NOAA Technical Memorandum NMFS-NE-178

Essential Fish Habitat Source Document:

Thorny Skate, *Amblyraja radiata*, Life History and Habitat Characteristics

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

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This series represents a secondary level of scientific publishing. All issues employ thorough internal scientific review; some issues employ external scientific review. Reviews are -- by design -- transparent collegial reviews, not anonymous peer reviews. All issues may be cited in formal scientific communications.

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Thorny Skate, *Amblyraja radiata*, Life History and Habitat Characteristics

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Woods Hole, Massachusetts

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Editorial Notes on Issues 122-152, 163, and 173-179 in the *NOAA Technical Memorandum NMFS-NE* Series

Editorial Production

For Issues 122-152, 163, and 173-179, staff of the Northeast Fisheries Science Center's (NEFSC's) Ecosystems Processes Division have largely assumed the role of staff of the NEFSC's Editorial Office for technical and copy editing, type composition, and page layout. Other than the four covers (inside and outside, front and back) and first two preliminary pages, all preprinting editorial production has been performed by, and all credit for such production rightfully belongs to, the staff of the Ecosystems Processes Division.

Internet Availability

Issues 122-152, 163, and 173-179 have been copublished, *i.e.*, both as paper copies and as Web postings. All Web postings are available at: *www.nefsc.noaa.gov/nefsc/habitat/efh*. Also, all Web postings are in "PDF" format.

Information Updating

By federal regulation, all information specific to Issues 122-152, 163, and 173-179 must be updated at least every five years. All official updates will appear in the Web postings. Paper copies will be reissued only when and if new information associated with Issues 122-152, 163, and 173-179 is significant enough to warrant a reprinting of a given issue. All updated and/or reprinted issues will retain the original issue number, but bear a "Revised (Month Year)" label.

Species Names

The NMFS Northeast Region's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes (*i.e.*, Robins *et al.* 1991[a]), mollusks (*i.e.*, Turgeon *et al.* 1998[b]), and decapod crustaceans (*i.e.*, Williams *et al.* 1989[c]), and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals (*i.e.*, Rice 1998[d]). Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species (*e.g.*, Cooper and Chapleau 1998[e]; McEachran and Dunn 1998[f]).

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[a]Robins, C.R. (chair); Bailey, R.M.; Bond, C.E.; Brooker, J.R.; Lachner, E.A.; Lea, R.N.; Scott, W.B. 1991. Common and scientific names of fishes from the United States and Canada. 5th ed. *Amer. Fish. Soc. Spec. Publ.* 20; 183 p.

[b]Turgeon, D.D. (chair); Quinn, J.F., Jr.; Bogan, A.E.; Coan, E.V.; Hochberg, F.G.; Lyons, W.G.; Mikkelsen, P.M.; Neves, R.J.; Roper, C.F.E.; Rosenberg, G.; Roth, B.; Scheltema, A.; Thompson, F.G.; Vecchione, M.; Williams, J.D. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. *Amer. Fish. Soc. Spec. Publ.* 26; 526 p.

[c]Williams, A.B. (chair); Abele, L.G.; Felder, D.L.; Hobbs, H.H., Jr.; Manning, R.B.; McLaughlin, P.A.; Pérez Farfante, I. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. *Amer. Fish. Soc. Spec. Publ.* 17; 77 p.

[d]Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. *Soc. Mar. Mammal. Spec. Publ.* 4; 231 p.

[e]Cooper, J.A.; Chapleau, F. 1998. Monophyly and interrelationships of the family Pleuronectidae (Pleuronectiformes), with a revised classification. *Fish. Bull. (U.S.)* 96:686-726.

[f]McEachran, J.D.; Dunn, K.A. 1998. Phylogenetic analysis of skates, a morphologically conservative clade of elasmobranchs (Chondrichthyes: Rajidae). *Copeia* 1998(2):271-290.

FOREWORD

One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats.

Magnuson-Stevens Fishery Conservation and Management Act (October 11, 1996)

The long-term viability of living marine resources depends on protection of their habitat.

NMFS Strategic Plan for Fisheries Research (February 1998)

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), which was reauthorized and amended by the Sustainable Fisheries Act (1996), requires the eight regional fishery management councils to describe and identify essential fish habitat (EFH) in their respective regions, to specify actions to conserve and enhance that EFH, and to minimize the adverse effects of fishing on EFH. Congress defined EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The MSFCMA requires NMFS to assist the regional fishery management councils in the implementation of EFH in their respective fishery management plans.

NMFS has taken a broad view of habitat as the area used by fish throughout their life cycle. Fish use habitat for spawning, feeding, nursery, migration, and shelter, but most habitats provide only a subset of these functions. Fish may change habitats with changes in life history stage, seasonal and geographic distributions, abundance, and interactions with other species. The type of habitat, as well as its attributes and functions, are important for sustaining the production of managed species.

The Northeast Fisheries Science Center compiled the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils. That information is presented in this series of 38 EFH species reports (plus one consolidated methods report). The EFH species reports are a survey of the important literature as well as original analyses of fishery-independent data sets from NMFS and several coastal states. The species reports are also the source for the current EFH designations by the New England and Mid-Atlantic Fishery Management Councils, and understandably have begun to be referred to as the "EFH source documents."

NMFS provided guidance to the regional fishery management councils for identifying and describing EFH of their managed species. Consistent with this guidance, the species reports present information on current and historic stock sizes, geographic range, and the period and location of major life history stages. The habitats of managed species are described by the physical, chemical, and biological components of the ecosystem where the species occur. Information on the habitat requirements is provided for each life history stage, and it includes, where available, habitat and environmental variables that control or limit distribution, abundance, growth, reproduction, mortality, and productivity.

Identifying and describing EFH are the first steps in the process of protecting, conserving, and enhancing essential habitats of the managed species. Ultimately, NMFS, the regional fishery management councils, fishing participants, Federal and state agencies, and other organizations will have to cooperate to achieve the habitat goals established by the MSFCMA.

A historical note: the EFH species reports effectively recommence a series of reports published by the NMFS Sandy Hook (New Jersey) Laboratory (now formally known as the James J. Howard Marine Sciences Laboratory) from 1977 to 1982. These reports, which were formally labeled as *Sandy Hook Laboratory Technical Series Reports*, but informally known as "Sandy Hook Bluebooks," summarized biological and fisheries data for 18 economically important species. The fact that the bluebooks continue to be used two decades after their publication persuaded us to make their successors – the 38 EFH source documents – available to the public through publication in the *NOAA Technical Memorandum NMFS-NE* series.

JAMES J. HOWARD MARINE SCIENCES LABORATORY
HIGHLANDS, NEW JERSEY
SEPTEMBER 1999

JEFFREY N. CROSS, (FORMER) CHIEF
ECOSYSTEMS PROCESSES DIVISION
NORTHEAST FISHERIES SCIENCE CENTER

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INTRODUCTION

The thorny skate [*Amblyraja radiata* (Donovan 1808); formerly *Raja radiata*, see McEachran and Dunn (1998); Figure 1] occurs on both sides of the Atlantic. In the western North Atlantic, it ranges from western Greenland, Davis straits, Hudson straits, Hudson Bay and Labrador to South Carolina. In the eastern North Atlantic, it ranges from Iceland, eastern Greenland, Barents Sea and off the coast of Spitzbergen to the English Channel and the southwestern coasts of Ireland and England (Bigelow and Schroeder 1953a, b; Stehmann and Bürkel 1984; McEachran 2002). Bigelow and Schroeder (1953a) also reported that in the east it extends from the White Sea and Barents Sea to the North Sea, Dutch coast, and western part of Baltic. In the eastern South Atlantic it is found off South Africa (Hulley 1970). Thorny skate is one of the most abundant skates encountered in the Gulf of St. Lawrence, off northeastern and southeastern Nova Scotia, and in the Gulf of Maine (McEachran and Musick 1975). This paper will focus mostly on the life history and habitat characteristics of thorny skate in the western Atlantic, especially in United States waters.

McEachran (2002) distinguishes thorny skates from other skates in the Gulf of Maine by a combination of the following characters: the rostrum is stout and extends distinctly anterior to the anterior-most pectoral rays. Thorns with radiate bases are present in a single row along the midline of the disc and tail. The mid-row thorns from nuchal region to origin of first dorsal fin range from 11to 19.

LIFE HISTORY

The single fertilized egg is encapsulated in an amber to brown egg case (Figure 2). The cases are rectangular in shape, with a hollow curved horn at each corner, and range in size from 48-96 mm long and 34-77 mm wide (McEachran 2002). In the Canadian Atlantic, case size increases with female skate length; cases are also larger in skates that become sexually mature at larger sizes compared to skates that become sexually mature at smaller sizes (Templeman 1982a). The dorsal surface of the case is strongly convex and the ventral surface is nearly flat. The cases are covered with longitudinal rows of tubercles. The horns are stout and less than the length of the capsule excluding the horns. The anterior horns are curved inward and are shorter than the posterior horns (McEachran 2002). The development of the egg case is described by Templeman (1982a). Berestovskii (1994) doing laboratory studies on Barents Sea skates, produced hatchlings that were 104-114 mm in length.

Females with fully formed egg capsules are captured over the entire year (Templeman 1982a), although the percentage of mature females with capsules is higher during the summer (McEachran 2002). Bigelow and Schroeder (1953a) reported that females with ripe eggs have been taken in Nova Scotian waters or in the Gulf of Maine in April, June, July, and September, and in January and February off Norway, and from February to June in Scottish waters. In the low temperature environment of the Barents Sea, Berestovskii (1994) believes that with year-round reproduction, females deposit 10-20 capsules/yr.

On the eastern Scotian Shelf during 1996, Simon and Frank (1996) found that nearly all sampled thorny skate < 50 cm TL were immature and nearly all individuals > 50 cm TL were mature. The results were comparable to maturity studies conducted by Templeman (1982a; 1987a) on the Newfoundland shelf. In other areas of the northwest Atlantic, Templeman (1987a) found size at maturity (L_{50}) ranges for females to be 44-47 cm TL for Baffin Island – Labrador Shelf (same for northern Iceland and West Greenland), 50-53 cm TL for the Gulf of St. Lawrence, and 65-74 cm TL for Grand Bank and St. Pierre Bank. Based on the predictive equations from Frisk *et al*. (2001) and the Northeast Fisheries Science Center (NEFSC) survey maximum observed length of 111 cm TL, L_{mat} is estimated at 84 cm TL and A_{mat} is estimated at 7 years (Northeast Fisheries Science Center 2000b). Size and age at maturity is lower for European thorny skate (Vinther 1989; van Steenbergen 1994); for example, in the North Sea, Skjæraasen and Bergstad (2000) report the L_{mat} to be 45 cm TL, while Walker and Hislop (1998) report L_{mat} to be 40 cm TL and A_{mat} to be 5 years. [See also Templeman (1987b) for a discussion comparing the length-weight relationships of thorny skate with their sexual maturity in the northwest Atlantic.]

The maximum size of adult thorny skate varies over the species range. (McEachran 2002). European thorny skate (e.g., from the North Sea) are smaller than those from Iceland and North America. Maximum sizes reported include 102 cm TL from Nova Scotia, 89.5 cm TL from Georges Bank, 80.0 TL from Massachusetts Bay, and 93.5 cm TL from off of New Jersey (Vladykov 1936; Scott and Scott 1988; McEachran 2002). Templeman (1987a) also noted that in the northwest Atlantic, in areas where sexual maturity occurs at small lengths, the maximum sizes were typically small, and in areas where sexual maturity occurs only at much greater lengths, the maximum sizes were considerably larger.

Based on tagging studies (Templeman 1984), thorny skate live up to 20 years.

FOOD HABITS

Prey of thorny skate in the western North Atlantic includes hydrozoans, aschelminths, gastropods, bivalves, squids, octopus, polychaetes, pycnogonids, copepods, stomatopods (larvae), cumaceans, isopods, amphipods, mysids, euphausids, shrimps, hermit crabs, crabs, holothuroideans, and fishes (Bigelow and Schroeder 1953a; McEachran 1973; McEachran *et al*. 1976; Templeman 1982b; Robichaud 1991; Pedersen 1995; Bowman *et al*. 2000; Garrison 2000; Garrison and Link

2000; Avent *et al*. 2001). It is an opportunistic feeder on the most abundant and available prey species in an area (Robichaud 1991; Pedersen 1995; also Skjæraasen and Bergstad 2000 for the North Sea).

McEachran (1973) studied skates collected from Nova Scotia to Cape Hatteras during 1967-1970; the following diet descriptions are from him and McEachran *et al*. (1976).

Polychaetes and decapods were the major prey items eaten, followed by amphipods and euphausids. Fishes and mysids contributed little to the diet.

Nephtys spp. and *Glycera* spp. were the most frequently eaten polychaetes on Georges Bank while *Nephtys* spp., *Eunice pennata*, and *Aphrodite hastata* were the most abundant polychaetes eaten in the Gulf of Maine and on the Nova Scotian shelf.

Orchomonella minuta and *Leptocheirus pinguis* were the most numerous amphipod prey in the Mid-Atlantic Bight, while *L. pinguis*, ampeliscids, and *Orchomonella* sp. were the most frequently eaten amphipods on Georges Bank. *Pontogeneia inermis* and *Tmetonyx* sp. were the most abundant amphipods eaten in the Gulf of Maine, while on the Nova Scotian shelf ampeliscids and *L. pinguis* were the most frequently eaten amphipods. On Georges Bank, *Hyas* sp., *Eualus pusiolus*, *Dichelopandalus leptocerus*, and *Crangon septemspinosa* were the most frequently eaten decapods. *Pandalus* spp., *Pagurus pubescens*, *Axius serratus*, and *Pasiphaea* sp. were the dominant species eaten in the Gulf of Maine. *Hyas* sp., *P. pubescens*, *E. pusiolus*, *A. serratus* were the major decapod prey eaten on the Nova Scotian shelf.

Meganctiphanes norvegica was the only euphausid in the diet. The mysids eaten were *Neomysis americana* and *Erythrops erythrophthalma*.

The most commonly eaten fishes were sand lance, longhorn sculpin, and Atlantic hagfish.

There was no indication of periodicity in intensity of feeding, although most of the euphausids were observed in skates that were collected during the night or early morning.

Templeman (1982b) conducted diet studies on skate from West Greenland to Georges Bank (1947-1967) and found that fish made up 74% of the stomach contents. The most important fish prey were redfish, haddock, and sand lance, as well as fish offal consisting of both cod and haddock. The large quantities of some of these prey fishes (e.g., haddock) and the offal came mainly from skates caught on Grand Bank and St. Pierre Bank. The higher percentage of fish prey in this study compared to the McEachran (1973) and McEachran *et al*. (1976) studies may be due to the relatively greater number of large skates caught and to extensive feeding by the skate on cod and haddock offal and on small haddock, which had been discarded in large quantities by fishing vessels on Grand Bank and St. Pierre Bank during that time period. Apparently, it is not uncommon for thorny skate to be feeding on trawler discards, as Berestovskiy (1989) also noted for thorny skate in the Barents and Norwegian Seas. In the Templeman (1982b) study, invertebrates constituted 25% of the stomach contents, important groups included decapods (spider and hermit crabs), cephalopods, and polychaetes. The most numerous prey items, in descending order of occurrence, were crabs, polychaetes, shrimps, sand lance, amphipods, and capelin.

McEachran (1973) and McEachran *et al*. (1976) found that the diet of thorny skate was size dependent. Fish ≤ 40 cm TL fed mostly on amphipods while fish > 40 cm TL fed mostly on polychaetes and decapods. Mysids decreased in the diet while fishes increased with increase in size of the skate. Fishes were a major component of the diet of skates > 70 cm TL. Consumption of euphausids was independent of skate size (McEachran 1973; McEachran *et al*. 1976). In Passamaquoddy Bay there was also a significant difference in the food habits between thorny skate ≤ 40 cm TL and those > 40 cm TL (Tyler 1972). The principal prey of the smaller skates were euphausids (*M. norvegica*), mysids (*Mysis stenolepis*), polychaetes (*Aphrodite aculeata*, *Lumbrineris fragilis*, *Nephtys incisa*, *Clymenella torquata*), and amphipods (*Unciola leucopis*). Larger skates ate decapods (*Hyas araneus*) and polychaetes (*A. aculeata*, and *N. incisa*). As in the McEachran (1973) and McEachran *et al*. (1976) studies, amphipods decreased and decapods increased in importance with increase in predator size; however, unlike those two studies, Tyler (1972) found that euphausids were important to only the smaller skates and polychaetes were important to both size classes. Templeman's (1982b) study found that the stomachs of smaller (21-60 cm TL) skates contained higher proportions of cephalopods, polychaetes, and amphipods and lower proportions of fish than the larger (61-102 cm) skates. Pedersen (1995) studied the feeding habits of thorny skate collected off of West Greenland during 1990-1991 and found that skates < 20 cm TL fed primarily on copepods, gammarids, mysids, and polychaetes, while skates > 19 cm TL fed on northern shrimp (*Pandalus borealis*) and redfish. As both Pedersen (1995) and Skjæraasen and Bergstad (2000) note, the feeding habits of thorny skate are size-dependent, but the food composition varies among the areas studied and the skate consumes a wide variety of both invertebrates and fishes which may reflect differences in prey availability. [For a discussion of the food habits and size-related shifts in diet of thorny skate from other regions, see the Pedersen (1995) and Skjæraasen and Bergstad (2000) studies.]

The 1973-1990 NEFSC food habits database for thorny skate [Figure 3; see Reid *et al*. (1999) for details] generally confirms the previous studies. Overall, crustaceans declined in importance with increasing skate size. Amphipods, which included species such as *Psammonyx nobilis* and *L. pinguis*, decreased with increasing skate size, while the percent occurrence of decapods, which included *C. septemspinosa*, *Cancer* and pagurid crabs, and pandalid shrimp, generally did not change with skate size. The percent occurrence of polychaetes, which included those from the Nephtyidae and Aphroditidae families, increased with increasing skate size until the skate were about 60 cm TL. Fish became noticeable in the diet of the larger skates, around > 50-60 cm TL, but were never a major component of the diet (at least as measured here in terms of percent occurrence).

The following is a detailed description of the diet from the NEFSC food habits database broken down by thorny skate size class (Figure 3).

For thorny skate 11-20 cm TL, 61-78% of the diet consisted of crustaceans, with 24-48% of the diet consisting of identifiable amphipods. The most abundant amphipod species included *Ericthonius rubricornis*, *Psammonyx nobilis*, *Monoculodes edwardsi*, and several unidentifiable gammarid amphipods. Identifiable decapods (11% of the diet during the 1973-1980 study period) included *C. septemspinosa* and *Cancer* and *Pagurus* crabs. Euphausids (*M. norvegica*), mysids (*E. erythrophthalma*), and cumaceans were also eaten. Identifiable polychaetes (15-34% of the diet) included those from the Nephtyidae and Aphroditidae families.

For skate 21-30 cm TL, 56-66% of the diet consisted of crustaceans, with 23-34% of the diet consisting of identifiable amphipods. Major amphipod species included *L. pinguis*, *Melita dentata*, and *Hippomedon serratus*. Identifiable decapods (5-10% of the diet) again included *C. septemspinosa* and *Cancer* and pagurid crabs. *Cirolana* (= *Politolana*?) *polita* was one of the identifiable isopods. Identifiable polychaetes made up 18-39% of the diet and included those from the Aphroditidae and Terebellidae families.

The percentage of crustaceans in the diet of thorny skate 31-40 cm TL dropped to 44-52%. Some of the more numerous identifiable amphipods (10-26% of the diet) included *P. nobilis*, *L. pinguis*, and *Byblis serrata*. *C. septemspinosa*, pagurid crabs, and *E. pusiolus* were the major identifiable decapod prey (8-15% of the diet). Identifiable polychaete prey (38-48% of the diet) included members of the families Aphroditidae, Nephtyidae, Lumbrineridae, as well as the species *Sternaspis scutata*.

The percent occurrence of crustaceans in the diet of thorny skate 41-50 cm TL was between 42-59%. Identifiable decapods (5-11% of the diet) included *C. septemspinosa*, pandalid shrimp, and *E. pusiolus*. Identifiable amphipods, which decreased to 8-17% of the diet, included *L. pinguis*, while identifiable euphausids (10% of the diet during the 1981-1990 study period) included *M. norvegica*. Identifiable polychaetes made up 35-50% of the diet; major families included the Aphroditidae and Nephtyidae.

The percent occurrence of crustaceans in the diet for skate 51-60 cm TL declined to 37-41%. Identifiable decapods (13-15% of the diet) included *E. pusiolus*, pandalid shrimp, pagurid crabs, and *D. leptocerus*. *M. norvegica* was a dominant euphausid (7% of the diet during the 1981-1990 study period). Among the polychaetes, which were 40-48% of the diet, were found members of the Nephtyidae (e.g., *N. discors*) and Aphroditidae (e.g., *A. hastata*) families, as well as *E. pennata*. The percent occurrence of identifiable fish in the diet increased to 5-11%.

The percent occurrence of crustaceans dropped to 34-40% for skate 61-70 cm TL. Among the identifiable decapods (13-23% of the diet) were pagurid crabs, pandalid shrimp, *Hyas* sp., *D. leptocerus*, and *C. septemspinosa*. Identifiable polychaetes (36-49% of the diet) again included members of the Nephtyidae and Aphroditidae families. The percent occurrence of identifiable fish in the diet increased to 10-14%.

For skate 71-80 cm TL, crustaceans made up 25-42% of the diet. Major identifiable decapods (16-18% of the diet) again included pagurid crabs, pandalid shrimp, *Hyas* sp., and *D. leptocerus*. Identifiable polychaetes made up 38-47% of the diet and included members of the Aphroditidae, Nephtyidae, Nereidae, Sabellidae, and Opheliidae families. The percent occurrence of identifiable fish in the diet increased to 13-17% and included sand lance, wrymouth, and silver hake.

Finally, the percent occurrence of crustaceans in the diet for skate 81-90 cm TL declined to 34-35%. Identifiable decapods (12-16% of the diet) included pandalid shrimp, *Hyas* sp., *Cancer* crabs, and *D. leptocerus*. *M. norvegica* was a dominant euphausid. Identifiable polychaetes comprised 31-35% of the diet, most of which were in the Nephtyidae, Aphroditidae, and Nereidae families. Identifiable fish, which made up 10-22% of the diet, included hagfish, wrymouth, and herring.

Using NEFSC data from 1977-1980, Bowman *et al*. (2000) found that in terms of percent weight, crustaceans and polychaetes were dominant in the diet of skate < 31-60 cm TL, while fish, including herring, sand lance, and wrymouth were dominant in the diet of skate 61-90 cm TL. Squid and herring dominated the diet of skate > 90 cm TL.

Templeman (1982b) found that fish made up 69% of the total food volume in the stomachs of skates from 17-200 m deep and 82% of skates from 201-700 m deep. Haddock and sand lance were the most important fish prey at the shallower depths, while redfish and sand lance were more important at greater depths. For invertebrates, crabs were most important as prey in the shallower depth range while cephalopods were most important at the deeper depth range. The shrimp, *Sergestes* sp., and octopus were found only in the stomachs of skates from depths > 400 m.

PREDATORS AND SPECIES ASSOCIATIONS

Thorny skate is eaten, at least as embryos within the egg capsules, by halibut, goosefish, and Greenland sharks, as well as predatory gastropods (e.g., naticid and muricid gastropods) (Jensen 1948; Cox *et al*. 1999;

Rountree 2001). Kulka and Mowbray (1998) report that around Newfoundland, thorny skate (juveniles/adults?) are preyed upon by seals, sharks, and halibut.

McEachran and Musick (1975) report that thorny and smooth skate (*Malacoraja senta*) had a high coefficient of associaton during 1967-1970 surveys from Nova Scotia to Cape Hatteras, and these two species were often negatively associated with little (*Leucoraja erinacea*) and winter (*Leucoraja ocellata*) skates. [However, see the Garrison (2000) study on Georges Bank, below.] They consider thorny and smooth skate to be sympatric species.

Co-occurrence, and possibly competition with thorny skate may have led to food specialization in smooth skate and could have caused the low abundance and low diversity of prey species in the diet of smooth skate (McEachran 1973; McEachran *et al*. 1976). Thorny skate has a diverse diet consisting of both infauna and epifauna while smooth skate has a very specialized diet consisting largely of epifauna, mostly amphipods, euphausids, decapods, and mysids (McEachran 1973; McEachran *et al*. 1976). Thorny skate also feeds on these prey items over part of the year, perhaps when the prey are in high abundance. Thorny skate is also the more widespread and abundant of the two.

Using 1973-1997 NEFSC data from Nova Scotia to Cape Hatteras, as well as the same NEFSC food habits database discussed above, Garrison and Link (2000) investigated the dietary guild structure of the fish community. Both small (10-30 cm TL) and medium (31-60 cm TL) sized thorny skate belonged to the "Benthivores" group, along with haddock, yellowtail flounder, winter flounder, witch flounder, gulfstream flounder, scup, American plaice, and croaker. Prey consisted mostly of polychaetes. The largest thorny skate (31 cm TL to > 80 cm TL) also belonged to a guild of the "Piscivores" group, along with spiny dogfish, Atlantic cod, silver hake, white hake, sea raven, goosefish, summer flounder, bluefish, spotted hake, fourspot flounder, and Atlantic sharpnose shark. Their prey consisted of a range of fish taxa including herrings, silver hake, scombrids, and sand lance; squid was also eaten.

The resilience of demersal fish assemblages on Georges Bank was investigated by Overholtz and Tyler (1985) using seasonal NEFSC trawl survey data from 1963-1978. Of the five assemblage species groups or associations present on Georges Bank in spring and fall throughout the survey period, thorny skate belonged to the "Gulf of Maine Deep" (on the northern edge of Georges Bank) and "Northeast Peak" assemblage groups. In the Gulf of Maine Deep assemblage the other major species present besides thorny skate included American plaice, witch flounder, white hake, silver hake, Atlantic cod, haddock, and cusk. In the Northeast Peak assemblage, Atlantic cod, haddock, pollock, white hake, winter flounder, ocean pout, and longhorn sculpin were some of the other major species. The two assemblages showed definite seasonal spatial changes between the spring and fall survey periods.

Garrison (2000) also investigated spatial assemblages and trophic groups from the Georges Bank region during spring and autumn using NEFSC trawl survey data as well as the same NEFSC food habits database discussed above. In terms of dietary guilds or trophic groups, the diet of thorny skate is similar to what was previously discussed in the Food Habits section above. In autumn, small (10-30 cm TL) and medium (31-60 cm TL) thorny skate were in the "Demersal predators" group, along with flatfish, haddocks, winter skate, and little skate. Prey included gammarid amphipods, polychaetes, isopods, *Cancer* crabs, and *C. septemspinosa*. Large (61-80 cm TL) thorny skate also belonged to the "Crab predators" group; prey included polychaetes and decapod crabs. During spring, small thorny skate was in the "Shrimp/amphipod predators" group, along with hakes, longhorn sculpin, Atlantic cod, fourspot flounder, winter skate, and little skate. Prey included gammarid amphipods, pandalids and *C. septemspinosa*, polychaetes, and *Cancer* crabs. Medium thorny skate was also in the "Demersal predators" group, along with yellowtail and winter flounder. Their diet consisted primarily of polychaetes and gammarid amphipods.

On the Scotian Shelf and in the Bay of Fundy, Scott (1989), using research trawl survey data from roughly 1970-1984 determined that the dominant mid-depth assemblage consisted of cod, haddock, and thorny skate. It was extremely strong in the Bay of Fundy, but diminished progressively southwest to northeast along the Scotian Shelf. Mahon (1997), also in surveys of the Scotian Shelf and Bay of Fundy from 1970-1993, discovered that thorny skate belonged to an assemblage found mainly in the mouth of the Bay of Fundy and the eastern Scotian Shelf. Major species in the assemblage from this study besides thorny skate included American plaice, smooth skate, and Vahl's eelpout.

GEOGRAPHICAL DISTRIBUTION

As stated in the Introduction, thorny skate is a boreal to arctic species found on both sides of the Atlantic, but whose center of abundance in the western North Atlantic extends northward from the Gulf of Maine probably as far as the Gulf of St. Lawrence, and is one of the most common or dominant skate species on the Grand Banks and northeast Newfoundland Shelf (McEachran and Musick 1975; Kulka and Mowbray 1998). In the west it has been reported from western Greenland, Davis straits, Hudson straits, Hudson Bay, the Atlantic coast of Labrador, east and south coasts of Newfoundland, Grand Banks, Gulf of St. Lawrence and outer coast of Nova Scotia, Banquereau, and Sable Island Bank, Bay of Fundy, Passamaquoddy Bay, Gulf of Maine, Massachusetts Bay, Georges Bank, the New Hampshire coast, and southward along the edge of the continental shelf to off of New York and as a stray off Charleston, South Carolina (Bigelow and Schroeder 1953a, b; Leim and Scott 1966, McEachran 1973; McEachran and Musick 1975; Nelson *et al*. 1983; Macdonald *et al*. 1984; Collette and Hartel 1988; Kulka and Mowbray 1998; McEachran 2002). In the Gulf of Maine, Bigelow and Schroeder (1953a) reported it from the vicinity of Mt. Desert Island, Platts Bank, and in deeper troughs, from Casco and Ipswich Bays, off Gloucester, Salem, Nahant, and Provincetown. McEachran and Musick (1975), during 1967-1970 surveys from Nova Scotia to Cape Hatteras, recorded thorny skate to be widespread along the eastern and northwestern slopes of Georges Bank. The NEFSC bottom trawl surveys from the Gulf of Maine to Cape Hatteras caught juvenile and adult thorny skates mostly in the Gulf of Maine and around the north and northeast perimeter of Georges Bank (see below).

Several reports indicate that thorny skate can make seasonal migrations and, conversely, be sedentary (Bigelow and Schroeder 1953a; Templeman 1984; Simon and Frank 1996; Kulka and Mowbray 1998; McEachran 2002). Seasonal migrations have been noted on the Scotian Shelf (Simon and Frank 1996) and the Grand Banks (Kulka and Mowbray 1998). In Passamaquoddy Bay it is a year-round resident (Tyler 1971) but Macdonald *et al*. (1984) noted that thorny skate increased in abundance during summer and declined after late fall and juveniles were often captured at beach sites during summer. Templeman (1984) tagged over 700 skates in the Newfoundland area and noted that within 20 years most of them were recaptured < 97 km from their tagging location. A few were recaptured 161-387 km from the tagging location after < 1 year to 11 years. Similarly, in the North Sea 85% of tagged thorny skate were recaptured within 93 km of their release point and the longest distance traveled was 180 km (Walker *et al*. 1997).

JUVENILES

NEFSC bottom trawl surveys [see Reid *et al*. (1999) for details] captured juvenile (≤ 83 cm TL) thorny skate year-round. (Note that winter and summer distributions are presented as presence/absence data, precluding a discussion of abundances.) In winter, juveniles were scattered throughout the Gulf of Maine and on the Northeast Peak of Georges Bank, as well as east/southeast of Cape Cod (Figure 4). In spring, great concentrations were found throughout the Gulf of Maine, Massachusetts Bay, the Bay of Fundy, the Scotian Shelf, and the perimeter of Georges Bank (Figure 5). In summer, juveniles also occurred in the same locations, although few were present on the southern perimeter of Georges Bank (Figure 6). There also appear to be more juveniles present along the coast of Maine than in the winter. In the fall, just like in the spring, dense concentrations were found throughout the Gulf of Maine, Massachusetts Bay, the Bay of Fundy, the Scotian Shelf, and especially around the perimeter of Georges Bank near the Northeast Peak (Figure 7).

Both the spring and fall 1978-2002 Massachusetts inshore trawl surveys [see Reid *et al*. (1999) for details] show concentrations of juvenile thorny skate around Cape Ann and into Massachusetts Bay, and in Cape Cod Bay (Figure 8). Higher concentrations were found northeast of Cape Ann and near Wellfleet Harbor on Cape Cod in the spring and southeast of Cape Ann in the fall. A scattered few were also found south of Cape Cod in the spring.

ADULTS

NEFSC bottom trawl surveys captured adult thorny skate (≥ 84 cm TL) during all seasons. The overall numbers of adults in spring and fall were much lower than for the juveniles during those same seasons. (As with the juveniles, the winter and summer distributions are presented as presence/absence data, precluding a discussion of abundances.) In winter, they occurred in the Gulf of Maine and on the northern edge of Georges Bank (Figure 9). In the spring, the adults were scattered throughout the Gulf of Maine, the Great South Channel, along the northern edge of Georges Bank, as well as the Scotian Shelf (Figure 10). Adults were also scattered throughout the Gulf of Maine in the summer (Figure 11). Distributions in the fall were similar to those in the spring (Figure 12).

Very few adult thorny skate were caught during the spring and fall Massachusetts inshore trawl surveys (Figure 13). They were found south of Cape Ann, in Massachusetts and Cape Cod Bays, and east of Cape Cod.

HABITAT CHARACTERISTICS

Information on the habitat requirements and preferences of thorny skate (based on both the pertinent literature and the most recent NEFSC and state surveys) are presented here and summarized in Tables 1 and 2.

The depth range of thorny skate is from approximately 18-1200 m. (McEachran 2002). It appears to be most common at 50-100 m in the northeast Atlantic (Stehmann and Bürkel 1984) and 37-108 m on the Scotian Shelf (Scott 1982a). McEachran and Musick (1975) in surveys during 1967-1970 from Nova Scotia to Cape Hatteras found it occurred between 27-439 m, but was most abundant between 111-366 m. Bigelow and Schroeder (1953b) reported its general depth range as 18-183 m, and as deep as 786-896 m off New York, although an isolated specimen was found from off Long Island at 59 m (Bigelow and Schroeder 1953b). Its maximum recorded depth is 1478-1540 m in the northeastern Norwegian Sea (Stehmann and Parin 1994). In Passamaquoddy Bay it has been found in 37-55 m waters (Tyler 1971). Bigelow and Schroeder (1953a) reported that thorny skate was frequently taken on the New

Brunswick side of the Bay of Fundy in waters ≥ 18 m or deeper, and in 37-55 m in St. Mary Bay on the Nova Scotia side. They also note that it is found in the Gulf of Maine in waters > 26 m, and down to 669 m along the upper part of the continental slope off southern New England. At the southern extreme of its range it is limited to the continental slope, and off Virginia it occurs at 300-1200 m (McEachran 2002), although isolated skates have previously been reported from off Charleston, South Carolina at 135 m (Bigelow and Schroeder 1953b). The spring and fall 1963-2002 NEFSC trawl surveys from the Gulf of Maine to Cape Hatteras (see below) indicated that juveniles were found at depths between 21-500 m and especially between 71-300 m (Figure 14). The adults were found at depths between 31-500 m, with most found between 141-300 m (Figure 16).

The temperature range of thorny skate from Nova Scotia to Cape Hatteras is from -1.3°C to 14°C (McEachran and Musick 1975), although it has been recorded down to -1.4°C off Labrador (Backus 1957) and only up to 10°C by Bigelow and Schroeder (1953a, b). On the Nova Scotian shelf it appears to have a temperature preference of 2-5°C (Scott 1982a; Scott and Scott 1988). Tyler (1971) recorded its temperature range in Passamaquoddy Bay as 1.2-10.2°C. The spring and fall 1963-2002 NEFSC trawl surveys from the Gulf of Maine to Cape Hatteras (see below) collected juveniles and adults over a temperatures range of about 2-16°C, with most found between about 4-9°C (Figures 14 and 16).

van Steenbergen (1994) compared the differences in reproduction and the storage of energy (food resources) in North Sea thorny skate in relation to their differences in distribution. One group of thorny skate that lived in a "warmer" area developed their gonads and reached maturity at a lower size than the group that lived in the "colder" area. The group of female skate that lived in the "colder" area stored more energy in the liver than the group that lived in the "warmer" area. These differences suggest a latitudinal influence in which temperature could play an important role.

Thorny skate is found over a wide variety of bottom types from sand, gravel, broken shell, pebbles, to soft mud (Bigelow and Schroeder 1953a; McEachran 2002). On the Scotian Shelf, Scott (1982b) reports that the distribution of thorny skate was widespread but mainly concentrated from the sandy bottom of the Sable Island facies to the sandy silt and clay of the LaHave facies. Scott (1982a) mentions that on the Scotian Shelf during the summers of 1970-1979, thorny skate was found at preferred salinities of 32-34 ppt.

EGGS

Berestovskii (1994) performed laboratory studies on the reproductive biology of Barents Sea skates. Successful incubation in the lab revealed that the development period of the embryos at temperatures ranging from –0.3-9.5°C lasted for 2-2.5 yrs. After hatching, juveniles consumed the internal supply of yolk and switched to active feeding in 2-4 months at temperatures of 2.5-4.5°C. Berestovskii (1994) extrapolates that in the low temperature environment of the Barents Sea, the embryonic development period for thorny skate must take 2.5-3 yrs.

JUVENILES

The spring and fall distributions of juvenile thorny skate relative to bottom water temperature, depth, and salinity based on 1963-2002 NEFSC bottom trawl surveys from the Gulf of Maine to Cape Hatteras are shown in Figure 14. In spring, they were found in waters between 2-13°C, with the majority at 4-8°C. Their depth range during that season was between 21-400 m, with most spread between 71-300 m. They were found over a salinity range of between 31-36 ppt, with the majority at 33 ppt. During the fall, juvenile thorny skate were caught over a temperature range of 3-16°C, with most found between 6-9°C and with close to 25% caught or occurring at 7°C. They were found over a depth range of 21-500 m, although most were found at depths between 91-300 m. They were found over a salinity range of between 31-35 ppt, with about 40% at 33 ppt.

The spring and autumn distributions of juveniles in Massachusetts coastal waters relative to bottom water temperature and depth based on 1978-2002 Massachusetts inshore trawl surveys are shown in Figure 15. In the spring they were found in waters ranging from about 2-16°C, with the greatest percentages found between 4-6°C. Their depth range was from 6-85 m, with the majority between 41-55 m. During the autumn they were found in waters ranging from 4°C to approximately 19°C, with most between 6-9°C and the majority of those between 8-9°C. Their depth range was from about 6-85 m, with peaks at 46-55 m.

ADULTS

The spring and fall distributions of adult thorny skate relative to bottom water temperature, depth, and salinity based on 1963-2002 NEFSC bottom trawl surveys from the Gulf of Maine to Cape Hatteras are shown in Figure 16. In spring, adult thorny skate were found at temperatures between 2-13°C, with the majority between 4-7°C. During that period they were found at a depth range of 31-400 m, with the majority spread between 141-300 m. They were found at salinities of 33-34 ppt. During the fall they were found over a temperature range of 3-13°C, with the majority found between 5-8°C. They were found over a depth range of 31-500 m, with most spread between about 141-300 m. They were found at salinities of 32-35 ppt, with > 60% at 33 ppt.

The spring and autumn distributions of the few adults found in Massachusetts coastal waters relative to bottom water temperature and depth are shown in Figure 17. In the spring they were found in waters ranging from about 4-10°C, with peaks at 4°C, 6°C, and 8°C. Their depth range was from approximately 21-65 m, with a peak between 31-35 m. During the autumn they were caught in waters ranging from 5-10°C, with the majority at 10°C. Their depth range was from 31-65 m, with most between 46-55 m.

STATUS OF THE STOCKS

The following section is based on Northeast Fisheries Science Center (2000a, b).

The principal commercial fishing method used to catch all seven species of skates [thorny, smooth, little, barndoor (*Dipturus laevis*), winter, clearnose (*Raja eglanteria*), rosette (*Leucoraja garmani*)] is otter trawling. Skates are frequently taken as bycatch during groundfish trawling and scallop dredge operations and discarded recreational and foreign landings are currently insignificant, at < 1% of the total fishery landings.

Skates have been reported in New England fishery landings since the late 1800s. However, commercial fishery landings, primarily from off Rhode Island, never exceeded several hundred metric tons until the advent of distant-water fleets during the 1960s. Landings are not reported by species, with over 99% of the landings reported as "unclassified skates." Skate landings reached 9,500 mt in 1969, but declined quickly during the 1970s, falling to 800 mt in 1981 (Figure 18). Landings have since increased substantially, partially in response to increased demand for lobster bait, and more significantly, to the increased export market for skate wings. Wings are taken from winter and thorny skates, the two species currently used for human consumption. Bait landings are presumed to be primarily from little skate, based on areas fished and known species distribution patterns. Landings for all skates increased to 12,900 mt in 1993 and then declined somewhat to 7,200 mt in 1995. Landings have increased again since 1995, and the 1998 reported commercial landings of 17,000 mt were the highest on record (Figure 18).

The biomass for the seven skate species is at a medium level of abundance. For the aggregate complex, the NEFSC spring survey index of biomass was relatively constant from 1968-1980, then increased significantly to peak levels in the mid- to late 1980s. The index of skate complex biomass then declined steadily until 1994, but has recently increased again. The large increase in skate biomass in the mid- to late 1980s was dominated by little and winter skate. The recent increase in aggregate skate biomass has been due to an increase in small sized skates (< 100 cm max. length: little, clearnose, rosette, and smooth), primarily little skate. The biomass of large size skates (> 100 cm TL max. length: barndoor, winter, and thorny) has steadily declined since the mid-1980s. The abundance of thorny skate has declined to historic lows and current abundance is about 10-15% of the peak observed in the late 1960s to early 1970s (Figure 18). Thorny skate is considered to be overfished (Northeast Fisheries Science Center 2000a, b).

RESEARCH NEEDS

Imprecise reporting of fishery statistics where several skate species are lumped together under one category (e.g., "unclassified skates" or "skates spp.") can mask basic changes in community structure and profound reduction in populations of larger, slower growing species (Dulvy *et al*. 2000; Musick *et al*. 2000). Thus, it is important to have fishery-independent data on skates where the individual species are reported.

Northeast Fisheries Science Center (2000b) also suggests the following research needs:

- More life history studies (including age, growth, maturity, and fecundity studies) are necessary.
- Studies of stock structure are needed to identify unit stocks.
- Explore possible stock-recruit relationships by examination of NEFSC survey data.
- Investigate trophic interactions between skate species in the complex, and between skates and other groundfish.
- Investigate the influence of annual changes in water temperature or other environmental factors on shifts in the range and distribution of the species in the skate complex, and establish the bathymetric distribution of the species in the complex in the western Atlantic.
- Investigate historical NEFSC survey data from the R/V Albatross III during 1948-1962 when they become available, as they may provide valuable historical context for long-term trends in skate biomass.

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Table 1. Summary of habitat parameters for thorny skate, based on the pertinent literature.

Life Stage	Depth	Substrate	Temperature
Eggs[1]			Laboratory studies on Barents Sea skates: successful incubation in the lab revealed the development period of embryos at temperatures from –0.3-9.5°C lasted for 2-2.5 yrs. After hatching, juveniles consumed the internal supply of yolk and switched to active feeding in 2-4 months at temperatures of 2.5-4.5°C. In low temperature environment of the Barents Sea, embryonic development period for thorny skate may take 2.5-3 yrs.
Juveniles [2]	Depth range is from 18-1200 m, most common at 50-100 m in the northeast Atlantic and 37-108 m on the Scotian Shelf. Surveys from Nova Scotia to Cape Hatteras found it occurred between 27-439 m but was most abundant between 111-366 m. Others report a general depth range of 18-183 m, as deep as 786-896 m off New York, and found off Long Island at 59 m. Maximum recorded depth is 1478-1540 m in the northeastern Norwegian Sea. In Passamaquoddy Bay, has been found in 37-55 m waters. Frequently taken on the New Brunswick side of the Bay of Fundy in waters $\geq$ 18 m or deeper, and in 37-55 m in St. Mary Bay on the Nova Scotia side. Found in Gulf of Maine in waters > 26 m, and down to 669 m along the upper part of the continental slope off southern New England. At southern extreme of its range it is limited to the continental slope; off Virginia it occurs at 300-1200 m, although isolated skates previously reported from off Charleston, South Carolina at 135 m.	Found over a wide variety of bottom types from sand, gravel, broken shell, pebbles, to soft mud.	Temperature range from Nova Scotia to Cape Hatteras is from -1.3°C to 14°C, although it has been recorded down to -1.4°C of Labrador and only up to 10°C by other authors. On the Nova Scotian shelf, it has a temperature preference of 2-5°C. In Passamaquoddy Bay it has a temperature range of 1.2-10.2°C. Differences in reproduction and the storage of energy (food resources) in North Sea thorny skate in relation to their differences in distribution were compared. One group of thorny skate that lived in a "warmer" area developed their gonads and reached maturity at a lower size than the group that lived in the "colder" area. The group of female skate that lived in the "colder" area stored more energy in the liver than the group that lived in the "warmer" area. These differences suggest a latitudinal influence in which temperature could play an important role.
Adults [3]	Same as for juveniles.	Same as for juveniles.	Same as for juveniles.

[1] Berestovskii (1994).
[2] Bigelow and Schroeder (1953a, b); Backus (1957); Tyler (1971); McEachran and Musick (1975); Scott (1982a, b); Stehmann and Bürkel (1984); Scott and Scott (1988); van Steenbergen (1994); Stehmann and Parin (1994); McEachran 2002).
[3] Bigelow and Schroeder (1953a, b); Backus (1957); Tyler (1971); McEachran and Musick (1975); Scott (1982a, b); Stehmann and Bürkel (1984); Scott and Scott (1988); van Steenbergen (1994); Stehmann and Parin (1994); McEachran 2002).

Table 1. cont'd.

Life Stage	Prey
Juveniles [1]	Opportunistic feeder on most abundant and available prey throughout its range. Prey in western Atlantic includes hydrozoans, aschelminths, gastropods, bivalves, squids, polychaetes, pycnogonids, copepods, stomatopods (larvae), cumaceans, isopods, amphipods, mysids, euphausids, shrimps, hermit crabs, crabs, holothuroideans, fishes. Polychaetes and decapods are the major prey items, followed by amphipods and euphausids. Fish can be major prey for larger skates. Mysids contribute little to the diet. Polychaete prey include: *Nephtys* spp., *Glycera* spp., *Eunice pennata*, *Aphrodite hastata*. Decapods: *Hyas* sp., *Eualus pusiolus*, *Dichelopandalus leptocerus*, *Crangon septemspinosa*, *Pandalus* spp., *Pagurus pubescens*, *Axius serratus*, and *Pasiphaea* sp. Amphipods: *Orchomonella minuta*, *Leptocheirus pinguis*, ampeliscids, *Pontogeneia inermis*, *Tmetonyx* sp., *Psammonyx nobilis*. Fishes: sand lance, longhorn sculpin, Atlantic hagfish. Not uncommon for thorny skate to feed on trawler discards. Euphausids: *Meganctiphanes norvegica*. Mysids: *Neomysis americana*, *Erythrops erythrophthalma*. Diet size dependent: NEFSC food habits database shows that overall, crustaceans declined in importance with increasing skate size. Amphipods decreased with increasing skate size; percent occurrence of decapods generally did not change with skate size. Percent occurrence of polychaetes increased with increasing skate size until skate were about 60 cm TL. Fish noticeable in the diet of larger skates, around > 50-60 cm TL. Other studies: fish $\leq$ 40 cm TL fed mostly on amphipods, fish > 40 cm TL fed mostly on polychaetes and decapods. Mysids decreased in the diet while fishes increased with increase in skate size. Fishes a major component of the diet of skates > 70 cm TL. Consumption of euphausids independent of skate size. In Passamaquoddy Bay, also a significant difference in food habits between skate $\leq$ 40 cm TL and > 40 cm TL. Principal prey of smaller skates were euphausids (*M. norvegica*), mysids (*Mysis stenolepis*), polychaetes (*Aphrodite aculeata*, *Lumbrineris fragilis*, *Nephtys incisa*, *Clymenella torquata*), amphipods (*Unciola leucopis*). Larger skates ate decapods (*Hyas araneus*) and polychaetes (*A. aculeata*, *N. incisa*). Again amphipods decreased and decapods increased in importance with increase in skate size; however, here euphausids important to only smaller skates and polychaetes important to both size classes. In terms of percent weight, 1977-1980 NEFSC data shows crustaceans and polychaetes were dominant in the diet of skate < 31-60 cm TL, while fish dominated in skate 61-90 cm TL. Squid and herring dominated in skate > 90 cm TL. From West Greenland to Georges Bank, fish made up 69% of total food volume in skates from 17-200 m deep and 82% of skates from 201-700 m. Haddock and sand lance most important fish prey at shallower depths, redfish and sand lance more important at greater depths. Invertebrates: crabs most important in shallower depths, cephalopods most important at deeper depths. *Sergestes* sp. (shrimp) and octopus found only in skates from > 400 m.
Adults [2]	Same as for juveniles, but note differences in diets of larger vs. smaller skates.

[1] Bigelow and Schroeder (1953a); McEachran (1973); McEachran *et al*. (1976); Tyler (1972); Templeman (1982b); Berestovskiy (1989); Robichaud 1991; Pedersen (1995); Bowman *et al*. (2000); Garrison (2000); Garrison and Link (2000); Avent *et al*. (2001); NEFSC food habits database.

[2] Bigelow and Schroeder (1953a); McEachran (1973); McEachran *et al*. (1976); Tyler (1972); Templeman (1982b); Berestovskiy (1989); Robichaud 1991; Pedersen (1995); Bowman *et al*. (2000); Garrison (2000); Garrison and Link (2000); Avent *et al*. (2001); NEFSC food habits database.

Table 1. cont'd.

Life Stage	Predators/Species Associations
Eggs [1]	Halibut, goosefish, Greenland sharks, predatory gastropods can eat embryos within egg capsules.
Juveniles [2]	Around Newfoundland, thorny skate (juveniles/adults?) preyed upon by seals, sharks, and halibut. Thorny and smooth skate (*Malacoraja senta*) are sympatric species and have high coefficient of associaton; these two species often negatively associated with little (*Leucoraja erinacea*) and winter (*L. ocellata*) skates (however, see Georges Bank studies, below). Co-occurrence, and possibly competition with thorny skate may have led to food specialization in smooth skate and could have caused low abundance and low diversity of prey species seen in diet of smooth skate. Thorny skate has a diverse diet consisting of both infauna and epifauna while smooth skate has a specialized diet consisting largely of epifauna, mostly amphipods, euphausids, decapods, and mysids. Thorny skate also feeds on these prey items over part of the year, perhaps when the prey are in high abundance. Thorny skate also the more widespread and abundant of the two. Using 1973-1997 NEFSC data from Nova Scotia to Cape Hatteras and NEFSC food habits database, both small (10-30 cm TL) and medium (31-60 cm TL) sized thorny skate belonged to the "Benthivores" group, along with haddock, yellowtail flounder, winter flounder, witch flounder, gulfstream flounder, scup, American plaice, croaker. Prey consisted mostly of polychaetes. Largest thorny skate (31 cm TL to > 80 cm TL) also belonged to a guild of "Piscivores" group, along with spiny dogfish, Atlantic cod, silver hake, white hake, sea raven, goosefish, summer flounder, bluefish, spotted hake, fourspot flounder, Atlantic sharpnose shark. Prey consisted of a range of fish taxa including herrings, silver hake, scombrids, sand lance; squid also eaten. Based on spring/fall 1963-1978 surveys on Georges Bank, thorny skate belonged to "Gulf of Maine Deep" and "Northeast Peak" assemblage groups. In Gulf of Maine Deep assemblage other major species included American plaice, witch flounder, white hake, silver hake, Atlantic cod, haddock, cusk. In Northeast Peak assemblage, Atlantic cod, haddock, pollock, white hake, winter flounder, ocean pout, and longhorn sculpin were the other major species. The two assemblages showed definite seasonal spatial changes between spring and fall periods. In a more recent study, small (10-30 cm TL) and medium (31-60 cm TL) thorny skate were in "Demersal predators" group in autumn, along with flatfish, haddocks, winter skate, little skate. Prey included gammarid amphipods, polychaetes, isopods, *Cancer* crabs, *C. septemspinosa*. Large (61-80 cm TL) thorny skate also belonged to "Crab predators" group; prey included polychaetes, decapod crabs. During spring, small thorny skate was in "Shrimp/amphipod predators" group, along with hakes, longhorn sculpin, Atlantic cod, fourspot flounder, winter skate, little skate. Prey included gammarid amphipods, pandalids, *C. septemspinosa*, polychaetes, *Cancer* crabs. Medium thorny skate was also in "Demersal predators" group, along with yellowtail, winter flounder. Their diet consisted primarily of polychaetes, gammarid amphipods.
Adults [3]	Same as for juveniles, but note differences between smaller and larger skates.

[1] Jensen (1948); Cox *et al*. (1999); Rountree (2001).
[2] McEachran (1973); McEachran and Musick (1975); McEachran *et al*. (1976); Overholtz and Tyler (1985); Kulka and Mowbray (1998); Garrison (2000); Garrison and Link (2000).
[3] McEachran (1973); McEachran and Musick (1975); McEachran *et al*. (1976); Overholtz and Tyler (1985); Kulka and Mowbray (1998); Garrison (2000); Garrison and Link (2000).

Table 2. Summary of habitat parameters for thorny skate, based on the most recent NEFSC and state surveys mentioned in the text.

Life Stage	Survey	Depth	Temperature	Salinity
Juveniles	1963-2002 spring and fall NEFSC trawl surveys from Gulf of Maine to Cape Hatteras.	*Spring*: range of 21-400 m, most spread between 71-300 m. *Fall*: range of 21-500 m, most found between 91-300 m.	*Spring*: range of 2-13°C, majority at 4-8°C. *Fall*: range of 3-16°C, most between 6-9°C, and close to 25% caught or occurring at 7°C.	*Spring*: range of 31-36 ppt, majority at 33 ppt. *Fall*: range of 31-35 ppt, about 40% at 33 ppt.
	1978-2002 Massachusetts inshore trawl surveys.	*Spring:* range of 6-85 m, with the majority between 41-55 m. *Fall*: range of about 6-85 m, peaks at 46-55 m.	*Spring:* range of about 2-16°C, greatest percentages between 4-6°C. *Fall*: range of 4°C to approximately 19°C, most between 6-9°C and majority of those between 8-9°C.	
Adults	1963-2002 spring and fall NEFSC trawl surveys from Gulf of Maine to Cape Hatteras.	*Spring*: range of 31-400 m, majority spread between 141-300 m. *Fall*: range of 31-500 m, most spread between 141-300 m.	*Spring*: range of 2-13°C, the majority between 4-7°C. *Fall*: range of 3-13°C, majority between 5-8°C.	*Spring*: range of 33-34 ppt. *Fall*: range of 32-35 ppt, > 60% at 33 ppt.
	1978-2002 Massachusetts inshore trawl surveys.	*Spring:* range of approximately 21-65 m, peak between 31-35 m. *Fall*: range of 31-65 m, most between 46-55 m.	*Spring:* range of about 4-10°C, peaks at 4°C, 6°C, and 8°C. *Fall*: range of 5-10°C, majority at 10°C.	

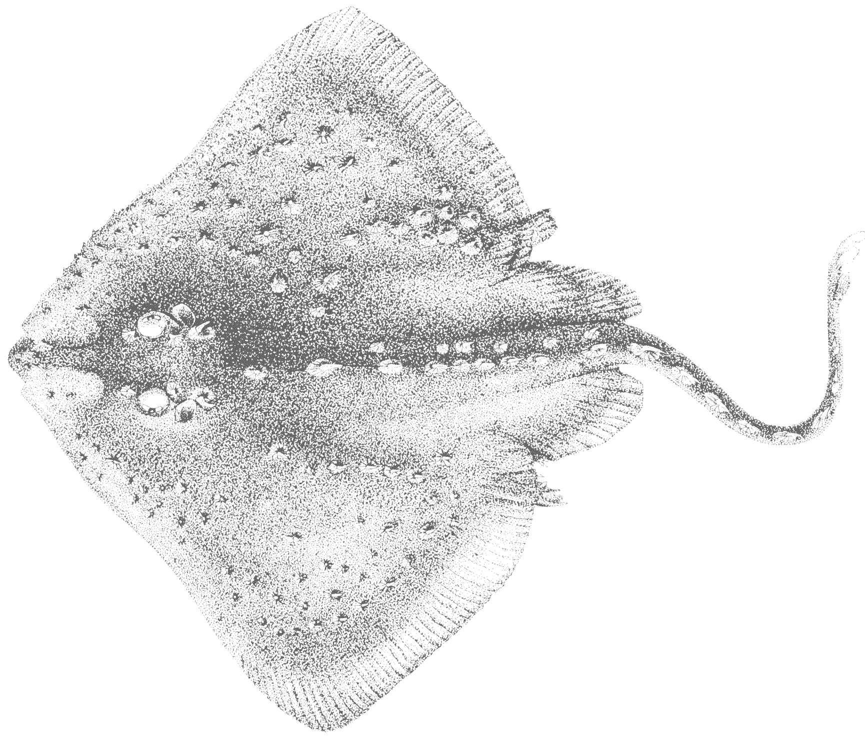


Figure 1. The thorny skate, *Amblyraja radiata* (Donovan 1808), female, from Scott and Scott (1988).

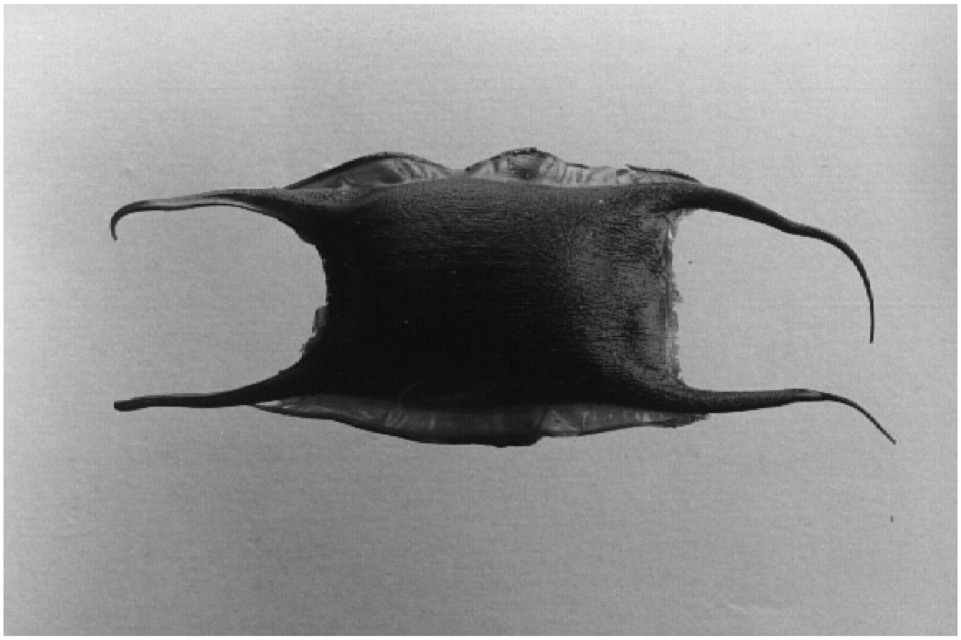


Figure 2. Egg case of thorny skate, from Bor (2001).

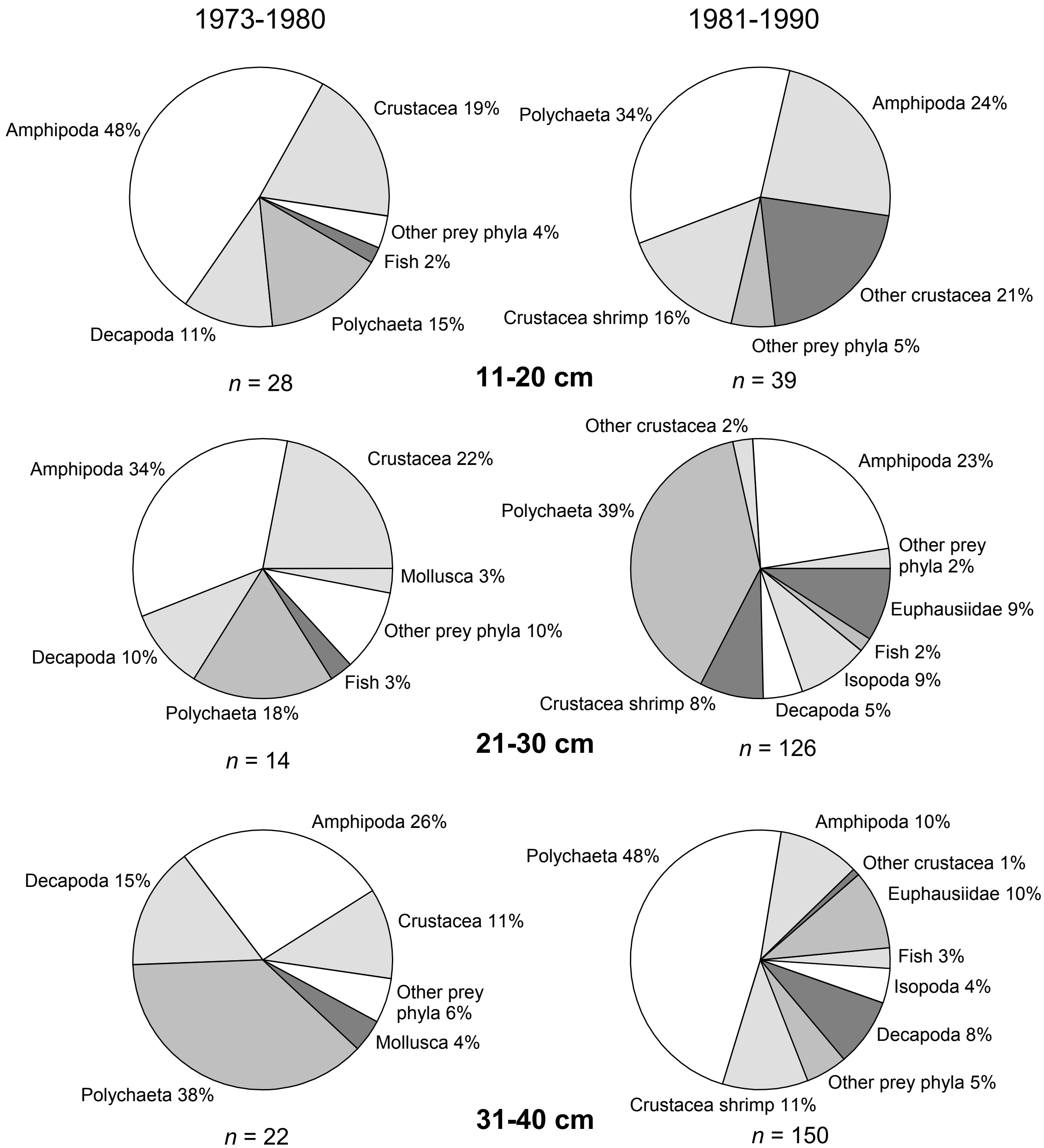


Figure 3. Abundance (% occurrence) of the major prey items of thorny skate collected during NEFSC bottom trawl surveys from 1973-1980 and 1981-1990. Methods for sampling, processing, and analysis of samples differed between the time periods [see Reid *et al.* (1999) for details].

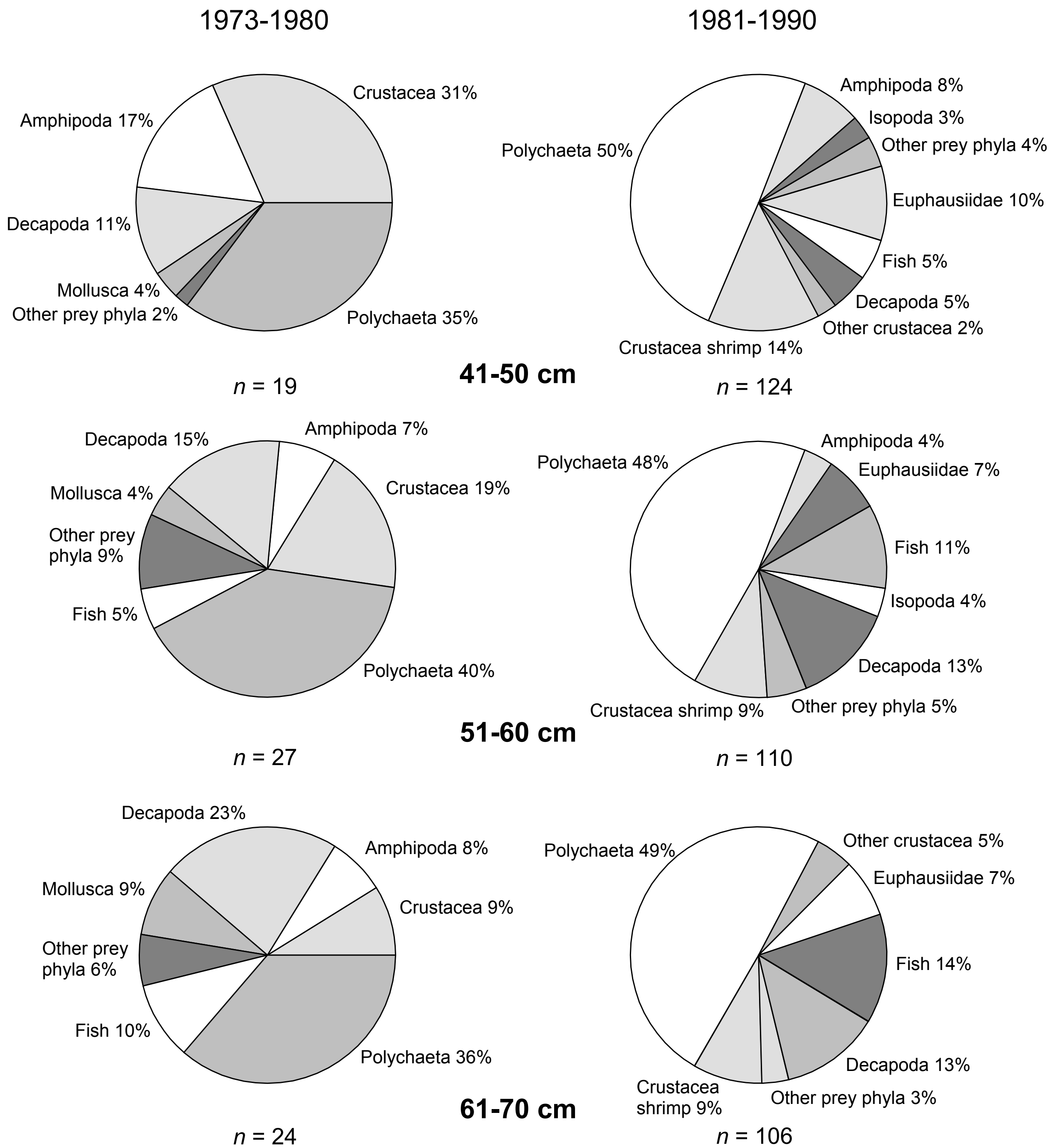


Figure 3. cont'd.

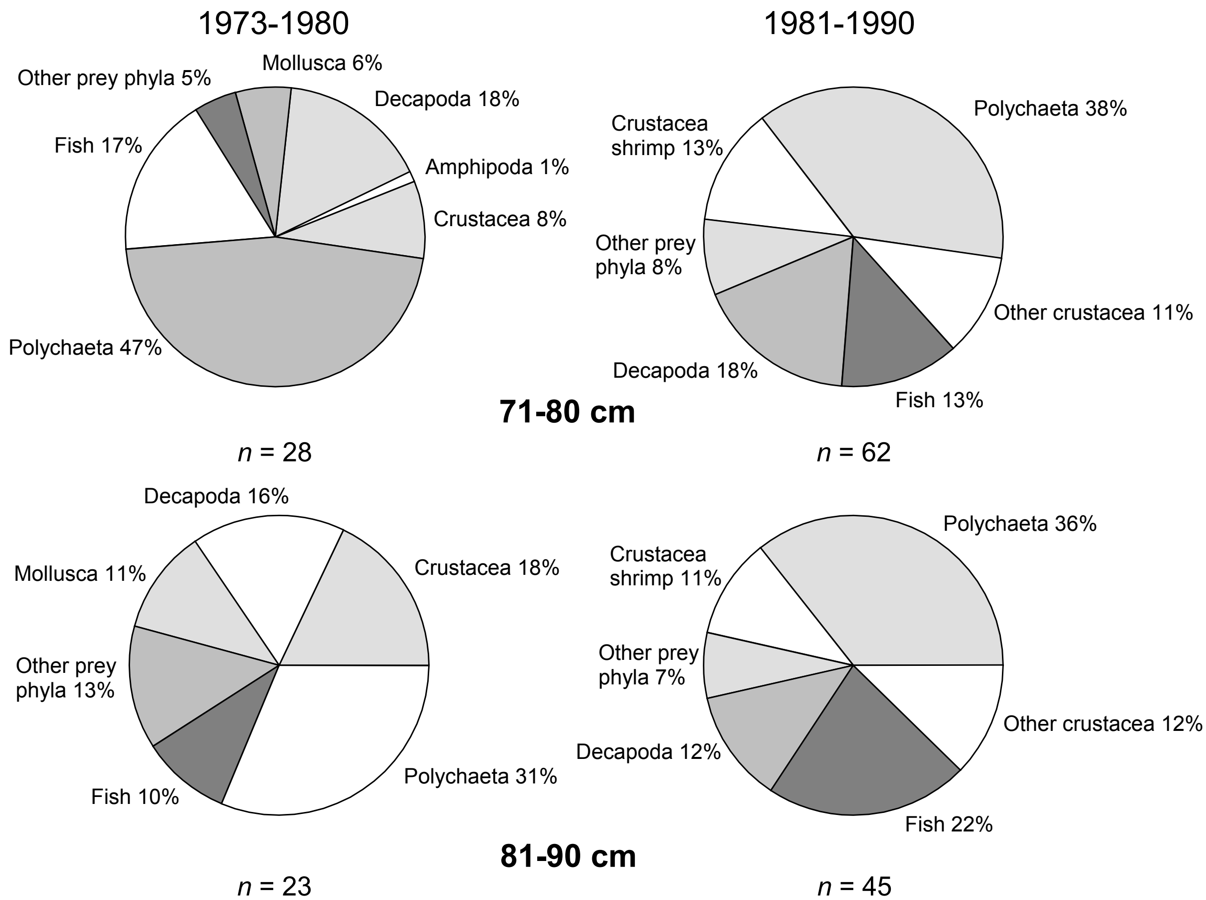


Figure 3. cont’d.

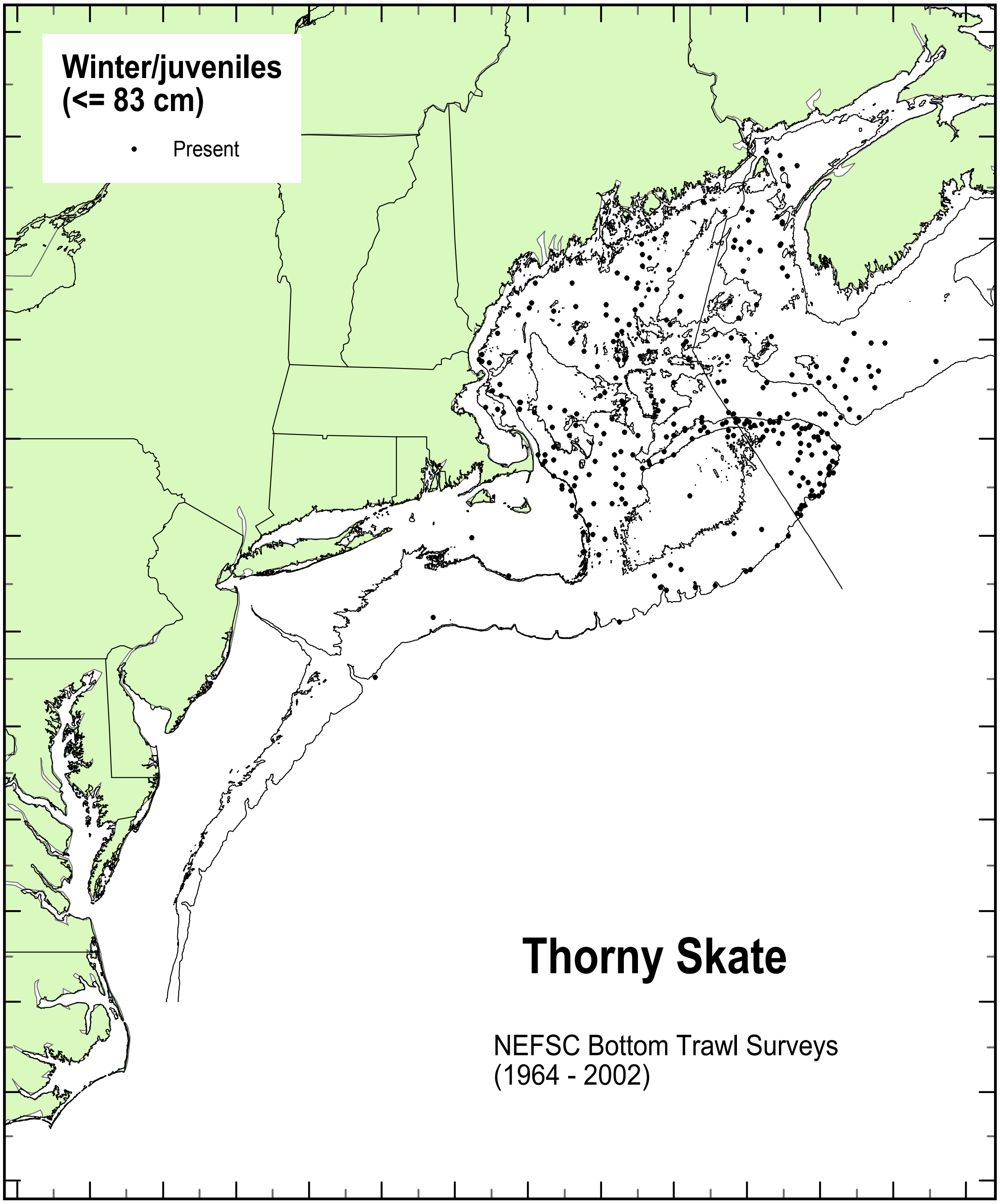


Figure 4. Distribution of juvenile thorny skate collected during winter NEFSC bottom trawl surveys [1964-2002, all years combined; see Reid *et al.* (1999) for details]. Survey stations where juveniles were not found are not shown.

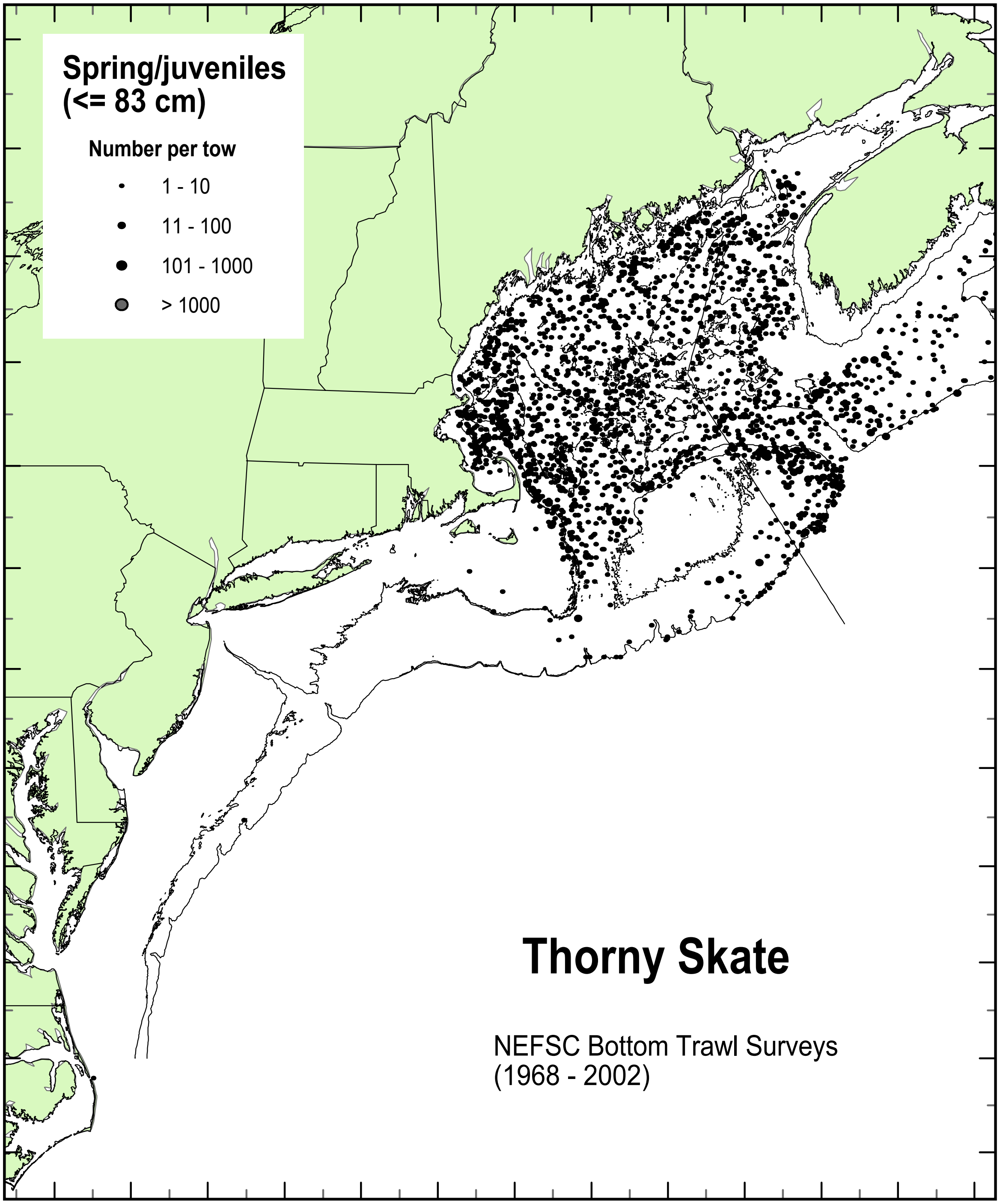


Figure 5. Distribution and abundance of juvenile thorny skate collected during spring NEFSC bottom trawl surveys [1968-2002, all years combined; see Reid *et al.* (1999) for details].

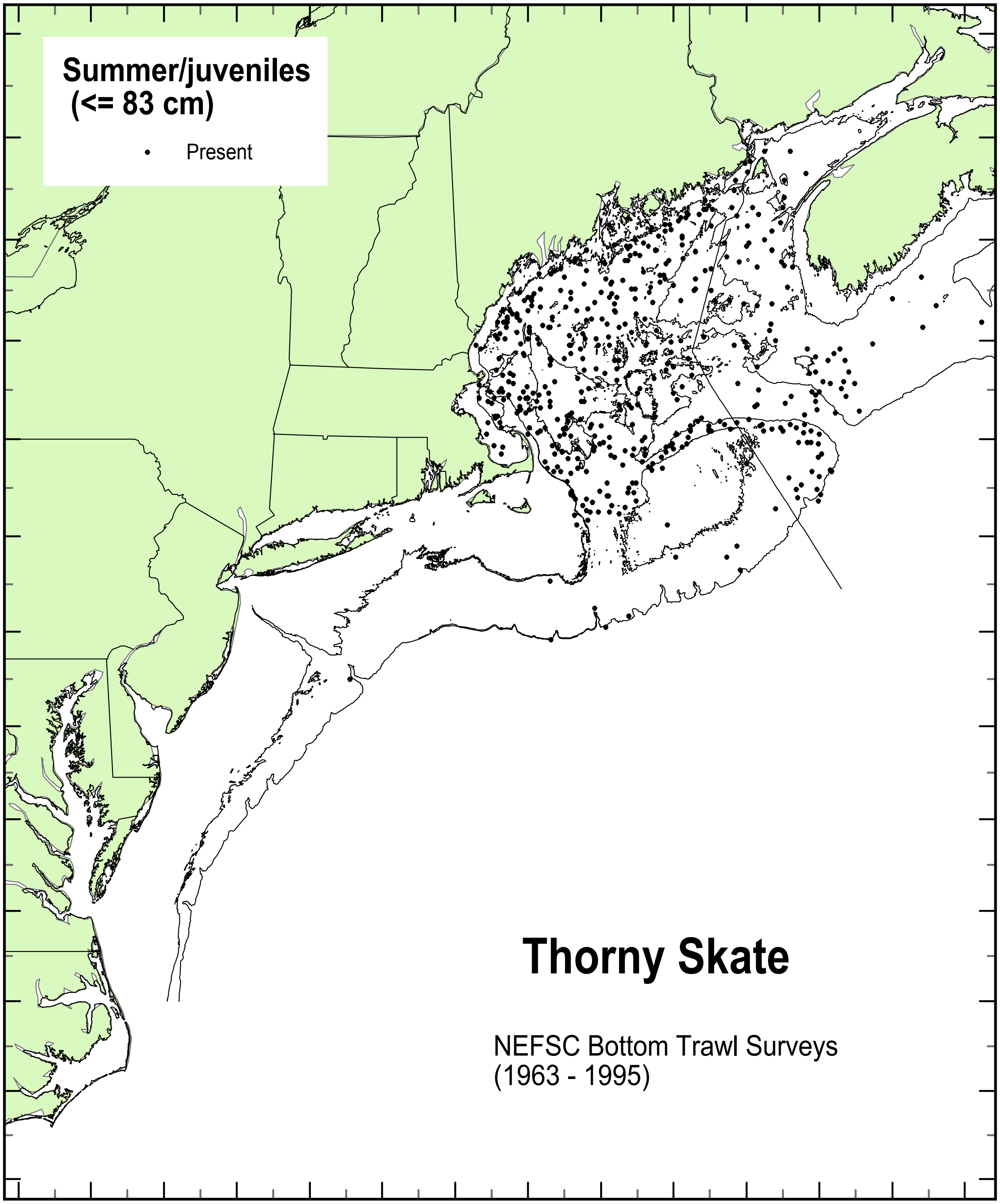


Figure 6. Distribution of juvenile thorny skate collected during summer NEFSC bottom trawl surveys [1963-1995, all years combined; see Reid *et al.* (1999) for details]. Survey stations where juveniles were not found are not shown.

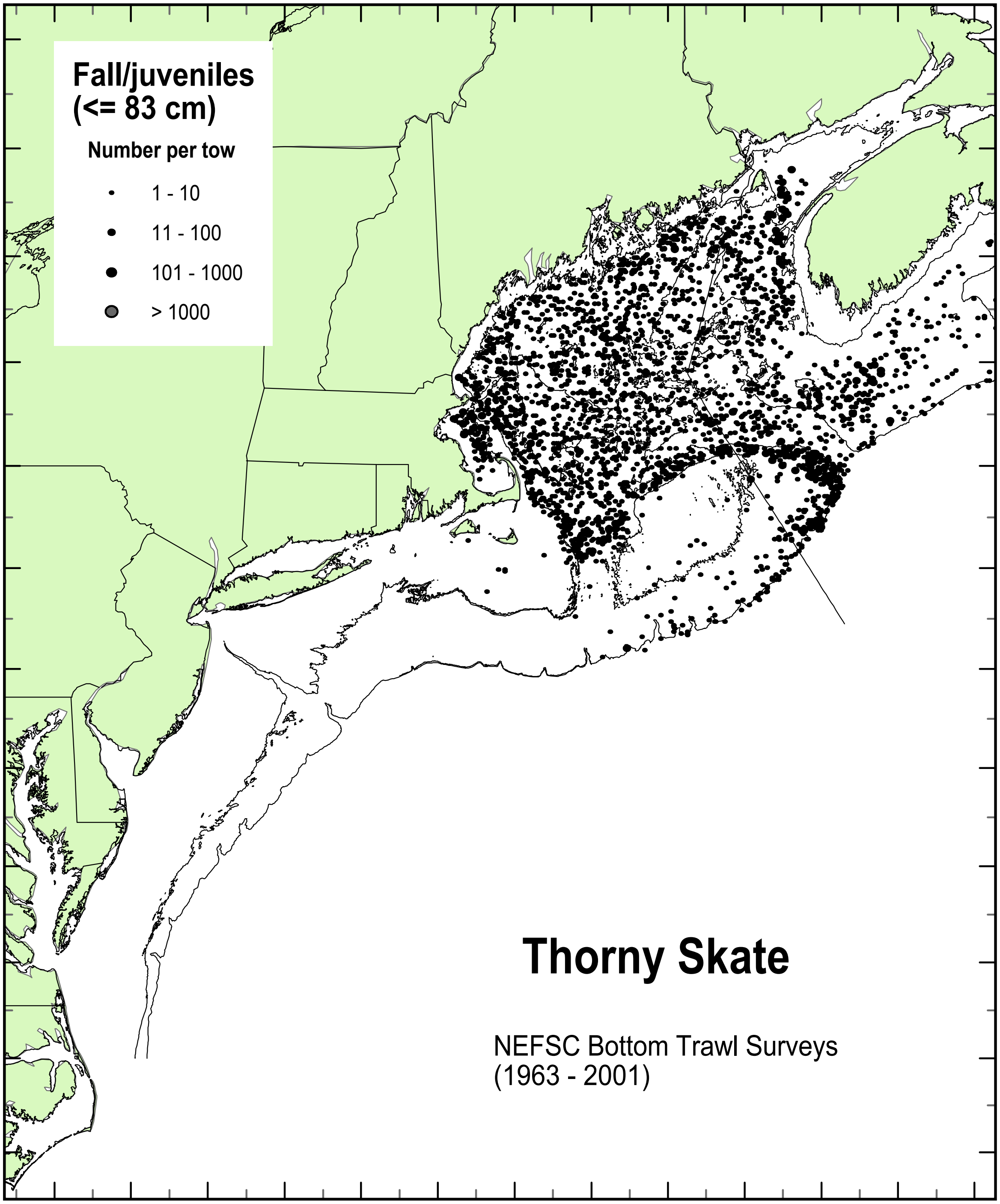


Figure 7. Distribution and abundance of juvenile thorny skate collected during fall NEFSC bottom trawl surveys [1963-2001, all years combined; see Reid *et al.* (1999) for details].

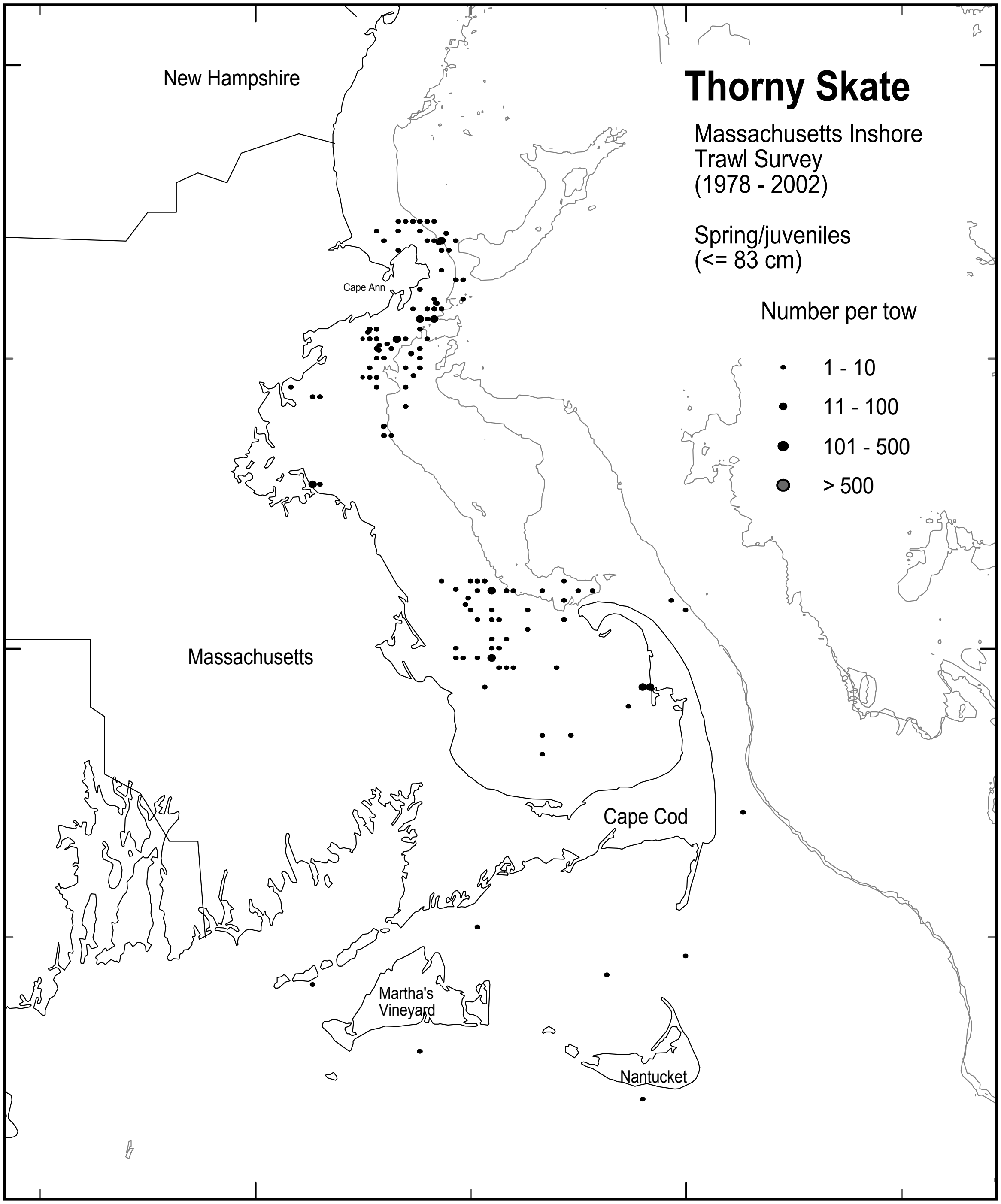


Figure 8. Distribution and abundance of juvenile thorny skate in Massachusetts coastal waters collected during the spring and autumn Massachusetts inshore trawl surveys [1978-2002, all years combined; see Reid *et al.* (1999) for details].

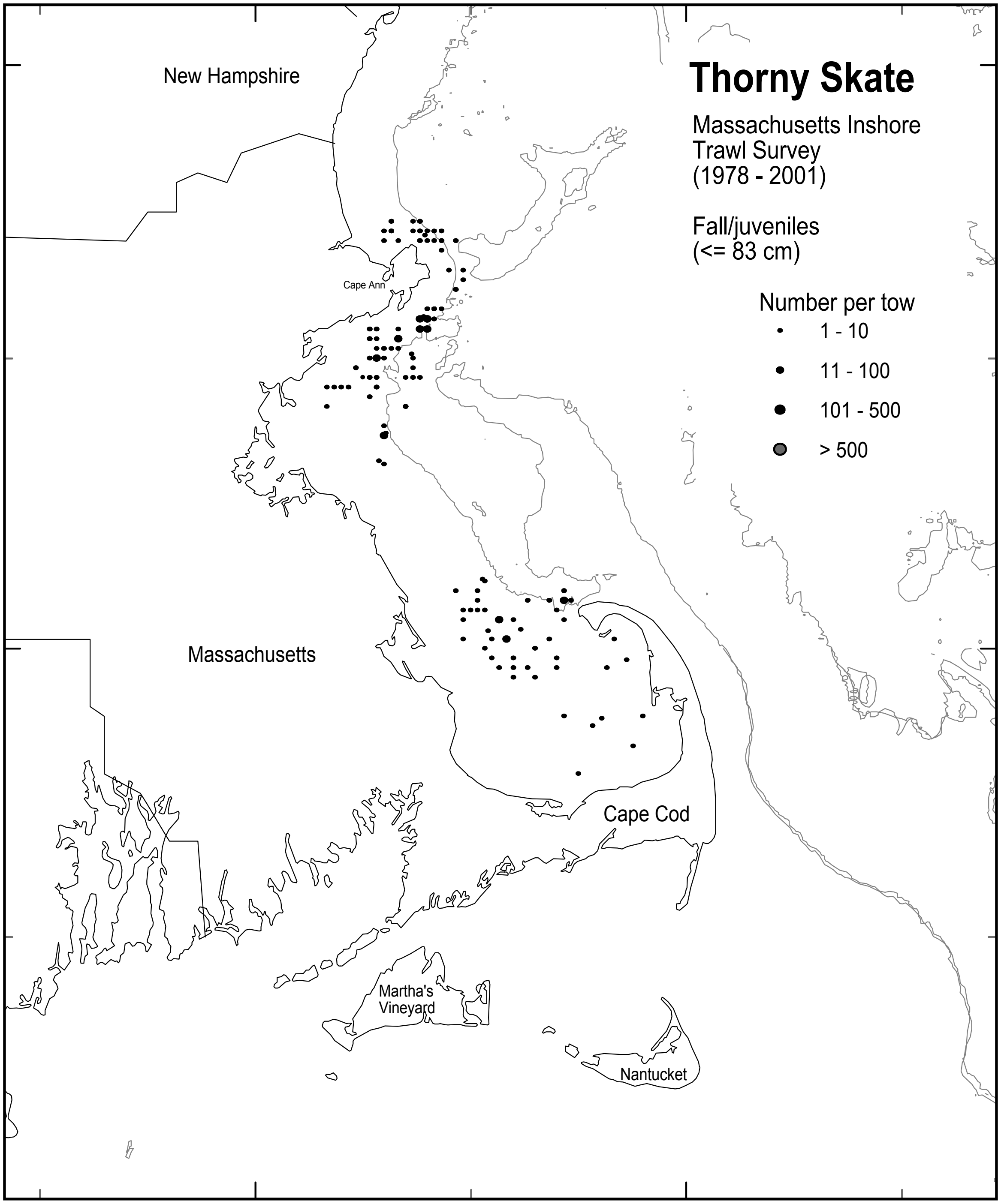


Figure 8. cont'd.

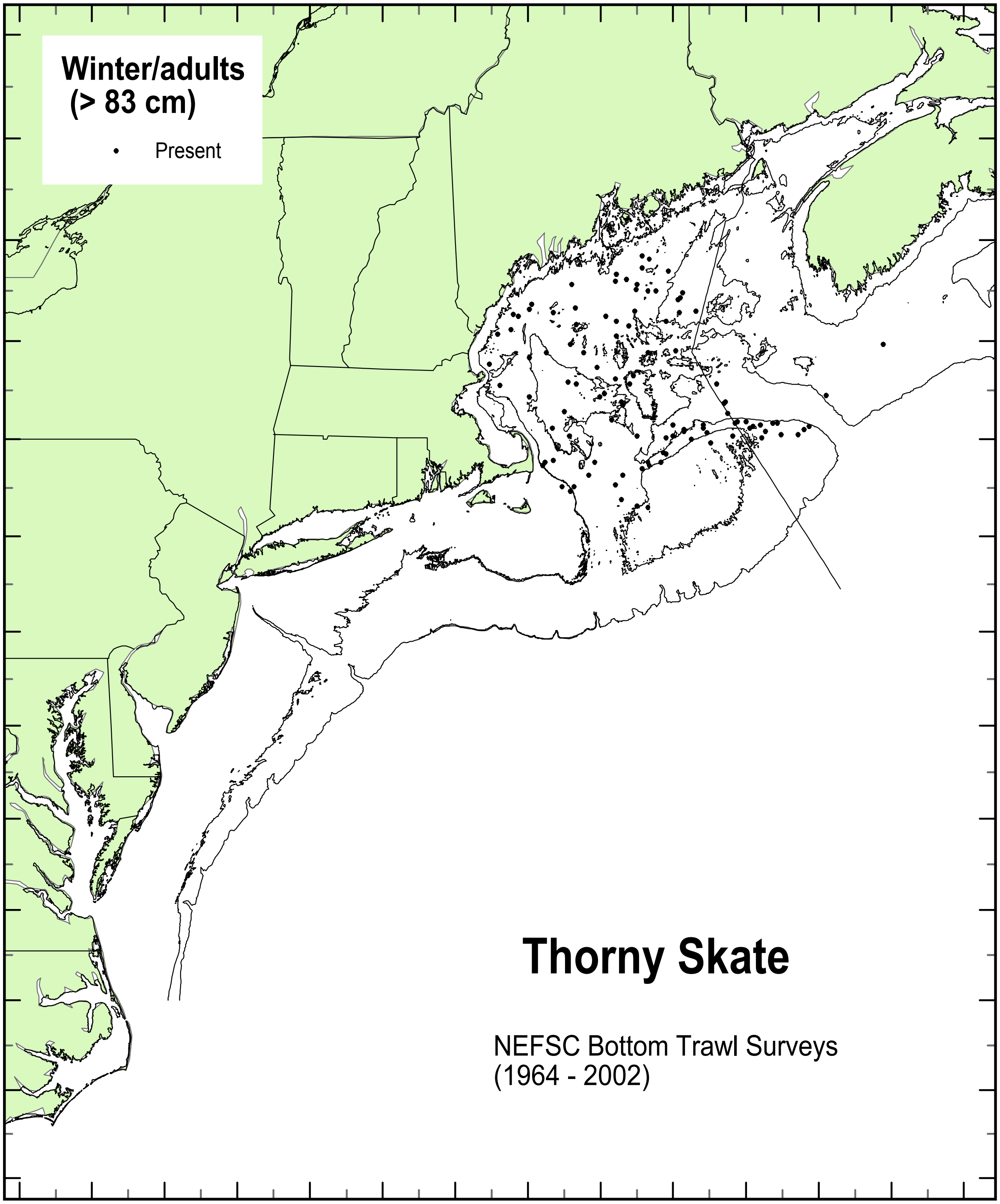


Figure 9. Distribution of adult thorny skate collected during winter NEFSC bottom trawl surveys [1964-2002, all years combined; see Reid *et al.* (1999) for details]. Survey stations where adults were not found are not shown.

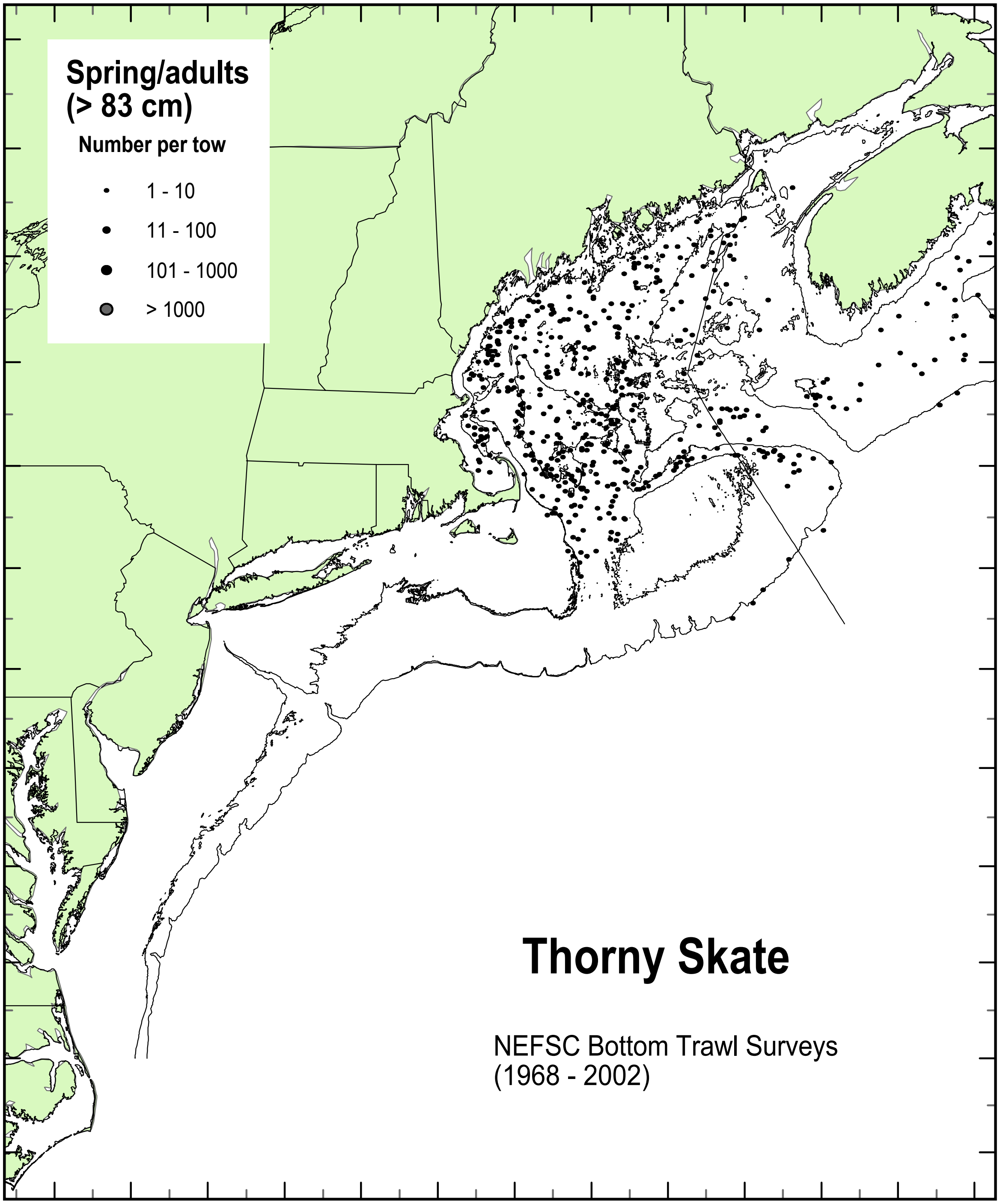


Figure 10. Distribution and abundance of adult thorny skate collected during spring NEFSC bottom trawl surveys [1968-2002, all years combined; see Reid *et al.* (1999) for details].

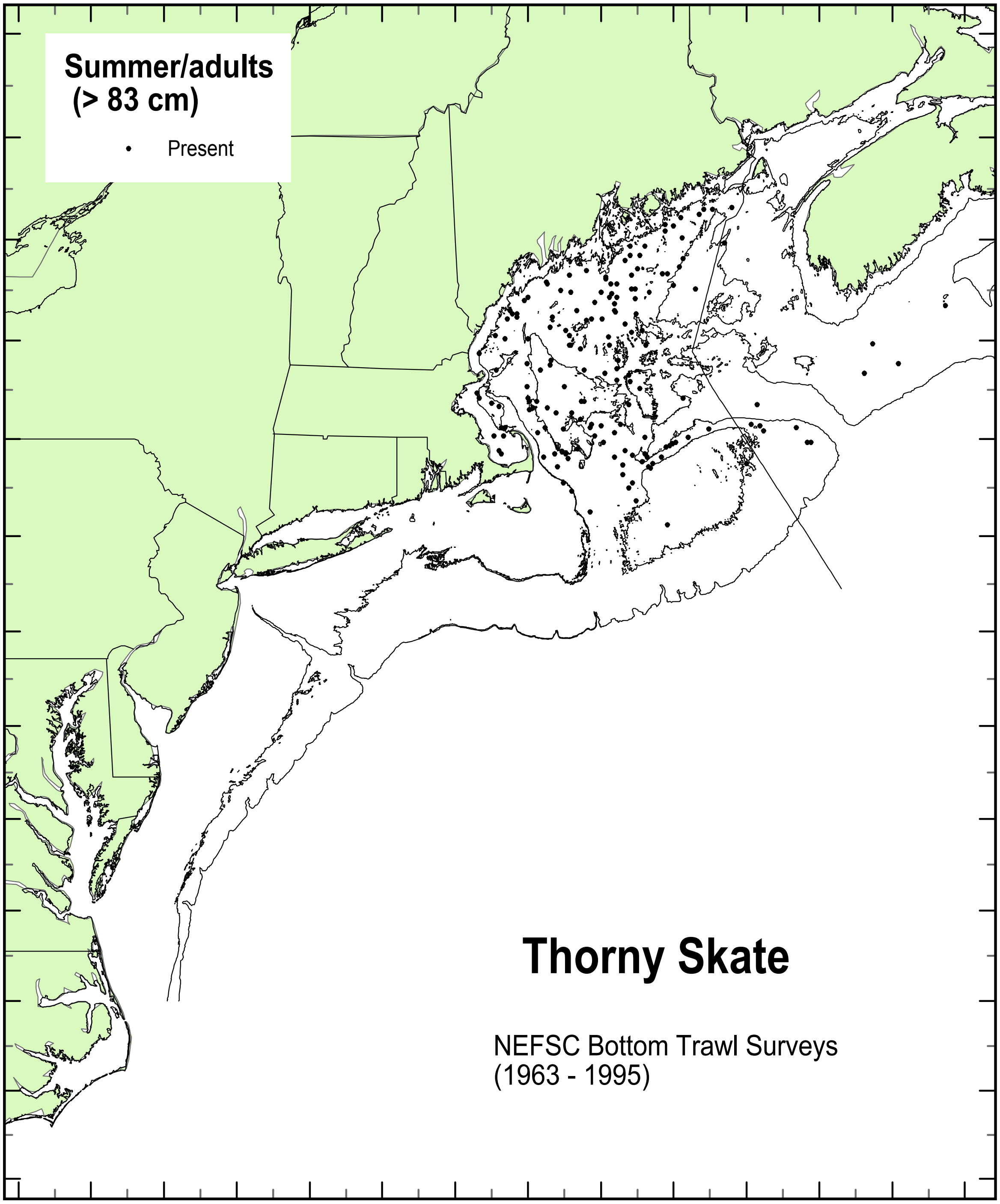


Figure 11. Distribution of adult thorny skate collected during summer NEFSC bottom trawl surveys [1963-1995, all years combined; see Reid *et al.* (1999) for details]. Survey stations where adults were not found are not shown.

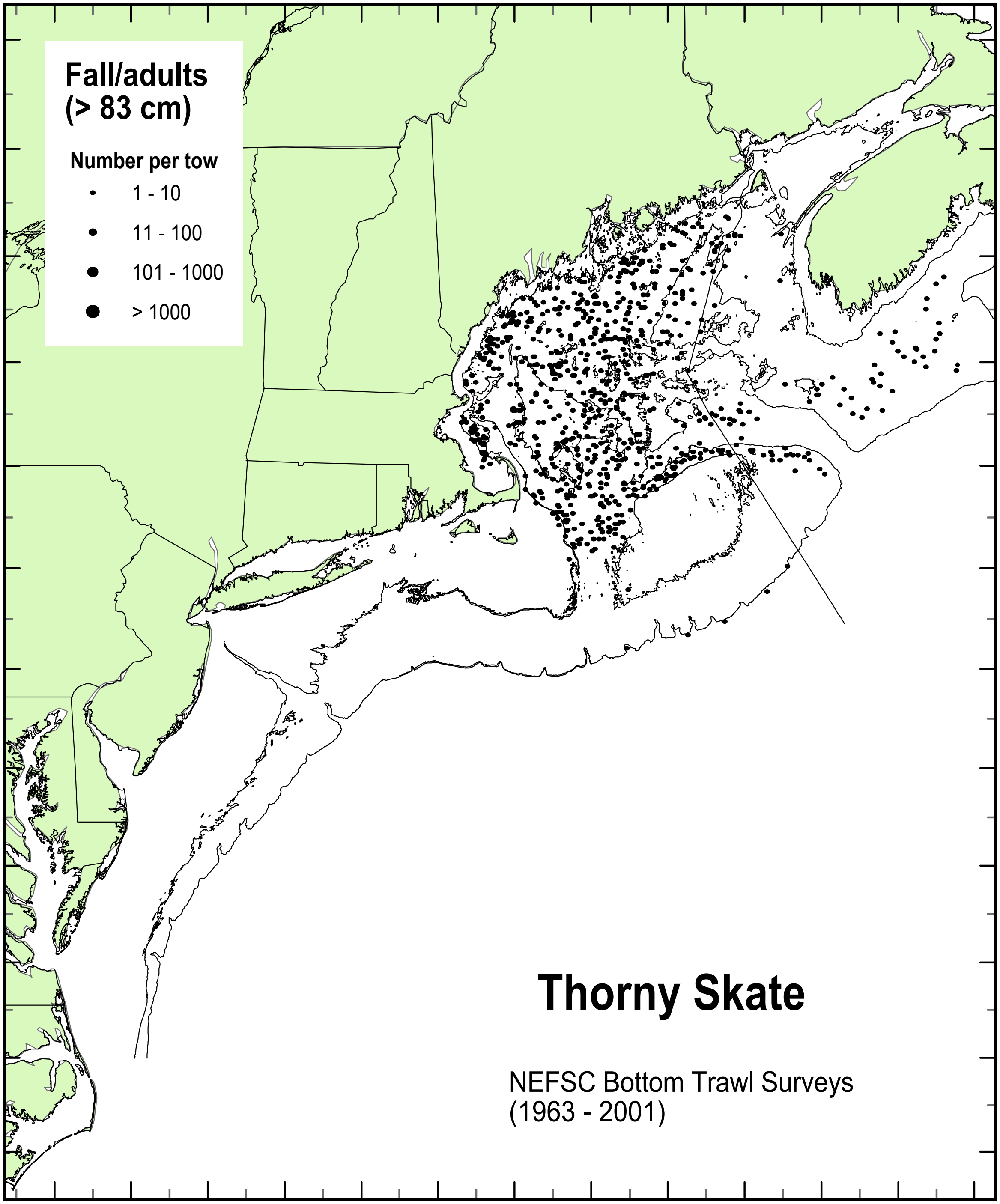


Figure 12. Distribution and abundance of adult thorny skate collected during fall NEFSC bottom trawl surveys [1963-2001, all years combined; see Reid *et al.* (1999) for details].

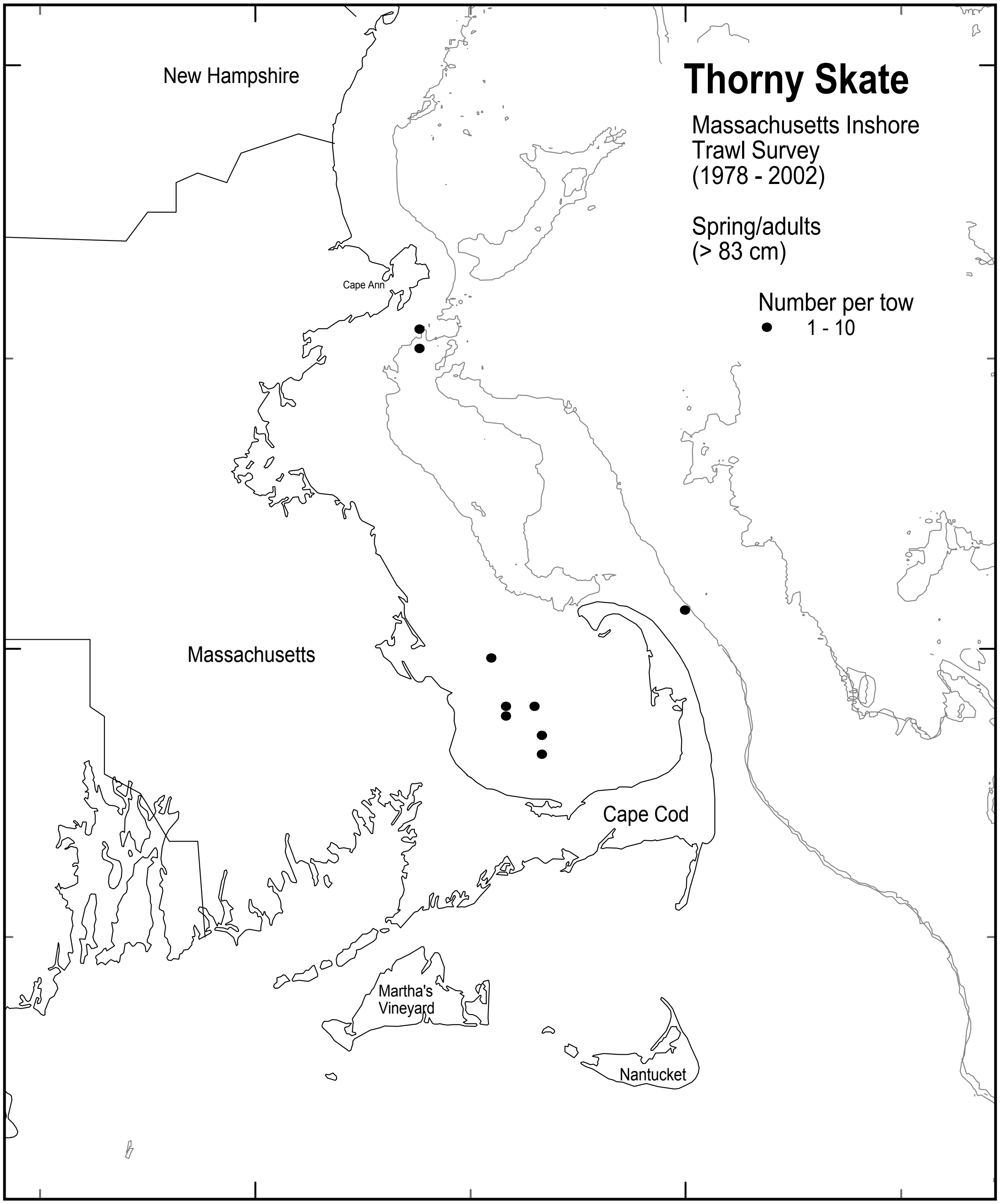


Figure 13. Distribution and abundance of adult thorny skate in Massachusetts coastal waters collected during the spring and autumn Massachusetts inshore trawl surveys [1978-2002, all years combined; see Reid *et al.* (1999) for details].

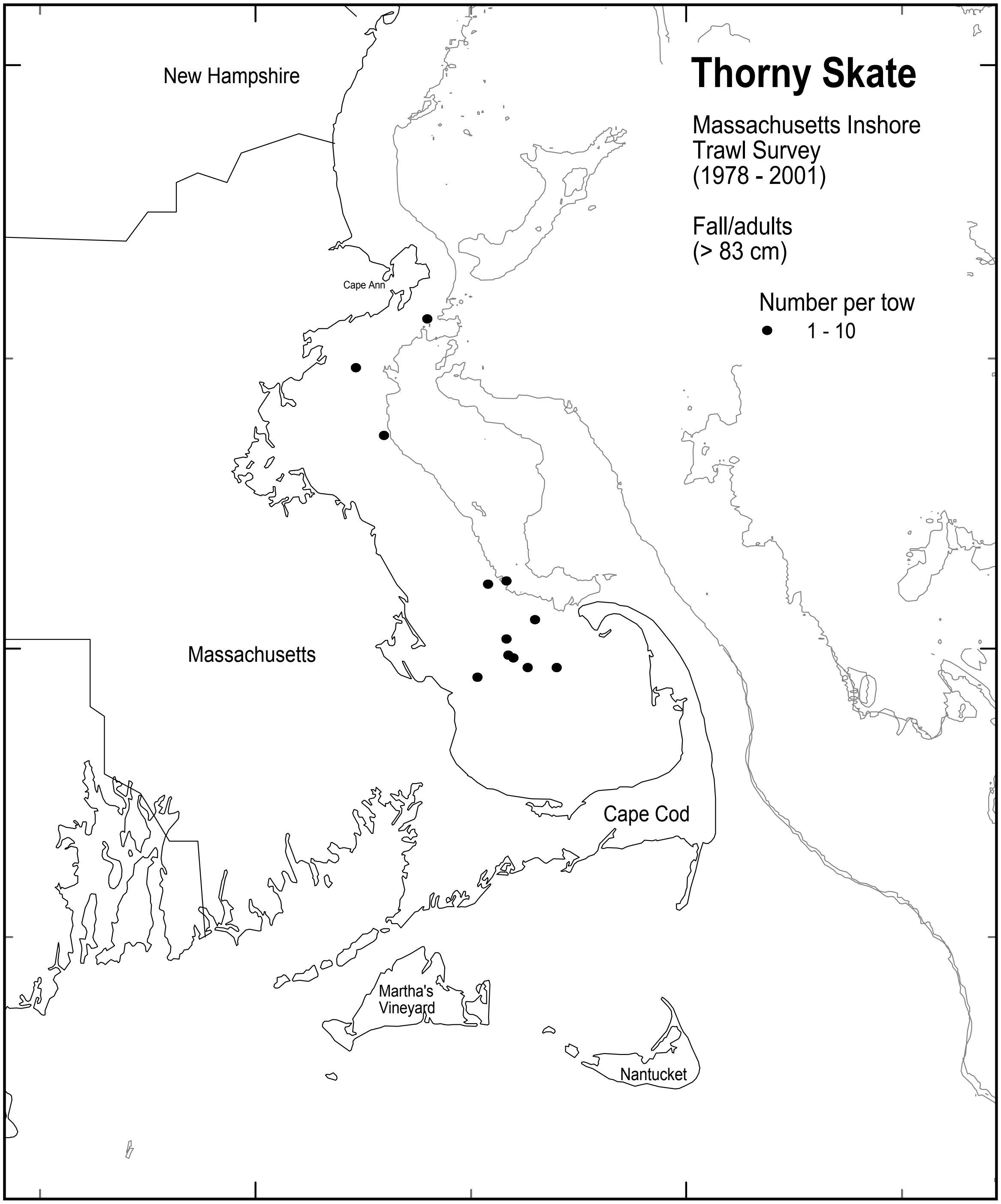


Figure 13. cont’d.

Thorny Skate
NEFSC Bottom Trawl Survey
Spring/Juveniles

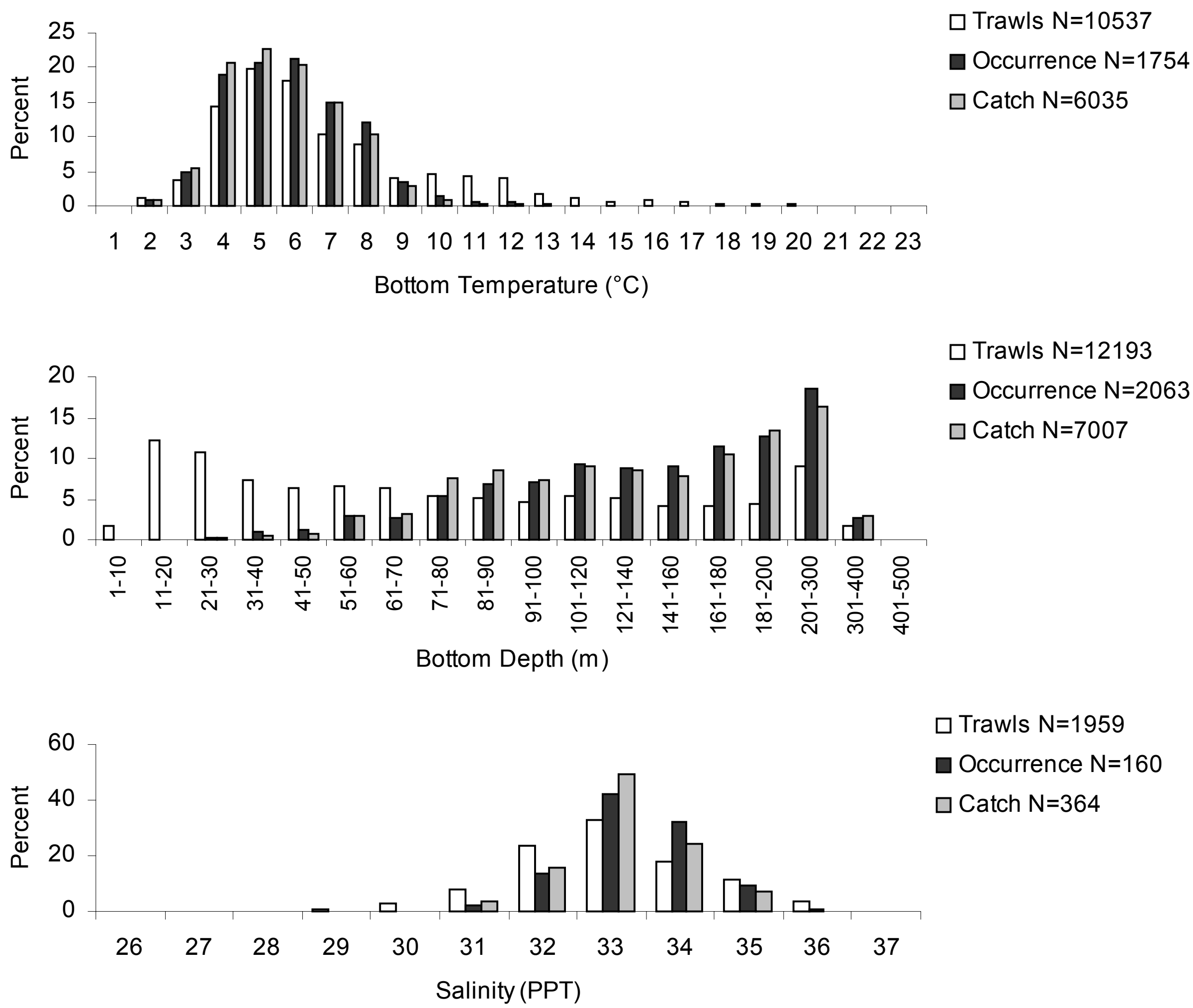


Figure 14. Spring and fall distributions of juvenile thorny skate and trawls relative to bottom water temperature depth, and salinity based on NEFSC bottom trawl surveys (1963-2002; all years combined). White bars give the distribution of all the trawls, black bars give the distribution of all trawls in which thorny skate occurred, and gray bars represent, within each interval, the percentage of the total number of thorny skate caught.

Thorny Skate
NEFSC Bottom Trawl Survey
Fall/Juveniles

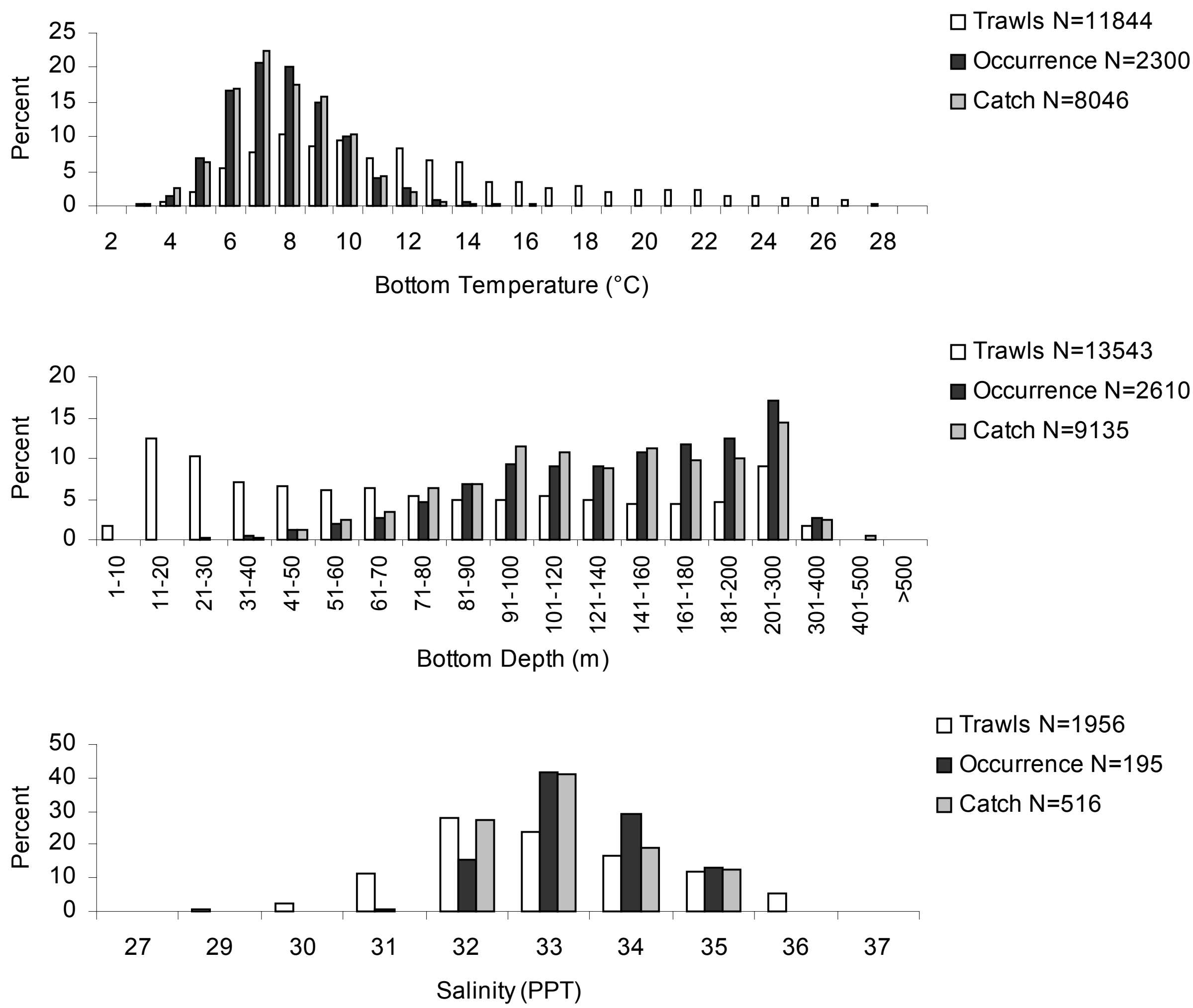


Figure 14. cont'd.

Thorny Skate

Massachusetts Inshore Trawl Survey
Spring/Juveniles

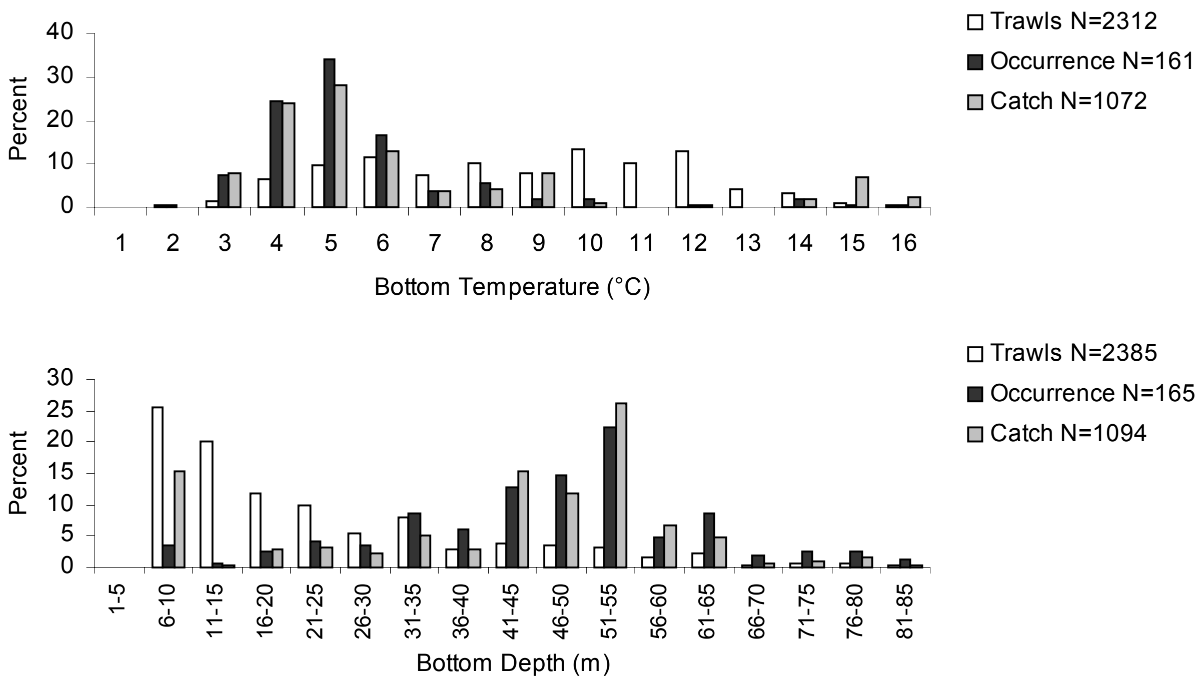
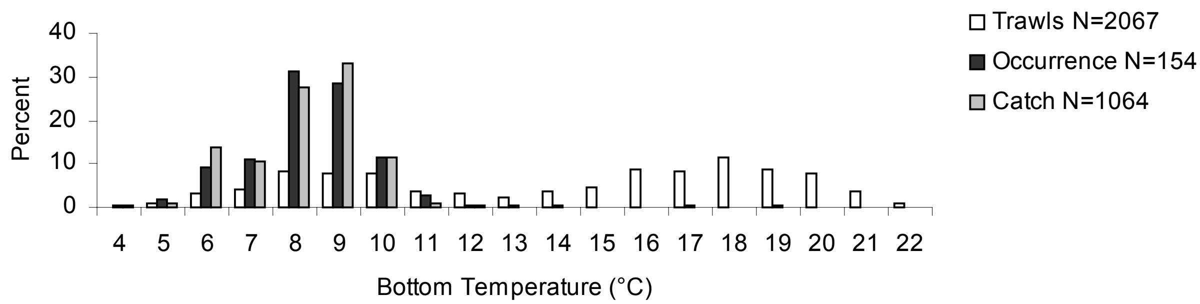


Figure 15. Spring and fall distributions of juvenile thorny skate and trawls relative to bottom water temperature and depth based on Massachusetts inshore trawl surveys (1978-2002, all years combined). White bars give the distribution of all the trawls, black bars give the distribution of all trawls in which thorny skate occurred, and gray bars represent, within each interval, the percentage of the total number of thorny skate caught.

Thorny Skate
Massachusetts Inshore Trawl Survey
Fall/Juveniles



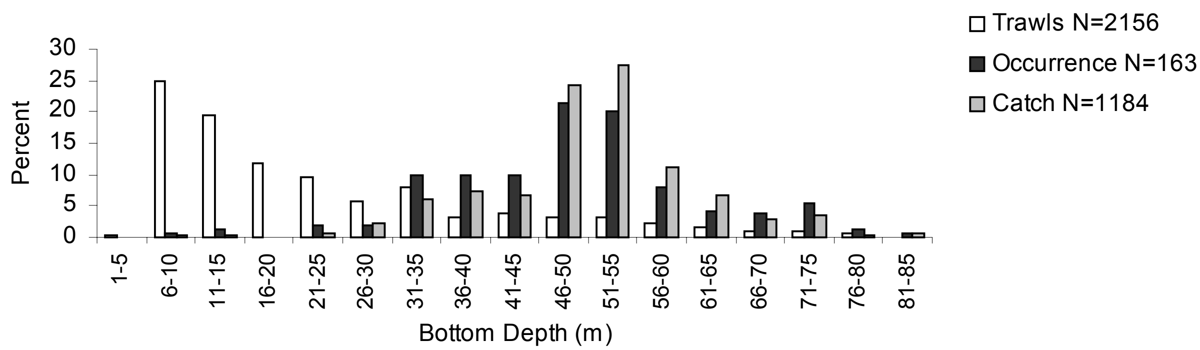


Figure 15. cont’d.

Thorny Skate
NEFSC Bottom Trawl Survey
Spring/Adults

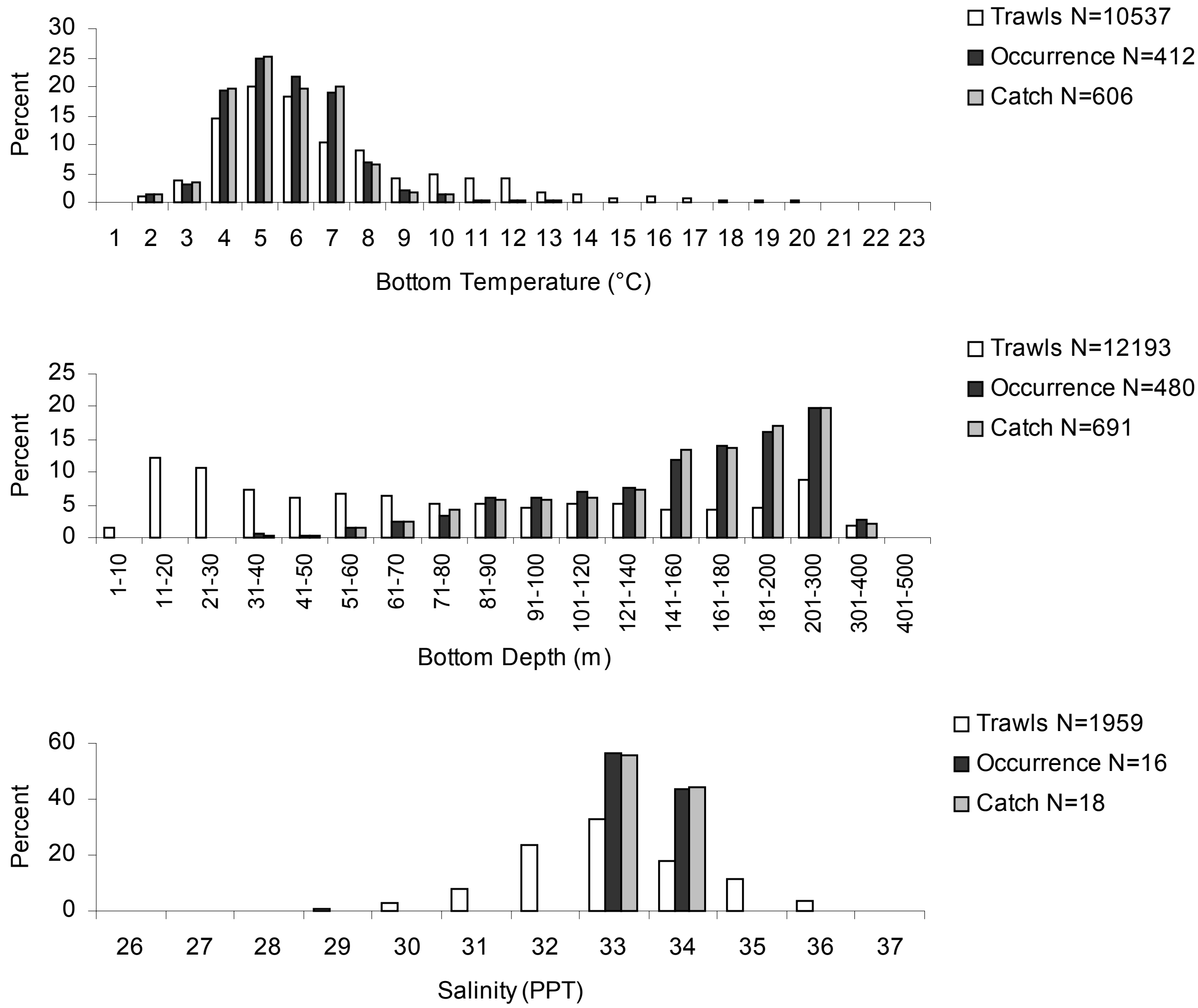


Figure 16. Spring and fall distributions of adult thorny skate and trawls relative to bottom water temperature and depth based on NEFSC bottom trawl surveys (1963-2002; all years combined). White bars give the distribution of all the trawls, black bars give the distribution of all trawls in which thorny skate occurred, and gray bars represent, within each interval, the percentage of the total number of thorny skate caught.

Thorny Skate
NEFSC Bottom Trawl Survey
Fall/Adults

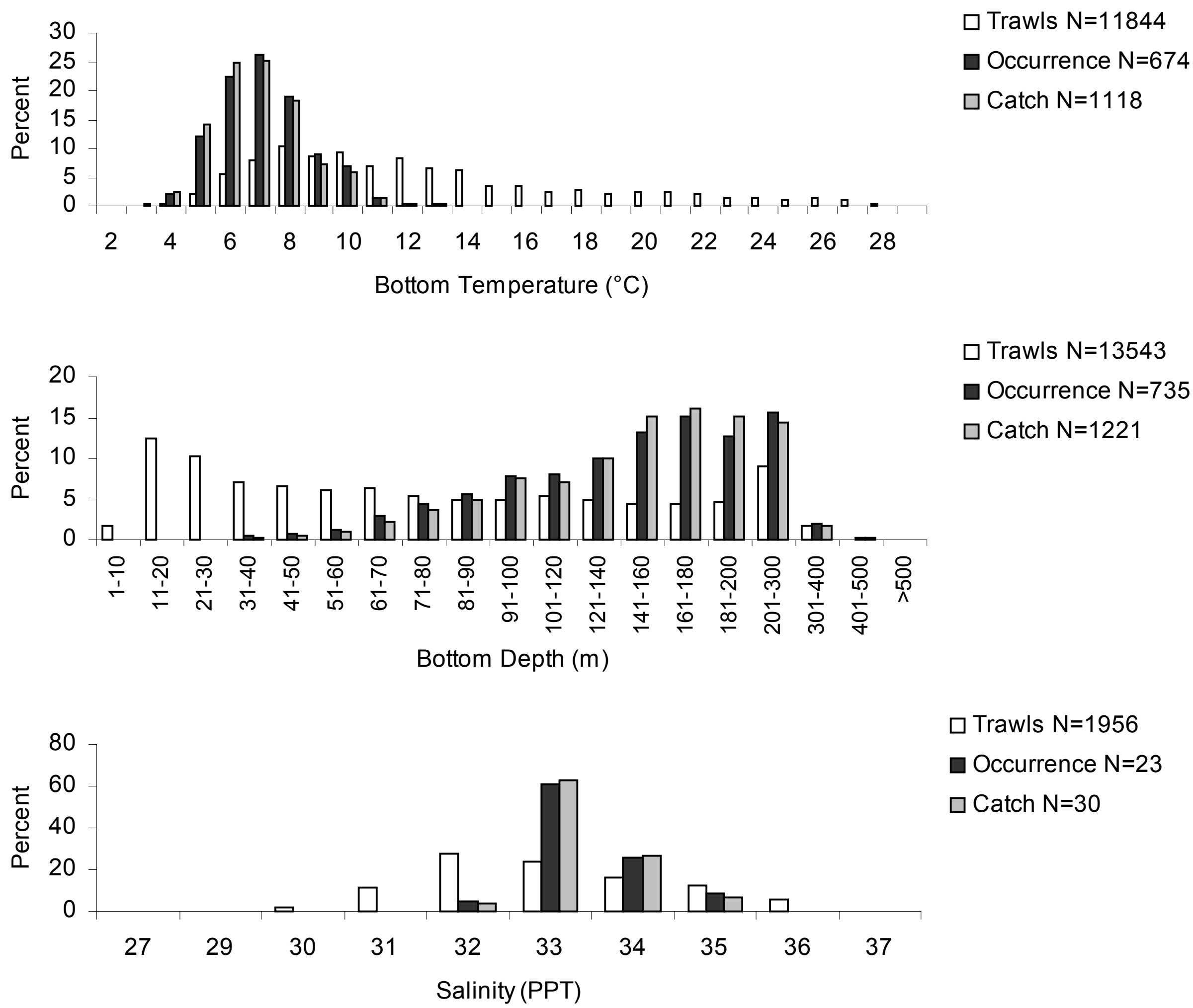


Figure 16. cont'd.

Thorny Skate

Massachusetts Inshore Trawl Survey

Spring/Adults

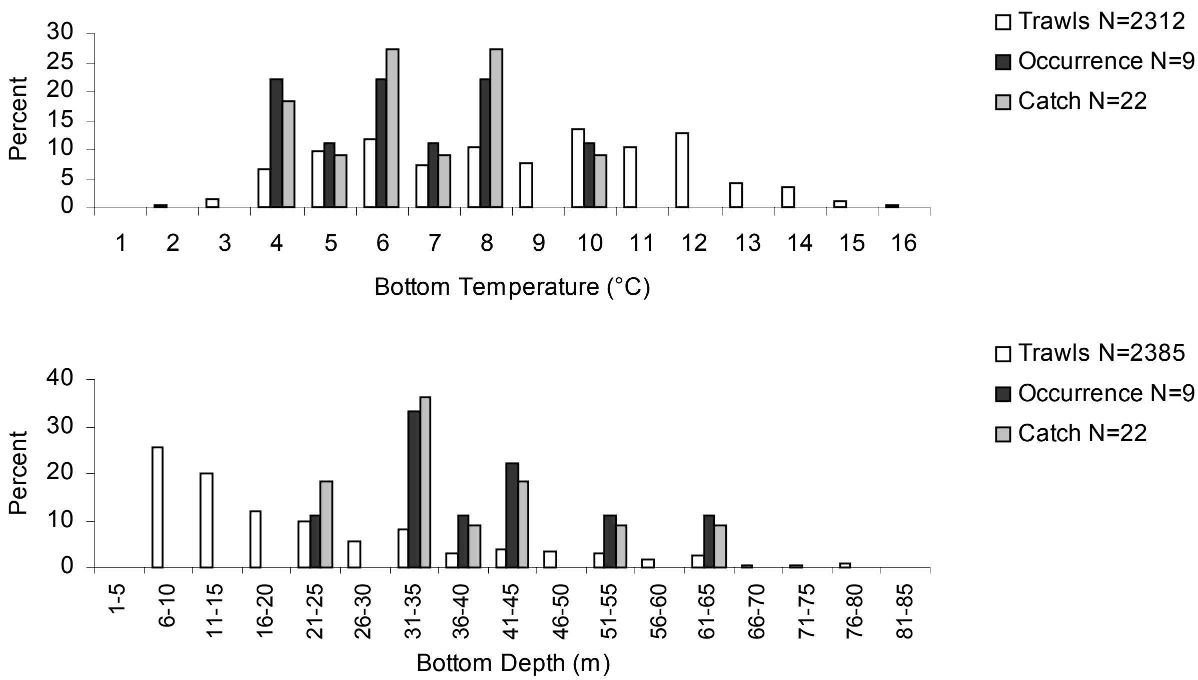


Figure 17. Spring and fall distributions of adult thorny skate and trawls relative to bottom water temperature and depth based on Massachusetts inshore trawl surveys (1978-2002, all years combined). White bars give the distribution of all the trawls, black bars give the distribution of all trawls in which thorny skate occurred, and gray bars represent, within each interval, the percentage of the total number of thorny skate caught.

Thorny Skate

Massachusetts Inshore Trawl Survey
Fall/Adults

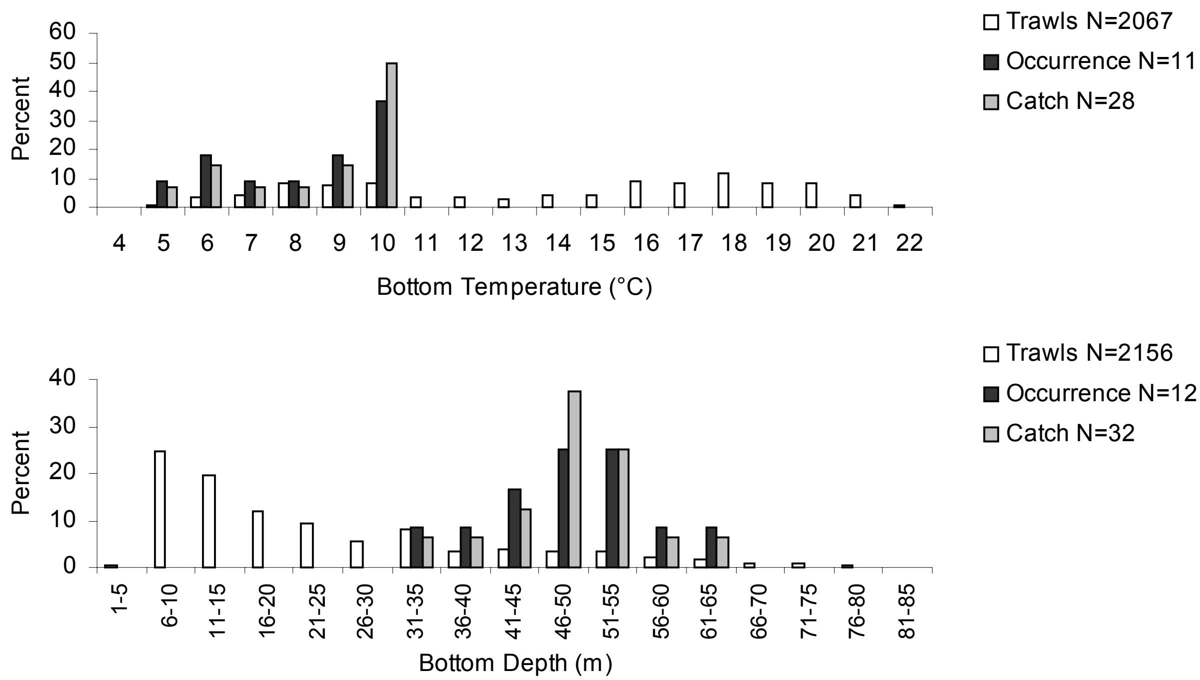


Figure 17. cont'd.

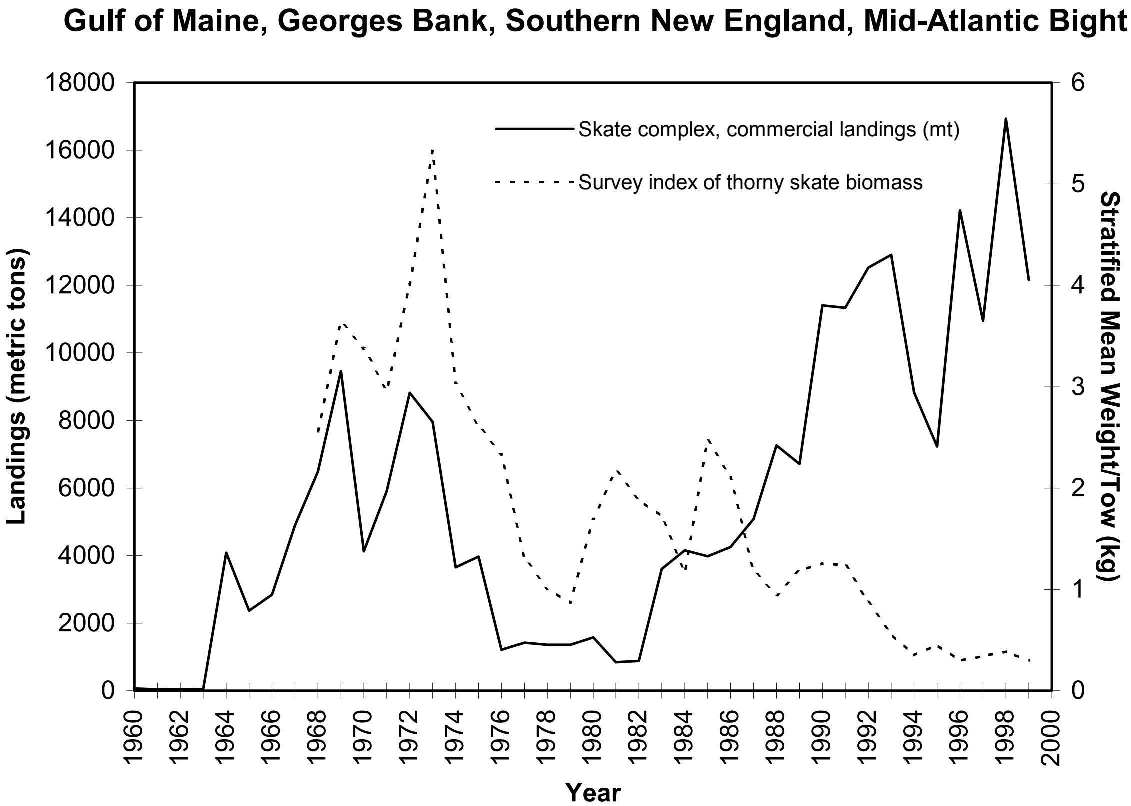


Figure 18. NEFSC spring survey index of thorny skate biomass and commercial landings of the seven species skate complex from the Gulf of Maine to the Mid-Atlantic Bight.

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Manuscript Qualification

This series represents a secondary level of scientific publishing in the National Marine Fisheries Service (NMFS). For all issues, the series employs thorough internal scientific review, but not necessarily external scientific review. For most issues, the series employs rigorous technical and copy editing. Manuscripts that may warrant a primary level of scientific publishing should be initially submitted to one of NMFS's primary series (*i.e.*, *Fishery Bulletin*, *NOAA Technical Report NMFS*, or *Marine Fisheries Review*).

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Each figure should be supplied both on paper and on disk, unless there is no digital file of a given figure. Except under extraordinary circumstances, color will not be used in illustrations.

Manuscript Submission

Authors must submit one paper copy of the double-spaced manuscript, one disk copy, and original figures (if applicable). NEFSC authors must include a completely signed-off "NEFSC Manuscript/Abstract/Webpage Review Form." Non-NEFSC authors who are not federal employees will be required to sign a "Release of Copyright" form.

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Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in four categories:

NOAA Technical Memorandum NMFS-NE -- This series is issued irregularly. The series typically includes: data reports of long-term or large-area studies; synthesis reports for major resources or habitats; analytical reports of environmental conditions or phenomena; annual reports of assessment or monitoring programs; manuals describing unprecedented field and lab techniques; literature surveys of major resource or habitat topics; proceedings and collected papers of scientific meetings; and indexed and/or annotated bibliographies. All issues receive internal scientific review and most issues receive technical and copy editing.

Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series typically includes: data reports on field and lab observations or experiments; progress reports on continuing experiments, monitoring, and assessments; manuals describing routine surveying and sampling programs; background papers for, and summary reports of, scientific meetings; and simple bibliographies. Issues receive internal scientific review, but no technical or copy editing.

Fishermen's Report -- This information report is a quick-turnaround report on the distribution and relative abundance of commercial fisheries resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of this report.

The Shark Tagger -- This newsletter is an annual summary of tagging and recapture data on large pelagic sharks as derived from the NMFS's Cooperative Shark Tagging Program; it also presents information on the biology (movement, growth, reproduction, etc.) of these sharks as subsequently derived from the tagging and recapture data. There is internal scientific review, but no technical or copy editing, of this newsletter.

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