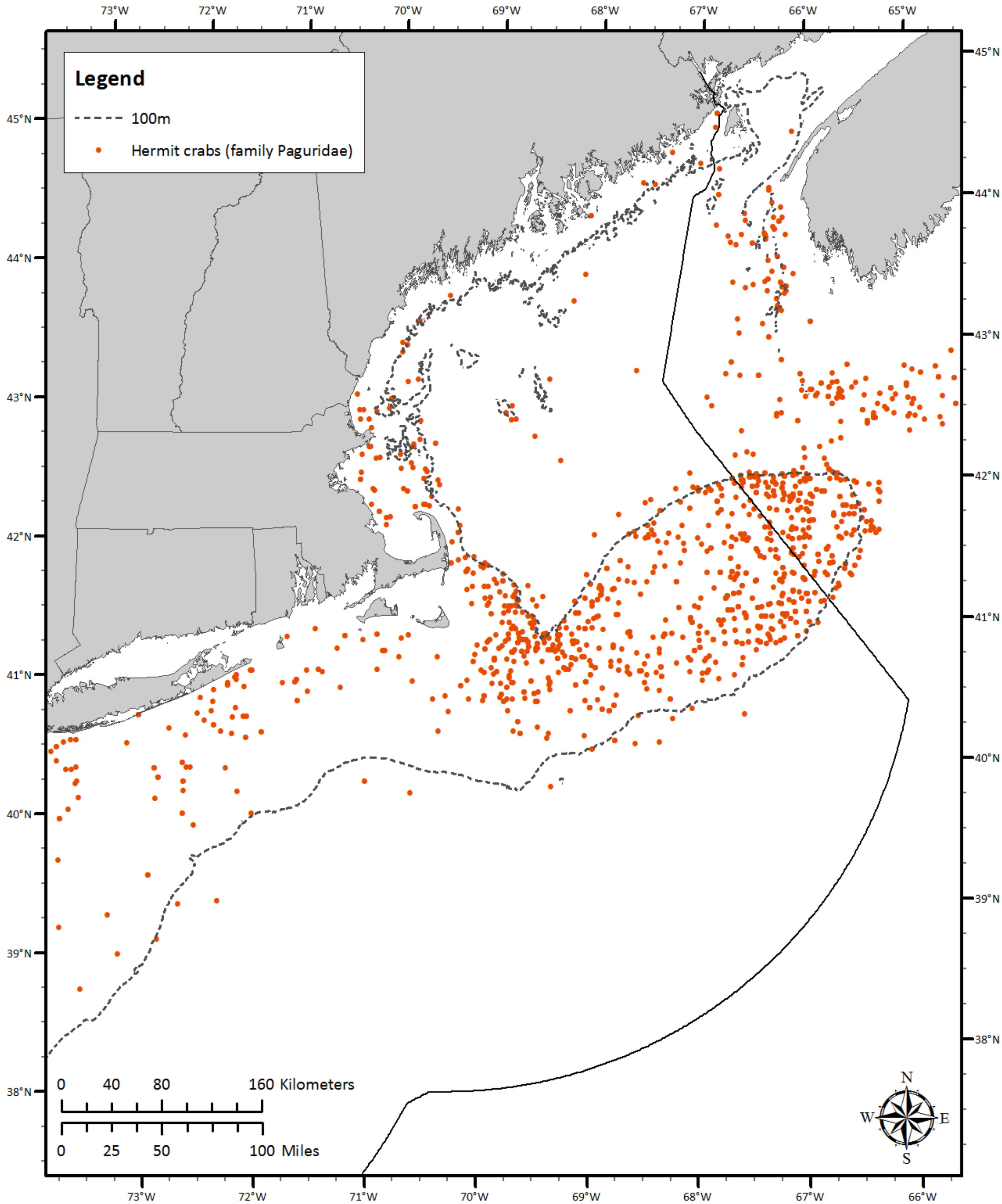
Map 2 – Cancer crabs



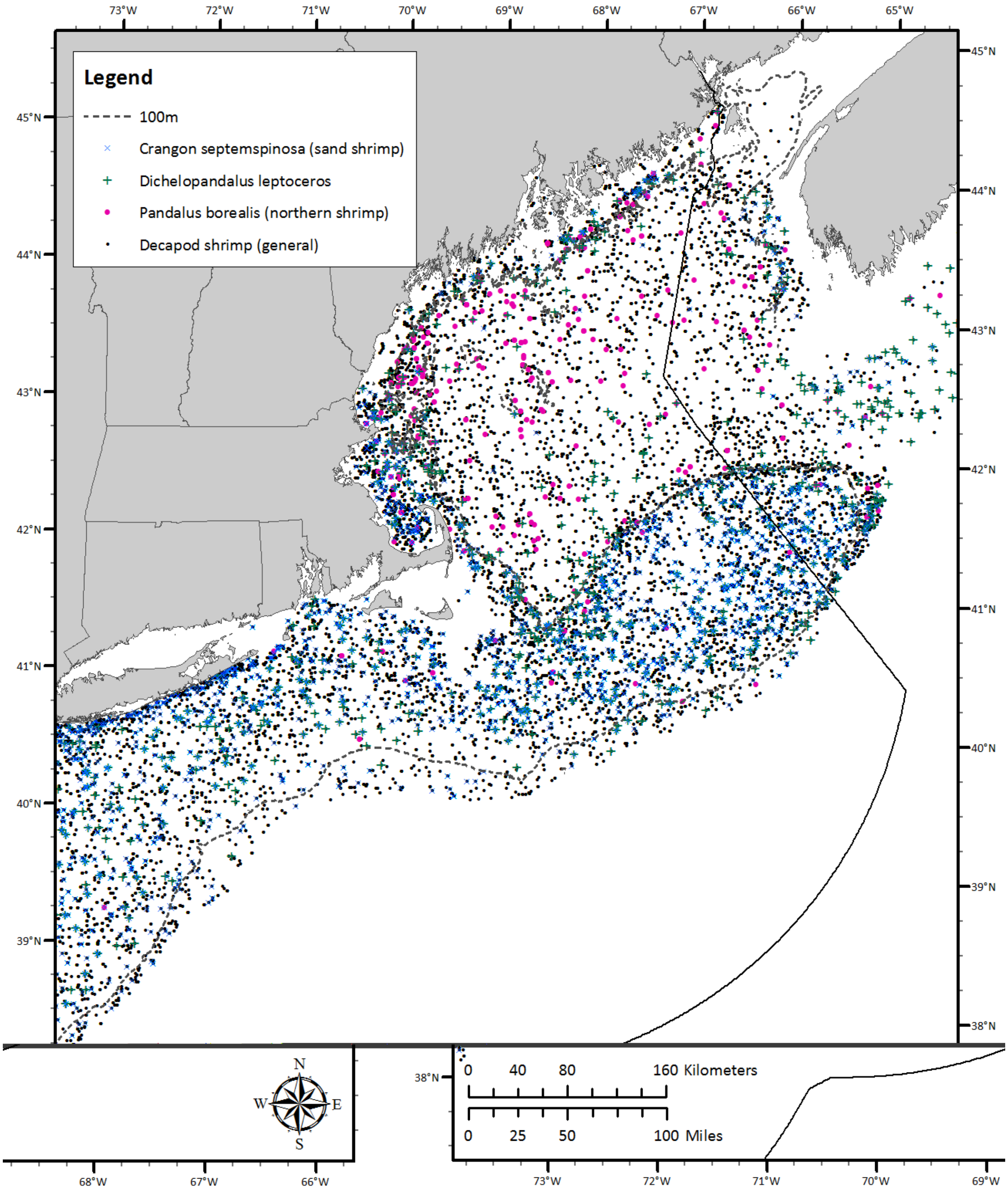
Map 3 – Lady crab



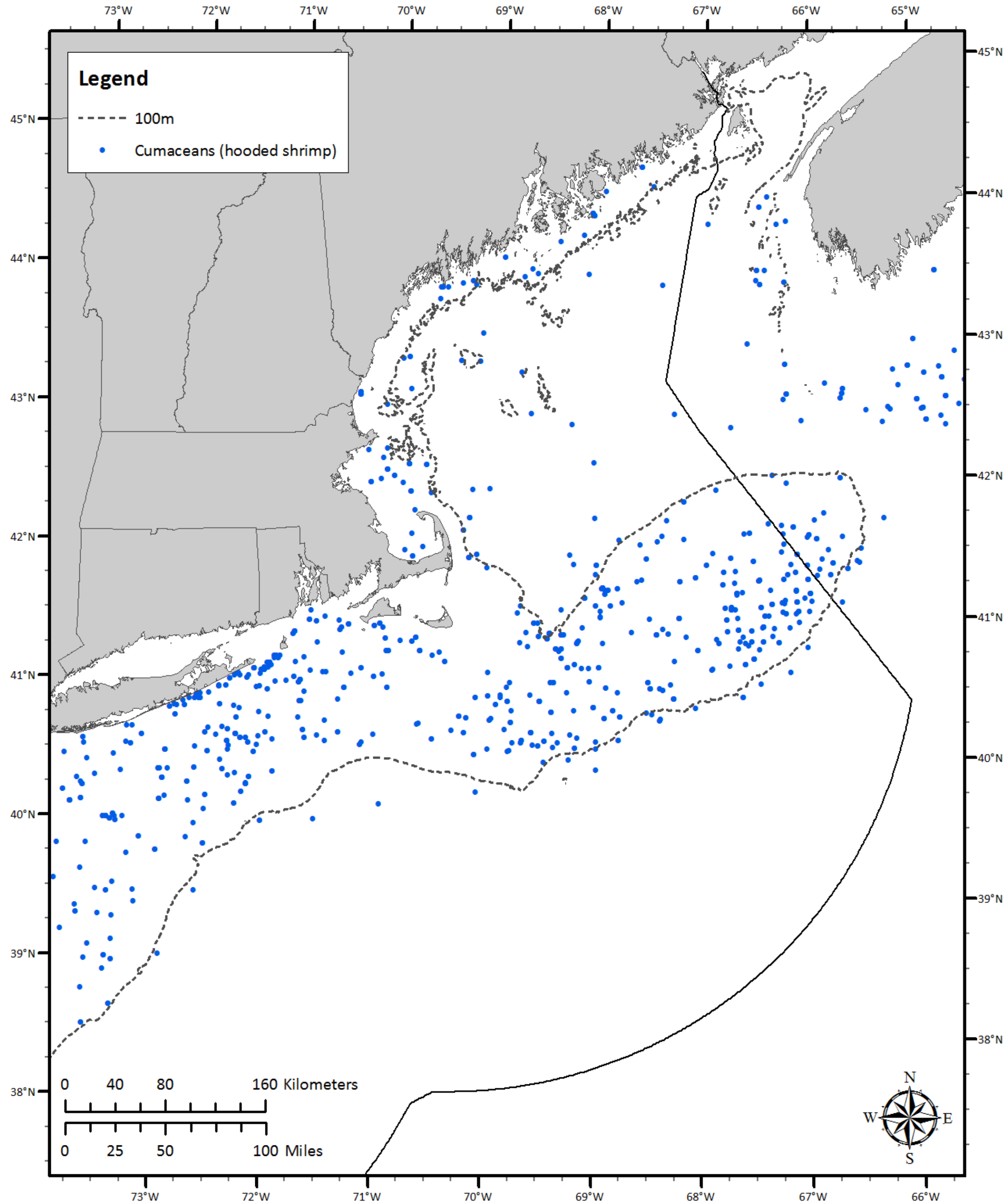
Map 4 – Hermit crabs



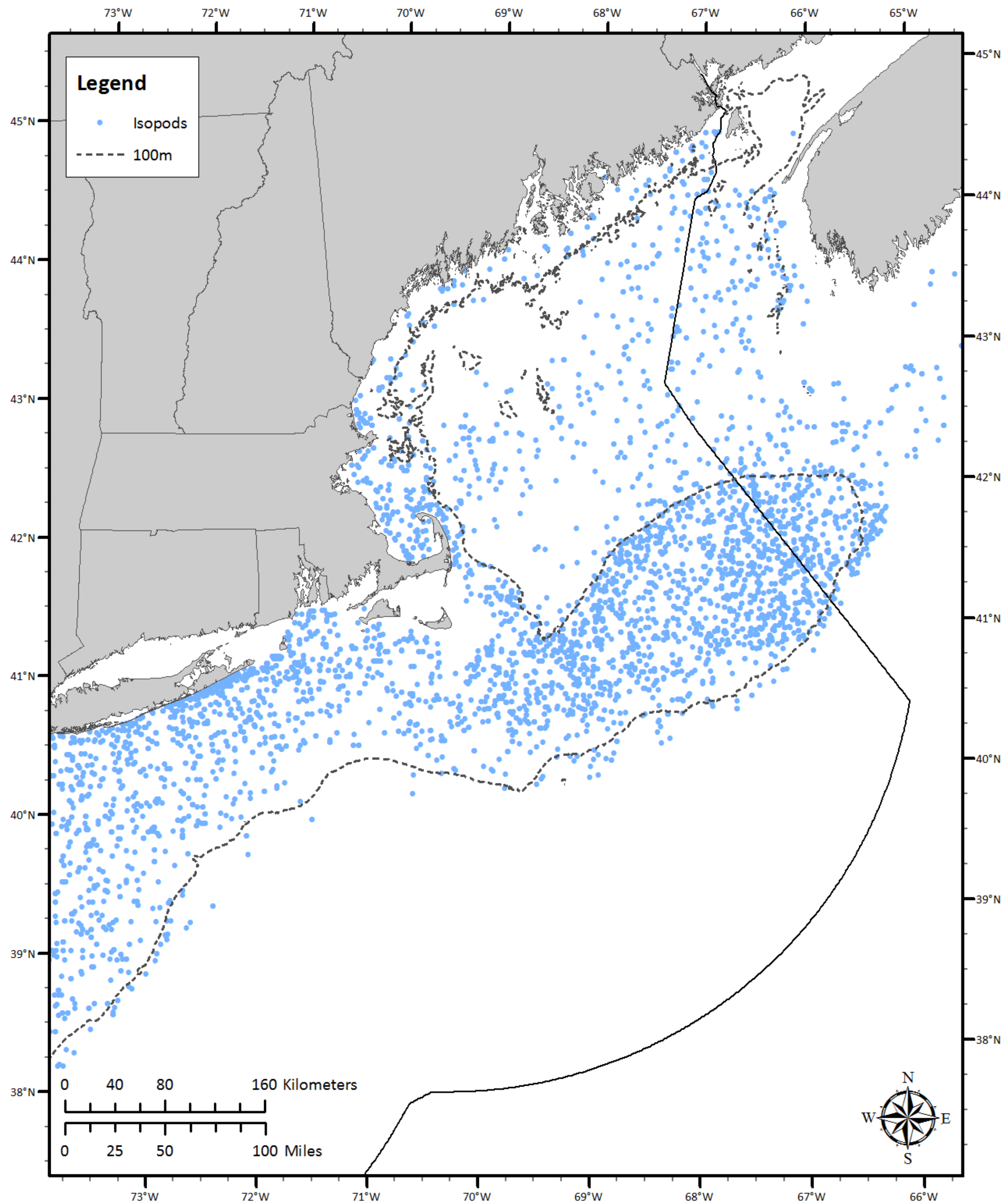
Map 5 – Decapod shrimp



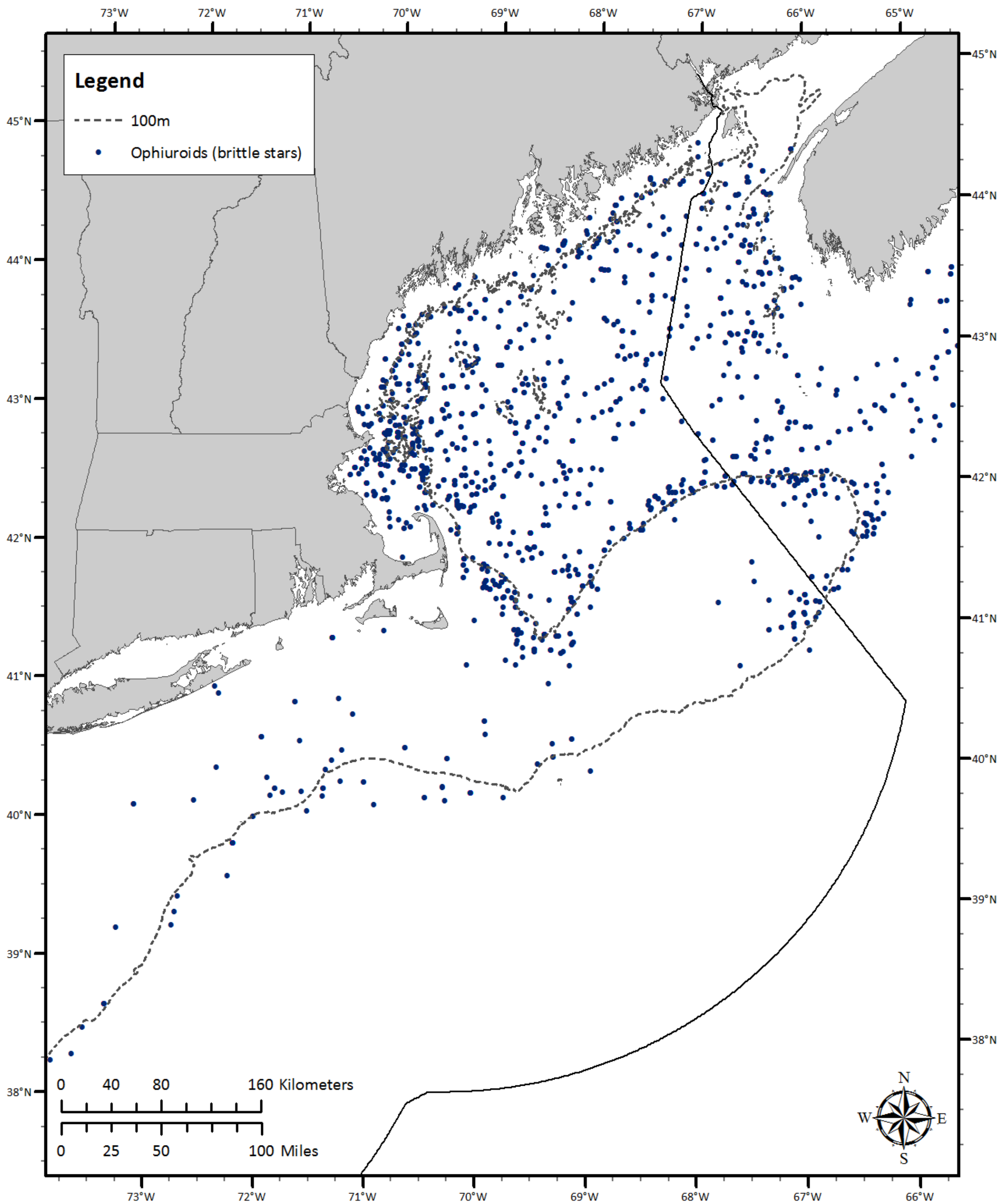
Map 6 – Cumaceans (hooded shrimp)



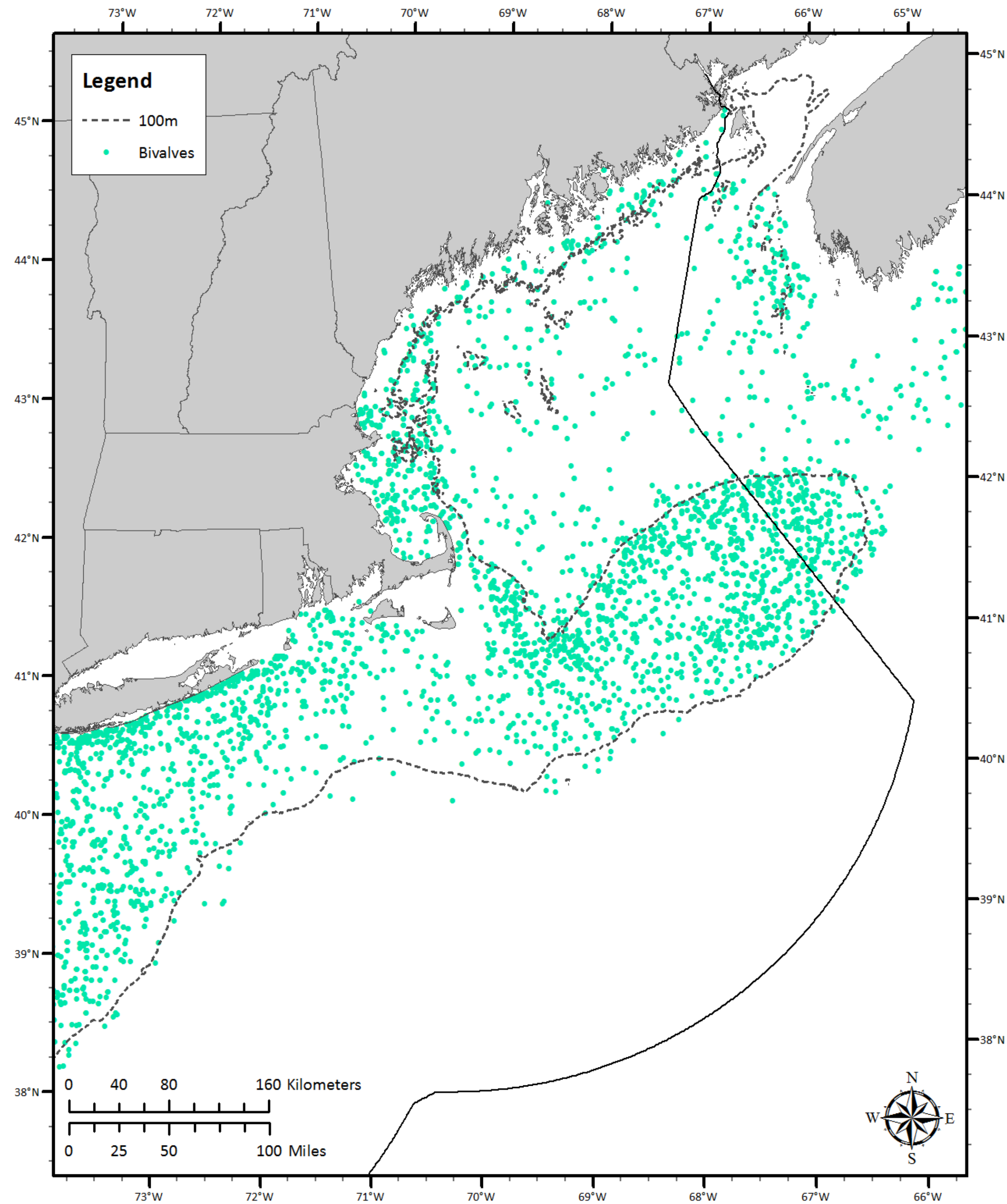
Map 7 – Isopods



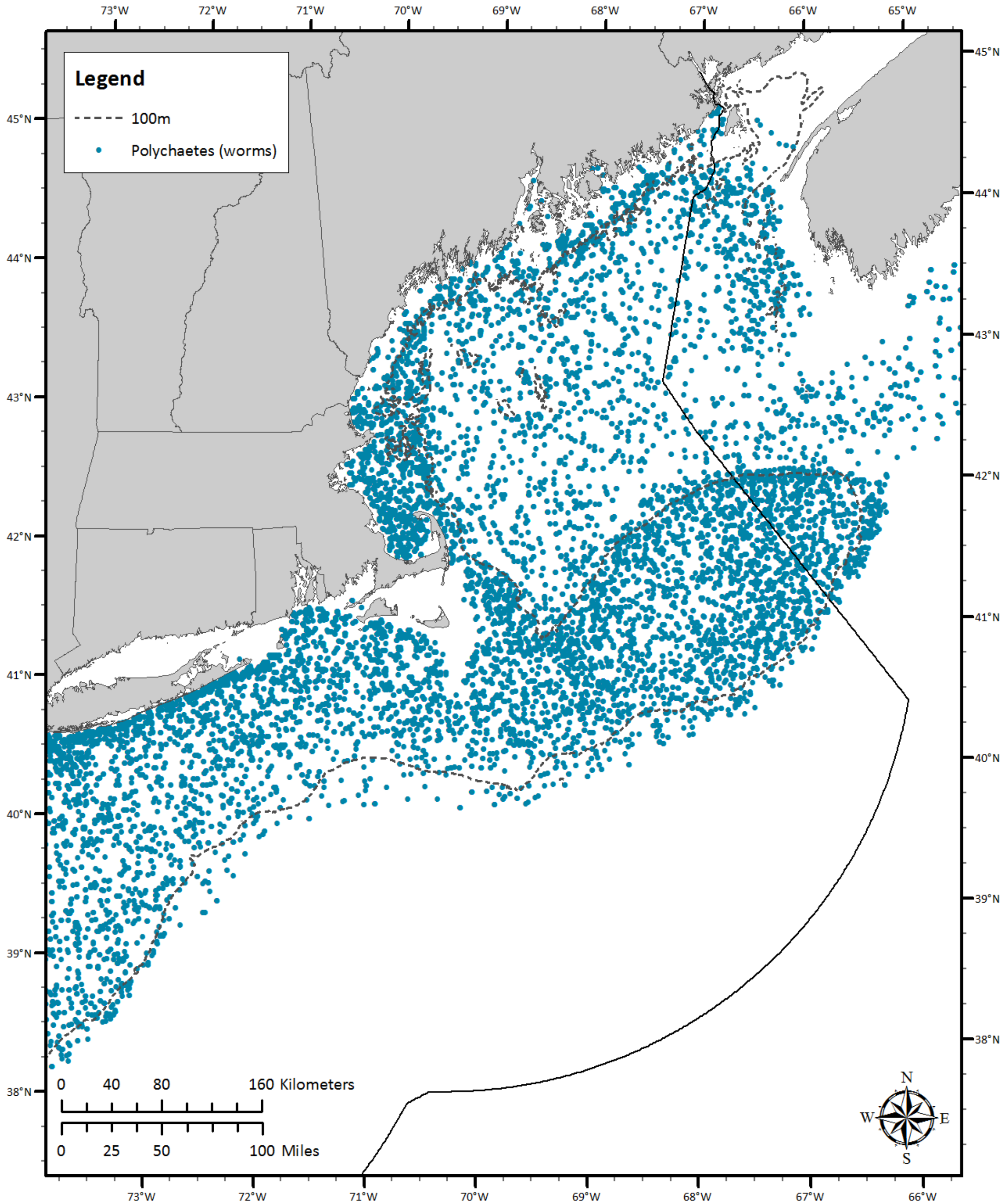
Map 8 – Brittle stars



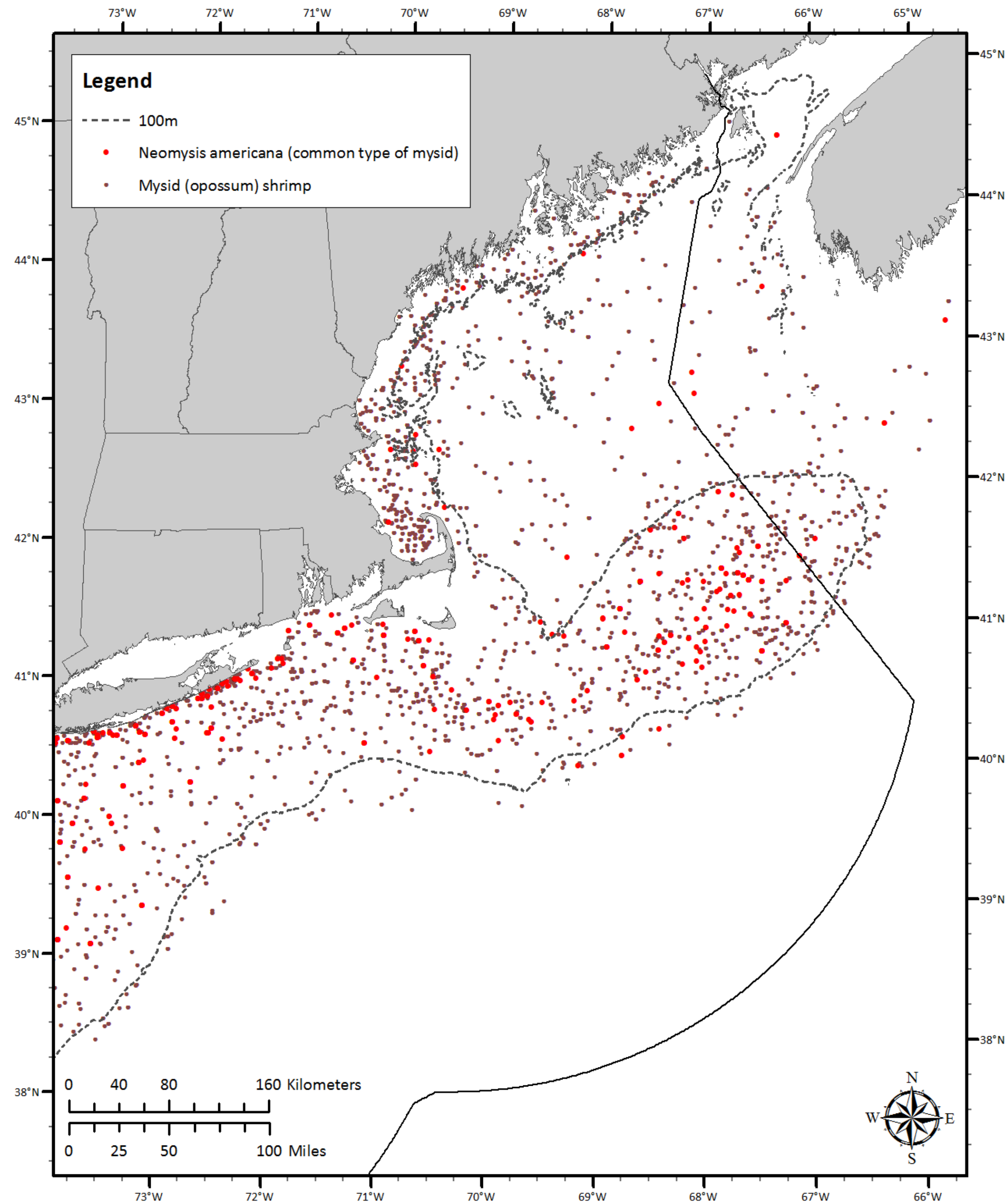
Map 9 - Bivalve molluscs



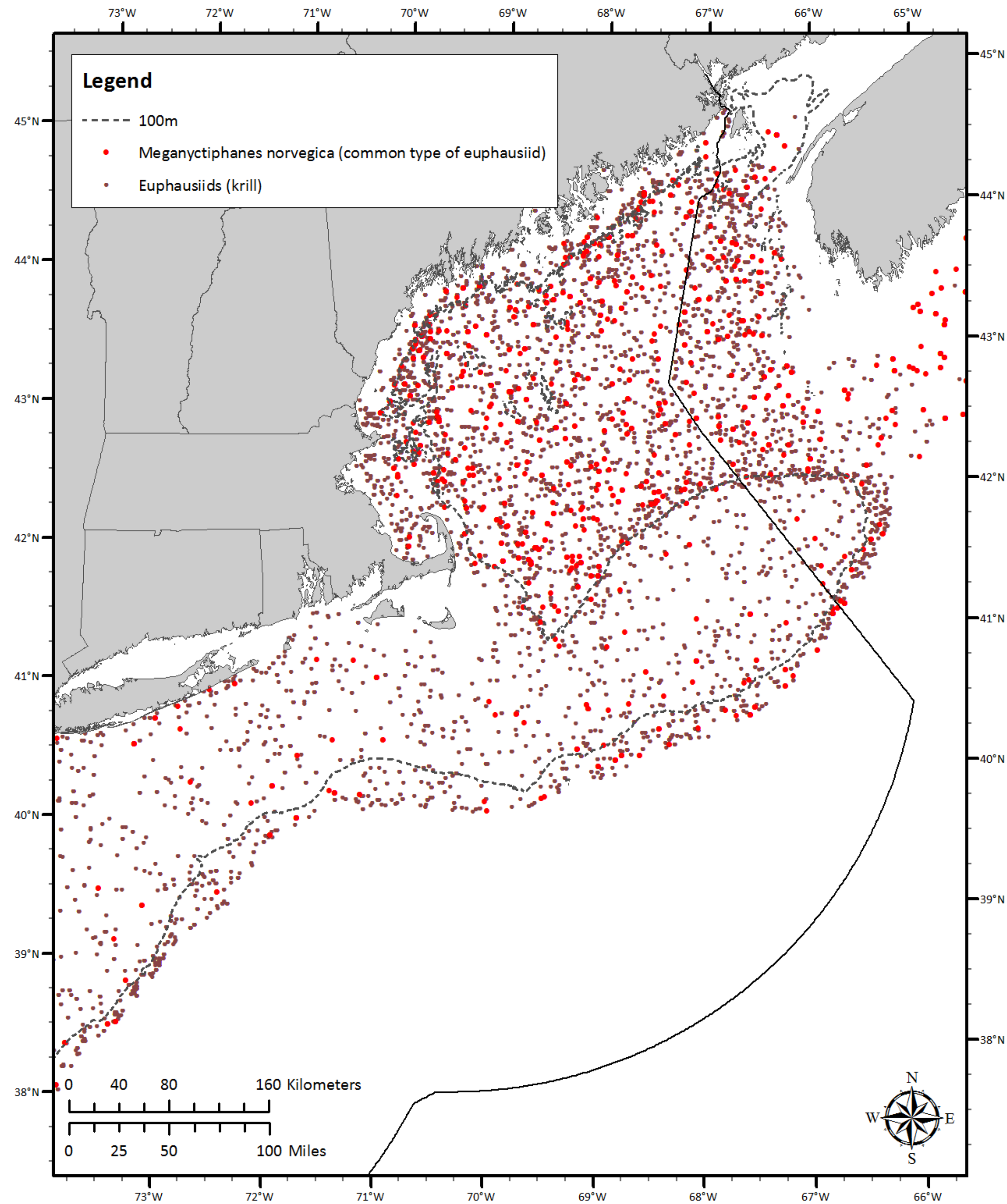
Map 10 - Polychaetes



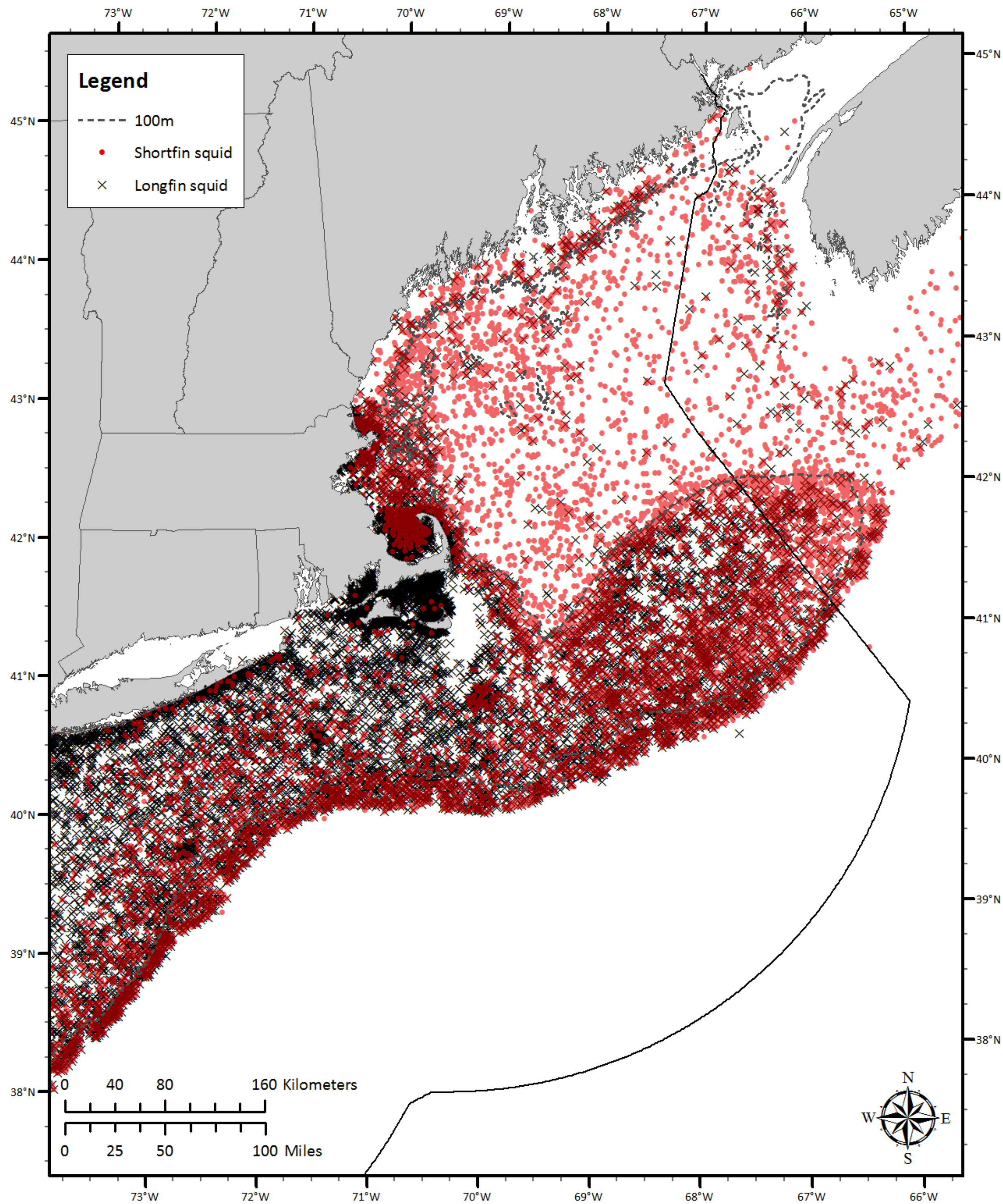
Map 11 – Mysid (opossum) shrimp



Map 12 - Euphausiids

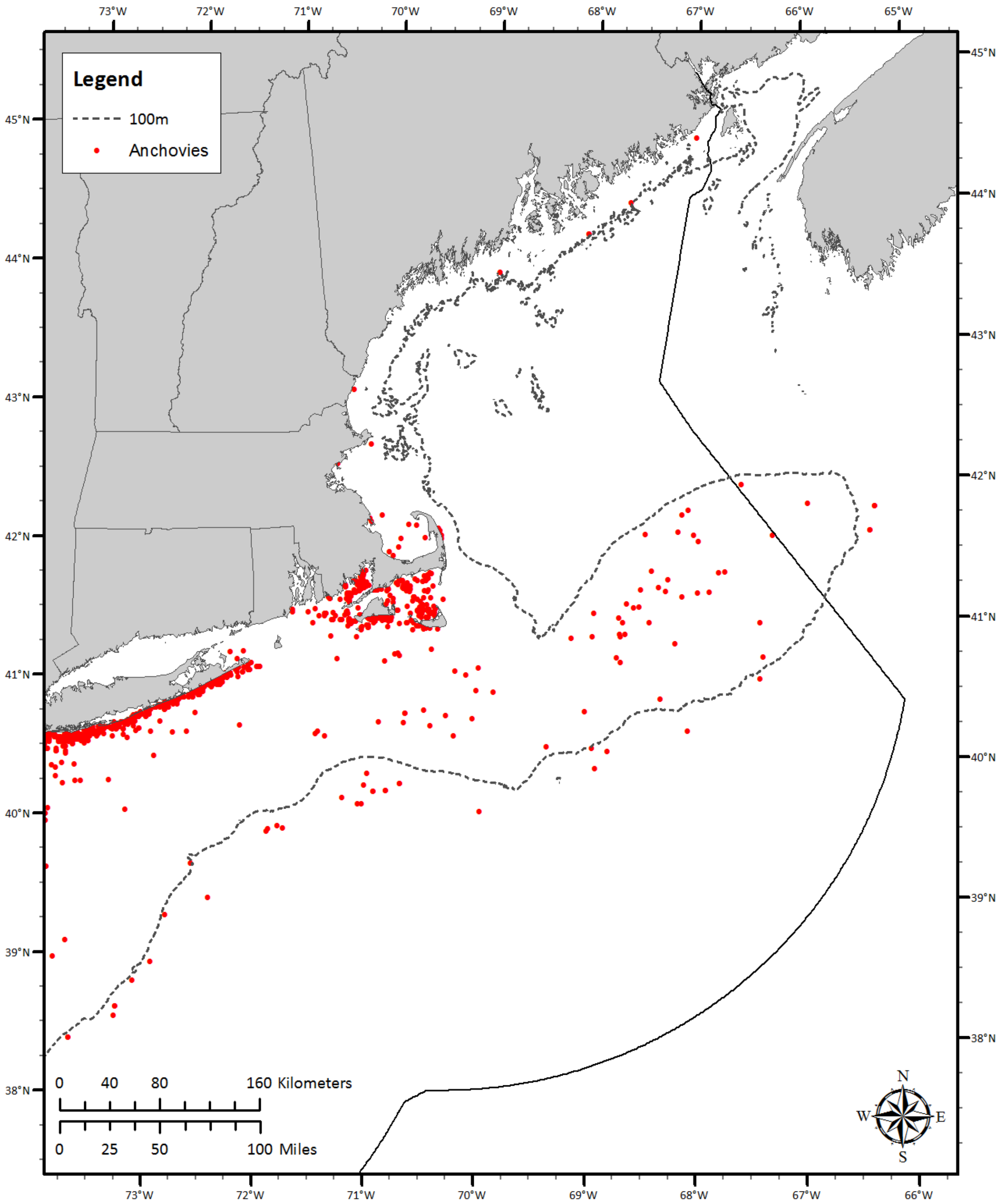


Map 13 – Squids

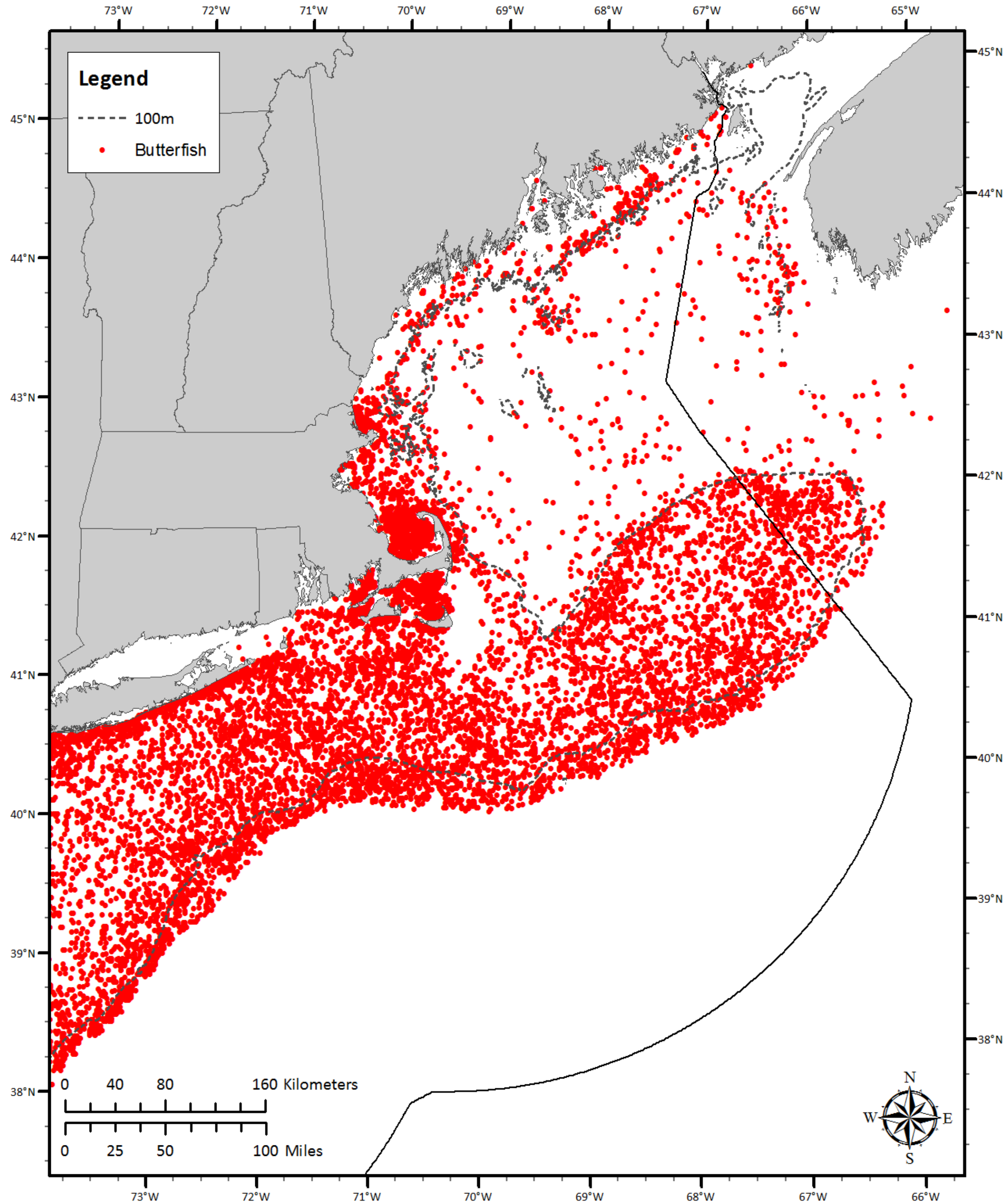


5.2 Fishes

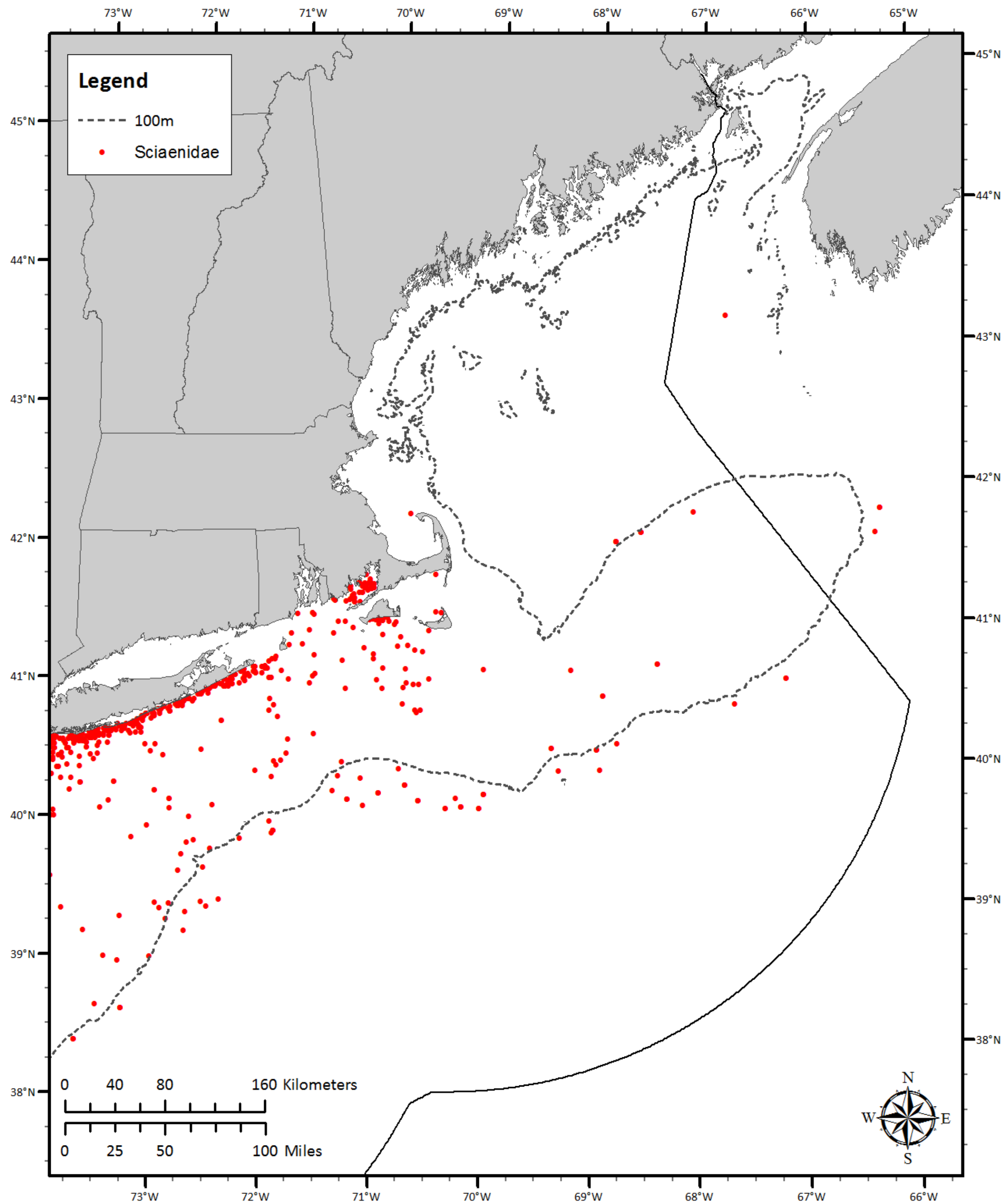
Map 14 - Anchovies



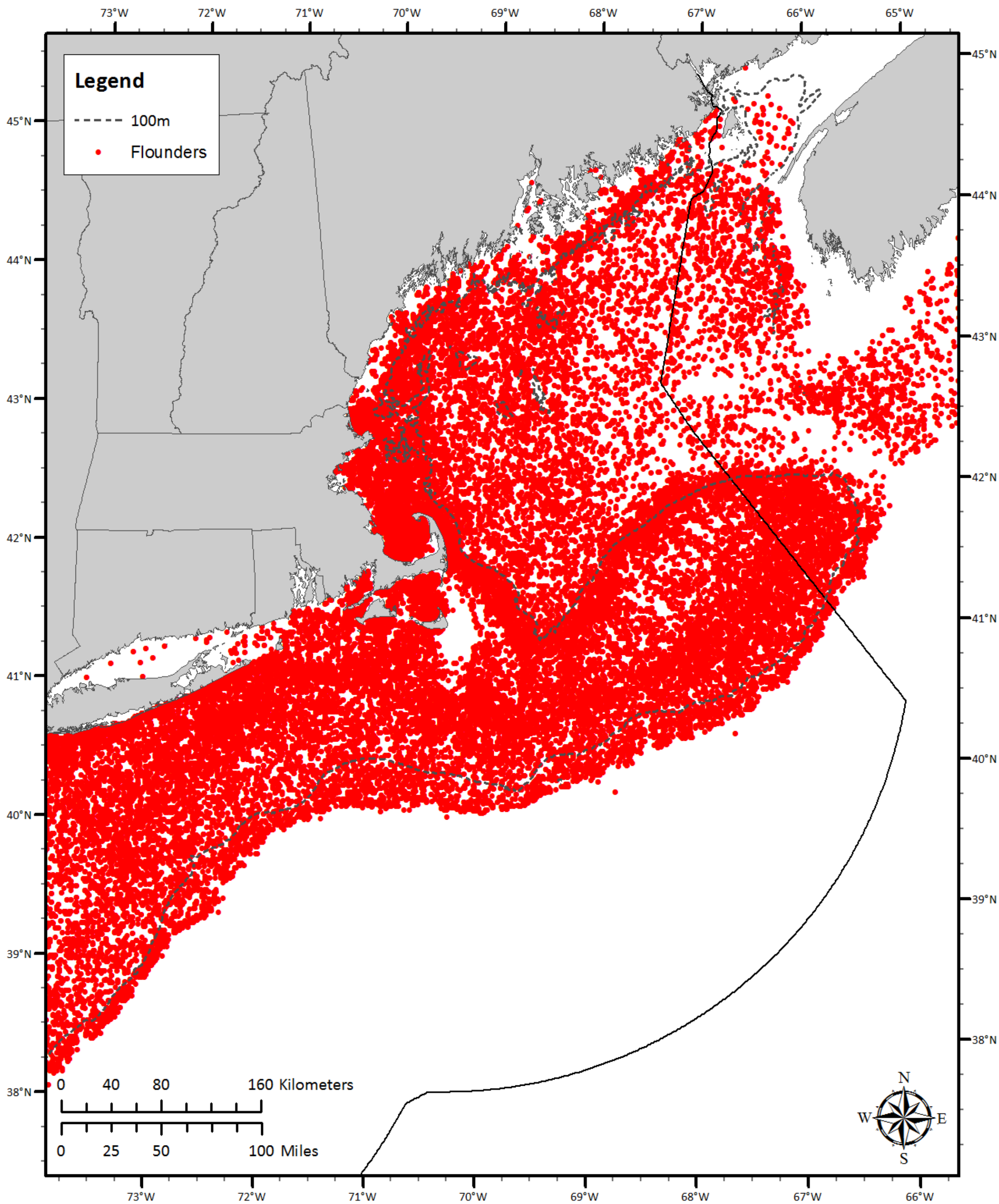
Map 15 - Butterfish



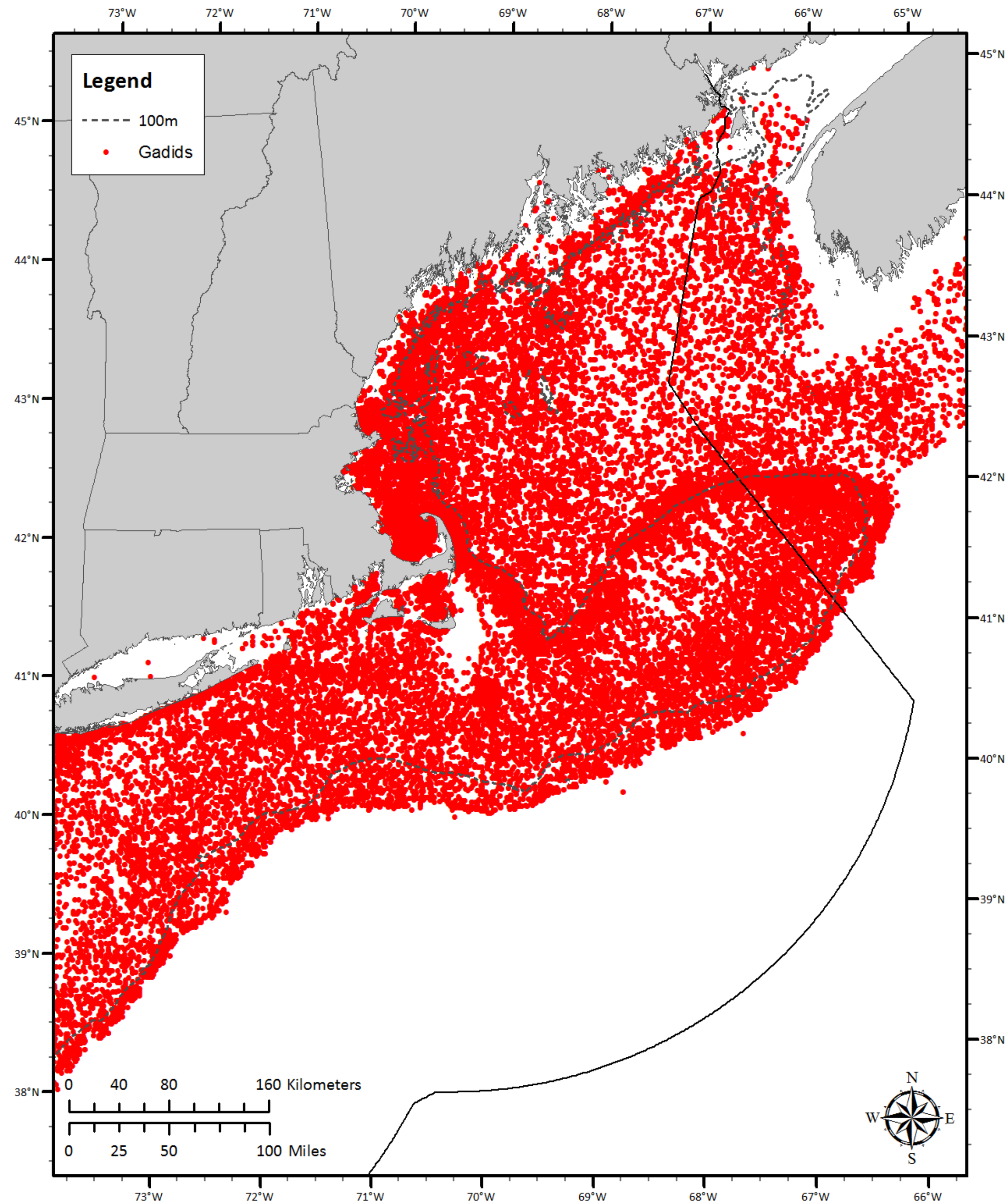
Map 16 – Sciaenids (drums, croakers, etc.)



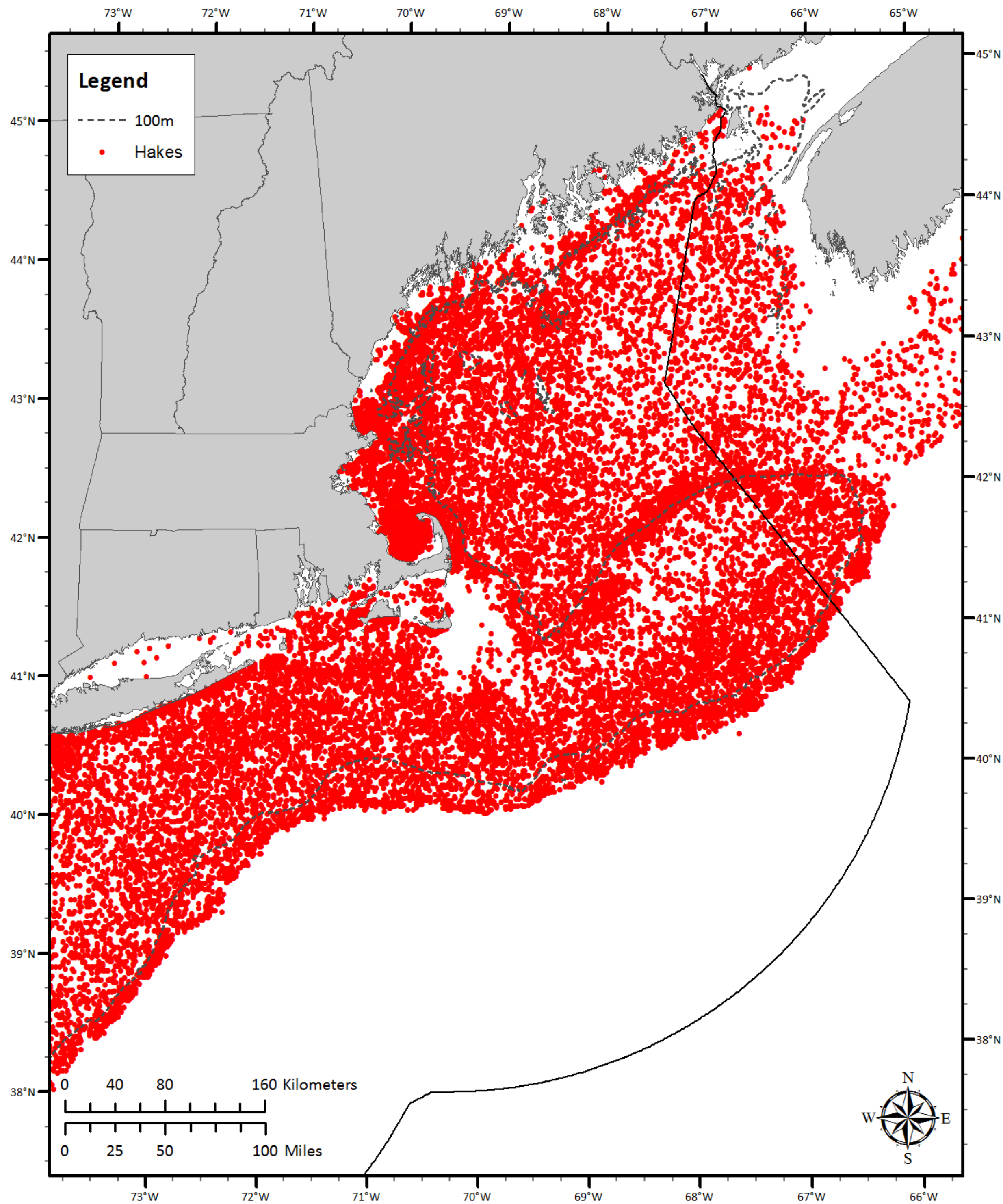
Map 17 – Flounders



Map 18 – Gadids



Map 19 – Hakes


Legend
100m
Hakes
73°W
72°W
71°W
70°W
69°W
68°W
67°W
66°W
65°W
45°N
44°N
43°N
42°N
41°N
40°N
39°N
38°N
0
40
80
160 Kilometers
0
25
50
100 Miles
N
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E
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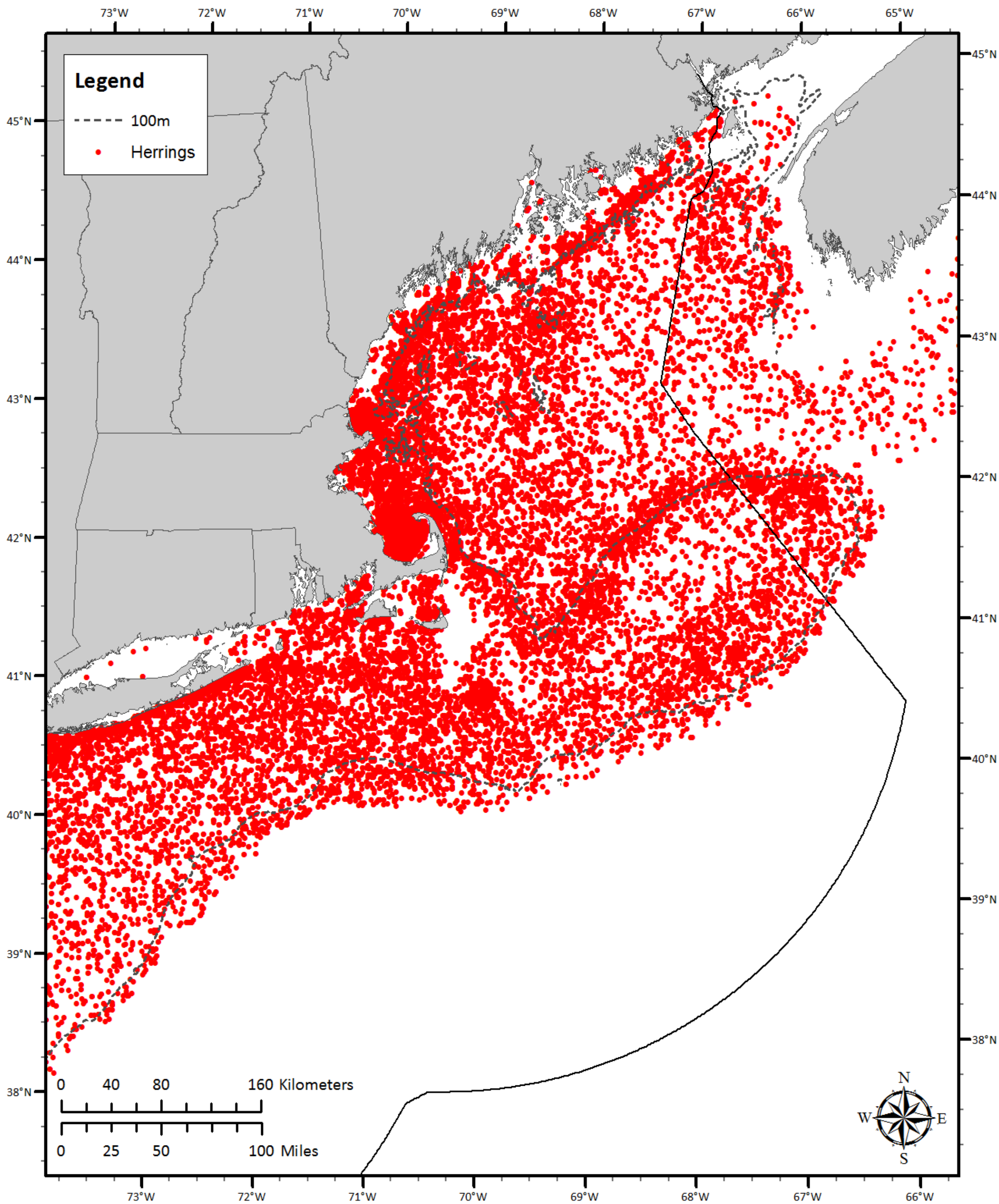
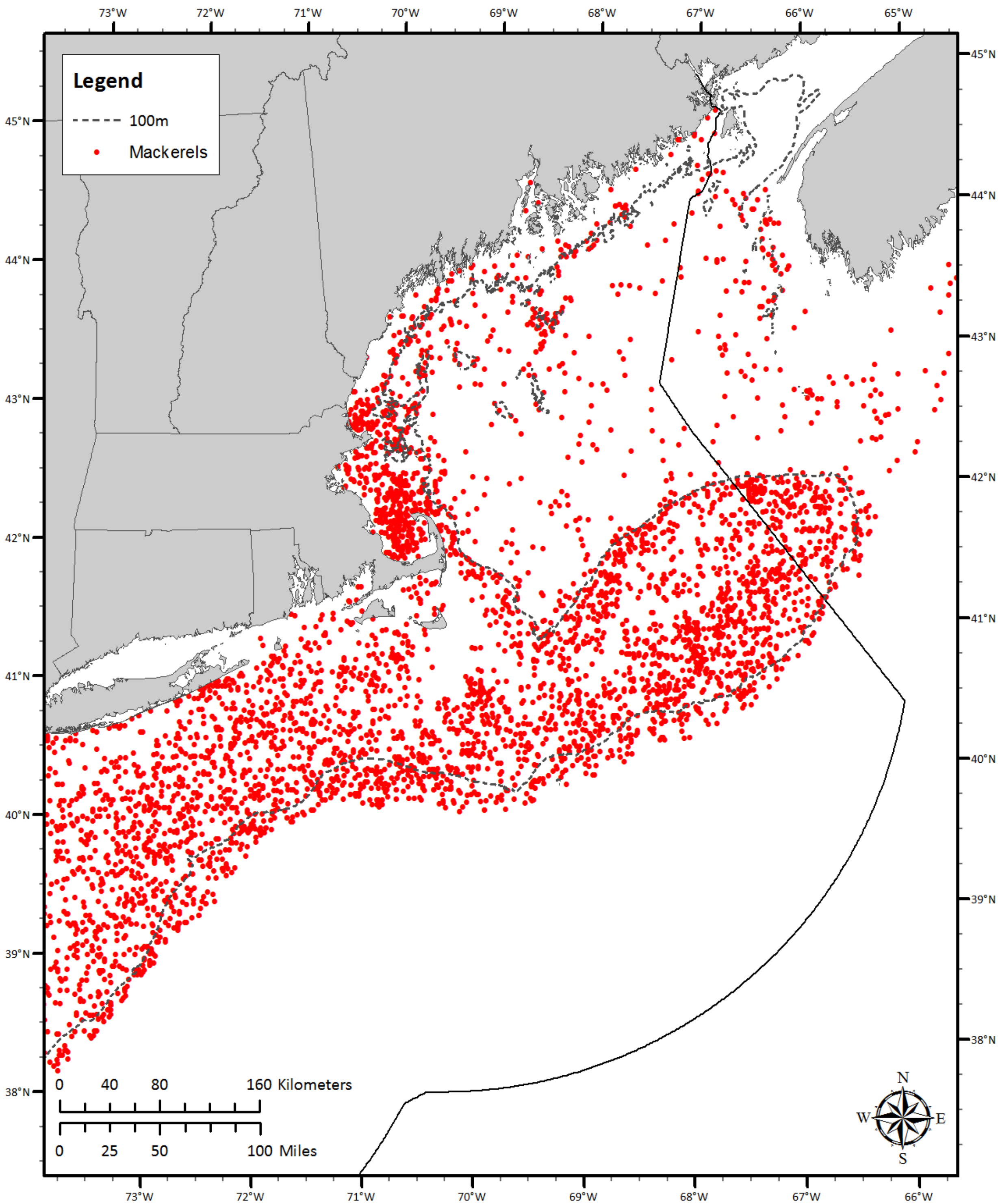
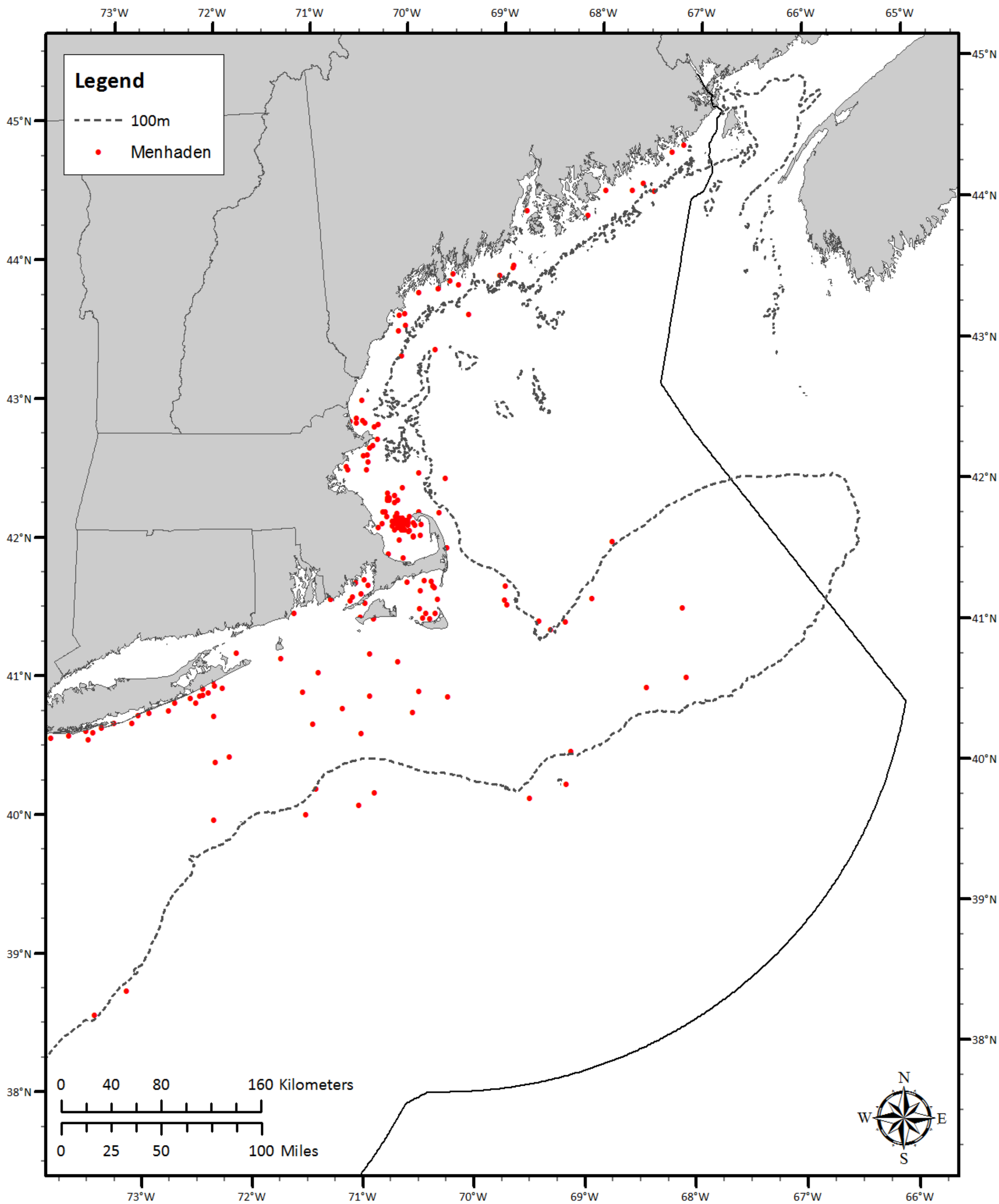
Map 20 – Herrings



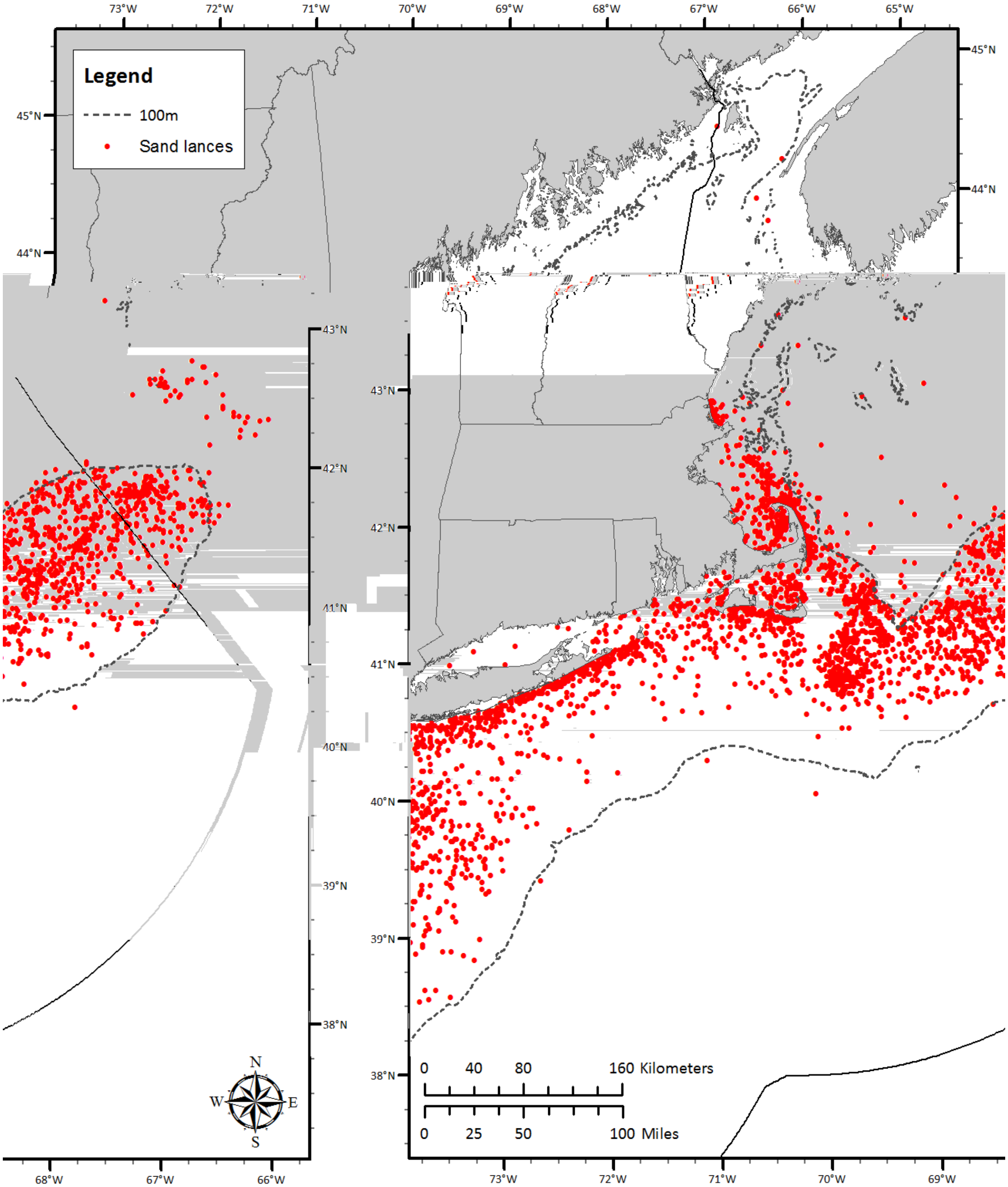
Map 21 – Mackerels



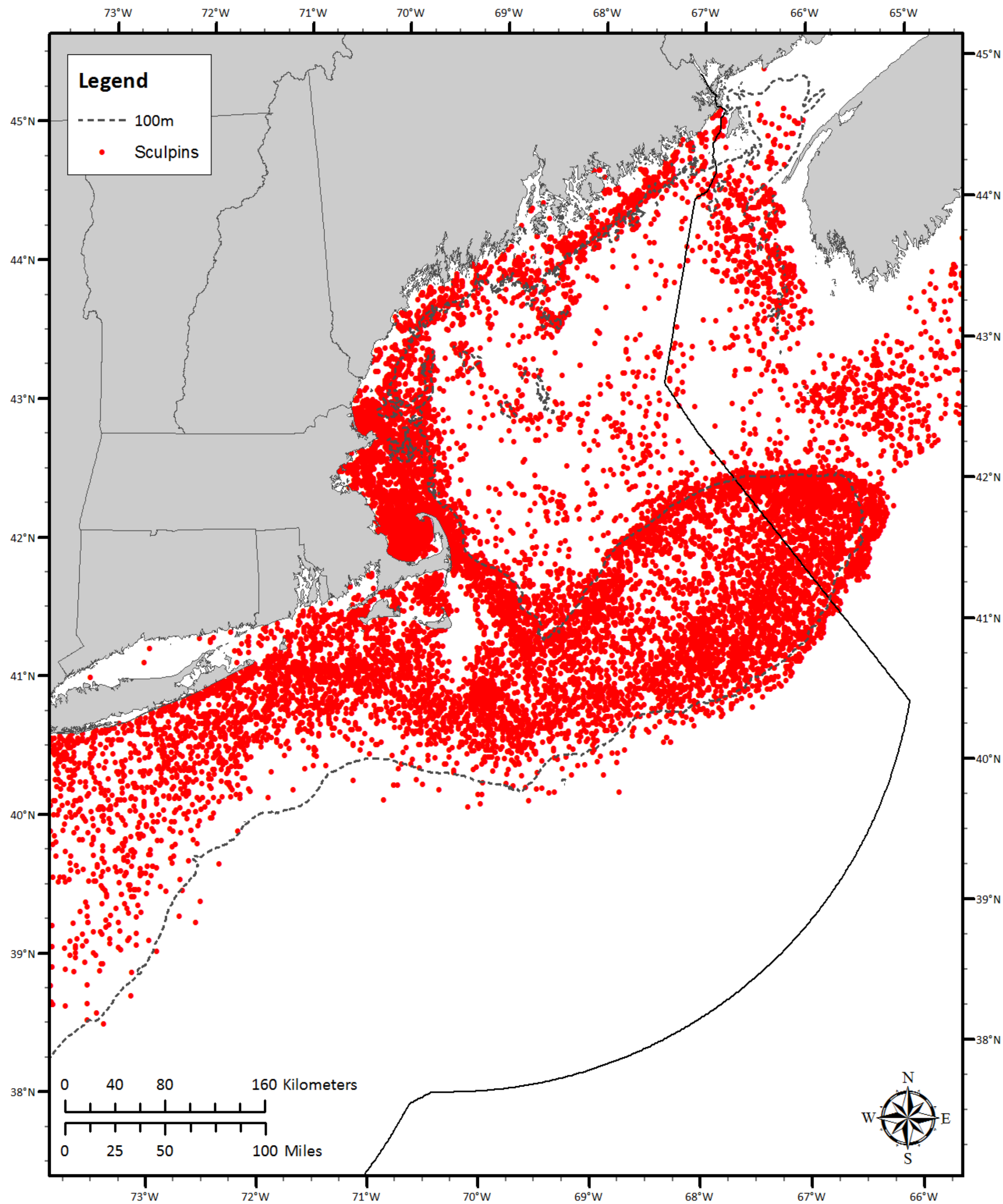
Map 22 – Menhaden



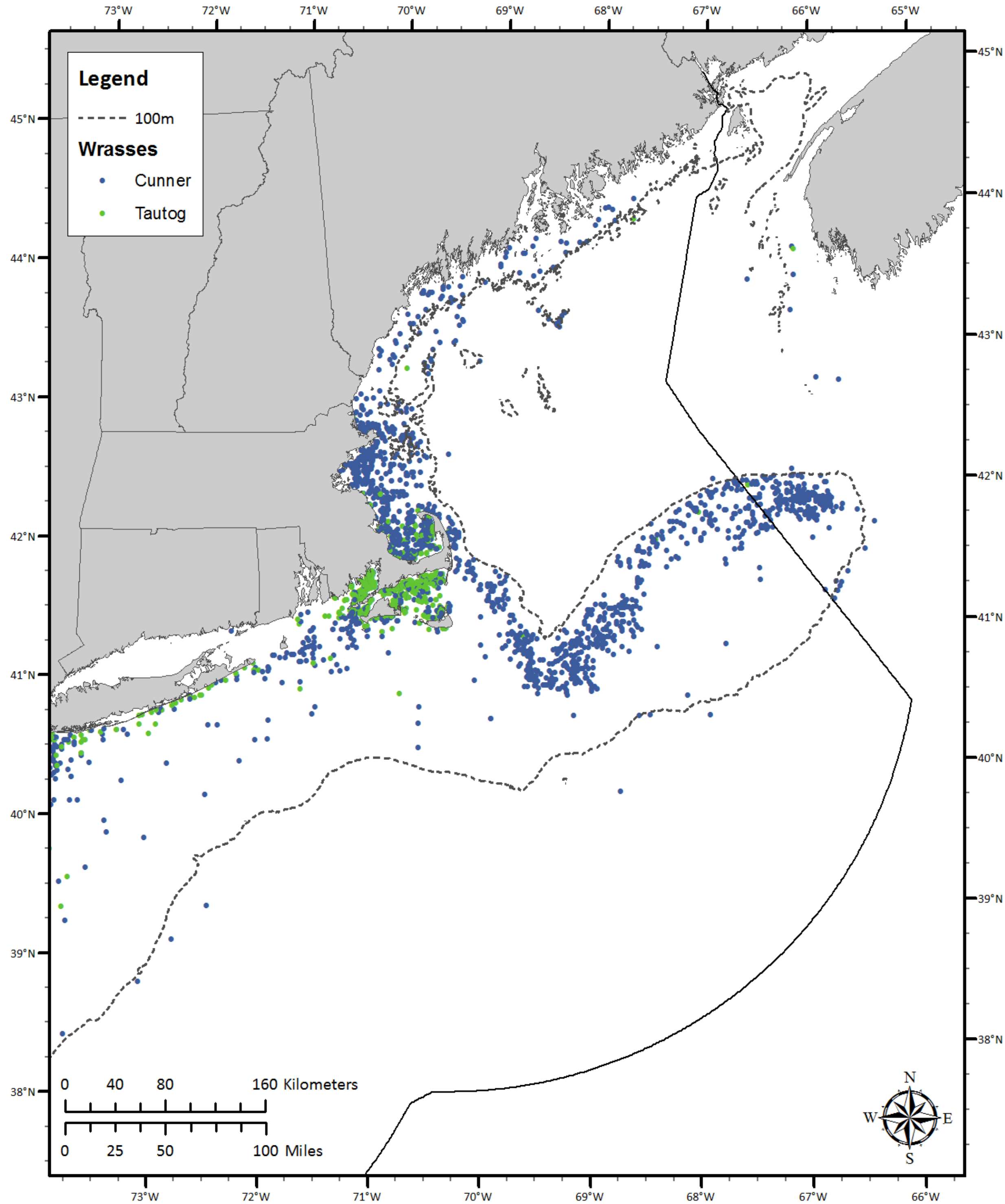
Map 23 – Sand lances



Map 24 – Sculpins



Map 25 – Wrasses (cunner and tautog)



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