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Anadromous Rainbow Smelt and Tomcod in Connecticut: Assessment of populations, conservation status, and need for restoration plan

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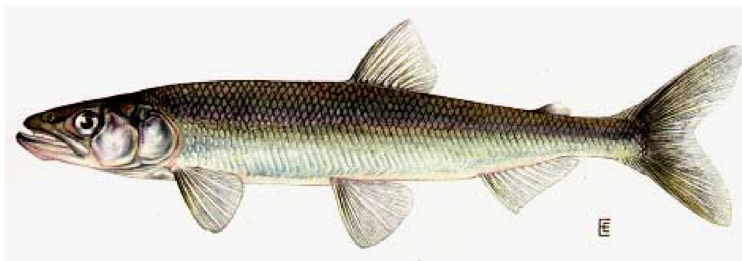
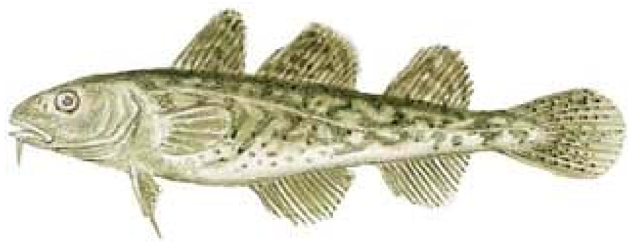
Anadromous Rainbow Smelt

and Atlantic Tomcod in Connecticut:

Assessment of Populations, Conservation Status,

and Need for Restoration Plan





Final Report

Submitted to the Connecticut Department of Environmental Protection

By

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RAINBOW SMELT EXECUTIVE SUMMARY

Purpose of the Project

Evidence indicates that anadromous rainbow smelt (*Osmerus mordax*) populations in Connecticut and elsewhere in the northeast United States have severely declined. Several sampling programs have documented declines in Connecticut’s smelt populations over the last three decades (Marcy 1976a, Marcy 1976b, Millstone Environmental Laboratory 2005). Similar declines have also been documented in the Hudson River (ASA Analysis & Communication 2005) and in Massachusetts (personal communication, Brad Chase, MA Division of Marine Fisheries 2004). Recreational and commercial fisheries in the region for this species have virtually ceased (Blake and Smith 1984). The Connecticut Fish Advisory Committee of the Endangered Species Program has recommended that rainbow smelt be listed as threatened in Connecticut, and the National Marine Fisheries Service (2004) has recently listed rainbow smelt as a Federal Species of Concern.

The purpose of this project is to develop an environmental history of rainbow smelt in Connecticut and surrounding regions, and document the current status of populations in Connecticut waters. An environmental history that assesses trends in abundance, environmental threats and historical efforts to ameliorate the threats will contribute to regional efforts to conserve these fish. Comprehensive review of the regional literature and trends associated with rainbow smelt has not been undertaken since Kendall (1926). Assessment of current abundance, distribution, areas of critical habitat, and whether the species is presently reproducing in state waters is critical for clarifying conservation status, designing a monitoring program and developing a recovery or enhancement plan, if this appears to be necessary.

Objectives

Specific objectives to be addressed were:

- Assess historical and contemporary trends in abundance and distribution in Connecticut and the surrounding region.
- Document environmental changes identified in early state and federal publications.
- Identify management actions taken to conserve the region’s populations and assess the impact of such actions.
- Determine the current use of selected estuaries by different life stages via sampling for:
    - adults and juveniles prior to the spawning season
    - adults on spawning runs, and eggs in spawning habitat;
    - larvae.

- Characterize the population structure, dynamics, and relative abundance in different estuaries by quantifying:
    - size structure and age structure of juvenile and adults prior to the spawning season;
    - female fecundity;
    - catch per unit effort of different life stages.

Methods

Historical Review

- Five source types were used: records of commercial landings and recreational catch, protective legislation, hatchery operations, reports of habitat condition, and ecological monitoring.
- Information on changes in smelt populations in the northeast United States was collected and interpreted.

Contemporary Assessment

- Sampling for rainbow smelt was concentrated in five estuaries along the central and eastern Connecticut coast: the Connecticut River, New Haven Harbor/Quinnipiac River, the Niantic River, the Thames River, and the Mystic River.
- Fyke and weir nets (fyke nets: set of 1 m diameter hoops, 2 m long, with 1 m X 2 m wings, 5 mm^2 delta mesh throughout; weir: 3 – 4 m wings closing to a 3 cm wide slot at entrance of 2 m X 6 m pen, constructed of PVC mesh throughout) were used to sample for adults on spawning runs in two tributaries of the Connecticut River, Pine Brook and Mill Brook, and the Poquonnock River, for a total of 51 sample-d.
- Spawning activity was assessed at thirteen locations in 2003 using burlap egg mats (1 ft^2) for a total of 1,584 mat-d. Spawning activity was assessed at twelve locations in 2004 via in-stream benthic habitat sampling (small stainless steel basket attached to 10 ft pole), for a total of 22 h of sampling.
- Experimental gill nets (50 ft, with equal-length sections of 9.5, 12.7, 15.9, 19.1, and 25.4 mm mesh [bar measure]) were deployed on six river systems in 2003 in 30 min to 1 hr sets, for a total of 66.4 net-h.
- Springtime larval sampling was conducted using multiple gears (benthic trawl, 1 m X 0.5 m X 5.3 m, 500 micron mesh; round plankton net, 0.38 m^2 opening X 3.5 m, 500 micron mesh; round plankton net, 0.2 m^2 opening X 1.8 m, 303 micron mesh). Round nets were fished in oblique tows. Sampling locations were selected randomly from the upper, mid, and lower reaches of each river system. Three estuaries were sampled in 2003 (N = 37) and five estuaries were sampled in 2004 (N = 36). All samples were preserved in 10% buffered formalin.
- Juveniles were sampled using three different seines based on season. Early spring sampling utilized a small seine (4.5 m x 1.15 m), with no bag and a coated cotton mesh of 5 mm^2 with constant haul width of 3.9 m. Late spring and early summer sampling was made using a small bag seine (5.5 m long, 1.25 m high and bag dimension of 1.1 m x 1.1 m x 1.1 m), with 50 mm^2 delta nylon mesh and a constant haul width of 3.9 m. Fall sampling was made using a large bag seine (8.6 m long, 1.6 m wide, bag dimension of 1.6 m x 1.6 m x 1.6 m) with a wing mesh of 50 mm^2 delta nylon mesh, and a bag mesh of 25 mm^2 with a weighted leading edge and constant haul width of 5 m. Samples were collected in four sequential 30 m hauls taken parallel to the shore line at each sampling location.

- All rainbow smelt specimens were measured to the nearest 0.01 mm standard length and weighed to the nearest 0.01 g. Lapillus and sagittae were extracted and preserved, and scale samples were taken from the dorsal region and retained.
- Sampling and animal handling conformed to protocols approved by the University of Connecticut Institutional Animal Care and Use Council.

Key Findings and Conclusions

Historical Review

- Smelt are a highly regarded food fish.
- The smelt fishery in New England has a long history beginning with the Native American peoples and continuing well into the 20th century. Commercial capture and exploitation of smelt were consistently reported in the anecdotal literature of the early to mid 19th century for local fisheries from New Jersey to Maine.
- Targeted or by-catch fisheries existed in every state with native smelt. Technical advancement in the long distance transport of fresh fisheries products during the late 1800's changed the smelt fishery from a strictly local seasonal enterprise to a larger regional export fishery.
- Commercial catch statistics indicate smelt populations from the Middle Atlantic and New England States suffered widespread declines throughout their range during the 20th century. Declines were most pronounced in the most southern states of the region (NY, NJ, CT, RI). Review of the cumulative commercial smelt catch along the U.S. Atlantic coast shows many of the commercial smelt fisheries have been exhausted for several decades.
- The Connecticut smelt fishery is not well documented in early State reports, suggesting that it was considered inconsequential by the State's fisheries biologists.
- Commercial harvest of smelt in Connecticut was focused on the April spawning run in the Saugatuck and Pawcatuck Rivers. Severe declines were being reported by 1922 and the Pawcatuck fishery crashed in 1937. In 1942, the Connecticut Board of Fisheries and Game declared the Saugatuck River fishery to be of little value.
- Recreational fishing for smelt was common in Connecticut, providing supplemental income and food during the fall and winter months. There are occasional reports of extremely large catches.
- Recreational fishing for rainbow smelt appears to have ended in Southern New England (CT, RI) and New York, but continues in more Northern States (ME, NH, MA) albeit at declining rates. The data on contemporary exploitation rates are scant because Federal fisheries reporting on recreational fisheries (MRFSS) does not cover the winter months when fishing for smelt is most active. Data available from individual state agencies would provide more comprehensive information on smelt fisheries in these areas.
- Smelt recreational fisheries are predominantly conducted from inland and near shore areas. Shore-based fisheries in both freshwater and marine environments are most productive. Historical information suggests the greatest pressure occurs during the winter months in southern states (MA, RI, CT), but may also be significant in the spring in northern states (ME). Approximately 78% of the smelt caught by recreational anglers is harvested.
- Limited historic information is available on the range of smelt in Connecticut, but presumably they occurred in most of the coastal streams and along tributaries of both the major and minor river systems. Contemporary long term monitoring and sampling programs indicate smelt are regularly identified in biological surveys of

Connecticut’s coastline but are considered less abundant or rare. Several long term studies have indicated juvenile and adult smelt periodically go absent from estuaries along Connecticut’s coast, only to return in subsequent years. Long term monitoring programs in New York indicate smelt were common in the Hudson River as recently as the 1990’s.Extensive sampling in the Hudson River has not detected smelt since 1996.

- Conservation of many smelt fisheries began during the early 19th century and was focused on fishing legislation. More aggressive stock enhancement efforts (hatchery production and stocking) were attempted in the late 19th and early 20th centuries in states with smaller, more vulnerable fisheries with limited success.
- Environmental factors may contribute to declining smelt populations. Degradation or loss of spawning grounds (due to development, sedimentation/road sand), poor water quality (due to nutrient enrichment, road salt, etc.), and global climate change may all be contributing to declining smelt populations. Predation from rebounding piscivorous fish species, particularly striped bass, may also negatively affect local smelt populations.

Contemporary Assessment

- Weir and fyke sampling yielded 464 fish of 19 species, but no rainbow smelt.
- No evidence of spawning activity was observed at any site in either year of sampling.
- In experimental gill net sets, 1,152 individuals of 17 species were collected. No smelt were collected during sampling.
- Large numbers of eggs and larvae were collected in ichthyoplankton tows, however smelt were absent in these samples.
- A total of 9 rainbow smelt were seined in the fall of 2004 in the upper Mystic River. An additional 11 specimens were collected from Niantic Bay in late February 2005 by the Millstone Environmental Laboratory. Specimens from both river systems showed similar length-weight relationships. Comparisons to fish collected in Massachusetts suggest all smelt collected belonged to the 2004 year class. Future otolith analysis may help to clarify age verification of these specimens.
- There are no known reproductively active anadromous rainbow smelt populations in Connecticut.

Recommendations

- The historical and contemporary assessment results meet the criteria for listing anadromous rainbow smelt as an endangered species. In particular, the data suggest that there are five or fewer occurrences in Connecticut, as they have been recently collected in only two estuaries and no estuary in eastern Connecticut appears to have a spawning population. In addition, the species has declined “seriously” and “noncyclically” in Connecticut and throughout a significant part of its range, and its spawning habitat is “unusually vulnerable to loss, modification or degradation in quality.”
- Conservation measures should be adopted to protect the spawning stock, because of its present vulnerability. These measures should include:
    - maintaining the inland fishery closure at all locations where anadromous runs may occur; extending the closure to coastal marine waters;

  - clarifying the status of published commercial regulations; closing the commercial fishery.
  - Investigating the feasibility of reestablishing runs by transplanting eggs into river systems most likely to support self-sustaining smelt populations.
- Further work on the population's status and threats to its welfare should be undertaken. This work should include:
  - designing creel surveys that accurately assess the impact of winter recreational fisheries;
  - conducting continued monitoring for spawning activity in multiple river systems;
  - examining potential causes contributing to low and declining abundance in Connecticut waters, such as fishing mortality, high summer water temperatures, poor water quality, impediments to spawning migrations, and piscivorous fish predation.
- Recovery goals for rainbow smelt should be established, including the number of river systems to target for restoration and levels of abundance.

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ATLANTIC TOMCOD EXECUTIVE SUMMARY

Purpose of the Project

Atlantic tomcod (*Microgadus tomcod*) are believed to have declined significantly in Connecticut and other estuaries of the Northeast and Middle Atlantic states. Several monitoring programs indicate that the species is scarce and/or declining in the region’s estuaries (Gottschall and Pacileo 2004, Molnar 2004, Millstone Environmental Laboratory 2005, ASA Analysis and Communication 2005). Once-active recreational (NMFS MRFSS 2005, http://www.st.nmfs.gov) and commercial fisheries for this species in Connecticut are now dormant. For the past 10 years, the Connecticut Fish Advisory Committee of the Endangered Species Program has recommended that studies be undertaken to quantify the status of tomcod populations and to determine if conservation actions should be initiated.

The purpose of this project is to develop an environmental history of Atlantic tomcod in Connecticut and surrounding regions, and document the current status of populations in Connecticut waters. An environmental history that assesses trends in abundance, environmental threats and historical efforts to ameliorate the threats will contribute to regional efforts to conserve these fish. Assessment of current abundance, distribution, areas of critical habitat, and whether the species is presently reproducing in state waters is critical for determining conservation status, designing a monitoring program and developing a recovery or enhancement plan, if this appears to be necessary.

Objectives

Specific objectives to be addressed were:

- Assess historical and contemporary trends in abundances and distribution in Connecticut and the surrounding region.
- Document environmental changes identified in early state and federal publications.
- Identify management actions taken to conserve the region’s populations and assess the impact of such actions.
- Determine the current use of selected estuaries by different life stages via sampling for:
    - adults and juveniles prior to the spawning season;
    - adults on spawning runs;
    - larvae.
- Characterize the population structure, dynamics, and relative abundance in different estuaries by quantifying:
    - size structure and age structure of juvenile and adults prior to the spawning season;
    - female fecundity;
    - catch per unit effort of different life stages.

Methods

Historical Review

- Five source types were used: commercial landings and recreational catch, protective legislation, hatchery operations, reports of habitat condition, and ecological monitoring.
- Information on changes in Atlantic tomcod populations in New England and Mid Atlantic coastal states was collected and interpreted.

Contemporary Assessment

- Sampling for Atlantic tomcod was concentrated in five estuaries along the central and eastern Connecticut coast: the Connecticut River, New Haven Harbor/Quinnipiac River, the Niantic River, the Thames River, and the Mystic River.
- Box traps were used to sample for adults on spawning runs along the shore of all target river systems. Four sites were sampled in the winter of 2002-03 for 1,850 trap-hours; seven sites were sampled in the winter of 03-04 for 46,782 trap-hours.
- Springtime larval sampling was conducted using multiple gears (benthic trawl, 1 m X 0.5 m X 5.3 m, 500 micron mesh; round plankton net, 0.38 m^2 opening X 3.5 m, 500 micron mesh; round plankton net, 0.2 m^2 opening X 1.8 m, 303 micron mesh). Round nets were fished in oblique tows. Sampling locations were selected randomly from the upper, mid, and lower reaches of each river system. Three estuaries were sampled in 2003 (N = 37) and five estuaries were sampled in 2004 (N = 36). All samples were preserved in 10% buffered formalin.
- Juveniles were sampled using three different seines based on season. Early spring sampling utilized a small seine (4.5 m x 1.15 m), with no bag and a coated cotton mesh of 5 mm^2 with constant haul width of 3.9 m. Late spring and early summer sampling was made using a small bag seine (5.5 m long, 1.25 m high and bag dimension of 1.1 m x 1.1 m x 1.1 m), with 50 mm^2 delta nylon mesh and a constant haul width of 3.9 m. Fall sampling was made using a large bag seine (8.6 m long, 1.6 m wide, bag dimension of 1.6 m x 1.6 m x 1.6 m) with a wing mesh of 50 mm^2 delta nylon mesh, and a bag mesh of 25 mm^2 with a weighted leading edge and constant haul width of 5 m. Samples were collected in four sequential 30 m hauls taken parallel to the shore line at each sampling location.
- All retained juvenile Atlantic tomcod specimens were measured to the nearest 0.01 mm standard length. Retained adults were measured to the nearest 0.1 cm.
- Lapillus and sagitta otoliths were extracted and preserved from all retained specimens.
- Daily age was determined from lapilli of juvenile specimens and yearly age was determined from sagittae from adult specimens.
- Sex of adult specimens was determined, and ovaries were extracted from all female specimens.
- Fecundity and gonosomatic indices (GSI) were estimated from ovaries.
- Sampling and animal handling conformed to protocols approved by the University of Connecticut Institutional Animal Care and Use Council.

Key Findings and Conclusions

Historical Review

- Atlantic tomcod historically were abundant and easily caught along the coastlines of mid-Atlantic and New England states.

- U.S. catch statistics of Atlantic tomcod reflect commercial fisheries throughout the range of the species, and a brief fishery in the Chesapeake Bay in the mid-20th century. Federally reported commercial catch of tomcod declined steadily during the early part of the 20th century. The only state reporting commercial catches consistently during the latter half of the 20th century was New York, where a fishery continued into the 1980's.
- Atlantic tomcod were not considered a fishery of consequence in Connecticut. Catches of Atlantic tomcod appear in the State of Connecticut Fish Commission accounts of the pound net fishery from 1896 to 1901. Federal statistics suggest Atlantic tomcod were commercially harvested in Fairfield and New London Counties.
- Recreational catches of Atlantic tomcod have been reported from Maine to Delaware along the Atlantic Coast since 1981. Catch most often occurs inshore during November and December, indicating that adults are susceptible during spawning runs. In Maine and New Hampshire, several-year pulses of catch were reported in the early 1980's and 1990's, followed by only one year of reported catch in each state. Reported catch has been relatively predictable in Massachusetts. In Rhode Island and Connecticut, reported catch declined steadily after 1985 and is now nonexistent. Reported catch in states further to the south have been sporadic with no temporal trend.
- Commercial and recreational catch have thus declined in Connecticut and the entire Northeast, with the exception of Massachusetts. The catch records do not supply strong evidence for population decline, because they are not adjusted for effort and because (in the case of the recreational survey) surveys do not occur when the fishery is likely to be most active.
- Data from regular sampling programs in Connecticut and New York waters present a mixed picture of recent changes in the abundance of Atlantic tomcod. Standardized for effort, catch has been episodically high but otherwise low and without trend in the Niantic River (Millstone Environmental Laboratory 2005), and has been increasing in New Haven Harbor. In the Hudson River, tomcod have mostly been declining for more than a decade (ASA Analysis and Communication 2005). Three of five lowest years of Hudson River records since 1976 have been 1999, 2000 and 2002 (2003, the last year of available data, was also well below average).
- There are multiple contemporary threats to Atlantic tomcod populations. High water temperatures during summer subject this boreal species to stress and will become a more acute problem should the region's temperatures increase with global warming. Predation from rebounding piscivorous fish species, particularly striped bass, may also negatively affect local populations. Liver cancer, possibly related to chemical contamination, is a common problem for tomcod in the Hudson River. Tomcod do not appear to be impacted by dams.
- Efforts to conserve or replenish the region's populations of tomcod have included hatchery-based stock enhancement attempts and limits on fisheries. Hatchery production of tomcod was attempted in New York, beginning in 1884 and continuing for decades into the 20th century, apparently supporting a winter recreational fishery. Connecticut's hatchery efforts, begun in the 1920's, ended within a few years because the fish were considered of little value commercially or recreationally. Current fisheries regulations effectively permit the taking of females before they have spawned for the first time.

Contemporary Assessment

- Box traps collected 1,596 individuals representing 26 species. Five tomcod were caught during the 2003-04 season, from four river systems (additional specimens were provided by cooperative agreements with other agencies). All fish collected were gravid, providing evidence that spawning was occurring in the Mystic, Thames, Connecticut and Quinnipiac Rivers.
- A total of 211 tomcod larvae were collected in ichthyoplankton samples. Eighty-nine percent of the larvae were collected from the Thames River. Spawning occurs in low-salinity regions of the Thames River during the winter months. Too few larvae were collected from the Connecticut, Poquonnock and Mystic Rivers to determine the location of spawning activity.
- A total of 10,110 individuals, representing 33 species, were caught in seine samples in 2003, and an additional 51,671 individuals, representing 37 species, were caught in 2004. A total of 498 juvenile Atlantic tomcod were collected. The highest catch per unit was 0.25 m^{-2}. Collections from the Mystic and Thames Rivers accounted for 80% of the juveniles collected. Sampling was most successful during early spring in the upper reaches of the estuary. Catch declined throughout the late spring and early summer months as juveniles moved downstream, and possibly then to cooler deep water.
- Thirty adult tomcod were collected between winter 2003 and spring 2005 from five river systems. The male to female ratio was 2:1. Males had a mean total length of 19.0 cm. Females were slightly smaller with a mean of 17 cm.
- Otolith analysis showed adult tomcod were collected from three age classes (age 0, 1 and 2). Age 1 fish represented 63% of the specimens. No Age 2 females were collected.
- A total of ten adult female tomcod were collected between December and April. Two mature females collected in December had GSI values close to 20%; both had 54,000 eggs to be spawned that season. Analysis of oocyte diameters suggested that tomcod are synchronous spawners.
- Tomcod spawn in Connecticut during the month of December. YOY females (i.e. almost 1 year old fish) are reproductively active. Larger sample sizes and more inclusive chronological sampling will provide better resolution of spawning seasonality, reproductive allotment, and fecundity estimates.
- Tomcod hatched between late March and early May.
- Juvenile growth rates, estimated as the change in standard length between collection dates, were 0.71 mm / day to 0.92 mm / day during the spring. Growth rates decreased during warm summer months.

Recommendations

- The historical and contemporary assessment results do not meet the criteria for listing Atlantic tomcod as a species of special concern. In particular, the data are not firm on whether the species has declined "seriously or noncyclically" in Connecticut, nor have factors been identified that cause the species to be "unusually vulnerable to extirpation". We therefore recommend that further work on the population's status and threats to its welfare be undertaken. This work should include:
    - designing creel surveys that accurately assess the impact of winter recreational fisheries;

  - conduct annual monitoring of juvenile settlement at index sites in multiple estuaries, scheduled to include early spring larval settlement in nearshore habitats;
  - investigate summer habitat use, focusing on benthic river channel habitats and offshore coastal areas;
  - examine potential causes contributing to low and declining abundance in Connecticut waters, such as fishing mortality, high summer water temperatures, piscivorous fish predation, and the incidence of liver cancer.
- Conservation measures (for Connecticut or regionally) that should be considered include several measures to protect the spawning stock, because of its present vulnerability to the fishery. These measures would include:
  - establish an inland fishery closure during the winter months;
  - set recreational size limits in coastal marine waters to 17 cm (8"), sufficient to insure YOY are able to complete their first spawning season;
  - clarify the status of published commercial regulations and close the commercial fishery.
- Considering recovery goals for Atlantic tomcod is not presently warranted but may be contemplated based on findings of future research and/or monitoring.

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF APPENDICES

LIST OF APPENDICES (continued)

CHAPTER 1

AN ENVIRONMENTAL HISTORY OF RAINBOW SMELT (*OSMERUS MORDAX*) AND ATLANTIC TOMCOD (*MICROGADUS TOMCOD*)

Section 1.1 INTRODUCTION

1.1.1 - DEVELOPING AN ENVIRONMENTAL HISTORY

During the last decade, considerable attention has been drawn to the hazard of using a limited contemporary time series of ecological data to set baselines for “normality” and assess ecological change (Pauly 1995, Jackson 1997, Jackson et al. 2001). Pauly (1995) and Sheppard (1995) have referred to this phenomenon of utilizing short term ecological data as “shifting baseline syndrome”, wherein each successive generation of scientists sets baseline environmental parameters from data collected during their career without consideration of the early history of a species. Compounding the problem, population assessment, including distribution, abundance and habitat use, can be difficult if not impossible to define resulting in grossly misestimated baselines (Rothschild et al. 1994, Casey and Myers 1998, Rogers-Bennett et al. 2002, Kirby 2004). The potential negative ramifications to the conservation and management of a species are obvious (Casey and Myers 1998, Rogers-Bennett et al. 2002) with risks including species declines going undetected and the potential for extinction (Pauly 1995, Casey and Myers 1998, Carlton et al. 1999). Recently Casey and Myers (1998) have shown that even common, widespread species, with available long term data, can experience largely undetected dramatic decline. Species largely associated with artesnal fisheries may be overlooked by a general lack of interest, data or economic incentive to monitor the species. The purpose of this study will be to help highlight the environmental history of two boreal fish species currently undergoing widespread population decline, rainbow smelt (*Osmerus mordax*) and Atlantic tomcod (*Microgadus tomcod*).

Environmental history is a multidisciplinary approach that intertwines past anecdotal ecology and human culture with quantitative analysis of contemporary data (Stewart 1998, Gross 2003), allowing for assembly of long-term data that can be used to assess

change over an environmentally relevant time period (Casey and Myers 1998) and help create a more sophisticated documentation of a species (Jackson et al. 2001). For species that have experienced change largely in the past, development of environmental histories can help overcome the limitations of a research field that tends to focus on the present by providing a historical perspective (Pauly 1995, Pauly and Maclean 2003). A number of recent publications have highlighted the benefits of constructing environmental histories for finfish and shellfish (e.g. salmon, Taylor 1999, oysters, Kirby 2004, and abalone, Rogers-Bennett et al. 2002). By adding a historical perspective to local and regional fisheries, attempts to develop effective management strategies can be placed in a relevant temporal and spatial framework through identification of the timing and possible reasons for population change (Rothschild et al. 1994, Jackson 1997, Jackson et al. 2001, Rogers-Bennett et al. 2002, Kirby 2004). Without examining the historical evidence of previous abundance, conservation efforts previously undertaken, and the environmental change that has occurred there exists the possibility that time, funding and effort will be wasted.

However, the use of historical anecdotal and quantitative data can pose challenging problems. Jackson et al. (2001) provide an overview of the potential problems associated with both anecdotal and quantitative historical records, pointing out that historical data often lacks the precision that allows for statistical analysis. Historical quantitative data is rarely collected with the particular question the researcher strives to answer in mind, and the methods and the quality are often not intercomparable. Anecdotal information can be highly subjective, and assessment of the worth of the information must be based upon the credentials of the observer and their knowledge of the system they are reporting on.

An alternative approach to a lack of directly relevant standardized data is the use of proxies to assess change and define baseline information for systems that have

undergone historical change. Paleoceanographers substitute proxies for desirable but unobservable parameters when attempting to reconstruct historical ocean records (Wefer et al. 1999). Similar techniques have been employed to utilize anecdotal and disparate quantitative information to describe population change and declines in various finfish and shellfish fisheries (Jackson et al. 2001, Kirby 2004). Common proxies used to identify and describe fishery declines have included early protective legislation, stock enhancement efforts and descriptive evidence of habitat change (Jackson et al. 2001, Kirby 2004). Catch data from commercial (Casey and Myers 1998, Rogers-Bennett et al. 2002) and recreational (Rogers-Bennett et al. 2002) fisheries can be used to identify change in distribution and abundance. While these proxies provide limited insight when viewed individually, in combination they can be useful for describing the patterns and reasons for ecological change, the start of fishery declines and to identify previous management activities and their outcomes.

1.1.2 - PROJECT RATIONALE

Rainbow smelt

Evidence indicates that rainbow smelt (*Osmerus mordax*) populations in Connecticut have severely declined in recent years. Several sampling programs in Connecticut, the Connecticut River Ecological Study (Marcy 1976a and Marcy 1976b) and the Fish Ecology Trawl and Seine Programs conducted by the Millstone Environmental Laboratory (2005), have documented declines in Connecticut’s smelt populations over the last three decades. Similar declines have also been documented in the Hudson River (ASA Analysis & Communication 2005) and in Massachusetts (personal communication, Brad Chase, MA Division of Marine Fisheries 2004) during the

last decade. A formerly active commercial and recreational fishery for this species in the state's estuarine waters has apparently ceased (Blake and Smith 1984).

Development of an environmental history of rainbow smelt in Connecticut is both relevant and timely, and will contribute to wider regional efforts to conserve these fish. The Connecticut Fish Advisory Committee of the Endangered Species Program has recommended that rainbow smelt be listed as threatened in Connecticut, and the National Marine Fisheries Service (2004) has recently listed rainbow smelt as a federal Species of Concern. Comprehensive review of the regional literature and trends associated with rainbow smelt has not been undertaken since Kendall (1926). Conducting a review of the historical environmental literature of smelt in surrounding states, including trends in catch statistics and conservation efforts, will allow for comparison of the trends and factors associated with decline in Connecticut.

Atlantic tomcod

Atlantic tomcod (*Microgadus tomcod*) are believed to have declined significantly in Connecticut and other estuaries of the northeastern and middle Atlantic states. A formerly active recreational fishery for this species in Connecticut's estuarine waters apparently has ceased (NMFS MRFSS 2005, http://www.st.nmfs.gov). Trawl survey data indicate that adult abundance of Hudson River tomcod has been consistently lower in the last decade than previous years (ASA Analysis and Communication 2005). Several long-term sampling programs in Connecticut, the Connecticut Department of Environmental Protection’s Long Island Sound Trawl Survey (Gottschall and Pacileo 2004) and Estuarine Seine Survey (Molnar 2004), and the Fish Ecology Trawl and Seine Programs conducted by the Millstone Environmental Laboratory (2005) have documented declines in Connecticut’s tomcod populations during the last two decades.

For the past 10 years, the Connecticut Fish Advisory Committee of the Endangered Species Program has recommended that studies be undertaken to quantify the status of tomcod populations and to determine if conservation actions should be initiated to ensure the species' continued survival in the state. Review of the historical literature related to tomcod in Connecticut has not been undertaken, making trends and factors associated with the perceived decline difficult to assess. Development of an environmental history for tomcod will assist with efforts to develop conservation actions designed to limit further decline in state waters.

1.1.3 - PROJECT OBJECTIVES

By reviewing the historic and contemporary literature for evidence of early changes, possible causes of decline, and, past conservation efforts, a more comprehensive baseline for both rainbow smelt and Atlantic tomcod in Connecticut can be developed. The ultimate goal will be to make effective management recommendations based on a synthesis of the available historic and contemporary data. Specific objectives to be addressed in this chapter are to:

(1) Assess historical and contemporary trends in abundances in Connecticut and the surrounding regions.

(2) Assess historical and contemporary trends in distribution in Connecticut and the surrounding regions.

(3) Document early environmental changes that were identified in state and federal publications.

(4) Identify and assess any management actions taken to conserve Connecticut’s populations and populations in surrounding regions.

1.1.4 - Approach to the Literature

Two types of early references about local and regional fisheries can be used to construct environmental history, anecdotal observations and catch statistics. Early anecdotal observations can be obtained from a variety of lay publications and provide interesting views on important aspects of a fishery including characterization of local resources, biogeography, biology, commercial fishing pressure, recreational popularity, and cultural and economic responses to the resource. We chose to incorporate early anecdotal observations into our analysis of the fishery despite the fact that there are widespread perceptions of inaccuracy. Pauly and MacLean (2003) have argued the opposite is largely true, that anecdotal observations are simply early history and may represent an accurate depiction of the changes a fishery is experiencing. Commercial catch statistics provide a statistical view of the changes associated with a fishery and have been collected for over a century by both state and federal agencies. Catch statistics provide information on abundance, distribution, and gear use providing early indications of the manner of exploitation and change to the fishery. MacIntyre et al. (1995) and Mowat (1984) use a selection of anecdotal quotes to illustrate that anecdotal reports of decline are reflected in modern fisheries analyses. By incorporating anecdotal references and catch statistics a more inclusive record of the changes associated with a fishery can be developed.

Historic fishery information exists in a variety of public and private sources of literature, including newspapers, industry gray literature, peer reviewed publications, and federal and state fishery reports. Fisheries literature from State and Federal Publications, such as fish and game commission reports, commercial and recreational catch statistics and informational bulletins, were given priority as they were most likely to contain applicable fishery information. Peer reviewed publications were searched for

species-specific information and studies that incorporated fish community sampling from the Connecticut region. Historical and contemporary newspaper articles were searched using available online bibliographic databases, after initial attempts to review hardcopy publications provided to be ineffective. Although this limited the number of titles available for review, it provided us with a number of valuable references (Appendix E.1). The published data from a number of contemporary private regional monitoring programs were searched for species occurrences and abundance. Many obscure publications, which had not been identified through the above process, were recommended by researchers working in fishery related fields.

We structured our approach by geographic region (spatial), timeframe (temporal) and information source (data). Selection of the geographic region for literature review was based on the reported distribution of both species within the United States (Collette and Klein-MacPhee 2002). While records of both species exist from Canada, limiting our review to the United States allowed us to focus on records that could be obtained locally. A cursory review of early Federal and State catch statistics for the Atlantic coast indicated that our target species were regularly included among the fisheries reports for the New England and Mid Atlantic regions. Therefore, emphasis was placed on the historical literature from these regions, with focus on records from New England and Mid Atlantic States. Temporal groupings included a range of resolution. Comprehensive publications such as Kendall (1926) and Pearson (1972) provided a broad review of the literature from the period of Colonial Settlement through the American Revolution into the start of the Industrial Revolution. Review of the Connecticut and Massachusetts Fish and Game Commission reports and various federal agencies provided annual perspectives of regional fisheries (Appendix A.1, D.1, F.1). Much of the contemporary monitoring data provided species related information on a monthly to yearly basis. We used a combination of bibliographic search engines, online library catalogs, Internet

searches and physical review of literature to identify sources of information. Selected sources were utilized based on their accessibility and the likelihood they would contain fisheries information relevant to the species of interest. These largely included print literature, but also more recent compilations of fishery statistics available through searchable Internet databases (National Marine Fisheries Service Commercial Landings Information and Marine Recreational Fishery Statistics Survey; http://www.st.nmfs.noaa.gov/).

I identified five types of references that could be used as proxies for fishery change following Kirby’s (2004) approach to classification of historical fisheries information: (a) commercial landings and recreational catch, (b) protective legislation, (c) hatchery operations, (d) reports of habitat condition, and (e) contemporary ecological monitoring. The following table summarizes the proxies used to fulfill each of the objectives identified for this portion of the study.

Specific Objective	Proxy Used
1. Identify trends in abundance	(a), (b) and (e)
2. Identify trends in distribution	(a) and (e)
3. Document early environment	(b), (c) and (d)
4. Identify conservation actions	(b) and (c)

SECTION 1.2: ANADROMOUS RAINBOW SMELT (*OSMERUS MORDAX*) - AN ENVIRONMENTAL HISTORY

"There *are fishes that I knew as a boy that are gone today; among them smelt, once so numerous they could be scooped with a bucket.*"

Robert F. Kennedy, Jr.

Foreword for Andersen, T. 2002

This Fine Piece of Water

SECTION 1.2.1: HISTORICAL AND CONTEMPORARY TRENDS IN ABUNDANCE

Early Abundance and Exploitation

The smelt fishery in New England has a long history beginning with the Native American peoples, continuing through the early colonial settlements and well into the 20th century. Early visitors to the American Colonies reported on the biogeography, biology and economic value of smelt in the areas surrounding Boston (Pearson 1972). As a result of their great abundance and ease of capture, smelt were commonly used as food, fertilizer and bait (Goode 1884, New York Times 1894b, Kendall 1926). Mowat (1984) included the following reported historical observation of farmers "smelting" for fertilizer, "It is an astonishing sight to paddle down the Restigouche and see the farmers 'smelting' – scooping up the little fish in handnets. The amount they take is incredible and most of their potatoes spring from this fishy manure." Their mention in the early literature speaks to their importance to both local economies and social activities of many New England and Canadian settlements.

The commercial capture and exploitation of great runs of smelt were consistently reported in the anecdotal literature of the early to mid 19th century, with large numerical catches reported for local fisheries from New Jersey to Maine. As early as 1833 wagonloads of smelt could be taken during their spawning runs in Newark Bay (NY Times 1881). In 1853, the annual catch of spawning smelt in Watertown, Massachusetts ran as high as 750,000 dozen and in central Maine, during the winter of 1883-84, 40 box cars were filled (Goode 1884). Given smelt are generally less than 6 ounces, these catches represent large numerical removal from fisheries that in certain regions had already undergone exploitation for several decades, if not centuries.

Every state with smelt had some form of fishery activity, whether targeted or by catch, that exploited these small fish. With the technical advancement in the long distance transport of fresh fisheries products during the late 1800’s, commercial exploitation of smelt began to change from a strictly local seasonal enterprise to a larger regional export fishery. Smelt were highly prized as a food fish, with demand for smelt in metropolitan areas such as Boston and New York far exceeding the capacity of local fisheries (Goode 1884), insuring that good wages could be made fishing for smelt during the long winter months (Kendall 1926). Prices in the Boston market were as high as 25 to 30 cents per pound in 1875 and in New York at 16 cents per pound (Kendall 1926). By the early part of the 20th century demand in metropolitan areas was so great that tariffs normally assessed on imported Canadian fishery products were waived, because the U.S. fisheries could not meet demand (Ackerman 1941).

Rise of Commercial Smelt Fisheries

Federal documentation of the commercial fisheries of the United States began with the formation of the US Fish Commission in 1871. The first complete statistical reviews of the New England and Mid Atlantic Regions are available in the 1892 Report of the US Fish Commissioners for the period 1887-88 (Collins 1892). Yearly reports are available for the same regions sporadically until 1950, and yearly thereafter. Commercial catch statistics published since 1950 are available in a query driven statistical database available online from the National Marine Fishery Service (http://www.st.nmfs.noaa.gov/).

Commercial catch statistics indicate smelt populations from the Middle Atlantic and New England States suffered widespread declines throughout their range during the 20th century, with the most pronounced changes in the southern extent of their range.

Over the last 116 years, the majority of the commercial anadromous rainbow smelt harvest in the United States has come from the New England Region (Fig. 1.1) with a limited contribution being reported for the Mid Atlantic Region (Fig. 1.2). Harvest of smelt from coastal New England waters began declining following a record catch of 1.7 million pounds in 1892, with regular commercial catches ending in many southern New England states by the mid 20th century. The Mid Atlantic fishery has been irregular and shows periods of complete commercial absence alternating with abundance throughout the last century, but shows a similar pattern to New England of diminished catch. The following state by state review of the commercial catch statistics show regional patterns of abundance and gear use, with associated temporal and spatial declines.

State Catch Statistics

The Maine smelt fisheries have historically dominated the commercial landings (Fig. 1.3). Fishery statistics for 1860, presented to the 38th Congress, reported 26 tons of smelt that year from Sagadahoc County in Maine alone (House of Representatives 1863-65). Goode (1884) provides early state-by-state documentation of the commercial smelt fishery in New England. Goode (1884) noted that in 1884 the simple artisanal smelt fishery for fertilizer and food in Maine was rapidly changing into a valuable commercial fishery. Smelt fisheries in this region were considered relatively obscure by those not directly involved, despite its economic importance during winter months (Goode 1884, Kendall 1926). Rise of the commercial fishery in Maine was swift and by 1890 it represented 88% of the New England smelt catch (Collins and Smith 1892). Commercial fisheries were quickly established on almost every river in the state, with principal fisheries occurring on the Bagaduce, Penobscot, and Kennebec Rivers (Collins and Smith 1892, Smith 1896). Peak catch of 1,620,000 pounds was reported for Maine in 1892 with slow but steady declines over the next century.

In New Hampshire, commercial activity (Fig. 1.3) was limited to the Merrimac River and its associated tributaries. Smelt were once considered the "most important fish" in the coastal waters of New Hampshire (Warfel *et al.* 1943), but intensive harvest was not reported commercially until the mid 1930's to early 1940's, with a peak catch of 143,000 pounds reported in 1943. The last reported commercial catch was 1996.

Massachusetts's fisheries show three peaks between 1879 and 1944 (Fig. 1.4), with maximum catches of 35,000 pounds in 1879, 39,000 pounds in 1919 and 25,000 pounds in 1938. Harvests in Massachusetts were predominantly reported for counties along the Gulf of Maine and Buzzards Bay with reports occurring from both regions until 1919. Following the 1919 report, regular catches only occur in counties bordering Boston Harbor and the Merrimac River, and occasional catches of several hundred pounds from counties surrounding Buzzards Bay. With the exception of two brief periods, 1966-74 and 1987-93, the commercial smelt fishery in Massachusetts ended in the early 1950's.

Peak catches for both Rhode Island and Connecticut occurred in 1880, with 95,000 and 27,000 pounds respectively (Fig. 1.5). Fisheries along the northern shore of Long Island Sound were predominately carried out on the Pawcatuck River in Rhode Island, and the Mystic, Thames and Saugatuck Rivers in Connecticut (Smith 1896, Connecticut Board of Fisheries and Game 1922). Although multiple watersheds were fished in Connecticut, the catch was comparatively small compared to Rhode Island's. Commercial activity in Rhode Island declined between 1880 and 1918, with complete failure on the Pawcatuck River reported in 1937 (Connecticut Board of Fisheries and Game 1940). The 1937 crash essentially ended the smelt fishery in Rhode Island, while commercial catch in Connecticut continued to decline. The largest catches reported for Connecticut and Rhode Island during the last 50 years were for 1960-69 when several thousand pounds were taken. Excepting 300 pounds reported in 1979, the commercial

fishery in Connecticut has been extinct since 1969. Rhode Island has fared only slightly better, with a total of 747 pounds taken between 1984 and 1995.

The smelt fisheries of the Mid Atlantic Region were confined to New York and New Jersey. Despite the collection of catch statistics from this region since 1887, smelt were not listed as commercial species until 1904 (Fig. 1.6). Commercial fisheries for smelt historically existed in Newark Bay as early as 1835 (New York Times 1881) and smelt could reportedly be caught on Long Island in the early 1880’s (New York Times 1883). The 1860 Fisheries Census Report submitted to the House of Representatives (1863-65) reported that “green” smelts, fish caught in Raritan Bay and other areas around New York City, were preferred in the local market to frozen smelt imported from further north. However, by the time the U.S. Fish Commission began collecting commercial catch statistics for this region in 1887, smelt had reportedly been declining in the waters of New Jersey and Long Island for several years and were not considered commercially viable (New York Times 1881, Mather 1887, Mather 1889). The condition of the fishery on the Hudson River during this time was not elicited from review of the federal catch statistics, but presumably was suffering in a similar manner.

Commercial catch from New Jersey was reported from as far south as Cape May in 1904, but by 1917 was confined to Middlesex County with the last regular commercial catch reported in 1921. Camp (1941) reported that smelt had been considered endangered in 1877 as a result of commercial exploitation, and that by 1941 there were no longer smelt in New Jersey. Smelt were listed as endangered in New Jersey in 1971 (Fried 1971). A total catch of 100 pounds taken by otter trawl was reported in 1985, but the smelt fishery in New Jersey appears to have gone extinct in the early part of the 20th century.

The history of the smelt fishery and the pattern of exploitation in New York is unclear, notwithstanding review of the Federal literature. Early years in which commercial records were listed by county (1904, 1917, 1921), show that the majority of smelt harvest in New York came from the marine waters surrounding Suffolk County on the eastern end of Long Island Sound, with a peak catch of 16,600 pounds of fish in 1917. The catch of smelt declined and through the late 1930’s up to 1950 the yearly catch of smelt ranged between 0 and 600 pounds with brief peaks of abundance from 1951-61 and again from 1974-77 (Fig. 1.6). Review of the New York Landings from this later time period show the catch during 1974-77 did not originate from counties border by marine waters, and the majority of the catch was harvested using dip nets (National Marine Fisheries Service 1975, 1976, 1977). This suggests New York’s commercial statistics include a component from freshwater systems, which may or may not be of anadromous origin, making it difficult to determine the degree to which the commercial marine harvest had declined. Since 1977, commercial harvest of smelt in New York has been virtually nonexistent.

Gear Use in the Smelt Fisheries

Information on the types of gear used by commercial fishermen in each state is provided in Table 1.1A and Table 1.1B, and includes gears that account for 99% of the total reported commercial catch. Gear information is sporadic between 1887 and 1950, but is complete from 1950-2003. The hand line fishery accounts for the greatest pressure on the US Atlantic smelt population representing 40-47% of the entire commercial catch. Haul seines, bag nets, and dip nets account for an additional 48%, with shifts away from seine use occurring after 1950. Gill nets, otter trawls and fixed gears, such as pound nets, trap nets and weirs, make up the remainder of the catch. In

addition to the gears listed in Table 1.1A-B, smelt are reported as by-catch in lobster and shrimp pots in the Maine fishery.

Gear use varied regionally with early fisheries in Maine and New Hampshire mostly dependent on hand lines, haul seines and bag nets, while more southern fisheries, those in Long Island Sound and the Mid Atlantic Bight, predominantly utilized seines and fixed gears (Table 1.1A). Gear use in more northern states appears to be related to the winter conditions, where hand lines and bag nets could easily be fished through the ice during winter months when smelt congregated in the upper reaches of large river systems (Goode 1887b). Seines were used in more southern states to take fish on their spawning runs (Connecticut Board of Fisheries and Game 1922) and smelt were regularly taken in fixed gears in Rhode Island and New York. Connecticut is one of the few southern states that regularly used dip nets, but their use appears to have been confined to river systems in New London County. It is unclear whether this activity was associated with ice cover or spring spawning runs. Smelt fisheries were still dominated by hand lines and bag nets after 1950 (Table 1.1B), but the southern fisheries show a shift with diminished haul seine catch and an absence of fixed gear catch. Despite the fact otter trawls had been in use prior to 1950, smelt are not reported as a component of the otter trawl fishery until after 1950, and only represent a significant portion of individual state catches in Massachusetts, Rhode Island and New Jersey (Table 1.1B).

Review of the cumulative commercial catch along the U.S. Atlantic coast shows many of the commercial smelt fisheries have been exhausted for several decades. The percent cumulative commercial catch for all states reporting smelt between 1887 and 2003 is shown in Fig. 1.7 and summarized in Table 1.2. With the exception of New Hampshire and New York, 75% of the commercial catch in each state was achieved prior to 1950. New Jersey reached 99% of its commercial catch in 1921, followed by

Rhode Island in 1967 and Connecticut in 1968. Maine and New York both reach 99% in the late 70’s followed shortly by New Hampshire. Massachusetts reached 99% in 1991. Presently there is no statistical data to identify the reasons for the various patterns of exploitation. The pattern of percent accumulation appears to be related to the size and number of watersheds being exploited in each state. In addition, proximity to the edge of the biological range appears to be an important factor and would be an interesting topic to pursue further.

The Connecticut Smelt Fishery

The early exploitation of the fishery within Connecticut is not well documented. Presumably smelt had been exploited in the state from the period of first colonization, much like other New England states. Unfortunately little information is available that would enlighten the history of smelt in Connecticut from this time period. Smelt are not incorporated into the early publications released by the State of Connecticut’s Fish Commission despite the fact the Commission was charged with reporting on and overseeing the preservation and protection of Connecticut’s Sea Fisheries.

Reports on Connecticut’s commercial fisheries are incorporated into the publications of the Connecticut Fish Commission beginning with their formation in 1867. Catch statistics were limited to edible fish species viewed as having substantial economic impact to the region. This included shad and salmon, and the focus of the reports was predominately on fisheries associated with the Connecticut River. All other marine fisheries and regions within the State were largely ignored; despite the fact that as early as 1871 many other marine species were of concern in surrounding States (Baird 1873).

Smelt statistics did not appear until 1896, when Connecticut's newly formed Fish and Game Commission criticized the narrow reporting focus of the previous administration. The Commission urged more aggressive legislation be passed that would document all of Connecticut's commercially important species, aligning them with the national activities being encouraged by the US Fish Commission. As a result, State laws were amended requiring commercial fishermen to report their catch of all edible food fishes for the entire year, rather than the two month shad window (mid April to mid June) they had formerly been required to document (Connecticut Commissioners of Fisheries and Game 1896).

The first smelt statistics are included in the 1896 report of the pound net fishery in coastal waters (Connecticut Commissioners of Fisheries and Game 1896). Between 1896 and 1902 the reports included the cumulative annual catch statistics for all pound net permits issued to a single individual, including the location each net was fished. The geographic range includes regions from the Rhode Island border to Milford, Connecticut. Smelt catches were reported variably as barrels, pounds or numbers of fish. The returns reported between 1896 and 1902 indicate smelt were not a widespread catch, being listed from only a few pound nets, with catch ranging from a low of 25 fish up to 100,000 fish. The 1897 report for the Milford smelt fishery 2,250 individuals weighed 450 pounds, giving a per fish weight of 3.2 ounces. Using this conversion, the total catch of fish reported for 1902, 145,100 individuals, would be equivalent to 29,020 pounds, 2,020 pounds more than the peak catch previously reported for 1880 by the U.S. Fish Commission.

Considerable discrepancies exist between the federal and state fishery reports as to the locations and types of gear used in Connecticut's smelt fisheries. State reports make no mention of the early haul seine and dip net fishery that was commonly reported

by the U.S. Fish Commission. Despite the active smelt fisheries reported in both New London and Fairfield Counties in the federal statistics, there is no mention of any fisheries in these regions in the early state reports. More problematic is the lack of information on the river fisheries and associated gears throughout the State. The limited documentation of the early smelt fishery in the State reports suggests they were considered inconsequential and were simply ignored by those reporting internally on the State’s fisheries.

Smelt were targeted for commercial harvest during their April spawning run in Connecticut on both the Saugatuck and Pawcatuck River (Connecticut Board of Fisheries and Game 1922). Both smelt fisheries began receiving public attention in 1922 when the fishery on the Saugatuck River failed (Connecticut Board of Fisheries and Game 1922). Local fishermen feared the Saugatuck fishery had reached its “vanishing point” and State biologists were proposing to regulate the fishery, through gear restrictions and artificial propagation, in order to sustain the population (Connecticut Board of Fisheries and Game 1922). Commercial seine nets were the common gear, with nets ranging from 125 to 300 ft and 14 to 18 ft deep, and mesh sizes ranging from ¾ to 5/8 inch for the wings and 5/8 in the bag. While there are no statistics given for the number of fish that could be taken during a single haul, estimates from similar nets used in Massachusetts suggests the potential for upwards of 80,000 fish or 6,700 pounds of smelt could be harvested in a single haul (Kendall 1926). This level of exploitation was feared to be driving the failure of the fishery (Connecticut Board of Fisheries and Game 1922). For several years the Connecticut reports comment on the condition and gears used in the fishery, noting the crash of the Pawcatuck fishery in 1937 followed by declining catches in the Saugatuck River.

Smelt continued to receive attention until 1942, when state biologist declared the fishery to be of little value and all but finished (Connecticut Board of Fisheries and Game 1942). No mention of the fishery follows the publication of the 1940-1942 Connecticut Fish and Game Commission Report, and the catch statistics reported by the U.S. Fish Commission would support the assumption the fishery had reached its vanishing point. Later reports on Connecticut marine fish resources would only mention smelt incidentally, with the commercial fishery regarded simply as a historic activity in Connecticut (Blake and Smith 1984).

Recreational Fisheries

Recreational fishing for smelt was a common activity during the fall and winter months in states with smelt populations (Goode 1884, Kendall 1926). Smelt were voracious and could be caught using light tackle either from docks or through the ice, and capture of these little fish required minimal skill (New York Times 1894b, New York Times 1910b). In the Boston area, smelt fishing crossed all social barriers, and both businessmen and paupers alike could be found fishing for a breakfast of smelt along the docks in the early mornings of the fall months when the fish came into the coastal embayments (Kendall 1926). Smelt were considered the “best pan fish of all” in the New York and New Jersey area, with the best fishing reported for the Raritan and the Hackensack, Rivers in December (New York Times 1893). Investment in fishing gear was minimal, and for many men and boys, it represented a source of income during winter months when little other type of outdoor employment was readily available (Kendall 1926). During the winter of 1878-79, at the head of the Medomak River in central Maine, 32 tons of smelt were taken as part of the recreational fishery with 225 boys and men casually participating for supplemental income (Goode 1887a). Clearly,

despite the recreational nature of the activity, it could represent excessive catches of smelt.

Little information is available on the recreational fishery that historically existed in Connecticut’s coastal waters. A general sense of the historical activities are alluded to in several publications (Connecticut Board of Fisheries and Game 1942, Blake and Smith 1984), and regulations governing the recreational take of smelt in inland waters have been published yearly in the Connecticut Angler’s Guide for many decades, however they provide little information about the location and scope of the fishery. Recreational capture of spawning fish using dipnets could not be documented and older fishermen who shared information on historical locations indicated they were only aware of fishing activities related to hook and line or commercial exploitation in the main river channel with seines.

The long term database of the NMFS Marine Recreational Fishery Survey Statistic (MRFSS) available online (http://www.st.nmfs.gov) was reviewed for recreational smelt activity on the Atlantic coast between 1981 and 2003. Recreational statistics are collected for three reporting categories (TYPE; Table 1.3), Type A – observed harvest, Type B1 – reported harvest, and Type B2 – reported live release, with the combination of these three categories giving an estimation of the total recreational catch for a state. Statistics are collected annually during six two month periods (WAVE), and are characterized further by fishing area (AREA; Table 1.4) and manner of collection, boat or shore based (MODE; Table 1.5). The results need to be viewed with extreme caution as the proportional statistical error (PSE) values ranged from 45-106%, a problem with fish reported infrequently (NMFS 2005). In addition, changes to the sampling methodology, which terminated survey activities during Wave 1 (January and February) for all regions in 1981, and during Wave 6 (November and December) for

Maine and New Hampshire in 1983, have lead to underreporting in areas where well documented and persistent winter recreational fisheries for smelt exist. Regardless of the obvious limitations of the dataset, the available information provides an important view of the recreational fishery.

The total estimated recreational catch of rainbow smelt for Maine, New Hampshire and Massachusetts are presented in Figure 1.8 and for Rhode Island, Connecticut and New York in Figure 1.9. The estimates indicate recreational smelt activity has ended in Southern New England and New York, but continues in more Northern States with the declines occurring in over the last several decades. Reporting problems are obvious for states such as Maine and New Hampshire, and any inferred decline must be viewed skeptically. Data available from individual state agencies would provide more comprehensive information on smelt fisheries in these areas.

Information on the seasonal nature of smelt fisheries and the potential mortality impacts can be obtained from the Wave and Type categories. Table 1.6 shows recreational activity by wave, with obvious limitations based on changes to the survey methodology mentioned above. Massachusetts may provide the best picture of the seasonal nature of this fishery, with the majority of their catch taken in the fall and winter (Wave 5 and 6) when the fish would begin to come into local bays. The limited fishing activity that has occurred in southern states during the last 20 years appears to be confined to the fall and winter, suggesting fish are not targeted in these areas during spawning runs. In contrast, reports from Maine suggest fishing pressure may be strong during late spring and early summer spawning activity. Mortality rates from recreational activity has the potential to be high as results indicate as much as 78% of the the catch is harvested.

The smelt fishery is predominantly conducted from inland and near shore areas (Ocean <= 3 mi), with limited open ocean (Ocean > 3 mi) catches observed (Table 1.4). All states reported inland activity except New York, and Connecticut and Rhode Island’s fisheries were exclusively inland. Only Massachusetts reports open ocean activity, but the amount is less than 1% of the total reported catch. Further review of the fishery statistics for the inland and near shore categories by mode shows that 62% of the catch comes from shore based activity, with Maine reporting the only beach and bank activity (Table 1.5). The fisheries in southern New England and New York are based exclusively on shore and manmade structures.

Review of the recreational data suggest smelt fisheries in areas where declines are most pronounced are susceptible to fishing related mortality, and that shore based fisheries in both freshwater and marine environments will pose the greatest threat. While the seasonal nature of the fishery is difficult to assess due to the limited reporting window, historical information suggests the greatest pressure will occur during the winter months.

Contemporary Ecological Observations in Connecticut and the Hudson River

A number of long term monitoring and sampling programs, as well as short term fish ecology studies, have been conducted in the waters of Long Island Sound and its associated tributaries. Shorter term ecological studies and biological surveys have documented smelt in Long Island Sound over the last century, and have been reviewed and compiled by the staff of Project Oceanology (Weiss et al. 1995, Appendix B.1). The Project Oceanology literature review indicates smelt are regularly identified in biological surveys of Connecticut’s coastline but are considered less abundant or rare, with few

studies listing them as abundant (e.g. Perra and Steinmetz 1980). Briggs (1991) has listed smelt as rare in the waters of Long Island, New York.

Several long term studies have indicated juvenile and adult smelt periodically go absent from estuaries along Connecticut’s coast, only to return in subsequent years. Data collection ranges from several to almost thirty years, and the results indicate smelt have declined in abundance over the last several decades and in some cases have disappeared completely. The following information is intended to provide a brief summary of several long-term sampling programs that have documented smelt in Connecticut and the Hudson River. These data sets provided the most complete picture of abundance change in Connecticut and the Hudson River over the last several decades. Studies in Connecticut are listed from west to east along the coast.

New Haven Harbor

Between July 1942 and June 1943, Warfel and Merriman (1944) made biweekly collections in Morris Cove, New Haven Harbor in an attempt to document Connecticut’s shore fishes and their temporal use of the near shore environment. Of more than 16,000 fish collected, only four smelt were observed, all taken on May 14, 1943, ranging in size from 60-79 mm. The author’s note that their absence from the biweekly samples was perplexing given they were well known from the surrounding region, but could offer no explanation for their absence. Fishery biologists with the NMFS Milford Connecticut Lab have conducted similar shore sampling since 1998, sampling biweekly from April to October with a total of one smelt collected in 1998. The CT-DEP has also conducted a seine survey in this area since 1988 with no smelt observed in New Haven Harbor (David Molnar, Connecticut DEP, Marine Fisheries Division, personal communication).

Two trawl survey programs have also been conducted in New Haven Harbor during the last three decades. Normandeau Associates, Inc. (1973, 1977-1983) conducted otter trawl surveys at several stations within the Harbor to assess the impact of the United Illuminating Company's New Haven Harbor Station. Fewer than 20 smelt were collected between May 1971 and April 1972, and relatively few smelt were taken between 1977 and 1983, with a maximum catch per 10 minute tow of 15 fish reported in 1983. No smelt were reported for the 1976 sampling season. Trawl surveys, conducted as part of the CT-DEP inshore winter flounder surveys, in New Haven Harbor from 1990-1995 did not detect smelt although smelt were collected in other Connecticut locations as part of the same study (David Molnar, Connecticut DEP, Marine Fisheries Division, personal communication).

Ichthyoplankton studies conducted for the U.I. Co. New Haven Harbor Station documented a single larva at the confluence of the Mill and Quinnipiac River in April, and eggs from February to May in 1977 (Normandeau Associates Inc. 1978), but none had been observed in the previous years sampling (Normandeau Associates Inc. 1977). Larvae and eggs were not collected between 1979 and 1983 (Normandeau Associates Inc. 1980-84). Appropriate spawning habitat does not exist on the Quinnipiac River, but does exist on the Mill River (Chapter 2), suggesting the eggs and larvae may have originated in the Mill River.

<u>Connecticut River</u>

The best known of Connecticut's long term fish monitoring programs is the Connecticut River Ecological Study, a program undertaken to study fish species inhabiting the lower Connecticut River from 1965 to 1972, and designed to assess the impact of the Connecticut Yankee Power Plant (Merriman and Thorpe 1976). All life

history stages of smelt were collected the first three years of the study, along the entire study region. A total of 132 juvenile fish were collected from mid summer through late fall with peak abundances in July and October, and 131 adults were collected from early spring through late fall with peak abundances occurring in April and October (Marcy 1976a). Following the 1968 collections, juvenile and adult smelt were absent from all the collections, suggesting the population that had inhabited the study area went extinct. A total of 221 smelt eggs and 494 larvae were collected between 1965 and 1969, but annual catch statistics are not presented making it impossible to determine whether or not smelt eggs and larvae were collected in 1969 (Marcy 1976b). Smelt at all stages represented less than 1% of the total catch for the entire study period. Most recently two smelt were collected in 1993 as part of the Connecticut Department of Environmental Protection, Marine Fisheries Division inshore trawl surveys (see Howell and Molnar 1995 for location information).

Millstone Environmental Laboratory, 1976 - Present

Since 1976 the Millstone Environmental Laboratory has been continuously monitoring the fish fauna associated with the waters surrounding the Dominion Nuclear Power Station, in Waterford, Connecticut through a combination of trawl, seine and ichthyoplankton entrainment surveys (Millstone Environmental Laboratory 2005). Smelt catch statistics from the trawl and seine surveys conducted between 1976 and 2003 were provided by Donald Danila, Millstone Environmental Laboratory. A total of 37 smelt were taken in seine surveys between 1976 and 2003 and the data provide limited information on the potential change in abundance. Smelt eggs and larvae have historically made up less than 1% of the total eggs and larvae entrained (Millstone Environmental Laboratory 2005).

Trawl survey data provides a clear picture of the changes in smelt abundance in the waters surrounding Niantic Bay. Biweekly trawls were made at six locations from 1976 to 1995, and at three locations since 1995 (Fig. 1.10). Smelt have been collected yearly since 1976, with variable annual abundance. Peak catches of 286 fish in 1977-78, 391 fish in 1986-87, and 334 in 1992-93 are reported with a brief period of elevated catches from 1984 to 1989 (Fig. 1.11). Most fish were taken between February and May, peak spawning months in Connecticut, with occasional reports of smelt in fall months. A total of 136 fish were observed between 1993 and 2003, with 5 fish observed between 2000 and 2003.

Hudson River, New York

Long term monitoring programs on the Hudson River indicate smelt had disappeared as early as 1981 (Daniels 1995), with other studies documenting smelt in the river between 1985 and 1995. Information on the temporal changes to the Hudson River population during this later time period is available in the 2003 Year Class Report of the Hudson River Ecological Monitoring Program (ASA Analysis & Communication 2005). The Hudson River Program has conducted yearly sampling to assess temporal and spatial changes in the distribution and abundance of the early life stages of several fish species on the Hudson River. The monitoring program covers the length of the river from Manhattan to Troy, New York, and includes three sampling programs, two of which provide a comprehensive overview of the decline of smelt on the Hudson River: the Long River Ichthyoplankton Survey (LRS, 1988-2002) and the Fall Juvenile Survey (FJS, 1985-2002). Following years of consistent presence but variable abundance, smelt have not been collected in the Hudson River since 1996.

SECTION 1.2.2: HISTORICAL AND CONTEMPORARY TRENDS IN DISTRIBUTION

Distribution along the Eastern Seaboard

The range of smelt along the U.S. Atlantic coast can be interpreted from a number of sources. The earliest records of occurrence occur in anecdotal reports from the initial colonial settlement of Northeastern America, and predominantly document smelt along the Gulf of Maine. But reports of smelt much further south can be found in the literature of the early 19th century. Kendall (1926) reports smelt in the Delaware River and its tributaries in the 1860’s as far north as Trenton. Commercial catch data for Cape May County, New Jersey supports this observation. Smelt were reported occasionally in Delaware Bay embayments in February, and could be caught from docks with a cast net by local fishermen (Kendall 1926). Whether or not these southern records document the range of spawning activity is unclear, but observations of smelt in local tributaries in early spring provide support.

Historical catch statistics represent a widespread form of population sampling that cannot be reconstructed from any other source and provide a broad picture of the regional changes associated with a fishery. Review of the commercial catch statistics indicate the southern range has been contracting northward over the last century. The southern most commercial fishery for smelt in the Cape May and Monmouth County, New Jersey region ended sometime around 1904. Declining catch was reported for Middlesex County, New Jersey through the 1920’s with the fishery ending sometime before 1938. Presumably the catch statistics for Middlesex County reflect changes to the fishery in Raritan Bay. Early declines on Long Island were also documented in the commercial statistics. Mather (1887, 1889) noted that smelt had been absent from Cold Spring Harbor, on the north side of the island, for a number of years. While fishermen in

Great South Bay, on the south side of the island, were still reporting fish near Brookhaven despite declines being reported for a number of years. By 1921 the smelt fishery on the eastern end of the Long Island in Suffolk County, had ended with only occasional catches of a few hundred pounds reported in later years (National Marine Fisheries Service 1975). Reports from local fishermen in 1927 indicate smelt had been absent from Jamaica Bay for 35 years (New York Times 1927). Smelt have not been documented in the Hudson River for the last several years (ASA Analysis & Communication 2005), and regular monitoring programs in two Connecticut estuaries suggests they have been virtually nonexistent for the last decade along both the western (Jose Pereira, National Marine Fisheries Service, Milford, Connecticut, personal communication) and eastern portions of the state (Millstone Environmental Laboratory 2005). Further east along the Massachusetts coast, smelt have been observed regularly during the last decade (Brad Chase, Massachusetts Department of Fish and Game, personal communication), suggesting smelt have retreated as far northeast as Buzzards Bay.

Historic and Contemporary Range in the State of Connecticut

There is limited historic information on the range of smelt in Connecticut, but presumably they occurred in most of the coastal streams and along tributaries of both the major and minor river systems. Early catch statistics reported by the Connecticut Fish Commissioners around the turn of the 20th century were limited to the pound and fyke net fishery between Milford and Stonington. Pound and fyke net data for the years 1896 – 1902 was reviewed for general location information (see Appendix D for a list of publications). The net returns indicate smelt were commonly taken on the eastern part of the state from the waters between Stonington, Connecticut and Pawcatuck, Rhode

Island. Smelt catches were also reported in Milford pound nets, but were absent from other areas along the shore. State of Connecticut reports do not indicate there was a smelt fishery in Fairfield County on the western part of the state until the 1921-22 biannual report. More comprehensive gear statistics compiled by the U.S. Fish Commission from the same time period indicate smelt fisheries in the State were confined to New London County in the east and Fairfield County in the west based on returns from hand lines and seine nets. The US Fish Commission annual report in 1892 indicates the principal smelt fisheries in Connecticut and Rhode Island were conducted on the Thames, Mystic and Pawcatuck River.

The reason for their apparent absence for Middlesex and New Haven County is likely an artifact of fishing regulations put in place to protect the shad fishery in those counties. Smelt were provided automatic protection by many of the commercial fishing gear restrictions for the shad fisheries associated with the Connecticut River, which limited mesh size for fixed gear and seines to a minimum of 2.5 inches (see Section 1.2.3: Protective Legislation for a review of gear limitations). It is unclear why there is a discrepancy but there is general geographic consensus that smelt were not a commercial fishery of the central part of the State.

<u>New Haven Harbor</u>

Smelt have been documented in New Haven Harbor by a number of sampling programs (Warfel and Merriman 1944, Normandeau Associates Inc. 1973, 1977-84, Molnar 2004, See Section 1.2.2 for details).

<u>Connecticut River</u>

Marcy (1976b) provides locations for the collections of eggs and larvae in the Connecticut River between 1965 and 1969. Eggs were collected from stations within the

main stem of the Connecticut River between the mouths of the Salmon and Eight Mile River, in the upper reaches of the Salmon and Eight Mile Rivers. Larvae were collected from the same locations, as well as the main stem of the Connecticut River in Windsor Locks, near Higganum Creek, the Farmington River, Wethersfield Cove, and Chapman Pond. Most recently two smelt were taken from the mouth of the Connecticut River in 1993 as part of an inshore winter flounder trawl program (David Molnar, Connecticut DEP, Marine Fisheries Division, personal communication).

Niantic River and Jordan Cove

Smelt have historically been collected from all waters around the Dominion Nuclear Power Station, in Waterford, Connecticut (Fig. 1.10, Fig. 1.12) (Millstone Environmental Laboratory 2005, Don Danila, Millstone Environmental Laboratory, personal communication). Smelt appear to be most common in Jordan Cove, with trawl catches between 1976 and 1995 four to seven times more abundant in this area (Fig. 1.12). It is unclear why smelt are more common in this location, but physical inspection of the Jordan Brook feeding Jordan Cove and the upper Niantic River suggest the upper reaches of Jordan Cove may support appropriate spawning habitat. Given the majority of the catches made in this area have occurred during the spring, this may be an indication of potential spawning activity.

Long Island Sound

Despite the apparent disappearance of smelt from the Connecticut River between 1969 and 1975, observations of adult smelt were made in Long Island Sound during the late 1980’s and early 1990’s (Figs. 1.13 and 1.14). In their review of the data collected from the Long Island Sound Trawl Survey (LISTS) from 1984 to 1994, Gottschall et al. (2000) concluded that smelt were associated with two river systems in

central and western Long Island Sound. The survey targets demersal finfish, lobster and squid in the Sound between New London, Connecticut and Hempstead Harbor, New York from April to November in water deeper than five meters and amenable to trawling. The survey utilizes a chain sweep otter trawl with a wing mesh of 102 mm and a cod end of 51 mm, effectively restricting the potential catch to large adult smelt. Between 1988 and 1994 a total of thirty-one smelt were observed from 2859 tows, with 97% caught in April; twelve near the mouth of the Connecticut River and seven near the mouths of the Saugatuck and Mill River (Fig. 1.14). Spawning activity has been historically documented in all three systems during March, April and May, suggesting the fish may have been collected during spawning activities.

Mystic, Poquonnock and Thames River

The earliest documentation of smelt in the Mystic and Thames River comes from Smith (1896) in his regional documentation of the smelt fishery along the northwest Atlantic coast. Pearcy and Richards (1962) documented smelt in the Mystic River and Whitworth and Marsh (1980) documented smelt during all seasons in the upper 5 km of the Thames River. Blake and Smith (1984) stated the most well known population in Connecticut occurred in the Thames River, and was the seasonal target of a small recreational fishery. Local fishermen stated smelt were regularly fished for with hook and line from the State pier in New London, but that they were unaware of other locations on the Thames River that allowed access to smelt. Trawl surveys of the Thames River conducted by the CT DEP from 1990-96 documented smelt in the Thames River in 1996 and seine sampling conducted since 1988, documented smelt in the Poquonnock River in 1994 and 2004 (David Molnar, Connecticut DEP, Marine Fisheries Division, personal communication). Smelt were also found in the Mystic River in 2004 as part of sampling program documented in Chapter 2.

Other Connecticut Estuaries

Smelt were documented as part of the CT DEP inshore trawl survey in Clinton in 1991 and 1993. Conversations with a number of older local fisherman indicate spawning activity was common in Guilford and in the tributaries surrounding of Barn Island prior to the 1950's, and that as recently as 1995 smelt could still be caught by hook and line in Palmer's Cove in Groton.

SECTION 1.2.3: ENVIRONMENTAL CHANGES IDENTIFIED IN EARLY STATE AND FEDERAL PUBLICATIONS

“ The future of smelt fishing can not be contemplated with enthusiasm…”

- Massachusetts Division of Fisheries and Game 1930

Traditional Causes of Decline

Despite the fact that routine recreational and commercial exploitation of smelt fisheries had continued along the Atlantic coast for many centuries, the critical factor contributing to declining abundance of anadromous fish has been environmental degradation of spawning grounds (Mowat 1984). States with active smelt fisheries all recognized environmental causes for the decline of local populations, and during the early 20th century specific mention of the effects on smelt began to appear in some State reports. Review of the historical literature points to water pollution and physical habitat degradation, resulting from dams and watershed development, as the most critical early causes of decline.

<u>Water Quality</u>

Historical issues of water pollution are in no way unique to Connecticut, and almost every region with human settlement suffered from declining water quality. The threat of water pollution to fisheries associated with affected watersheds is obvious. Understanding when the State first recognized a pollution problem, what was done to

correct the problem and the potential impact it may have had on local fisheries will help to place the potential impact on the historical reduction of local smelt populations in perspective.

Water pollution was historically cited by the Connecticut Fish Commissioners as a serious threat to Connecticut’s fisheries industries. From their first report in 1867, water pollution “by lime, dyes, soap, saw dust, and other mill refuse” was considered a principal cause of declining catches of all fish species and a serious concern for both non-piscine aquatic and human life, and has continued to be discussed regularly in state reports for more than a century. In their 18th Annual Report, the Connecticut Fish Commissioners report that changes to the fish composition of the Connecticut River were largely attributed to water pollution of the main stem and its tributaries by local manufacturers (Connecticut Fish Commissioners 1884). They go on to report that “the more common sorts [species of fish, were] different from what they were twenty years ago” and that age structure changes were most obvious in the tributaries where young fish were common, with older larger fish rarely seen. The Commissioners also reported that local fishermen were increasingly interested in the problem, recognizing the seriousness of the situation to their livelihood. In 1884, a local Hartford newspaper reported shad were unwilling “…to enter a stream so polluted by sewage and manufacturers' chemicals as the Connecticut is becoming." (Connecticut Fish Commissioners 1885). In 1885, the Fish Commissioners questioned what to do with chemical wastes from manufacturing if they were going to attempt to improve water quality for both fish and humans. By 1894, water pollution on the Connecticut River was reportedly originating not only from factory chemicals and sewage discharge, but also from sediment resuspension by increasing boat traffic. Declining numbers of shad, alewife, salmon and trout, along with other “food fish” were credited as a direct result of these pollutants. By the end of the 19th century the pollution problem was so widespread

that State officials believed all hatchery restoration efforts would be futile as the “increased pollution of the streams in which the fry is placed” prevented their immediate survival (Connecticut Commissioners of Inland Fisheries 1894). While it is unclear what the historic effect was on the smelt fishery, by 1922, the State Commissioners were laying blame for a failing Connecticut smelt fishery squarely on water pollution, stating “the disappearance of this delicate table fish from many of the estuaries connected with the Sound in undoubtedly due to pollution conditions (Connecticut Board of Fisheries and Game 1922).”

Warnings about water pollution and declining smelt abundance were not unique to Connecticut and historical references from both the 19th and 20th century can be found from both watersheds in the Mid Atlantic Bight and the Gulf of Maine. In 1881, the New York Times reported that long time local fisherman “Joe” Dodd, then 81, blamed the decline in the smelt fishery in the Passaic River and Newark Bay on water pollution resulting from factory chemical discharge and raw sewage (New York Times 1881). He hoped New Jersey State officials would take immediate action to clean up the persistent pollution, recalling that prior to 1855 he had been able to regularly catch large numbers of smelt from Plum Point, in Newark Bay, but that uncontrolled pollution of the local waters had lead to increasingly diminished numbers of fish. In 1926, the Massachusetts Division of Fisheries and Game questioned the State’s ability to protect its declining smelt populations if no action was taken to clean up polluted spawning habitat (Massachusetts Division of Fisheries and Game 1926).

While gradual changes in the abundance or species composition of the ichthyofauna of a river or stream may have been subtle, the most obvious effects of the pollution problem has always been widespread fish kills resulting from direct chemical contamination or related hypoxia events. Connecticut fish kills were reported by the local papers, and occasionally were reproduced in the State reports. Fish kills were visually

obvious, but more insidious was the timing and the number of species, at all life stages that were reportedly affected.

Fish Kills – Smelt Victims? While the actual causes of fish kills can rarely be determined without concurrent ecological monitoring, the occurrence and timing of such events can identify potential environmental threats that may have impacted smelt. Some of the earliest reports appear in 1883, with accounts of many small fishes dead for a considerable distance downstream of local mills on tributaries of the Connecticut River (Connecticut Fish Commissioners 1883). The 1886 Fish Commission Report includes an article from the New Haven Palladium, on June 26, 1885 (Connecticut Fish Commissioners 1886). The article covered a fish kill that occurred downstream of the Wilkinson paper mill in Shelton when the mill released a large quantity of chemicals into the Housatonic River. The result was the immediate death of hundreds of adult shad and other large fish, and the presumed death of innumerable juvenile fishes that could not be directly observed. Locals immediately collected the fish from the water, presumably for consumption. Again on Aug. 11, 1885 the Palladium ran an article opening, “The usual slaughter of fish took place yesterday (Connecticut Fish Commissioners 1886).” The Wilkinson paper mill again released large quantities of chemicals resulting in a fish kill including large bass, pickerel, shad and other adult fish, with men and boys collecting large numbers of the fish. A similar account was reported on August 17, 1894, in a Hartford Post article documenting a substantial fish kill on the Park River as a result of an acid release from one of the factories in downtown Hartford (Connecticut Commissioners of Fisheries and Game 1896). Given the timing of these pollution events, countless larval and juvenile fish were undoubtedly killed, potentially including young smelt.

While these early fish kills have an apparent cause, more modern kills appear to result from a variety of influences including hypoxic events and undetermined fish stressors. Moss et al. (1976) documented the regular occurrence of fish kills consisting predominantly of blueback herring on the Connecticut River during July 1965, 1966 and 1967 and in June 1971. Richards (1970) reports on other prominent fish kill events during late September and October of 1970 involving Menhaden in the lower reaches of the Connecticut River. The occurrence of these kill events is relevant, when placed into a perspective related to the early life history of smelt in Connecticut.

Marcy (1976a, 1976b) determined that juvenile smelt were most abundant in the Connecticut River from July through October, with the greatest abundances occurring at either end of their period of capture. The blueback herring and menhaden kills recounted above occurred during times and in locations that juvenile smelt were most common, potentially placing them at increased susceptibility to die-off as a result. As the fish are small during these periods of time and are not as obvious as adult herring or menhaden, smelt mortality would have been difficult to assess.

Physical Habitat Degradation

Dams. One of the earliest forms of habitat degradation for many anadromous species was the construction of mill and factory dams on coastal tributaries, which prevented upstream passage during the needed spawning season. The Connecticut Fish Commissioners (1870) associated the construction of dams on the Connecticut, Thames and Housatonic, along with other dams on many of the State’s smaller streams, with the loss of shad and salmon, but also other migratory sea fish, presumably including smelt. Early historical reports of the effects dams had on smelt spawning activity are sparse but suggest that dams had a negative effect (New York Times 1872). In Massachusetts, biologists observed “Annually there is an enormous loss of eggs, due to

the heavy deposit on the restricted spawning grounds” (Massachusetts Division of Fisheries and Game 1930). On the Saugatuck River, the mill dam located in Westport prevented smelt from reaching preferred spawning habitat forcing fish to deposit eggs several inches deep resulting in high egg mortality (Connecticut Board of Fisheries and Game 1926). Similar observations have been made historically in other regions (McKenzie 1964, Ross 1991). While dams are not presently thought to affect smelt in the Connecticut River (Gephard and McMenemy 2004), limited spawning information and associated records of abundance make it difficult to assess historic impacts.

Spawning Habitat. Loss of critical spawning habitat as a result of human activities has historically lead to the loss of local smelt fisheries (Ross 1991). Habitat degradation was recognized as a critical factor to smelt survival by the 1920’s in Massachusetts. State commissioners urged the legislature to pay attention to the condition of smelt spawning grounds if they wished to preserve many runs (Massachusetts Division of Fisheries and Game 1925). Development of the buffer land surrounding critical spawning habitat lead to increased silt loading (Massachusetts Division of Fisheries and Game 1927) and high egg mortality (Ross 1991). Massachusetts biologists believed egg mortality was increased by trampling as a result of in stream seining and dip netting activity (Massachusetts Division of Fisheries and Game 1924, 1926) and research by Brown and Taylor (1995) confirmed these fears. While there is no documentation of these types of threats in Connecticut, presumably similar habitat changes were occurring in Connecticut and surrounding regions.

<u>Later Causes of Decline</u>

Climate Changes. Global climate change has been implicated in changes to fish abundance (Jeffries and Terceiro 1985, Power and Attrill 2002), range and species composition (Southward et al. 1995, Oviatt 2004). The potential for long-term ecological

change as a result of changing mean water temperature in ecosystems worldwide is obvious. In the North Sea, warming trends during the 1930’s were associated with declines in northern species and increases in southern species (Southward et al. 1995). Oviatt (2004) and Nixon et al. (2004) have both documented long-term warming and cooling trends for waters in Narragansett Bay, Rhode Island and Great Bay, Massachusetts, respectively. Recent warming trends in Narragansett Bay have been associated with declines in demersal boreal fish species and the widespread death of eel grass (Oviatt 2004) critical as juvenile fish habitat. These results suggest boreal species in Connecticut, such as smelt, may have been affected in a similar manner.

Smelt prefer cool waters (Bigelow and Schroeder 1953), and increases in mean winter and summer temperatures may have negative effects. Kendall (1926) documents multiple spawning events as a consequence of variable winter temperatures that resulted in a deadly build up of eggs in some stream sections. Massachusetts state reports also note changes in spawning behavior related to warmer than normal winter water temperatures, with fish observed attempting to spawn up to several months early. Early spawning may be detrimental if it puts larvae out of sync with an available food resource, resulting in high larval mortality. High summer temperatures may force juveniles from preferred habitat or may lead to declining physiological conditions, both increasing juvenile mortality.

Review of smelt catch statistics during the 20th century show increases and declines in local catches associated with periods of winter water cooling and warming reported for Narragansett Bay (Oviatt 2004). Between 1920 and 1930 there was a winter cooling episode during which time commercial catches of smelt in Rhode Island and Connecticut increased slightly, followed by a warming episode between 1930 and 1938 in which smelt catches declined. During a winter cooling episode in the 1960’s, commercial activity for smelt recovered briefly in Connecticut, followed by a warming

episode in the mid 1970’s during which commercial activity again ceased. Ecological monitoring in the Niantic River estuary conducted during the 1970’s documented a early decline in smelt, followed by a brief period of recovery in the late 1970’s and early 1980’s (Millstone Environmental Laboratory 2005) during which time a winter cooling trend occurred (Oviatt 2004). Continuing ecological monitoring during the last 20 years shows a decline in smelt populations coincident with increasing winter temperature reported for Narragansett Bay. Smelt have recently been reported in a number of eastern Connecticut estuaries following several years of cool winter temperatures.

Predators. Smelt are an important forage species for a number of piscivorous fish, mammals and birds. Fish predators include striped bass, bluefish, pollock, white perch, and windowpane flounder (Ross 1991), as well as salmonids (Rothschild 1961). Harbor seals (Clayton et al. 1978) and numerous bird species may also pose a threat to smelt (Ross 1991). Norwalk residents recall large numbers of smelt being captured by sea gulls and cormorants near spawning grounds on the Saugatuck River during the brief recovery of the Saugatuck River population in the 1960’s. Bluefish and other piscivorous fish species in Long Island Sound have historically been credited with declining smelt stocks in Connecticut and Rhode Island (Connecticut Board of Fisheries and Game 1932, 1936). Early declines in known predatory fish species such as Atlantic salmon, bluefish and striped bass may have lead to an early historical predator release resulting in early increases in smelt abundance.

Recovery of Connecticut’s striped bass population over the last quarter century has the potential for significant consequences to local forage species, including smelt. Increasing numbers of striped bass have been considered a factor in the decline of river herring in the Connecticut River (Savoy and Crecco 2004) and smelt may have been similarly affected. Increasing water temperatures between 1980 and 2000 would have allowed striped bass to continue actively feeding during fall and winter months, the

period of time adult smelt prefer to inhabit coastal estuaries while preparing for early spring spawning runs. Resident bass are now present in many of Connecticut coastal estuaries potentially posing a year round threat to both adult and juvenile smelt. The potential for striped bass to negatively affect local smelt populations may be an area of further study.

Contemporary Water Quality Issues. Since the passage of the Clean Water Act in 1972, and more recently with the efforts of the EPA’s Long Island Sound Survey, water quality in Connecticut’s coastal regions have improved significantly. However, the potential for both direct and indirect pollution related habitat degradation still exists.

Currently the main direct pollution threat smelt face may occur during the spring as a result of storm water runoff laden with sand and salt from winter snow removal activities. Pollution threats related to snow removal are a recent occurrence throughout much of the northeast and during the mid 20^{th} century the use of salt and sand to improve winter road conditions increased steadily (Robinson et al. 2003). Increased salt content in natal waters may lead to a decrease in survival and hatching of eggs, and related sediment inputs have the potential to bury benthic eggs. Smelt eggs are susceptible to both elevated salt levels (Bigelow and Schroeder 1953) and silt deposition. Smelt are known to commence spawning during spring thaw events, a life history that would bring them into local streams when the effects of salt and sand runoff would be greatest.

Indirect pollution effects may occur as a result of nitrogen loading and associated algal blooms in streams where smelt spawn. Early benthic algal blooms often occur in streams where excessive nutrient deposition occurs, and can prevent adhesion and smother benthic eggs. Benthic algal blooms were observed in a number of our study streams where storm water runoff occurred a short distance upstream, and may represent a potential threat to any eggs spawned in these areas. Similar blooms were

not observed in areas where storm water drains were absent. While these observations are anecdotal, they suggest an area of potential further study.

SECTION 1.2.4: CONSERVATION ACTION TAKEN TO PRESERVE SMELT POPULATIONS

Early Conservation Efforts

"…particular attention and much time is devoted to the protection of smelts." –

Massachusetts Commissioners of Fisheries and Game 1905

States with smelt populations all recognized population level problems in one form or another. Understanding the types of legislation passed and the conservation actions taken to protect smelt, helps to define the start of population declines and identify potentially effect conservation measures. The early smelt fisheries declines resulted from a persistent lack of regulation. By the later part of the 19th century many states were moving to protect their smelt fisheries by implementing fishing legislation, with specific restrictions being enacted as early as 1810. More aggressive stock enhancement was attempted in the late 19th and early 20th century in states with smaller, more vulnerable fisheries.

Protective Legislation

Some of the earliest documented protective legislation for smelt comes from Massachusetts (Massachusetts Secretary of the Commonwealth 1887). In 1810, Massachusetts passed Public Act 112 to severely restrictive the use of seine nets in Middlesex County with offenders to forfeit between ten and twenty dollars for each offence. In 1886, Public Act 179 was passed making it illegal to take smelt by means other than hook and line or dipnet between February 1 and May 1. Violation of the law would result in a twenty-five cent fine for each smelt. By 1874, Public Act 153 was

passed to further increase the financial penalty to a dollar for each smelt. Similar measures were undertaken in Waldborough, Maine in 1880 where historically, a single fisherman was capable of taking 30 bushels of smelt a day with a dip net. Following the near demise of the local run of smelt, Waldborough town officials made it illegal to take smelt during their spawning run with dip nets (Goode 1887). On Long Island, fishermen were complaining that inadequate legislative protection had allowed smelt to be harvested to near extinction near Cold Spring Harbor (Mather 1887). New Jersey conservationists attempted to implement legislation in 1877 (Camp 1941), and again in 1895 (New York Times 1895) to protect smelt and other fishes from commercial exploitation, but the legislature failed to act upon the recommendations and by 1971 smelt were listed as endangered in New Jersey (Fried 1971, Miller 1972). The process of imposing protective legislation and severe financial penalty is an indication that fisherman and others utilizing the resource recognized an immediate threat to the population during the late 19th century in many areas.

Connecticut Regulations. The earliest commercial regulations related to smelt in Connecticut were implemented in 1897, restricting the take of smelt on the Mystic River to hook and line (Connecticut Commissioners of Fisheries and Game 1898). Later legislation restricted the commercial gear that could be used to harvest smelt in inland waters; take of smelt in Groton waters by net, seine, or trap was prohibited, and in Greenwich was restricted to hook and line. The reasons for implementation of the various laws are not known, but presumably were in response to perceived population decline.

Commercial seine nets and bag nets historically posed the greatest threat to the early commercial smelt fishery in Connecticut, but the extent of their use in Connecticut and their potential impact can only be inferred from early catch statistics of the U.S. Fish Commission. However, an anecdotal measure of the early impact these gears had on

commercial activities can be inferred from early protective legislation. Restrictions for waters around Greenwich, Groton and the Mystic River specifically prohibited the use of seines for taking smelt, and no less than 30 public acts were passed in Connecticut by 1897 to limit the use of seines in general and in numerous specific coastal estuaries, rivers and ponds (Connecticut Commissioners of Fisheries and Game 1900). Many of the specific location restrictions provided general protection for smelt by limiting the use of seines in potential spawning habitat. In other locations, such as the Thames River, mesh size restrictions of no less than one and one-quarter (1-1/4) inches provided protection for juvenile smelt, but still allowed the potential catch of adult smelt (Connecticut Commissioners of Fisheries and Game 1900). By 1921, in response to observed declining harvest in Connecticut’s historic smelt fisheries, statewide regulations were proposed enforce commercial smelt permits and set minimum mesh sizes for seines (Connecticut Board of Fisheries and Game 1922).

Fixed gears also posed serious and early threats to many fish species in Connecticut, including smelt. Pound nets, extensively in use the mid 19th century, were considered the most noxious form of commercial fishing gear, posing a regional threat with their rapid rise in popularity and the obvious and immediate impact to all coastal fisheries (Connecticut Fish Commissioners 1867, 1868, Baird 1873, New York Times 1895b). Many states, including Massachusetts and Rhode Island, were interested in abolishing pound nets, and proposed legislation that would severely restrict their use (Baird 1873). New Jersey proposed to close all inland waters in which anadromous species such as smelt would be present, to commercial fishing with pound nets from May 15 to September 1 (New York Times 1895b). Connecticut attempted to eliminate pound nets in the mid 19th century, but attempts to implement the legislation were met with failure despite widespread impacts to all coastal fisheries (Connecticut Fish Commissioners 1870).

Notwithstanding the failure of the Connecticut Fish Commission to eliminate pound nets from coastal waters, minimum mesh sizes of 2.5 inch were implemented to protect shad in the vicinity of the Connecticut River and adjacent shoreline, providing early automatic protection for smelt in Connecticut (Connecticut Commissioners of Fisheries and Game 1900). Juvenile shad were thought to be in greatest peril, but even small fish such as young of the year menhaden were regularly reported as pound nets catch during the spring and summer, typically being used as fertilizer for local agricultural fields (Connecticut Fish Commissioners 1873). Presumably smelt were also caught and used as fertilizer, much as they were in other areas of the northeast. However, mesh restrictions did not extend to areas other areas of the state, in particular the eastern part of the state between the Thames and the Pawcatuck River (Connecticut Commissioners of Fisheries and Game 1900), and eastern populations were regularly taken in the commercial fishery as a result.

Many states, including Connecticut, implemented closed periods to offset the detrimental effects of fishing during spawning runs. Early closed periods generally consisted of a total moratorium on fishing for a period of two to three days (Connecticut Fish Commissioners 1870). It was believed these few days would allow fish to reach spawning grounds unmolested (New York Times 1895b, Connecticut Fish Commissioners 1870, 1871, 1873). Later Connecticut legislation took into account longer periods of time during which critical life history stages were occurring, by closing fisheries for several months. By the early part of the 20th century, many northern states had closed seasons for smelt during the spring and summer months, when adults and juveniles were most common. Ackerman (1941) reported closed seasons to inshore commercial fishing from March 15 to June 1 in Massachusetts, and April 15 to September 1 and May 1 to October 1 in Maine streams, and from February 15 to October 15 in New Brunswick, Canada. Early Connecticut legislation did not have

specific regulations related to smelt, however closed seasons associated with other anadromous species, such as shad and river herring, provided smelt automatic protection.

Despite the perceived benefit protective legislation was thought to provide, the reality was fishermen frequently violated these laws (Connecticut Fish Commissioners 1871). Connecticut’s commissioners frequently discussed the need for paid wardens to enforce protective legislation and protect the resources of the State, but limited funds and hostile fishermen prevented adequate protection (Connecticut Fish Commissioners 1877). In many areas local fishermen attempted to form fish conservation groups, but found it difficult to help enforce the local laws when even the wealthiest individuals flagrantly violated the law (Connecticut Fish Commissioners 1879). Poaching was also common in surrounding states and may have contributed to the decline of smelt in many areas. Massachusetts state wardens reported that smelt were being taken illegally by seine, despite protective legislation (Massachusetts Division of Fisheries and Game 1925, Kendall 1926). In Oyster Bay, Long Island smelt were seined illegally on their spawning runs (New York Times 1895a). Most of the poaching occurred at night while smelt were on their spawning run making it particularly difficult to capture offenders (New York Times 1895a, Kendall 1926). Presumably similar violations were occurring in Connecticut, further contributing to continued declines.

The current status of the commercial laws regulating the take of smelt in Connecticut is unclear. Commercial regulations governing the take of smelt in inland Connecticut are published in the 2005 Marine Fisheries Information Circular (Connecticut Department of Environmental Protection 2005). Commercial seine regulations currently published by the DEP mandate a mesh no less than one and one-half (1-1/2) inches for the wings and one and one-quarter (1-1/4) inches for the center or bunt of the net (Connecticut Department of Environmental Protection 2005). If these

commercial regulations are still currently in effect smelt are vulnerable to harvest by commercial bait fishermen. Current pound net restrictions mandate a two (2) inch mesh in Connecticut waters (Connecticut Department of Environmental Protection 2005), representing little threat to smelt. Currently, inland commercial take of smelt in Connecticut is closed from April 16th to the last day of February (Connecticut Department of Environmental Protection 2005), a period of time that would not protect most spawning activity, but would in fact promote exploitation during this critical life history stage. Chapter 490 Fisheries and Game, Secs. 26-144 to 26-148 of the General Statutes, lists restrictions on net type, mesh specifications, penalties, registration fees and open season for rainbow smelt, but is listed on the State of Connecticut General Assembly web site (http://search.cga.state.ct.us/) as having been repealed sometime after 1949 (Appendix G) suggesting the current published regulations are no longer in effect. A complete review of the status of Connecticut legislation related to smelt in Connecticut will be an important area for further investigation.

Manufacturing Fish – Stock Enhancement

With the formation of the US Fish Commission, came the thought that habitat degradation and over fishing could be ameliorated by "manufacturing fish" (Weber 2002). Stock enhancement was the "cure all" for fish declines, and smelt were relatively easy to culture, making them a perfect test subject for stock enhancement. Attempts to stock smelt in the southern extent of their range occurred as early as 1877 (Table 1.7). Maryland officials attempted to establish smelt, unsuccessfully, through the release of adult fish and propagation of fry in the Patapsco and Elk Rivers, tributaries feeding Chesapeake Bay (New York Times 1877). A review of the state reports for Maryland might help clarify the extent of the conservation efforts, and the reasons behind the

activity, particularly if the attempts were for enhancement of declining or extinct stocks. New Jersey began attempting to improve its smelt fisheries in 1878, through in stream habitat improvement and stocking of eggs and fry (New York Times 1880). New Jersey stock enhancement was continuing in 1895, but was not pursued as vigorously as the public thought it should be (New York Times 1895b). It is unclear when stock enhancement efforts ended, but presumably deficient results ended the program. By 1910, Massachusetts had begun stock enhancement in multiple watersheds, but the program had limited results and was discontinued (Ross 1991). The longest running smelt enhancement program was that undertaken in Cold Spring Harbor, New York, first by the U.S. Fish Commission and later by the State of New York.

Cold Spring Harbor – Long Island, New York

The U.S. Fish Commission began propagating fish at the Cold Spring Harbor facilities on Long Island, New York in 1883 (United States Commission of Fish and Fisheries 1886). The facility was under the direction of Mr. Fred Mather, and was a joint operation carried out by the New York Fish Commission and the US Fish Commission. Charged with hatching both fresh and salt water fishes, Mr. Mather immediately set about experimenting with anadromous rainbow smelt and tomcod. He reported (Mather 1887), “Considerable success was attained in hatching these [smelt] eggs, which, on account of their adhesive nature, give a good deal of trouble. The fish were obtained from streams emptying into Great South Bay, and brought to the station during the first week of March, 120 in number, from which about 200,000 eggs were taken. About 50 percent of the eggs hatched; and 100,000 fry were liberated in different streams near Cold Spring Harbor.” By 1886, two million fry were released into Cold Spring Harbor (United States Commission of Fish and Fisheries 1889) and fish were observed returning to local streams the following year (Mather 1889). By 1890, Cold Spring Harbor

was releasing 4.6 million fry into multiple watersheds throughout New York (New York Times 1890). By 1892 the U.S. Fish Commission had turned the facility over to the State of New York and smelt propagation continued, with a minimum of 13.4 million fry released between 1892 and 1894 (New York Times 1892, 1894a). Smelt stock enhancement was still being undertaken in 1910 (New York Times 1910a).

The continued success of the smelt hatchery efforts in New York can be attributed in large part to the media coverage both smelt and the Cold Spring Harbor Hatchery received. In 1885, Fred Mather took 25 live smelt for a display at the Fulton Fish Market in an effort to drum up support for the hatchery (New York Times 1885). By touting the success of the Cold Spring Harbor lab in the local newspaper, the public began to embrace the hatcheries and even petitioned for increased releases. Stock enhancement was thought to result in smelt that were “larger, firmer and better” than imported fish (New York Times 1889a) and towns along Long Island, Staten Island and Westchester County petitioned for greater releases in response to increasing smelt catches (New York Times 1892). As the New York Times was read widely, presumably this type of media attention lead Connecticut to consider similar efforts as a way to enhance their dwindling smelt stocks.

Connecticut Stock Enhancement Efforts

Connecticut has a long tradition of supplemental stocking activities, particularly for commercial species such as shad and salmon, and recreational species, such as trout. Declining catch of important economic species such as salmon, shad and alewife prompted the State’s Commissioners began to explore the possibility of stock enhancement of “food fish,” moving away from their traditional recreational agenda. As early as 1868, Connecticut Fish Commissioners encouraged the establishment of state run hatcheries, quoting Col. Lyman of the MA Fish Commission, when they stated the

State had a duty to “sow fish as you would sow corn” (Connecticut Fish Commissioners 1868). In 1896, the summary for the Report of the Fish and Game Commissioners pointed out that Connecticut’s efforts at artificial propagation were “far behind other States” citing the nine hatcheries operated by New Hampshire and two in Wyoming as proof that both “old and new” states recognized the value and economy of stock enhancement (Connecticut Commissioners of Fisheries and Game 1896). These efforts appear to have been encouraged by the national movement to improve commercial fish stocks being supported by the US Fish Commission, and an economic desire to improve the condition of the State’s commercial fishing industry. The Commissioners go on to lament that “Neither the fishermen nor the public realize the value and economic importance to the State of the fishing industry (Connecticut Commissioners of Fisheries and Game 1896).” Following early experimental efforts in Birmingham, Rocky Hill and Lyme for American shad (Connecticut Commissioners of Inland Fisheries 1894) the State established hatcheries in Shelton for shad and Windsor Locks for trout and salmon (Connecticut Commissioners of Fisheries and Game 1898). Hatchery efforts continued to expand eventually including both fresh and marine finfish, and shellfish propagation began in conjunction with US Fish Commission. Hatchery efforts were not attempted for smelt suggesting they had been largely overlooked by state officials despite the fact both Federal and State catch statistics indicated the commercial catch in Connecticut had declined between 1880 and 1919.

The declining condition of Connecticut’s smelt stocks caught the attention of State officials in 1923, following published narratives of the depauperate condition of the smelt fishery in Connecticut waters (Connecticut Board of Fisheries and Game 1922). In an attempt to rehabilitate local stocks, the Board initiated experiments to assess the feasibility of artificially propagating smelt and establishing hatcheries (Connecticut Board of Fisheries and Game 1926). The Commissioners focused their efforts on the two

remaining commercial fishing grounds, the Saugatuck and Pawcatuck Rivers. By 1924 successful hatchery operations had been established in Westport and Noank, Connecticut in what were referred to as portable hatcheries (Connecticut Board of Fisheries and Game 1926). Hatchery operations continued at both Noank and Westport from 1924 to 1936, but by 1937 the Noank hatchery had ceased operation due to the inability to obtain brood stock from the Pawcatuck River (Connecticut Board of Fisheries and Game 1938). Operations in Westport ended by 1940 resulting from a lack of brood stock (Connecticut Board of Fisheries and Game 1940). Presumably the 1938 hurricane that destroyed the Noank lobster hatchery (Connecticut Board of Fisheries and Game 1940), also caused considerable damage to the Westport hatchery, essentially ending smelt hatchery efforts within the State.

Brood stocks for both hatcheries were obtained from local populations with assistance from commercial smelt fishermen (Connecticut Board of Fisheries and Game 1926, 1934). Fish collected from the Pawcatuck River were generally taken in ripe condition, but in the Saugatuck River were rarely ripe (Connecticut Board of Fisheries and Game 1926, 1930) necessitating artificial and natural hatchery techniques. Initial attempts at artificial spawning lead to high egg mortality (Connecticut Board of Fisheries and Game 1926), but fish allowed spawn naturally in the hatchery tanks had improved hatching success (Connecticut Board of Fisheries and Game 1926, 1930) and both hatcheries quickly began utilizing natural spawning techniques. Year to year variability in the commercial catch had direct impacts on the number of eggs and larvae that could be hatched (Connecticut Board of Fisheries and Game 1932, 1936) and declining brood stock availability was attributed to adverse weather conditions (Connecticut Board of Fisheries and Game 1930, 1932, 1934) and bluefish predation along the Connecticut coast (Connecticut Board of Fisheries and Game 1932, 1936). There is no information contained in the Connecticut reports indicating the manner in which larvae were

maintained, collected and released, but given the "portable" nature of the hatcheries (Connecticut Board of Fisheries and Game 1926), it is presumed larvae were released shortly after hatching.

Fry were transported to coastal streams over a wide geographic area in an effort to bolster local runs and introduce fish into areas with potential for supporting new runs. A total of 398.3 million fry were released between 1924 and 1938 (Fig. 1.15), into more than 22 streams (Table 1.8) and lakes (Table 1.9) covering a broad geographic area. Fry from marine stocks were released into many inland lakes throughout the years, with results reported to be "good" (Connecticut Board of Fisheries and Game 1932) to "infrequent success" (Connecticut Board of Fisheries and Game 1942). By 1941, smelt with marine origins were known to be established in Crystal and Shenipsit [Snipsic] Lakes (Connecticut Board of Fisheries and Game 1942).

It is unclear whether hatchery efforts helped to improve the condition of Connecticut's smelt populations and reports by the Board of Fisheries and Game are ambiguous. The Board initially hoped that hatchery efforts would sustain the commercial fisheries, and potentially increase the returns to local fishermen (Connecticut Board of Fisheries and Game 1926). The Board reflected on its success reporting individual hauls, not yearly returns, increasing from lows of one-half bushel in 1924 to six bushels in 1932, stating continued hatchery operations were desirable as a result of these improvements (Connecticut Board of Fisheries and Game 1932). However, trends for both the commercial catch of Rhode Island and Connecticut (Fig. 1.5) show an overall yearly decline continuing throughout the period of stock enhancement despite increases in individual hauls, suggesting hatchery efforts were having little effect on the overall condition of the population. The discrepancy between the individual returns and the overall yearly returns were most likely due to fewer fishermen participating in the fishery and improved gear types. This would be an interesting area of further investigation. As

noted in previous sections, the declines were most likely the result of climate change, habitat damage and persistent overexploitation.

Presently landlocked smelt are confined to West Hill Pond, Hogback Reservoir and Colebrook Reservoir, but are thought to be the result of stocking efforts during the 1960’s and 70’s from inland Massachusetts lakes (William Hyatt, Connecticut Department of Environmental Protection, Division of Inland Fisheries, personal communication). If any of these early lakes populations still exist, they may represent a source of genetic material for anadromous Connecticut stocks, and therefore confirmation of the status of any of the earliest populations would be beneficial for future conservation planning interests.

SECTION 1.3: HISTORICAL REVIEW – ATLANTIC TOMCOD (*MICROGADUS TOMCOD*)

SECTION 1.3.1: HISTORICAL AND CONTEMPORARY TRENDS IN ABUNDANCE

Early History of Abundance and Exploitation

There is limited anecdotal information about Atlantic tomcod along the Atlantic coast, but several early references suggest they were common, abundant and easily caught. Storer (1839, cited in Howe 1971) estimated 2000 bushels of tomcod were taken in Watertown, MA annually and DeKay (1842, cited in Howe 1971) reported fish abundant enough along Long Island to be easily collected from shore. Goode (1884) described their abundance in Boston Harbor, and alluded to their marketability in many locations due to their delicate flavor. In 1889, the prospect of catching tomcod along the North River in New York attracted crowds of people (New York Times 1889a,b) and again in 1893 the recreational fishery for tomcod was reported to be increasing locally, becoming the principal target for wharf fishermen in winter (New York Times 1893). Men in small boats reported daily catches of more than 100 fish from the waters between Hell Gate and Westchester Creek (New York Times 1893), with more than half of the catch ending up in Fulton Market (New York Times 1889c).

Our present understanding of the abundance of tomcod along the US Atlantic coast is largely inferred from U.S. Federal catch statistics and a limited number of long-term ecological monitoring programs. Commercial catch statistics of tomcod along the Atlantic coast of the U.S. indicate commercial fisheries for tomcod existed throughout New England and the Mid Atlantic, as well as a brief fishery in the Chesapeake Bay Region in the mid 20th century. Current fishery activity indicates the take of Atlantic tomcod is predominantly the result of recreational activities. Recreational activity has also declined in recent years and a long-term ecological monitoring program in Connecticut indicates tomcod were declining in abundance during the last decade, but

recent increases have been noted (Donald Danila, Millstone Environmental Laboratory, personal communication). Long term monitoring on the Hudson River indicates tomcod have varied in abundance over the last 30 years and have declined during the last decade (ASA Analysis and Communication 2005).

Commercial Tomcod Fisheries

Commercial catch statistics for tomcod are available sporadically for the period 1879 to 1950 for the New England, Middle Atlantic, and Chesapeake Regions and yearly for all three regions from 1950 to 2003. Commercial catch statistics published since 1950 are available in a query driven statistical database available online from the National Marine Fishery Service (National Marine Fisheries Service, Commercial Landings Information http://www.st.nmfs.noaa.gov/). Federally reported commercial catch of tomcod declined steadily during the early part of the 20th century, with the majority of commercial fisheries ending by the mid 20th century. The only state reporting commercial catches consistently during the later half of the 20th century was New York, with the last catch reported in 1985 of 100 pounds. As recently as 1982, tomcod was still available for purchase in New York fish markets (New York Times 1982).

Historically the majority of the commercial tomcod harvest in the United States came from the New England Region (Fig. 1.16) with contributions being reported for the Mid Atlantic (Fig. 1.17) and Chesapeake Regions (Fig. 1.18). Regular commercial catches of tomcod ended prior to 1950 in New England and the Chesapeake Region, but continued into the early 1980’s in the Mid Atlantic Region. State by state review of the commercial catch statistics show regional patterns of abundance and gear use associated with the tomcod fishery. Gear information is sporadic between 1887 and 1950, but is complete between 1950 and 2003, and is included along with the catch

statistics to show the nature of the regional fisheries and the degree of exploitation associated with each state.

Commercial catch statistics occur for all of the New England states except New Hampshire. The last reported commercial catch for the New England occurred in 1942. The reasons tomcod were not reported for New Hampshire are unclear as they are common in New Hampshire’s coastal waters, and were most likely taken as by-catch from the active smelt fishery in the region. Information on gear types reported for commercial catch of tomcod is presented in Tables 1.10A and B.

Maine’s tomcod fishery represented 80% of the total New England catch between 1887 and 1942 (Fig. 1.19), and was largely based on bag and dip net fisheries. As previously mentioned, tomcod were most likely the result of by-catch from Maine’s widespread smelt fisheries. Following a peak catch of 477,000 pounds in 1887, the fishery steadily declined and commercial activity appears to have ended following 1942.

The tomcod fishery in Massachusetts was sporadic, with peak catches of 32,000 pounds reported in 1902 and again in 1931 (Fig. 1.19) taken predominantly by seine and pound net. The last commercial catches of tomcod in Massachusetts were taken between 1938 and 1940 by otter trawl.

Peak commercial activity in Rhode Island occurred between 1898 and 1933 (Fig. 1.20) with a maximum catch of 23,000 pounds reported in 1930. However, the fishery quickly declined and by 1933 a total of 200 pounds was reported. Fixed gears such as fyke, hoop and pound nets accounted for 94% of the total catch for Rhode Island. The last commercial catch for Rhode Island was reported in 1954 with a total of 100 pounds caught in haul seines.

In Connecticut, peak commercial activity was reported between 1887 and 1889 (Fig. 1.20) with a total of 366,000 pounds taken from fixed gears, seines and hand lines.

Commercial catches were low throughout the 1920’s and 30’s with a final catch of 5,200 pounds reported in 1935.

Tomcod are reported from New York and New Jersey in the Mid Atlantic Region (Fig. 1.21). New York catches fluctuated through several peaks from 1887 to the early 1930’s with a maximum catch of 278,000 pounds in 1892, then virtually disappeared. Limited catches were reported between 1955 and 1965 and again between 1974 and 1985. The commercial tomcod fishery in New York was primarily based on fixed gears, with a limited hand line fishery (Table 1.10 A and B). There is presently no commercial fishery of tomcod in New York.

New Jersey had a brief commercial fishery for tomcod between 1892 and 1932, with a total of 297,000 pounds reported. A single major peak catch was reported at the turn of the century, with relatively little catch otherwise. New Jersey’s tomcod fishery during this period was based on fixed gears with the exception of a brief hand line fishery reported for 1908 in which 11,000 pounds were harvested. Between 1940 and 1944 a brief otter trawl fishery for tomcod emerged in New Jersey, with a total of 27,000 pounds harvested and a peak of 21,000 reported for 1944. There has been no reported commercial catch of tomcod in New Jersey since 1944.

The tomcod fishery in the Chesapeake Region was not commercially reported until 1925 and had largely ended by 1948. Early catches from the Chesapeake were from shore based fisheries, but between 1935 and 1948 were the product of off shore trawl fisheries. The majority of the catch from the Chesapeake was reported from Virginia, with otter trawl fisheries accounting for 100% of Virginia’s reported commercial catch. Maryland’s fishery was active between 1925 and 1940 with pound nets and later otter trawls the dominant gear type. Since 1950 there has only been one commercial report from the Chesapeake Region, 1,100 pounds from a Virginia hand line fishery in 1988.

The Connecticut Tomcod Fishery

Tomcod were not considered a fishery of any consequence in Connecticut by the early part of the century (Connecticut Board of Fisheries and Game 1922) and only appear in the State of Connecticut Fish Commission reports from 1896 to 1901 as part of the accounting of the pound net fishery. The State Boards of Fisheries and Game reported they provided “much food and some angling” during their winter spawning migrations and were primarily harvested recreationally for home consumption (Connecticut Board of Fisheries and Game 1930). Tomcod were harvested as by-catch and a target species commercially in Fairfield and New London Counties. Commercial fishermen active in the 1960’s and 70 harvested tomcod as by-catch in eel pots and fish traps, and sold them as lobster bait. Presently, commercial lobster fishermen on the eastern end of the Sound report occasional young-of-the-year tomcod in lobster gear in the late summer and early fall, and adults in November and December.

Recreational Fisheries

Active recreational fisheries for tomcod have historically existed along the Atlantic coast. In Quebec, Canada an estimated 6 – 9 million fish are taken annually between December and March from the Ste-Anne River (Aquin 2004). In the United States, recreational activity appears to have declined over the last 20 years with an estimated total catch between 1981 and 2004 of 1.87 million tomcod. Tomcod were a favored recreational fish during the fall and winter months in many of the northern states, as they were easily caught during spawning migrations and were considered a table delicacy. In areas where river systems regularly froze over, recreational activities were centered on ice fishing. Sampson (1981) stated tomcod were "…the most important winter species to Connecticut shore-based recreational anglers, and are exploited by

over 25% of those fishermen." Local fishermen have reported that they were abundant in winter and could easily be taken by hook and line from manmade structures such as bridges and piers or in fish pots set along seawalls and other in stream barriers along the Connecticut coast. In early spring it was not uncommon to catch tomcod just below the head of tide on smaller systems such as the Mystic River. In Norwich Harbor, fishermen reported they could historically be caught on jigs fished close to bottom, and made excellent bait for striped bass. Tomcod have not been regularly caught in either of these areas during the last ten years.

I reviewed of the long term database of the NMFS Marine Recreational Fishery Survey Statistic (MRFSS) available online (http://www.st.nmfs.gov) for information regarding recreational activity related to tomcod on the Atlantic coast from 1981 to 2004 (Table 1.11). Recreational activity has declined throughout the contemporary range of the tomcod during the last 20 years, however much of the decline may be a result of sampling bias as the lack of information during Waves 1 and 6 (January/February and November/December respectively) would eliminate information available during the most common winter fishery activity in Connecticut, and surrounding regions (see Smelt subsection 1.2.1 for a review of the data set and the potential biases associated with winter fisheries in the MRFSS data set). Still, the limited information that are available on the tomcod fisheries of the northwest Atlantic provides an important view of the recreational activity associated with this fish and points out the need for recreational management of this species.

Recreational catches of tomcod are reported from Maine to Delaware along the Atlantic Coast. Estimates of the recreational activity in Maine and New Hampshire (Fig. 1.22) are temporally variable with occasional estimates of tens of thousand of fish, but the catch is generally estimated between zero and a few thousand fish. The recreational fishery in Massachusetts (Fig. 1.22) is the most consistent of all states reporting tomcod,

with catch estimates for all but two years since 1981. Massachusetts estimates are temporally variable with a maximum catch of 245,524 individuals in 1988, but no clear pattern of decline exists. Estimates from Rhode Island and Connecticut (Fig. 1.23) indicate recreational activity declined following peak catches in 1982 and 1986 respectively, and ended in 1999.

Unlike more northern states, recreational catches of tomcod are sporadic in the Mid Atlantic Bight and successive years of no catch are punctuated with years of relatively large catches (Fig. 1.24). New Jersey and Delaware reported catches twice during the last 23 years and New York reported for six years. The 2004 catch of tomcod in New York was the second highest reported recreational catch with an estimated 20,280 individuals and followed an eight year period of zero estimated catch. Inferred declines must be viewed skeptically as the error estimates are high, but the data indicate recreational activity has declined in the southern part of the tomcod range. Data available from individual state agencies may provide more comprehensive information on tomcod fisheries in these areas.

Inland fishing areas account for more than 94% of the total catch of tomcod on the Atlantic coast (Table 1.12). Connecticut, New Jersey and Delaware's fisheries were exclusively inland. Review of the fishery statistics for the inland and near shore (Ocean <=3 mi) categories by mode indicates that 64% of the catch results from shore based activity (Beach/Bank and Shore), and an additional 25% are caught from small boats (Private/Rental). In Connecticut, shore based activity accounts for 88% of the reported harvest.

Information on the seasonal nature of tomcod fisheries and the potential mortality impacts can be obtained from the Wave and Type categories. Table 1.13 shows recreational activity by wave, with obvious limitations based on changes to the survey methodology mentioned above. Tomcod caught along the Atlantic coast are taken most

often during Wave 6 (November/December). Since 1981, 66% of the reported catch has occurred during this Wave, representing the period most strongly associated with spawning activity. Absence of data from Wave 1 makes it difficult to estimate the potential impact to winter spawning activity, however, it is likely similar to Wave 6. The potential mortality posed by recreational activity during winter months is presented in Table 1.11. Results indicate overall less than 37% of fish caught are released alive, with live release estimates ranging from lows of 0 to 2.8% in Delaware and Connecticut, to a high of 65.2% in New York. These estimates of harvest may represent a significant impact to tomcod populations in states showing decline because recreational activities appear to target tomcod during winter spawning activity.

The available recreational data suggest tomcod fisheries are extremely susceptible to fishing related mortality during spawning runs from recreational activities being carried out from inland shore areas. Given the strong seasonal nature and the tendency of fishermen to harvest their catch, recreational fishing may pose a significant recreational to adults ascending coastal streams during the winter months to engage in spawning activity.

Contemporary Ecological Observations in Connecticut and the Hudson River

Tomcod appear in the data sets of a number of long term monitoring programs conducted in the waters of Long Island Sound and the Hudson River. These data sets provided the most complete picture of abundance change over the last several decades. Studies in Connecticut are listed from west to east along the coast. Several shorter term ecological studies and biological surveys document tomcod in Long Island Sound over the last century, and have been reviewed and compiled by the staff of Project Oceanology (Weiss et al. 1995, Appendix C.1). Results indicate tomcod are widespread and common, but have experienced decline in recent years.

Details about the sampling methods used in the various studies cited in the following sections have been reviewed above in the smelt section and will be briefly treated here.

Long Island Sound

In their review of the data collected from the Long Island Sound Trawl Survey (LISTS) from 1984 to 1994, Gottschall et al. (2000) noted tomcod were fairly uncommon. A total of 38 tomcod were observed between 1988 and 1994 from 2859 tows, with 95% caught from April to June, and a little over half observed near the mouth of the Connecticut River (Fig. 1.25). Few tomcod have been observed by the LISTS since 1994 and none have been reported since 1999 (Gottschall and Pacileo 2004). Their absence from the trawl survey is not unexpected, as they appear to prefer near shore shallow habitats with structure, such as rocks and vegetation (see Chapter 2 for habitat discussion), areas the trawl survey is less amenable to sampling (David Simpson, CT DEP Marine Division, personal communication). Additionally, the survey is conducted primarily in months tomcod are less commonly observed.

New Haven Harbor

Weekly shore based sampling of the fin fish community in New Haven harbor has collected of 166 young of the year tomcod, making them the 12th most abundant species in the survey (Jose Periera, National Marine Fisheries Service, Milford, Connecticut, personal communication). Recent years’ collections suggest tomcod may be increasing in abundance. Results from a number of other ecological surveys conducted in New Haven Harbor, including beach seine surveys (Warfel and Merriman 1944, David Molnar, Connecticut DEP, Marine Fisheries Division, personal communication) and trawl surveys (Normandeau Associates Inc. 1973,1977-1983, David Molnar, Connecticut

DEP, Marine Fisheries Division, personal communication), suggest tomcod are common, but not abundant. Results from the NMFS surveys indicate seasonal declines in catch are associated with rising water temperature and increasing size, suggesting surveys conducted during the late summer and early fall may not detect tomcod. Seine surveys conducted in New Haven by the CT DEP target winter flounder during fall months and in sandy habitats. Both criteria reduce the ability to detect tomcod, which are more strongly associated with a structured habitat, such as cobble and vegetation, and early spring months (see Chapter 2).

Niantic River / Jordan Cove

Tomcod have been observed annually since 1976 as part of the fish ecology studies conducted by the Millstone Environmental Laboratory (Millstone Environmental Laboratory 2005). Tomcod catch statistics from the trawl and seine surveys were provided by Donald Danila Millstone Environmental Laboratory. A total of 238 tomcod were taken from seine surveys conducted between 1976 and 2003. Trawl survey data offers a clear picture of the changes in tomcod abundance in the waters surrounding Niantic Bay. Peak catches were recorded in 1981-82 and again in 1993-94 (Fig. 1.26). Despite these years of high abundance, tomcod have generally exhibited low annual abundance over the entire survey period. Review of the annual catch statistics for individual trawl stations indicates tomcod are most common in the Niantic River (NR) and in Jordan Cove (JC) (Fig. 1.27). Results from the ichthyoplankton survey indicate tomcod eggs and larvae have historically made up less than 3% of the total eggs and larvae entrained (Millstone Environmental Laboratory 2005).

Hudson River, New York

Information on the temporal changes to the Hudson River tomcod population is available in the 2003 Year Class Report of the Hudson River Ecological Monitoring Program (ASA Analysis & Communication 2005). Results from the Long River Ichthyoplankton Survey (LRS, 1974-2003) and the Fall Juvenile Survey (FJS, 1985-2003) indicate tomcod show consistent presence but variable abundance. Results from the FJS indicate tomcod have been declining in abundance since 1997.

SECTION 1.3.2: HISTORICAL AND CONTEMPORARY TRENDS IN DISTRIBUTION

Distribution Along the Eastern Seaboard

The Atlantic tomcod (*Microgadus tomcod*) was historically a common demersal fish of coastal estuary regions from southern Labrador to Virginia (Bigelow and Schroeder 1953) and has been noted as far south as North Carolina (F.J. Schwartz, pers. comm. cited in Scott and Scott 1988). Tomcod were reported as occurring in Chesapeake Bay by Massman (1957), and commercial catch data supports these observations (see review of commercial catch statistics, Tomcod Section 1). However, they are noticeably absent from the recent publication *Fishes of Chesapeake Bay* (Murdy et al. 1997), suggesting their disappearance from the Chesapeake during the last fifty years. Reproductively active populations of tomcod are thought to reach their southern extension in the Hudson River (Grabe 1978). Able and Fahay (1998) note that from 1929-33 Atlantic tomcod were the fifth most abundant fish taken in trawls in southern New Jersey, but by the 1971-72 season not a single fish was collected and currently the distribution of Atlantic tomcod in the Mid Atlantic Bight is restricted to the northern regions of the New Jersey shoreline. Declines in the commercial and recreational catch from states in the southern extent of their range, as well as long-term monitoring on the Hudson River, suggest tomcod may be undergoing range contraction.

Historic and Contemporary Range in the State of Connecticut

Review of the historical fishery literature for Connecticut indicates tomcod were ubiquitous in the coastal marine waters of Connecticut. Historical returns reported for the pound net fishery, indicate tomcod could be harvested along a wide range of the Connecticut shoreline (Appendix D.1), but were not commonly taken. Federal catch

statistics indicate they were most common on the western and eastern extremes of the state, but were not commonly caught in Middlesex and New Haven County. Unlike smelt, the lack of tomcod catch in these areas is not likely an artifact of fishing regulations put in place to protect the shad fishery in those counties (See smelt subsection 1.2.4). Mesh size restrictions for shad would still have allowed adult tomcod to be captured and the reasons for their absence in this region of the state are unclear.

Tomcod have historically been common in the upper brackish reaches of many of Connecticut’s estuaries, including the Saugatuck (Connecticut Board of Fisheries and Game 1922), Thames (Whitworth and Marsh 1980), and the Mystic River (Booth 1967), but were rarely observed north of Essex on the Connecticut River (Marcy 1976a). Conversations with older local fishermen on the Connecticut River suggest that tomcod rarely travel north of the Baldwin Bridge during winter months. Historical data from the Connecticut River Study and our current study support these claims. On the Thames River tomcod were commonly taken in Norwich Harbor during the winter months (Dec, Jan, Feb) as by-catch by striper fishermen, but were rarely taken at the base of the Greenville Dam. Distribution within Connecticut’s estuaries suggests that tomcod in Connecticut exhibit different life history traits than those documented for fish in the Hudson River to the south and the more northern systems such as the St. Lawrence where extensive upstream migrations are undertaken during the winter spawning season.

SECTION 1.3.3: ENVIRONMENTAL CHANGES IDENTIFIED IN EARLY STATE AND FEDERAL PUBLICATIONS

Traditional Causes of Decline

Causes of decline in the tomcod population are not obvious, but are likely the result of a combination of factors including environmental change that has historically plagued Connecticut’s waters (see Smelt Section 1.2.3 for a review of traditional environmental issues).

Habitat Degradation

While dams have historically been a problem for anadromous species such as smelt, tomcod in Connecticut do not appear to conform to life history descriptions given for the Hudson River (Dew 1991), the Merrimac River (Mark Mattson, Normandeau Associates, New Hampshire, personal communication) or the St. Lawrence River system (Aquin 2004). Historical observations of spawning activity on the Saugatuck River (CT BFG 1930) and the Mystic River (Booth 1967), suggest that tomcod travel to the head of tide to spawn, but rarely travel further upstream, preferring to spawn in fresh to brackish waters rather than travel extensively upstream to freshwater. This would imply that dams are not a significant threat to tomcod populations in Connecticut.

In addition to the potential problems associated with physical changes to tomcod habitat, one of the most damaging may be the chemical contamination of many of the environments tomcod inhabit. Research conducted on tomcod from the Hudson River had documented high levels (55-90%) of liver cancer, thought to be in response to PCB contamination (Wirgin et al. 1989). However, control fish from Maine and Rhode Island did not show the same level of affliction. Pathological examination of fish from

Connecticut estuaries would allow for comparison with the Hudson River population and indicate the degree to which liver cancer may be affecting local populations.

Predatory Fish

As reviewed for smelt, recovery of many predatory fish populations, in particular striped bass (Dew 1980, Gardinier and Hoff 1982, Rulifson and McKenna 1987, Dew and Hecht 1994) and bluefish (Juanes et al. 1993) may have had negative impacts on tomcod populations in Connecticut. While the above cited studies reviewed feeding patterns from spring to fall, tomcod may also be susceptible during winter months. In years when warmer winter water temperatures would allow striped bass to continue actively feeding during fall and winter months, tomcod congregating for winter spawning activities may become targets for foraging bass. Resident bass are now present in many of Connecticut’s coastal estuaries potentially posing a year round threat to both adult and juvenile tomcod and the potential for striped bass to negatively affect local tomcod populations in Connecticut may be an area of further study.

Climate Change

Presumably tomcod, a boreal species, would be similarly affected by the impacts climate change would have for smelt. Results from the NMFS Milford Laboratory seine survey (Jose Pereira, National Marine Fisheries Service, Milford, Connecticut, personal communication) and our present sampling efforts indicate tomcod move out of near shore habitats by early June in response to increasing water temperature, possibly in search of cooler deeper water. Thermal stress has been identified as a potential factor contributing to the decline of tomcod on the Hudson River (ASA Analysis & Communication 2005), and may be similarly affecting tomcod in Connecticut waters. Otolith analysis conducted by Howe (1971) indicates tomcod growth slows during

summer months, and resumes during the fall and winter when cooler water temperatures are encountered. In years during which warm water conditions persist into the fall months, tomcod may endure extended periods of thermal stress that can lead to declining physiological condition and increasing mortality rates.

SECTION 1.3.4: CONSERVATION ACTIONS TAKEN TO CONSERVE TOMCOD POPULATIONS

Early Conservation Efforts

"These little fish, although very plentiful here, are more numerous than ever since our efforts in cultivating them."

- Mather, F. 1889. Report of Operations at Cold Spring Harbor, New York, during the Season of 1886. In: *United States Commission of Fish and Fisheries, Report of the Commissioner for 1886*

There is very little information about conservation efforts that may have been undertaken to protect tomcod historically along the Atlantic coast. Limited legislation was passed and the majority of effort was focused on stock enhancement efforts.

Protective Legislation

A review of the historical protective legislation for fisheries in Massachusetts and Connecticut indicates numerous general regulations were passed to restrict fishing activities. There are several regulations that would have benefited tomcod (see Smelt subsection 1.2.4 *Connecticut Regulations* for a review of relevant regulations); however few laws were implemented to protect tomcod specifically. In 1818, Massachusetts passed Public Act 109 in an effort to protect both tomcod and smelt (Massachusetts Secretary of the Commonwealth 1887). The law severely restricted the use of seine nets and regulated the types of obstacles that could be erected in the Charles River. Use of the seine net was limited to three days a week and offenders were required to forfeit forty dollars for each offence. The severity of the penalty suggests tomcod were considered a valuable species near Boston and were being threatened by the fishing

practices of the day. Connecticut did not pass legislation until the late 1920's and early 1930's to regulate the tomcod fishery. The legislation regulated trap mesh size allowing juvenile tomcod to escape, however Connecticut fishery biologists were recommending more stringent regulation of the tomcod fishery stating the present laws were "not at all adequate" for appropriate management (Connecticut Board of Fisheries and Game 1930).

Connecticut Commercial Regulations. The current status of the commercial laws regulating the take of tomcod in Connecticut are unclear. Commercial regulations governing the take of tomcod in marine and inland waters of Connecticut are published in the 2005 Marine Fisheries Information Circular (Connecticut Department of Environmental Protection 2005). The minimum legal size for tomcod is seven (7) inches (Connecticut Department of Environmental Protection 2005), which is a size attained by young tomcod by the end their first year. This would allow for the harvest of fish prior to their first spawning event. Commercial seine regulations for tomcod mandate a mesh no less than one and one-half (1-1/2) inches for the wings and one and one-quarter (1-1/4) inches for the center or bunt of the net (Connecticut Department of Environmental Protection 2005) ensuring take of adult tomcod. Current pound net restrictions mandate a two (2) inch mesh in Connecticut waters (Connecticut Department of Environmental Protection 2005), representing a threat to adult tomcod. Currently, inland commercial take of tomcod in Connecticut is closed from April 16th to November 30th (Connecticut Department of Environmental Protection 2005), a period of time that would allow exploitation during critical spawning activity. Chapter 490 Fisheries and Game, Secs. 26-144 to 26-148 of the General Statutes (Appendix G.1), lists restrictions on net type, mesh specifications, penalties, registration fees and open season for tomcod, but is listed on the State of Connecticut General Assembly web site

(http://search.cga.state.ct.us/) as having been repealed sometime after 1949 suggesting the current published regulations are no longer in effect. A complete review of the status of Connecticut legislation related to tomcod in Connecticut will be an important area for further investigation.

Stock Enhancement

Hatchery efforts targeting tomcod were begun in New York in 1884 (United States Commission of Fish and Fisheries 1886), and in Connecticut in 1929 (Connecticut Board of Fisheries and Game 1930). New York’s hatchery efforts were carried out at the Cold Spring Harbor hatchery (Mather 1887, see Smelt Subsection 1.2.4 for a review of the hatchery) first by the U.S. Fish Commission and later by the State of New York. In 1893, New York State officials planted 16 million larvae (New York Times 1894a) and in 1921 they released 171 million larvae (New York Times 1921) into the marine waters of New York. New York’s stock enhancement efforts were aggressive and continued well into 20th century, apparently supporting a winter recreational fishery for many years. In Connecticut, despite the apparent success of the hatcheries (Beck 1931) efforts at tomcod stock enhancement were ended within a few years because the fish were considered of little value commercially or recreationally (Connecticut Board of Fisheries and Game 1932).

CHAPTER 2

LIFE HISTORY REVIEW AND CURRENT POPULATION STATUS OF ANADROMOUS RAINBOW SMELT (*OSMERUS MORDAX*) AND ATLANTIC TOMCOD (*MICROGADUS TOMCOD*) IN CONNECTICUT

Section 2.1 INTRODUCTION

2.1.1 - LIFE HISTORY REVIEW AND POPULATION ASSESSMENT

Autecology, the study of single species ecology, includes identifying critical life history parameters related to age, growth, reproduction, distribution and abundance (Baltz 1990). Understanding the habitat needs of all life stages is a first step towards understanding population function (Grenouillet and Post 2001) and establishing baseline information that will allow for informed conservation decisions. However, little is known of many species’ habitat needs or life history requirements, and widespread habitat degradation has resulted in the loss of critical spawning and nursery habitat without adequate understanding of the long-term impacts (Schultz and Ludwig 2005). Documentation of essential fish habitat (EFH) has become a priority for developing and designing management and restoration programs for many fish species (Grenouillet and Post 2001, Goldberg et al. 2002, Schultz and Ludwig 2005), in particular, those currently threatened or likely to become extinct in the near future.

Documenting the age, size, fecundity, spawning season and location of spawning activity is essential for helping to establish closed seasons, fishing limits and protecting critical habitat (Baltz 1990, Schultz and Ludwig 2005). In particular, understanding parameters associated with spawning activity, such as seasonal abundance and site utilization, can be critical for protecting species from increased exploitation when reproductive activities bring fish into proximity of easily accessible fishing sites (Arendt et al. 2001). For some species, identification of estuaries supporting reproductive populations may be critical as recent research suggests many populations represent closed units with limited transfer between adjacent systems (Schultz and Ludwig 2005) making certain populations even more vulnerable to overfishing pressures. Identifying

the habitat requirements of a species makes conservation efforts more effective and helps to define areas of particular concern (Beck et al. 2001).

This study attempts to establish the current geographic distribution, habitat utilization and basic reproductive parameters of rainbow smelt and Atlantic tomcod in Connecticut waters. Our analysis represents a first step towards identifying critical habitat for multiple life stages within Connecticut waters.

2.1.2 - PROJECT RATIONALE

A detailed rationale for documenting the current status of both rainbow smelt and Atlantic tomcod in Connecticut has been presented in Chapter 1. Management decisions will benefit from information on the population abundance, structure and dynamics of both species in Connecticut, including knowledge of the current number of estuaries occupied, areas of critical habitat, and whether the species is presently reproducing in state waters. This study, combined with the information presented in Chapter 1, will make it possible to assess the current status of both species in Connecticut and to take steps towards designing a monitoring program and developing a recovery or enhancement plan for either species, if this appears to be necessary.

2.1.3 - PROJECT OBJECTIVES

The main component of this project was sampling in the field for multiple life stages in several estuaries. Adults and juveniles were collected at different times of the year, to document seasonal patterns of use in individual estuaries. Effort were directed at adults entering spawning areas, eggs on spawning habitat, and larvae in estuaries to confirm that spawning was taking place in the estuary. The goal was to document critical

life history traits and habitat usage of anadromous rainbow smelt and Atlantic tomcod to determine what actions if any should be taken to ensure their long-term viability. Specific objectives to be addressed in this chapter are to:

(1) Document the current utilization of selected estuaries and the presence of different life stages by:

a. sampling for adults and juveniles prior to the spawning season; specifically

b. 1. for rainbow smelt, sampling for adults on spawning runs, and eggs in spawning habitat;

b. 2. for Atlantic tomcod, sampling for adults during the spawning season, at spawning habitat;

c. sampling for larvae.

(2) Characterize the population structure, dynamics, and relative abundance in different estuaries by:

a. quantifying size structure and age structure of juvenile and adults prior to the spawning season;

b. quantifying female fecundity;

c. quantifying catch per unit effort of different life stages, based on sampling described in Objective 1.

Section 2.2 ANADROMOUS RAINBOW SMELT

The anadromous rainbow smelt is an inshore fish that migrates up estuaries to reproduce and is found in numerous coastal waters of the north Atlantic (Bigelow and Schroeder 1953). The northern limit of the anadromous form is Labrador and the southern limit is northern New Jersey along the Hudson River (Able and Fahay 1998). Non-reproducing smelt remain within a mile of shore and within 2 or 3 fathoms depth (Bigelow and Schroeder 1953). Rainbow smelt have historically been reported in almost all the large rivers that empty into Long Island Sound (see Chapter 1 for a review of local and regional distribution). Natural landlocked populations exist in the northern extent of the range, and many stocked populations are established in lakes throughout the northeast United States. Discussion of the life history of landlocked populations is beyond the scope of this presentation.

2.2.1 - LIFE HISTORY

Smelt spawning migrations take place in late winter and early spring throughout their range and are thought to be triggered by seasonal changes (McKenzie 1964). Over a period of one to three weeks, individuals move upstream to spawn in nightly excursions, returning to the estuary each day (Bigelow and Schroeder 1953, Jilek et al. 1979). Peak reproductive activity occurs from April through May (Buckley 1989), and has historically been reported to begin as early as February in some locations (Kendall 1926). In the Hudson River, early larval stages were collected in late April, and later larval stages from late April through June (ASA Analysis & Communication 2001). In some systems such as the Miramichi River there are distinct early and late cohorts of spawners (Scott and Scott 1988).

Rainbow smelt are short lived (1 – 5 years) and reach sexual maturity during their second year (Scott and Crossman 1973). Males reportedly rarely live more than two years (Burbidge 1969). A small to moderate percentage of spawning males are precocious one year olds, and the presence of precocious spawners is well documented in many populations. Precocious spawners have been documented to represent 33% of the male spawning population, suggesting that alternative mating strategies may be used to achieve reproductive success. Males who are maturing into precocious spawners, have larger body size and higher caloric values than males of the same year class, suggesting that early maturation is related to differences in growth and body condition.

Fecundity of anadromous rainbow smelt ranges from 8500 – 69,600 eggs, increasing with the size of the fish (Scott and Scott 1988). Egg diameter is 0.8 – 1 mm (Able and Fahay 1998; Cooper 1978). There are no reported fecundity estimates for fish collected from Connecticut waters. Larvae hatch from demersal eggs and remain in the estuary. The adhesive eggs attach to the substrate and incubate for a week up to two months, depending on water temperature (Able and Fahay 1998; Buckley 1989). Larvae are 5.5 – 6 mm in length at hatching and are retained in the estuary turbidity zone by actively migrating between surface and bottom waters depending on tidal stage (Able and Fahay 1998). Locke and Courtenay (1995) found post hatch larvae were most abundant in waters from 0 – 20 ppt in the Miramichi estuary during May – June, but begin migrating towards salt salinities during the late June to August period upon transformation to juvenile stages. Pearcy and Richards (1962) report a similar pattern for rainbow smelt in the Mystic River estuary.

2.2.2 - Taxonomy and Evolution

Two distinct races of rainbow smelt are found in the eastern North Atlantic, Acadian and Atlantic. Bernatchez's (1997) genetic analysis of 49 native populations identified two races that appear to have diverged during the Wisconsonian glaciation. The Atlantic race was isolated to the Atlantic coastal plain and the Acadian race to the Grand Banks area, near Newfoundland and south-east of Nova Scotia. The common ancestor of the two races existed along much of the same geographic range on the western Atlantic coast that rainbow smelt have occupied in recent geologic history. While samples of rainbow smelt DNA from Connecticut have not been tested for inclusion or exclusion from the Atlantic race, analysis of the Hudson River population and the Town River, MA (Bernatchez 1997) put both populations within the Atlantic race grouping. Presumably, all native populations of rainbow smelt in coastal Connecticut waters also belong to the Atlantic race.

Knowledge of the two Atlantic rainbow smelt races will need to be considered if stock restoration efforts are undertaken in Connecticut waters. Identifying source stock that most closely represents our local stocks will be important if stock enhancement efforts are to be successful.

2.2.3 - Habitat Utilization

Little information is available on the habitat requirements for rainbow smelt beyond general descriptions of the locations in which they were captured, most commonly during spawning events. The lack of information on the marine phase of their life history represents a serious gap in our understanding of smelt habitat utilization. The following literature review provides an overview of habitats and behavior observed during field studies of smelt in northeastern stream and lake habitats, generally during spring spawning events.

Numerous authors have described the spawning ecology and demography of the Atlantic rainbow smelt (*Osmerus mordax mordax*) (e.g. Langlois 1935; Rothschild 1961; Rupp 1965; McKenzie 1964; Murawski et al. 1980) and casual descriptions of spawning behavior have been reported (Langlois 1935), but careful documentation of spawning behavior in this species has not been undertaken.

With respect to spawning, critical habitat requirements include salinity and substrate type. Rainbow smelt spawn above the head of tide in fresh water, long thought to be essential as the eggs suffer severe mortality if saline waters intrude (Bigelow and Schroeder 1953). Recent research suggests smelt eggs are capable of surviving and hatching in low salinity conditions (D.M. Berlinsky, Dept. of Zoology, University of New Hampshire, pers. comm.). Smelt spawn on substrates of cobble, gravel and sand (Bigelow and Schroeder 1953; Jilek et al. 1979; Langlois 1935) in high-flow waters (Buckley 1989).

McKenzie (1964) and Murawski et al. (1980) have both reported smelt returning to specific river systems during spawning events, but individual stream fidelity was not well documented. Smith and Saalfeld (1955) documented tributary use by the related species *Thaleichthys pacificus*, the Columbia River smelt or eulachon, noting that smelt runs were reported yearly in the main stem of the Columbia River, but that tributary use was sporadic. Spawning areas for Columbia River smelt occurred in the main stem of the Columbia, at the mouth of some tributaries and as far upstream as 20 miles on others, with adult fish showing no great tendency to return to natal streams. All of the major tributaries failed to produce a run during at least one of five seasons, and abundances fluctuated from no fish to over two million fish within a few years time.

Review of the literature to identify historical spawning runs of anadromous fish, particularly smelt, has been proposed in the past (Visel and Savoy 1989), but to date

had not been carried out. Smelt fishermen have long reported runs on specific river systems (e.g. the Pawcatuck and Saugatuck Rivers in Connecticut), however there is limited documentation of natal fidelity which would be significant for long-term management or stock enhancement efforts. The ability to document consistent use of spawning habitats in Connecticut waters will be critical if reintroduction to specific locations is anticipated.

SECTION 2.3 ATLANTIC TOMCOD

The Atlantic tomcod was historically a common demersal fish of coastal estuary regions. The listed range is from southern Labrador to Virginia (Bigelow and Schroeder 1953) but it has been noted as far south as North Carolina (Scott and Scott 1988). Southern records should probably be viewed as reflecting incidental catches; the reported occurrence in Chesapeake Bay was based on a single individual. The present status of the species in New Jersey is questionable. Reproductively active populations of tomcod are thought to presently reach their southern extension in the Hudson River (Grabe 1978). Atlantic tomcod have been reported for almost all the large rivers that empty into Long Island Sound (see Chapter 1 for a review of local and regional distribution).

2.3.1 - LIFE HISTORY

Atlantic tomcod are a short lived, winter-spawning, anadromous species. The lifespan in Canada is four years (Salinas and McLaren 1983), while in the Hudson River reproduction is dominated by annual fish (M. Mattson, Normandeau Associates, pers. comm.). Spawning generally takes place from November to February (Bigelow and Schroeder 1953; Booth 1967; Peterson et al. 1980).

Tomcod produce large numbers of benthic eggs. Fecundity ranges from 5,000 to 32,000 during October to December with a mean of ~ 18,000 (Shaner and Sherman 1960). Egg sizes range from 1.3-1.93 mm diameter (Able and Fahay 1998; Peterson et al. 1980). The properties of egg masses and their mobility are unclear. Some published reports describe the eggs as being adhesive and clumping together in masses (Able and Fahay 1998; Bigelow and Schroeder 1953), however it is also reported that egg mortality is high when eggs are aggregated into layers (Booth 1967) and that eggs may drift

downstream of spawning sites (Peterson et al. 1980). Klauda et al. (1988) have reviewed the literature on egg adhesion and have concluded that eggs spawned naturally are not adhesive, and reports of adhesive eggs are largely based on reports from fish that were artificially stripped.

Hatching and development occur primarily near spawning habitat. Reported hatching times range from 52 days at 2-4°C (Scott and Scott 1988) to 30 days at 4.4°C and 24 days at 6.6°C (Bigelow and Schroeder 1953). Upon hatching, larvae rise to the surface to fill the swim bladder (Peterson et al. 1980) and then take up a demersal existence. Larvae have been collected from late January to mid-April in the Mystic River estuary (Booth 1967; Pearcy and Richards 1962), from March to mid-April on the Weweantic River (Howe 1971) and from early May to mid-June in the St. Lawrence estuary (Able 1978). Larvae are consistently more abundant at depth. Salinity appears to be a useful predictor of larval location. Dew and Hecht (1976) and Locke and Courtenay (1995) have both reported that larvae can be found in the greatest abundance in salinities from 2 – 10 ppt during the post hatch period.

2.3.2 - HABITAT UTILIZATION

Atlantic tomcod are found near the mouths of rivers in tidal estuaries, in salt creeks and can be found as far upstream as the head of tide in tributary streams (Bigelow and Schroeder 1953; Booth 1967; Lambert and Fitzgerald 1979). Tomcod avoid the warm waters of small streams and shallow coastal regions during the summer (Bigelow and Schroeder 1953; Lambert and Fitzgerald 1979; Targett and McCleave 1974). Tort (1995) reported that juvenile tomcod prefer rocky habitats to mud or vegetation in the Sheepscot Estuary, Maine, but Howe (1971) only collected young-of-

the-year (YOY) tomcod in the eelgrass (*Zostera* spp.) beds of the Weweantic River Estuary, Massachusetts. Tomcod can tolerate extreme, sudden changes in salinity.

The current distribution of spawning activity in the Long Island Sound region is unknown. Review of the historical literature suggests spawning occurred in the Mystic River Estuary (Booth 1967; Marcy 1976; Pearcy and Richards 1962) and the Saugatuck River (Connecticut Board of Fisheries and Game 1926). Conversations with older local fishermen suggest many small tributaries along the coast supported populations of spawning tomcod during winter months. In large systems (e.g. the Hudson River, the St. Lawrence River) the species is anadromous; undergoing extensive upriver migrations to reach preferred spawning habitat in fresh water (Klauda et al. 1988, Aquin 2004). However, Everly and Boreman (1999, see Table 1) list tomcod as euryhaline spawners and adult tomcod in Connecticut have historically limited spawning migrations into the upper low-salinity regions of estuaries (Connecticut Board of Fisheries and Game 1926). Spawning may occur on substrates of ledge, boulders and cobble (Peterson et al. 1980, Connecticut Board of Fisheries and Game 1926), or near shore in shallow (5 cm deep) water full of ice and slush (Booth 1967).

2.4 - ASSESSMENT METHODS

2.4.1 - SAMPLING PROTOCOL

Sampling for rainbow smelt and Atlantic tomcod was concentrated in five estuaries along the central and eastern Connecticut coast: the Connecticut River, New Haven Harbor/Quinnipiac River, the Niantic River, the Thames River, and the Mystic River. Sampling in the Quinnipiac River and the Niantic River was supplemented via cooperative agreements. In the Niantic River region, the Millstone Environmental Lab shared specimens that were collected as part of their ongoing monitoring efforts. Sampling in the New Haven Harbor region was conducted with the assistance of The Sound School.

Habitat characteristics, including air and water temperature, salinity, conductivity, pH and general stream bed descriptions were recorded during each collection event. Air temperature was recorded using a standard metric thermometer. Water conditions were recorded using a YSI 85. Location information was recorded using local road intersections and geographic landmarks and longitude and latitude were determined using 7.5” series topographic maps of Connecticut. A GPS unit (Magellan - Meridian Platinum) was used to record collection locations during the second year of sampling. Use of a GPS device was not available until the second year of sampling; year one location information was augmented post sampling for many locations.

2.4.1.1 - RAINBOW SMELT (*OSMERUS MORDAX*)

Adult Sampling

Fyke Nets and Weirs

To sample adults on spawning runs, we deployed fyke nets downstream of likely spawning habitat. Fyke deployment was ruled out at several locations due to concern about interfering with alewife runs. The fyke nets were 1 m hoops x 2 m length with 1 m x 2 m wings off the inlet hoop; the mesh throughout the net was $5mm^2$ delta nylon. We deployed fyke nets in three locations. Nets were deployed in the main channel in the deepest stream sections to insure the net opening would remain submerged in locations where the stream was under tidal influence. The net wings were positioned for only a partial stream block to help limit the number of alewives taken as by-catch. At each location, the fyke net was checked on a daily schedule. Deployments were often interrupted for days because of heavy stream flows following precipitation events. Catch was identified to species and enumerated. All non-target fish were released immediately.

Spawning adult smelt were also sampled using fish pens or weirs, which we deployed at locations where there was concern about alewife mortality in fyke nets. The larger pen size allowed all fish captured to continue swimming normally. The weirs were constructed of iron rebar pounded into the stream bed and were oriented with the opening facing downstream. Panels of PVC mesh were then fastened between the rebar anchors with cable ties. Two wings (3 - 4 m long) were constructed such that they extended into the mouth of the pen and formed a narrow slot that allowed fish to pass through the opening into a large pen (12 m^2 area, 2 m x 6 m). Fish were prevented from exiting the pen as the slot protruded into the bowl of the pen. The slot was 3 cm wide, permitting passage of individual fish. Weirs were constructed in two locations. At each,

we were asked to limit the scope of the weir to a partial block, rather than a full stream block to prevent capture of alewives. Weirs were checked every day or every other day depending on prevailing weather and in stream conditions.

In the second year of sampling, benthic sampling was favored over fyke and weir sampling for evidence of spawning activity. Benthic sampling allowed us to sample a wider range of locations and habitats, increasing our ability to detect potential spawning activity.

Gill Nets

Experimental gill nets were deployed in five estuaries, the Mystic, Thames, Niantic, Connecticut River and New Haven Harbor. Gillnets were composed of five 10-foot panels of mesh sizes 9.5, 12.7, 15.9, 19.1 and 25.4 mm (bar measure) to catch as wide a range of sizes as possible. Nets were deployed in short sets, 30 to 60 minutes, at randomly chosen locations, based on a design that stratifies each estuary by region. Nets were deployed just off channel to prevent damage from boat traffic, in areas that would insure the nets remained in position throughout the tidal cycle. The GPS location of the head and tail of each net was recorded at the time of deployment. Catch was identified to species and enumerated. All non-target fish were released immediately.

Egg Sampling

Egg Mats

During the 2003 spring spawning season, efforts to identify potential spawning habitat were made using burlap sampling mats. Mats similar to this have been used previously to sample spawning habitat (Rothschild 1961, Rupp 1965). Mats were constructed of burlap cloth, stretched over flat, gray, concrete paving bricks (12”X12”X2”) and attached with strips of 2” industrial Velcro applied to the bricks and the

burlap. A length of yellow polypropylene was attached to each block for easy location and retrieval and mats were placed so that the rope was always on the downstream side of the mat, ensuring the rope would not interfere with potential egg attachment.

Spawning mats were deployed at twelve locations, selected in consultation with members of the CT DEP Anadromous Fish Program. Mats were deployed at slightly different times in late February at each location, following ice break up. One to three mats were deployed at each location in areas identified as appropriate spawning habitat, i.e. sand/gravel and cobble bottoms. Mats were distributed over the entire length of appropriate habitat and were located in areas were they would remain submerged during periods of low flow. Mats were retrieved and examined at least weekly and immediately replaced. Eggs persist for up to two weeks in the location of spawning activity prior to hatching (Crestin 1973) making weekly in-stream examinations adequate for detecting spawning activity. The decision to conclude mat monitoring was made on the basis of water temperatures exceeding 14°C, and indications that no smelt had been spawning in these sites.

Habitat Sampling

During the 2004 spring spawning season direct sampling of stream substrate was made in an effort to locate eggs. Similar sampling efforts have been used in Massachusetts in conjunction with their smelt conservation program with successful results (Bradford Chase, Massachusetts Division of Marine Fisheries, pers. comm.). Substrate samples were collected using a sampling basket constructed from a small wire test tube basket attached to a 10’ length of wood closet pole. Samples were obtained by scraping up gravel and cobble from the stream bed. Samples were then searched for evidence of eggs. Eggs remain attached to the substrate during sampling and are easily observed by visual inspection *in situ* (Bradford Chase, Massachusetts Division of Marine

Fisheries, pers. comm.). Sampling was conducted over the entire length of stream bed that was identified for the egg mat sampling described above. Field personnel made continuous substrate collections over the entire bed length, once a week for 30 minutes during the spawning season. Sampling was timed to low tide in streams that are under tidal influence.

Larval Sampling

Plankton Survey

Larval sampling was conducted from early April to early June in the Mystic, Thames, Niantic, Connecticut and Quinnipiac River. Sampling locations were chosen randomly from the upper, mid and lower sections of the navigable reaches of each river system. Samples were taken from the main channel and were possible were also taken from river stretches adjacent to tributary inflows that contained areas identified as appropriate spawning habitat.

Two types of gear were used, a small beam-type benthic trawl plankton net (1.0m x 0.5m x 5.3m with a mesh of 500 microns and a cod end made of a plastic jar) and a standard round mid-water plankton net (0.38 m^2 opening X 3.5m with a mesh of 500 microns with a PVC cod end with mesh windows); for some of the New Haven samples, the net had a 0.20 m^2 opening X 1.8 m of 303 microns with a PVC cod end with mesh windows. The beam trawl was only used during the 2003 sampling season and was abandoned in favor of the round plankton net for the 2004 sampling season. The beam trawl was deployed with a 5:1 scope, and the plankton nets were deployed with a 4:1 scope. The beam trawl was lowered over the side and the rope paid out so that the line was taut at all times to insure that the gear remained upright prior to coming to rest on the bottom. During the 2003 season the plankton net was released in the same manner, but was kept at the surface. Scope ratio was maintained to ensure that

the net was not fishing in the prop wash. Oblique tows were used to insure sampling of the entire water column. Both gear types were deployed for a total of 3 minutes per tow. Flow meter readings were taken prior to the gear going in the water, and then again as soon as it was retrieved. During the 2004 season start and stop GPS positions were recorded for each tow. Time constraints limited our sampling to two replicate samples at each location. The contents of the net were then washed down into the cod end and transferred into 10% buffered formalin. When the beam trawl was loaded with sediment we subsampled and fixed as above. Sediment laden samples were sieved using a 500 micron metal sieve in the laboratory and fixed in 10% buffered formalin.

Juvenile Sampling

Seine Surveys

Sampling for juveniles was made using a large bag seine (8.6 m long, 1.6 m wide, bag dimension of 1.6 m x 1.6 m x 1.6 m) with a wing mesh of 50 mm^2 delta nylon mesh, and a bag mesh of 25 mm^2. The leading edge was weighted with 12 strands of ½“ cotton cording. A spreader rope was attached between the brails so the net swept a constant width of 5 meters. Sampling consists of taking four 30m hauls in sequence parallel to the shore line. Haul distance was designated by a 30 m length of rope laid out along the shore prior to each haul. If the bed presented obstacles such as rocks or trees, the area to be sampled was shifted slightly down the shore from the previous sample. Bed type was recorded for each haul as mud, sand, sand with vegetation, cobble or cobble with vegetation. All specimens were enumerated and identified to species in most cases, but at a minimum to genus. Specimens were separated by haul. Two voucher specimens were collected for each species observed, and all smelt were retained for further analysis.

2.4.1.2 - ATLANTIC TOMCOD (*MICROGADUS TOMCOD*)

Adult Sampling

Sampling for adult specimens was carried out during winter months in January 2003, and from November 2003 to January 2004. Sampling during December 2004 and January 2005 was limited due to extensive ice cover. Catch was enumerated and measured. All adults collected were retained for analysis of age and fecundity.

Box Traps

We selected box trapping to collect tomcod because it is reportedly effective and relatively easy to conduct. Traps were deployed at locations that were accessible from shore but would be most likely to intercept fish on their spawning migrations into upper estuary regions. In areas of limited manmade development, efforts were made to locate structure such as docks and rocky outcrops, areas where tomcod are thought to seek refuge or had historically been caught with similar gears. Traps fished on developed estuaries were placed along manmade structures, such as bulkheads, that would act as a leads for the traps. Where possible we distributed traps along a salinity gradient within each estuary. The traps were initially fished unbaited, but then were baited with canned cat food, which has proved effective in attracting tomcod in other areas (M. Mattson, Normandeau Associates, pers. comm.). Traps were checked every other day unless weather prevented travel to the site or ice prevented removal of the trap.

Larval Sampling

Ichthyoplankton Survey

Plankton sampling for tomcod larvae was carried out in the same manner as the smelt plankton sampling.

Juvenile Sampling

Seine Surveys

Sampling for juveniles began using a small seine (4.5 m x 1.15 m), with no bag and a coated cotton mesh of 5 mm^2. A spreader rope was attached between the brails so the net swept a constant width of 3.9 meters. Late spring and early summer sampling for juveniles was made using a small bag seine (5.5 m long, 1.25 m high and bag dimension of 1.1 m x 1.1 m x 1.1 m), with 50 mm^2 delta nylon mesh. A spreader rope was attached between the brails so the net swept a constant width of 3.9 meters. Sampling with both nets consisted of taking four 30m hauls in sequence parallel to the shore line. Haul distance was designated by a 30 m length of rope laid out along the shore prior to each haul. If the bed presented obstacles such as rocks or trees, the area to be sampled was shifted slightly down the shore from the previous sample. Bed type was recorded for each haul as mud, sand, sand with vegetation, cobble or cobble with vegetation. All specimens were enumerated and identified to species in most cases, but at a minimum to genus. Specimens were separated by haul. Two voucher specimens were collected for each species observed, and all tomcod were retained for further analysis.

2.4.2 **– Population Characteristics Protocol**

2.4.2.1 - Rainbow smelt

Smelt specimens were measured to the nearest 0.01 mm standard length and weighed to the nearest 0.01 g. Lapillus and sagittae were extracted and preserved, and scale samples were taken from the dorsal region and retained.

2.4.2.2 - Atlantic tomcod

<u>*Adults*</u>

Age Determination

Otoliths were extracted from all tomcod collected from early fall through late winter for age determination. Selected specimens were photographed, measured to the nearest 1 mm, weighed to the nearest gram and their otoliths (sagitta and lapilli) were extracted, cleaned, and stored in 35% ethanol and water in a small glass vial. Sagittae were used to determine age following Howe (1971). Distinct annuli were apparent in older tomcod when their otoliths were viewed in transmitted light. When viewed with transmitted light, the central origin of the otolith is opaque, or white, surrounded by concentric bands of translucent hyaline bands, dark in appearance, and opaque bands. Opaque bands represent active growth during cool months and translucent hyaline bands represent slow growth during warmer months (M. Mattson, Normandeau Associates, pers. comm.). Tomcod form one opaque and one hyaline band each year. Formation of the first opaque band, following formation of the opaque central core, represents the start of the second growing season. In age 0 fish, the second opaque band can begin developing by 10 months of age (around October) and will continue to form until the end of July the following summer, followed by formation of a dark hyaline band between July and October (Howe 1971). Annuli, opaque and hyaline bands, were counted using a dissecting microscope with light transmitted up through the otolith while immersed in a Petri dish of water.

Sex Determination / GSI

Gender of all adult specimens was determined through visual inspection of the gonads. Incisions were made ventrally from the urogenital vent to the pectoral girdle.

Females were blot dried using paper towels and weighed with a digital balance to the nearest 0.1-g. Both ovaries were excised from the body cavity and weighed to the nearest 0.1 g. Gonads were identified as immature, mature or spent based on visual inspection. Gonads were preserved in ten percent buffered formalin. Gonad somatic index was estimated as 100% x gonad mass (g) / body mass (g).

Fecundity and Oocyte Size

We estimated annual fecundity as the absolute fecundity, the total number of eggs ovulated per fish, in a single season. The total number of mature and maturing oocytes per individual fish was determined using a slurry of eggs scraped from a single ovary. A subsample was taken and weighed to the nearest 0.01 g. The oocyte sample was then evenly distributed on a gridded Petri dish and all mature oocytes (those undergoing hydration or with yolk granules) were counted for each subsample. Total fecundity was then calculated as the paired gonad mass (g) / subsample mass (g) x subsample count.

Oocyte size in relation to ovary maturity was determined by randomly measuring the diameter of 20 - 30 oocytes from each ovary subsample. Oocyte diameters were measured using a digital image of an oocyte subsample taken with a digital camera linked to a dissection scope on 0.1x magnification. Oocyte diameters were measured to the nearest 0.01 mm using Sigma Scan Pro V (2003).

Juveniles

Otolith Sampling

Otoliths were extracted from all YOY juvenile tomcod collected during the spring of 2003 and 2004 for daily increment analysis. Otoliths extracted from individuals collected in the late summer and early fall were too large to determine discern daily increments. Selected specimens were measured to the nearest 0.1 mm and their otoliths

(sagitta and lapilli) were extracted, cleaned, and conditioned in immersion oil on a microscope slide. Only the lapilli were used to back calculate spawning dates. One lapillus from each pair was embedded in a thermoplastic resin (Crystalbond; Aremco Products, Ossining, New York) and ground on one side using wet-dry sandpaper, in a graded series from 400 to 1,200 grit. The second lapillus was maintained in immersion oil and only used if the first was damaged or unreadable. Age analysis was not possible for all individuals because of extensive cracks or chemical etching. Daily increments were counted at 400X, through a 40X oil immersion objective. One reader counted each otolith a minimum of two times. Replicate counts were counted on different days and were blind to previous counts of that otolith. Otoliths were eliminated from the analysis if the replicate counts differed by more than five increments, or we were unable to obtain two or more counts.

Growth Rates

Juvenile growth rates were determined using the average change in length over the length of the sampling season. We fitted a simple least squares regression to the early spring seine data, using the sampling date as the age estimate and the change in the average length of all the specimens collected on a single date as a proxy for growth. We chose to use the sampling date as a proxy for age because of concern over the validity of the age estimate obtained from the juvenile otolith analysis.

2.5 - ASSESSMENT RESULTS

2.5.1 - Rainbow smelt

2.5.1.1 - Sampling Results

Fyke and Weir Sampling

Fyke nets were deployed in three river systems and weirs were constructed in two locations following ice break up between mid March and mid April 2003 (Table 2.1, Appendix A.2). Water temperature ranged between 5.3 and 17.4 °C during gear deployment. Several flood events during the sampling season prevented deployment of fyke nets. The weirs in both locations continued to function properly despite experiencing several severe flooding events.

Weir sampling on the upper Poquonnock resulted in only 1 non-target fish being caught. In an attempt to determine if the weir was functioning properly, we simultaneously deployed a fyke net slightly downstream from the weir. No additional fish were caught in the fyke, suggesting the system is simply depauperate.

Weir and fyke sampling on the Connecticut River tributaries Mill Brook and Pine Brook resulted in 464 fish, representing 19 species, but did not result in the collection of any rainbow smelt (Table 2.2). Alewives and yellow perch were both collected in spawning condition on Pine Brook throughout the sampling season, suggesting the stream may represent important spawning habitat for both species.

Egg Mat and Benthic Habitat Sampling

No evidence of spawning activity was observed at any site in either year of sampling. Egg mats were deployed at thirteen locations between February 21 and May 7, 2003 for a total of 1584 mat days (Table 2.3, Appendix B.2). Mat monitoring was concluded on May 7th. In-stream benthic habitat sampling was conducted at twelve

locations between March 9 and April 8, 2004 (Table 2.4). Extensive ice cover and multiple flooding events delayed sampling efforts. Water temperatures ranged between 2.5 and 13.8 °C during the sampling season.

Gillnet Sampling

Gill nets were deployed on six river systems between September 7 and October 17, 2003 for a total of 66.4 net hours (Table 2.5, Appendix C.2). Water temperature and salinity ranged from 13.5 to 23.0 °C and 0.1 to 30.2 ppt during net deployments. A total of 1152 individuals, representing 17 species, were caught (Table 2.6).

Juvenile menhaden and adult *Menidia* represented 63% and 24.5% of the total catch respectively. No target species were collected during sampling. The presence of adult *Menidia* in the nets suggests rainbow smelt would have been sampled had they been present, as they are similar in body conformation and size to adult rainbow smelt. Gill net deployments on the Quinnipiac, Connecticut and Thames Rivers were hampered by high water flows and a significant amount of terrestrial debris becoming entangled in the nets.

Ichthyoplankton Sampling

Ichthyoplankton samples were collected from three estuaries in 2003 (Appendix D.2) and five estuaries in 2004 (Appendix E.2). Samples were collected between late April and late May in 2003 and late March and early May in 2004. Sampling on the Niantic River had to be abandoned as a result of a large swarm of jellyfish that persisted during the sampling season. No smelt larvae were collected as a result of ichthyoplankton sampling.

2.5.1.2 - Rainbow Smelt Specimens

A total of 9 rainbow smelt were collected the fall of 2004 in upper Mystic River as a result of seine sampling (see Atlantic tomcod sampling results). An additional 11 specimens were collected during late February 2005 by the Millstone Environmental Laboratory. Specimens from both river systems showed similar length weight relationships (Fig. 2.1). Specimens collected from the Mystic River had a smaller size range, and were generally larger than the Niantic River fish.

Comparisons between the Massachusetts and Connecticut length and weight data suggest all smelt collected were 2004 year-class. Age 1 specimens collected in during the 2004 spring spawning run in Massachusetts were 106 to 161 mm total length and averaged 12.7 g (Chase 2004). We believe that the fish collected in late February 2005 were also 2004 year-class. Their size and the date of collection make it unlikely that they were from either the 2003 or 2005 year-class; therefore we feel the fish collected during early 2005 were likely early Age 1 fish. Future otolith analysis may help to clarify age verification of these specimens.

2.5.2 - Atlantic Tomcod

2.5.2.1 - Sampling Results

Box Trap Sampling

Box traps were deployed on four river systems between November 2002 and January 2003, and on seven river systems between November 2003 and February 2004. Traps locations are listed in Appendix F.2. During the 2002-03 sampling season, twenty traps were fished for a total of 1,850 trap hours (Table 2.7). A total of 21 individuals, representing 6 species, were caught during the first season (Table 2.8). We increased to a total of thirty-six traps during the 2003-04 sampling season, for a total of 46,782 traps hours (Table 2.9). During the second season, 1575 individuals, representing 26 species,

were caught (Table 2.10). A total of five tomcod were caught during the 2003-04 season, from four river systems. All tomcod were collected from the lower reaches of the river systems sampled. We were unable to identify spawning habitat based on the results of the adult sampling protocol. All fish collected were gravid, providing evidence that spawning activity was occurring in the Mystic, Thames, Connecticut and Quinnipiac Rivers.

Ichthyoplankton Sampling

Ichthyoplankton samples were collected from three estuaries in 2003 (Appendix D.2) and five estuaries in 2004 (Appendix E.2). Samples were collected between late April and late May in 2003 and late March and early May in 2004. Sampling on the Niantic River had to be abandoned as a result of a large swarm of jellyfish that persisted during the sampling season. A total of 211 tomcod larvae were collected as a result of ichthyoplankton sampling (Table 2.11). Eighty-nine percent of the larvae were collected from the Thames River between Norwich Harbor and the Route 2A Bridge. Collection of larvae in this location suggests tomcod migrate into the upper low salinity regions of the Thames River during the winter months to spawn. It is unclear whether tomcod migrate further than Norwich Harbor to spawn. Spawning migrations beyond this region are prevented by the Greenville Dam on the Shetucket River, and Indian Falls on the Yantic River. Several larvae were also collected from the Connecticut, Poquonnock and Mystic Rivers, however there were too few larvae to determine the location of spawning activity.

Seine Sampling

Seine sampling was conducted on nine river systems during 2003 and seven during the 2004 sampling season. Sampling location information is given in Appendix G.2. Twenty-seven samples were collected during 2003 (Table 2.12) covering a total of

12,246 m^2. Water temperature and salinity ranged from 14.2 to 29.2 °C and 0.1 to 29.1 ppt during seine sampling. A total of 10,110 individuals, representing 33 species, were caught in 2003 (Table 2.13). Ninety-five samples were collected in 2004 (Table 2.14) covering 43,506 m^2. Water temperature and salinity ranged from 8.1 to 26.5 °C and 0.0 to 29.2 ppt. An additional 51,671 individuals, representing 37 species, were caught in 2004 (Table 2.15).

A total of 42 juvenile tomcod were collected during 2003. The number of tomcod per square meter ranged from 0.00 to 0.01. Collections from the Mystic and Thames Rivers accounted for 80% of the juveniles collected in 2003. Sampling during the 2004 season resulted in the collection of 456 juvenile tomcod. The number of tomcod per square meter ranged from 0.00 to 0.03, only slightly higher than the previous year. Collections from the Mystic and Thames Rivers accounted for 96% of the juveniles collected in 2004.

Sampling for tomcod on the Mystic and Thames Rivers was most successful during early spring shortly after hatching occurred in the upper reaches of both systems, presumably close to the location of spawning activity. Catch declined throughout the late spring and early summer months. Few fish were collected during the summer months, possibly as a result of habitat shifts in favor of cooler offshore waters. Four tomcod (three from the lower reaches of the Thames River and one from Ram Island near the mouth of the Mystic River), were collected in October 2004 as water temperatures began to cool. Effective sampling programs should be timed to correspond with hatching date and should target river reaches closest to potential spawning habitat. Fall sampling programs appear to have limited value for detecting tomcod as the fish appear to prefer offshore habitats during fall months.

2.5.2.2 - Specimens

<u>*Adults*</u>

Demographics

Thirty adult tomcod were collected from between winter 2003 and spring 2005 from five estuaries. The Connecticut Department of Environmental Protection, Marine Division provided 3 specimens from the mouth of Latimer Brook on the Niantic River during the 2003-04 winter. The Sound School, New Haven, Connecticut provided 2 specimens during the early fall 2003. Millstone Environmental Laboratory provided 18 tomcod from the Niantic River in spring 2005. Another 2 were provided by local fishermen in the Mystic area. The male to female ratio was 2:1. Males ranged in size from 9.3 to 34.9 cm total length, with a mean of 19.0 cm. Females were slightly smaller and ranged in size from 11.7 to 21.5 cm total length, with a mean of 17 cm. Adult tomcod were collected from three age classes (Fig. 2.2). Age 1 fish represented 63% of the specimens. No Age 2 females were collected.

Reproduction

A total of ten adult female tomcod were collected. Gonad inspection identified four specimens with mature or spent ovaries, all collected during the month of December from the Connecticut, Niantic and Mystic Rivers (Table 2.16). Mature and spent ovaries had a yellowish cast, as a result of the orange color of the maturing and mature eggs, while immature or undeveloped ovaries were white in color with thick ovarian envelopes. Female GSI estimates ranged from 0.2 to 22 percent. The highest GSI estimates were for mature females collected in December. The absolute fecundity estimates of the two mature females were 53,658 and 54,360 and both fish were YOY (determined by otolith aging). Oocyte diameters ranged in size from 0.6 to 1.7 mm and showed distribution clustered by resting, mature and spent ovaries (Fig. 2.3). This finding suggests tomcod

are synchronous spawners, simultaneously investing energy in all oocytes that will be spawned in a season.

The reproductive analysis suggests tomcod spawn in Connecticut during the month of December and that some YOY females (females just short of 1 year of age) are reproductively active. Larger samples sizes and more inclusive chronological sampling will provide better resolution of spawning seasonality, reproductive allotment, and fecundity estimates.

Juveniles

Hatching Dates

We were able to successfully analyze a total of 42 and 52 YOY tomcod lapilli from the 2003 and 2004 sampling seasons respectively (Table 2.17 a and b). The average coefficient of variation between replicate counts ranged from 0.0 to 13.86. Back calculated hatching dates suggest tomcod hatching occurred between April 7 and May 9 in 2003 and March 19 and April 19 in 2004.

These hatching dates are inconsistent with our knowledge of the natural history of this species. Reported hatching times range from 52 days at 2-4°C (Scott and Scott 1988) to 30 days at 4.4°C (Bigelow and Schroeder 1953). At 52 days, spawning would have occurred between mid February and mid March in 2003 and between late January and late February in 2004. Two possible explanations exist for the discrepancy. First, although extensive ice cover prevented us from collecting water temperature data during late winter in both seasons, water temperatures ranged from -0.1 to 2.3 °C during our 2002-03 box trap sampling season and were only slightly warmer during our 2003-04 sampling season. Given water temperatures continue to cool during late January and early February, it is possible hatching may have been delayed longer than 52 days

during both years. Secondly, our resolution of the daily increments near the origin of the lapilli may have been limited, which could significantly alter our ability to determine hatching dates. Validation of the otolith age record will be useful for verification of hatching dates and may help to clarify the length of the spawning season. Validation will provide needed information about egg development times in Connecticut and provide more robust estimates of larval growth rates.

Growth Rates

Change in standard length between collection dates is presented for the 2003 (Fig. 2.4) and 2004 (Fig. 2.5) sampling seasons. We measured the standard length of 139 juvenile tomcod collected between May and August, 2003, and 298 between April and June, 2004. Change in length was positive during both sampling seasons for all locations, with intra-estuary differences observed.

Only three estuaries were used to estimate growth rates; New Haven Harbor in 2003, and the Mystic and Thames Rivers in 2004, due to low sample size in the other locations. Simple linear regressions were used to calculate growth rates and are presented in Figures 2.4 and 2.5, along with the R^2 value. Growth rates were similar among the three systems with slightly higher rates in New Haven. Juvenile tomcod growth was 0.92 mm / day in New Haven Harbor, 0.71 mm / day in the Mystic River and 0.78 mm / day in the Thames River.

Juvenile tomcod growth is reported to slow down during warm summer months, in response to increasing water temperatures, but we do not currently have enough data to support similar observations in Connecticut waters. However, forward calculation of a length using the growth estimate from the Thames River would suggest tomcod growth does seasonally decline. Assuming a growth rate of 0.78 mm / day for 300 days (10 months), YOY tomcod could attain a length of 23.4 cm by late December assuming a

hatch date of early March. The maximum size observed in specimens collected during late December was 18.0 cm, indicating growth does begin to decline during summer and fall months. Future studies would benefit from using deeper water gears during summer months to collect specimens.

CHAPTER 3

MANAGEMENT RECOMMENDATIONS FOR ANADROMOUS RAINBOW SMELT AND ATLANTIC TOMCOD

3.1 - ANADROMOUS RAINBOW SMELT

3.1.1 - Management Recommendations

The following management recommendations are made based on the preceding information:

- List anadromous rainbow smelt as endangered rather than threatened within Connecticut waters. In particular, the data (sections 1.2.1, 1.2.2, 2.5.1) suggest that there are five or fewer occurrences in Connecticut, as they have been recently collected in only two estuaries and no estuary in eastern Connecticut appears to have a spawning population. In addition, the species has declined “seriously” and “noncyclically” in Connecticut and throughout a significant part of its range, and its spawning habitat is “unusually vulnerable to loss, modification or degradation in quality”.
- Conservation measures should be adopted to protect the regional spawning stock, because of its present vulnerability. These measures should include (section 1.2.4):
    - maintaining the inland fishery closure at all locations where anadromous runs may occur ;
    - extending the closure to coastal marine waters;
    - clarifying the status of published commercial regulations; closing the commercial fishery.
    - Investigating the feasibility of reestablishing runs by transplanting eggs into river systems most likely to support self-sustaining smelt populations.
- Further work on the population’s status and threats to its welfare should be undertaken (section 1.2.3). This work should include:
    - designing creel surveys that accurately assess the impact of winter recreational fisheries;
    - conducting continued monitoring for spawning activity in multiple river systems;
    - examining potential causes contributing to low and declining abundance in Connecticut waters, such as fishing mortality, high summer water temperatures, effects of road sand and salt, deterioration of spawning habitat, impediments to spawning migrations, and piscivorous fish predation.
- Recovery goals for rainbow smelt should be established, including the number of river systems to target for restoration and levels of abundance.

3.2 - ATLANTIC TOMCOD

3.1.2 - Management Recommendations

The following management recommendations are made based on the preceding information:

- The historical (section 1.3.1), and contemporary (sections 1.3.2, 2.5.2) assessment results do not meet the criteria for listing Atlantic tomcod as a species of special concern. In particular, the data are not firm on whether the species has declined “seriously or noncyclically” in Connecticut, nor have factors been identified that cause the species to be “unusually vulnerable to extirpation”. We therefore recommend that further work on the population’s status and threats to its welfare be undertaken. This work should include:
    - designing creel surveys that accurately assess the impact of winter recreational fisheries (section 1.3.1);
    - conduct annual monitoring of juvenile settlement at index sites in multiple estuaries, scheduled to include early spring larval settlement in nearshore habitats (sections 1.3.1, 1.3.2, 2.5.2);
    - investigate summer habitat use, focusing on benthic river channel habitats and offshore coastal areas (section 2.5.2);
    - examine potential causes contributing to low and declining abundance in Connecticut waters, such as fishing mortality, high summer water temperatures, piscivorous fish predation, and the incidence of liver cancer (section 1.3.3).
- Conservation measures (for Connecticut or regionally) that should be considered include several measures to protect the spawning stock, because of its present vulnerability to the fishery. These measures would include (section 1.3.4):
    - establish an inland fishery closure during the winter months;
    - set recreational size limits in coastal marine waters to 17 cm (8”), sufficient to insure YOY are able to complete their first spawning season;
    - clarify the status of published commercial regulations and close the commercial fishery.
- Recovery goals for Atlantic tomcod are not presently warranted but may be contemplated based on findings of future research and/or monitoring.

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Table 1.1. Reported Federal commercial catch of rainbow smelt (*Osmerus mordax*) from shore based fisheries by gear type for the entire Atlantic range. Gear types listed for both A. and B. account for 99% of the commercial catch.

A. Gear types reported for commercial catches irregularly from 1887 – 1950. Percent of total catch for these gears by state and all states combined are indicated by ( ).

B. Gear types reported for commercial catches yearly from 1950 - 2003. Percent of total catch for these gears by state and all states combined are indicated by ( ).

A.

State		Lines, Hand and Trawl	Haul Seine	Bag Net and Dip Net	Fixed Gear	Gill Nets
Maine	Total	7,183,482	5,640,332	3,872,622	973,775	874,697
	%	(38.3)	(30.1)	(20.6)	(5.2)	(4.7)
New Hampshire	Total	991,267	0	282,230	260,000	0
	%	(64.5)	0	(18.4)	(16.9)	0
Massachusetts	Total	207,632	10,136	0	4,125	1,700
	%	(86.9)	(4.2)	0	(1.7)	(0.7)
Rhode Island	Total	0	91,600	0	207,958	0
	%	0	(30.6)	0	(69.4)	0
Connecticut	Total	9,090	110,045	29,667	13,500	0
	%	(5.6)	(67.8)	(18.3)	(8.3)	0
New York	Total	0	4,875	245	3,000	5,300
	%	0	(36.3)	(1.8)	(22.4)	(39.5)
New Jersey	Total	0	16,030	0	0	0
	%	0	(100)	0	0	0
All States	Total	8,391,471	5,873,018	4,184,764	1,462,358	881,697
	%	(40.4)	(28.2)	(20.1)	(1.0)	(4.2)

B.

State		Lines, Hand and Trawl	Bag Net	Dip Net	Seine, Haul	Gill Nets	Trawl Gear (Otter and Unspecified)
Maine	Total	1,329,810	1,711,594	134,868	242,700	148,300	38,000
	%	(36.9)	(47.5)	(3.7)	(6.7)	(4.1)	(1.1)
New Hampshire	Total	961,900	115,500	115859	0	0	346
	%	(80.6)	(9.7)	(9.7)	(0)	(0)	(0)
Massachusetts	Total	37,900	0	2,000	7,000	0	14,800
	%	(61.4)	(0)	(3.2)	(11.3)	(0)	(24.0)
Rhode Island	Total	0	0	0	8,200	0	4,277
	%	(0)	(0)	(0)	(65.7)	(0)	(34.3)
Connecticut	Total	100	0	0	14,300	0	0
	%	(0.7)	(0)	(0)	(99.3)	(0)	(0)
New York	Total	0	0	29,400	1,100	35,600	638
	%	(0)	(0)	(44.1)	(1.6)	(53.3)	(1.0)
New Jersey	Total	0	0	0	0	0	100
	%	(0)	(0)	(0)	(0)	(0)	(100)
All States	Total	2,329,710	1,827,094	282,127	273,300	183,900	58,161
	%	(47.0)	(36.9)	(5.7)	(5.5)	(3.7)	(1.2)

Table 1.2. Year in which each state reached 50%, 75% and 99% of the total reported Federal commercial catch of rainbow smelt (*Osmerus mordax*) from 1887 - 2003.

State	Total Catch (Pounds)	50%	75%	99%
Maine	25,200,000	1930	1945	1979
New Hampshire	3,140,000	1945	1965	1982
Massachusetts	389,000	1928	1940	1991
Rhode Island	475,000	1889	1905	1967
Connecticut	211,000	1919	1929	1968
New York	112,000	1953	1974	1977
New Jersey	17,000	1904	1908	1921

Table 1.3. Recreational catch of rainbow smelt (*Osmerus mordax*) by reporting TYPE from 1981 – 2004. Catch statistics are from the National Marine Fisheries Service, Marine Recreational Fishery Statistical Survey (http://www.st.nmfs.gov) and are based on observed harvest (Type A), reported harvest (Type B1), and reported live release (Type B2). Percent of total catch by state and all states combined are indicated by ( ).

State		Observed Harvest (Type A)	Reported Harvest (Type B1)	Total Harvest (Type A + B1)	Live Release (Type B2)	Total State Catch (Type A + B1 + B2)
Maine	Total	577,815	532,503	1,110,318	1,067,143	2,177,461
	%	(26.5)	(24.5)	(51.0)	(49.0)	
New Hampshire	Total	26,950	4,405	31,355	1,155	32,510
	%	(82.9)	(13.5)	(96.4)	(3.6)	
Massachusetts	Total	2,206,576	625,267	2,831,843	56,477	2,888,320
	%	(76.4)	(21.6)	(98.0)	(2.0)	
Rhode Island	Total	465	0	465	0	465
	%	(100)	(0)	(100)	(0)	
Connecticut	Total	829	361	1,190	0	1,190
	%	(69.7)	(30.3)	(100)	(0)	
New York	Total	197,831	0	197,831	0	197,831
	%	(100)	(0)	(100)	(0)	
All States Combined	Total	3,010,466	1,162,536	4,173,002	1,124,775	5,297,777
	%	(56.8)	(21.9)	(78.8)	(21.2)	

Table 1.4. Recreational catch of rainbow smelt (*Osmerus mordax*) by reporting AREA from 1981 – 2004. Catch statistics are from the National Marine Fisheries Service, Marine Recreational Fishery Statistical Survey (http://www.st.nmfs.gov) and are based on observed harvest (Type A), reported harvest (Type B1), and reported live release (Type B2). Percent of total catch by state and all states combined are indicated by ( ).

State		Inland	Ocean (<= 3 Mile)	Ocean (> 3 Mile)
Maine	Total	2,175,852	1,610	0
	%	(99.9)	(0.1)	(0)
New Hampshire	Total	10,822	21,688	0
	%	(33.3)	(66.7)	(0)
Massachusetts	Total	1,878,713	1,007,318	2,290
	%	(65.0)	(34.9)	(0.1)
Rhode Island	Total	465	0	0
	%	(100)	(0)	(0)
Connecticut	Total	1,190	0	0
	%	(100)	(0)	(0)
New York	Total	0	197,831	0
	%	(0)	(100)	(0)
All States Combined	Total	4,067,042	1,228,447	2,290
	%	(76.8)	(23.2)	(0.0)

Table 1.5. Recreational catch of rainbow smelt (*Osmerus mordax*) by MODE for INLAND and OCEAN (<=3 MI) reporting areas from 1981 – 2004. Catch statistics are from the National Marine Fisheries Service, Marine Recreational Fishery Statistical Survey (http://www.st.nmfs.gov) and are based on observed harvest (Type A), reported harvest (Type B1), and reported live release (Type B2). Percent of total catch by state and all states combined are indicated by ( ).

State		Beach / Bank	Man Made	Shore	Private / Rental	Party / Charter
Maine	Total	1,696,617	16,889	192,275	271,681	0
	%	(77.9)	(0.8)	(8.8)	(12.5)	(0)
New Hampshire	Total	0	4,405	27,205	900	0
	%	(0)	(13.5)	(83.7)	(2.8)	(0)
Massachusetts	Total	0	4,802	2,845,683	33,848	1,698
	%	(0)	(0.2)	(98.6)	(1.2)	(0.1)
Rhode Island	Total	0	165	300	0	0
	%	(0)	(35.5)	(64.5)	(0)	(0)
Connecticut	Total	0	0	1,190	0	0
	%	(0)	(0)	(100)	(0)	(0)
New York	Total	0	0	197,831	0	0
	%	(0)	(0)	(100)	(0)	(0)
All States Combined	Total	1,696,617	26,261	3,264,484	306,429	1,698
	%	(32.0)	(0.5)	(61.6)	(5.8)	(0.0)

Table 1.6. Recreational catch of rainbow smelt (*Osmerus mordax*) by reporting WAVE from 1981 – 2004. Catch statistics are from the National Marine Fisheries Service, Marine Recreational Fishery Statistical Survey (http://www.st.nmfs.gov) and are based on observed harvest (Type A), reported harvest (Type B1), and reported live release (Type B2). Percent of total catch by state and all states combined are indicated by ( ).

State		Wave 2 (Mar - April)	Wave 3 (May-June)	Wave 4 (July-Aug)	Wave 5 (Sept-Oct)	Wave 6 (Nov-Dec)
Maine	Total	426,045	1,746,428	619	1,610	2,760
	%	(19.6)	(80.2)	(0)	(0.1)	(0.1)
New Hampshire	Total	192	154	0	32,164	0
	%	(0.6)	(0.5)	(0)	(98.9)	(0)
Massachusetts	Total	0	0	19,789	1,319,329	1,546,913
	%	(0)	(0)	(0.7)	(45.7)	(53.6)
Rhode Island	Total	0	0	0	0	465
	%	(0)	(0)	(0)	(0)	(100)
Connecticut	Total	0	0	0	0	1,190
	%	(0)	(0)	(0)	(0)	(100)
New York	Total	0	0	0	197,831	0
	%	(0)	(0)	(0)	(100)	(0)
All States Combined	Total	426,237	1,746,582	20,408	1,550,934	1,551,328
	%	(8.0)	(33.0)	(0.4)	(29.3)	(29.3)

Table 1.7. Earliest identified date, location and effort for smelt stock enhancement along the Atlantic Coast.

Year	State	Location (s)	Restoration Effort
1877	Maryland	Patapsco River, Elk River	Adult Release
1878	New Jersey	Hackensack River	Spawning Habitat Enhancement, Egg Production
1885	New York	Cold Spring Harbor, Streams around Great Bay	Fry Production
1890	Washington, D.C.	Potomoc River, near Chain Bridge	Fingerling Release
1910	Massachusetts	Multiple Drainage Systems	Egg Transplant, Adult Transplant
1924	Connecticut	Saugatuck River, Pawcatuck River, coastal streams surrounding these regions	Fry Production

Table 1.8. Number of rainbow smelt (*Osmerus mordax*) fry released into Connecticut rivers by the State of Connecticut, Board of Fisheries and Game between 1925 and 1932 by county and specific location. Location information is not provided in State reports between 1933 and 1938.

County	River	Total Fry Released	Years Released
Fairfield	Five Mile River	2,000,000	1928-1930
	Horse Neck Brook	2,150,000	1927-1930
	Mianus River	2,150,000	1927-1930
	Mill River	7,050,000	1925-1930
	Rippowan River	2,000,000	1928-1930
	Saugatuck River	112,087,500	1925-1932
New Haven	Hammonassett River	450,000	1925
	Wepawaug River	7,500,000	1925-26, 1928-30
New London	Bakers Cove	1,000,000	1931
	Mystic River	18,950,000	1925-1932
	Niantic River	8,000,000	1928-1931
	Palmer's Cove	6,272,000	1925-1931
	Pawcatuck River	24,500,000	1925-1932
	Poquonnock River	500,000	1930
	Quambaug Cove	4,732,000	1925-1932
	Shetucket River	650,000	1925
	Thames River	5,000,000	1930-1931
	Wequeteuqock Cove	450,000	1925

Table 1.9. Number of rainbow smelt (*Osmerus mordax*) fry released into Connecticut lakes by the State of Connecticut, Board of Fisheries and Game between 1925 and 1932 by county and specific location. Location information is not provided in State reports between 1933 and 1938.

County	Lake	Total Fry Released	Years Released
Fairfield	Candlewood Lake	1,000,000	1929
Litchfield	Highland Lake	450,000	1925
	Toby’s Pond	200,000	1927
	Twin Lakes	5,450,000	1925, 1928-31
	Waramaug Lake	2,000,000	1928-29
	Wononscopomuc Lake	2,450,000	1925, 1928-1929
New London	Smith Lake	3,300,000	1925-26, 1928-29
Tolland	Coventry Pond	700,000	1927
	Crystal Lake	1,200,000	1927, 1931
	Snipsic Lake	1,200,000	1927, 1931

Table 1.10. Reported Federal commercial catch of Atlantic tomcod (*Microgadus tomcod*) from shore based fisheries by gear type for the entire Atlantic range.

A. Gear types reported for commercial catches periodically between 1887 – 1949. Percent of total catch for these gears by state and all states combined are indicated by ( ).

B. Gear types reported for commercial catches yearly between 1950 - 2003. Percent of total catch for these gears by state and all states combined are indicated by ( ).

A.

State		Fyke And Hoop Nets, Fish	Pound Nets, Fish	Lines Hand, Other	Gill Nets, Drift, Other	Haul Seines	Bag and Dip Nets	Otter Trawl
Maine	Total	156,288	168,150	52,739	0	140,030	1,634,436	0
	%	(7.3)	(7.8)	(2.5)	(0)	(6.5)	(76.0)	(0)
Massachusetts	Total	2,300	13,573	6,666	0	32,000	0	18,000
	%	(3.2)	(18.7)	(9.2)	(0)	(44.1)	(0)	(24.8)
Rhode Island	Total	10,400	9,010	0	0	1,300	0	0
	%	(50.2)	(43.5)	(0)	(0)	(6.3)	(0)	(0)
Connecticut	Total	105,064	164,470	98,030	0	49,980	0	0
	%	(25.2)	(39.4)	(23.5)	(0)	(12.0)	(0)	(0)
New York	Total	574,170	51,500	112,400	8,500	12,750	182	0
	%	(75.6)	(6.8)	(14.8)	(1.1)	(1.7)	(0)	(0)
New Jersey	Total	13,070	231,091	11,400	0	715	0	27,600
	%	(4.6)	(81.6)	(4.0)	(0)	(0.3)	(0)	(9.7)
Virginia	Total	0	17,400	0	0	0	0	115,987
	%	(0)	(13.0)	(0)	(0)	(0)	(0)	(87.0)
All States Combined	Total	861,292	655,194	281,235	8,500	236,775	1,634,618	161,587
	%	(22.4)	(17.1)	(7.3)	(0.2)	(6.2)	(42.6)	(4.2)

B.

State		Fyke And Hoop Nets, Fish	Pound Nets, Fish	Lines Hand, Other	Gill Nets, Drift, Other	Haul Seines, Beach	Dip Nets, Common
Rhode Island	Total	0	0	0	0	100	0
	%	(0)	(0)	(0)	(0)	(100)	(0)
New York	Total	13,900	3,100	0	1,000	0	100
	%	(0)	(0)	(0)	(0)	(0)	(0)
Virginia	Total	0	0	1,100	0	0	0
	%	(0)	(0)	(100)	(0)	0	0
All States Combined	Total	13,900	3,100	1,100	1,000	100	100
	%	(72.0)	(16.1)	(5.7)	(5.2)	(0.5)	(0.5)

Table 1.11. Total recreational catch of Atlantic tomcod (*Microgadus tomcod*) by reporting TYPE from 1981 – 2004. Catch statistics are from the National Marine Fisheries Service, Marine Recreational Fishery Statistical Survey (http://www.st.nmfs.gov) and are based on observed harvest (Type A), reported harvest (Type B1), and reported live release (Type B2). Percent of total catch by state and all states combined are indicated by ( ).

State		Observed Harvest (Type A)	Reported Harvest (Type B1)	Total Harvest (Type A + B1)	Live Release (Type B2)	Total State Catch (Type A + B1 + B2)
Maine	Total	54,678	74,133	128,811	25,302	154,113
	%	(35.5)	(48.1)	(83.6)	(16.4)	
New Hampshire	Total	24,648	12	24,660	5,011	29,671
	%	(83.1)	(0.04)	(83.1)	(16.9)	
Massachusetts	Total	379,885	10,889	390,774	172,420	563,194
	%	(67.5)	(1.9)	(69.4)	(30.6)	
Rhode Island	Total	120,894	51,896	172,790	309,665	482,455
	%	(25.1)	(10.8)	(35.8)	(64.2)	
Connecticut	Total	413,040	19,917	432,957	12,335	445,292
	%	(92.8)	(4.5)	(97.2)	(2.8)	
New York	Total	19,792	86	19,878	148,146	168,024
	%	(11.8)	(0.1)	(11.8)	(8.2)	
New Jersey	Total	527	8,967	9,494	17,765	27,259
	%	(1.9)	(32.9)	(34.8)	(65.2)	
Delaware	Total	0	1,251	1,251	0	1,251
	%	0	(100)	(100)	0	
All States Combined	Total	1,013,464	167,151	1,180,615	690,644	1,871,259
	%	(54.2)	(8.9)	(63.1)	(36.9)	

Table 1.12. Total recreational catch of Atlantic tomcod (*Microgadus tomcod*) by reporting AREA from 1981 – 2004. Catch statistics are from the National Marine Fisheries Service, Marine Recreational Fishery Statistical Survey (http://www.st.nmfs.gov) and are based on observed harvest (Type A), reported harvest (Type B1), and reported live release (Type B2). Percent of total catch by state and all states combined are indicated by ( ).

State		Inland	Ocean (<= 3 Mile)	Ocean (> 3 Mile)	Total Catch
Maine	Total	152,954	1,050	109	154,113
	%	(98)	(1.8)	(0.2)	
New Hampshire	Total	21,712	2,843	5,116	29,671
	%	(73.2)	(9.6)	(17.2)	
Massachusetts	Total	498,473	27,835	36,888	563,196
	%	(88.5)	(4.9)	(6.5)	
Rhode Island	Total	452,695	5,859	23,901	482,455
	%	(93.8)	(1.2)	(4.9)	
Connecticut	Total	445,294	0	0	445,294
	%	(100)	(0)	(0)	
New York	Total	163,115	4,909	0	168,024
	%	(97.1)	(2.9)	(0)	
New Jersey	Total	27,259	0	0	27,259
	%	(100)	(0)	(0)	
Delaware	Total	1,251	0	0	1,251
	%	(100)	(0)	(0)	
All States Combined	Total	1,762,753	42,496	66,014	1,871,263
	%	(94.2)	(2.3)	(3.5)	

Table 1.13. Recreational catch of Atlantic tomcod (*Microgadus tomcod*) by MODE for INLAND and OCEAN (<=3 mi) reporting areas from 1981 – 2004. Catch statistics are from the National Marine Fisheries Service, Marine Recreational Fishery Statistical Survey (http://www.st.nmfs.gov) and are based on observed harvest (Type A), reported harvest (Type B1), and reported live release (Type B2). Percent of total catch by state and all states combined are indicated by ( ).

State		Beach / Bank	Man Made	Shore	Private / Rental	Party / Charter
Maine	Total	125,256	1,108	6,868	20772	0
	%	(81.3)	(0.7)	(4.5)	(13.5)	(0)
New Hampshire	Total	89	367	2,684	21415	0
	%	(0.4)	(1.5)	(10.9)	(87.2)	(0)
Massachusetts	Total	22759	39244	421398	42907	0
	%	(4.3)	(7.5)	(80.1)	(81.5)	(0)
Rhode Island	Total	0	128,416	13,349	314075	2714
	%	(0)	(28.0)	(2.9)	(68.5)	(0.6)
Connecticut	Total	391,828	10,209	10,651	32311	295
	%	(87.9)	(2.3)	(2.4)	(7.3)	(0.1)
New York	Total	1,276	1,543	140,346	24859	0
	%	(0.8)	(0.9)	(83.5)	(14.8)	(0)
New Jersey	Total	0	13,535	13,724	0	0
	%	(0)	(49.7)	(50.3)	(0)	(0)
All States Combined	Total	541,208	194,422	609,020	456,339	3,009
	%	(30.0)	(10.8)	(33.8)	(25.3)	(0.2)

Table 1.14. Recreational catch of Atlantic tomcod (*Microgadus tomcod*) by reporting WAVE from 1981 – 2004. Catch statistics are from the National Marine Fisheries Service, Marine Recreational Fishery Statistical Survey (http://www.st.nmfs.gov) and are based on observed harvest (Type A), reported harvest (Type B1), and reported live release (Type B2). Percent of total catch by state and all states combined are indicated by ( ).

State		Wave 2 (Mar - April)	Wave 3 (May-June)	Wave 4 (July-Aug)	Wave 5 (Sept-Oct)	Wave 6 (Nov-Dec)
Maine	Total	303	3,353	20,390	4,994	125,073
	%	(0.2)	(2.2)	(13.2)	(3.2)	(81.2)
New Hampshire	Total	20,170	1,043	744	7,530	184
	%	(68.0)	(3.5)	(2.5)	(25.4)	(0.6)
Massachusetts	Total	303,438	13,908	44,729	40,524	160,597
	%	(53.9)	(2.5)	(7.9)	(7.2)	(28.5)
Rhode Island	Total	10,068	14,948	22,034	18,165	417,240
	%	(2.1)	(3.1)	(4.6)	(3.8)	(86.5)
Connecticut	Total	4,508	16,089	0	32,869	391,828
	%	(1.0)	(3.6)	(0)	(7.4)	(88.0)
New York	Total	4,396	0	4,947	19,958	138,723
	%	(2.6)	(0)	(2.9)	(11.9)	(82.6)
New Jersey	Total	0	13,724	0	5,273	8,262
	%	(0)	(50.3)	(0)	(19.3)	(30.3)
Delaware	Total	0	1,251	0	0	0
	%	(0)	(100.0)	(0)	(0)	(0)
All States Combined	Total	342,883	64,316	92,844	129,313	1,241,907
	%	(18.3)	(3.4)	(5.0)	(6.9)	(66.4)

Table 2.1. Fyke and weir summary for the 2003 sampling season.

Location	River System	Start Date	End Date	Gear Type	Total Days Deployed	Water Temperature Range (°C)	
Lower Mill Brook	Connecticut	18-Mar-03	21-Mar-03	fyke	3	6.4	n/a
Lower Pine Brook	Connecticut	26-Mar-03	18-Apr-03	fyke	8	5.3	12.2
Lower Pine Brook	Connecticut	21-Apr-03	9-May-03	weir	17	7.7	17.4
Upper Poquonnock	Poquonnock	24-Apr-03	25-Apr-03	fyke	1	11.1	n/a
Upper Poquonnock	Poquonnock	14-Apr-03	6-May-03	weir	22	9.7	16.3
			Total Sample Days		**51**		

Table 2.2. Fish species collected during the 2003 fyke and weir sampling season by gear type and river system.

Species	Common Name	Fyke: Lower Mill Brook, CT River	Fyke: Lower Pine Brook, CT River	Fyke: Upper Poquonnock River	Weir: Lower Pine Brook, CT River	Weir: Upper Poquonnock River	**Total**	**Total % of Observations**
Alosa pseudoharengus	Alewife	0	23	0	53	1	77	16.6
Ameiurus nebulosus	Bullhead catfish	0	1	0	0	0	1	0.2
Anguilla rostrata	American eel (elvers)	0	11	0	0	0	11	2.4
Anguilla rostrata	American eel (juv)	0	39	0	0	0	39	8.4
Apeltes quadracus	Fourspine stickleback	0	2	0	0	0	2	0.4
C. commersoni[1]	White sucker	0	0	0	4	0	4	0.9
Etheostoma olmstedi	Tesselated sarter	1	0	0	2	0	3	0.6
Fundulus heteroclitus	Mummichog	42	2	0	0	0	44	9.5
G. aculeatus[2]	Threespine stickleback	1	0	0	0	0	1	0.2
Lepomis auritus	Redbreast sunfish	2	0	0	0	0	2	0.4
Lepomis gibbosus	Pumpkin seed	2	0	0	1	0	3	0.6
Lepomis macrochirus	Bluegill	2	0	0	0	0	2	0.4
Luxilus cornutus	Common shiner	21	0	0	1	0	22	4.7
Notropis hudsoni	Spottail shiner	1	0	0	0	0	1	0.2
Perca flavescens	Yellow perch	0	182	0	53	0	235	50.5
P. nigromaculatus[3]	Black crappie	0	0	0	1	0	1	0.2
Rhinichthys atratulus	Black nose dace	0	1	0	0	0	1	0.2
Salvelinus fontinalis	Brook trout	0	1	0	0	0	1	0.2
S. atromaculatus[4]	Creek chub	1	2	0	5	0	8	1.7
Semotilus corporalis	Fallfish	0	2	0	5	0	7	1.5
	Total Fish / Gear	73	266	0	125	1	**465**	

[1] *Catostomus commersoni*
[2] *Gasterosteus aculeatus*
[3] *Pomoxis nigromaculatus*
[4] *Semotilus atromaculatus*

Table 2.3. Egg mat sampling summary for the 2003 sampling season.

Location	River System	Start Date	End Date	Mat-Days	Water Temperature Range (°C)	
Eightmile River	Connecticut	5-Mar-03	7-May-03	176	0.6	16
Mill Brook (upper)	Connecticut	21-Feb-03	7-May-03	192	2.6	18.1
Mill Brook (lower)	Connecticut	21-Feb-03	7-May-03	118	2.4	17.9
Pine Brook	Connecticut	5-Mar-03	30-Apr-03	145	0.2	15.3
Roaring Brook	Connecticut	26-Feb-03	7-May-03	179	0	16.8
Mill River	Mill River	28-Mar-03	9-May-03	33	9.9	16.1
Whitney Dam	Quinnipiac	28-Mar-03	17-Apr-03	13	10.4	
Ward Road	Quinnipiac	28-Mar-03	7-May-03	35	10.3	15.1
Defco Park Road	Quinnipiac	28-Mar-03	7-May-03	35	10.3	15
Oil Mill Brook	Niantic River	26-Feb-03	7-May-03	189	0.4	16.2
Hunts Brook	Thames River	5-Mar-03	7-May-03	146	1.9	16.2
Oxoboxo Creek	Thames River	21-Feb-03	7-May-03	134	0.8	17
Trading Cove	Thames River	26-Feb-03	7-May-03	189	0.7	15.1
		Total Mat Days		1584		

Table 2.4. In river, egg sampling summary for the 2004 sampling season.

Location	River System	Start Date	End Date	Monitoring Time (min)	Water Temperature Range (°C)
Bride Brook	Bride Brook	9-Mar-04	8-Apr-04	129	5.2 - 8.3
Eightmile River	Connecticut	23-Mar-04	13-Apr-04	90	3.9 - 8.3
Mill Brook (lower)	Connecticut	9-Mar-04	8-Apr-04	272	6.0 - 13.8
Pine Brook	Connecticut	9-Mar-04	13-Apr-04	266	2.8 - 7.4
Eccelston Brook	Eccelston Brook	11-Mar-04	11-Mar-04	46	3.3
Whitford's Brook	Mystic	8-Apr-04	8-Apr-04	46	10.4
Poquonnock	Poquonnock	11-Mar-04	8-Apr-04	64	4.9 - 8.8
Hunts Brook	Thames	11-Mar-04	13-Apr-04	137	4.2 - 10.3
Oil Mill	Thames	11-Mar-04	13-Apr-04	126	3.7 - 9.9
Poquetonnock	Thames	18-Mar-04	18-Mar-04	26	2.5
Stony Brook	Thames	11-Mar-04	8-Apr-04	92	3.6 - 9.1
Trading Brook	Thames	8-Apr-04	8-Apr-04	36	9.6
			Total Time	**22 hours**	

Table 2.5. Gillnet summary for the 2003 sampling season.

River System	Date	Total Gill Net Hours	Range Water Temp (°C)	Salinity (ppt)
Connecticut	2-Oct-03	4.3	16.6 - 16.6	0.1 - 0.1
	6-Oct-03	8.9	14.5 - 14.5	0.1 - 0.1
Mystic	12-Sep-03	4.2	19.6 - 20.1	29.6 - 30.2
	22-Sep-03	4.5	23.0 - 23.0	25.1 - 25.1
New Haven	29-Aug-03	2.1	22.4 - 23.0	22.3 - 27.7
	15-Sep-03	6.7	21.4 - 21.5	6.4 - 21.4
Niantic	7-Sep-03	8.2	20.2 - 23.0	29.2 - 30.6
Poquonnock	17-Sep-03	9.3	20.0 - 21.9	28.3 - 29.7
Thames	10-Oct-03	9.3	13.5 - 18.7	4.9 - 20.4
	17-Oct-03	8.9	13.6 - 13.9	4.4 - 6.6
Total Net Hours		66.4		

Table 2.6. Fish species collected during the 2003 gillnet sampling season by river system.

		River System							
Species Name	**Common Name**	Connecticut	Mystic	Niantic	Poquonnock	Qunnipiac	Thames	**Total**	**% of Observations**
Alosa aestivalis	Blueback herring	0	3	0	1	0	0	4	0.3
Alosa pseudoharengus	Alewife	1	0	1	0	0	0	2	0.2
Brevoortia tyrannus	Menhaden	0	46	280	11	69	320	726	63.0
Cynoscion regalis	Weakfish (YOY)	0	6	9	4	0	0	19	1.6
Menidia spp.	Silverside	1	8	4	256	10	3	282	24.5
Micropterus salmoides	Largemouth bass	1	0	0	0	0	0	1	0.1
Morone americana	White perch	7	0	0	0	0	1	8	0.7
Morone saxatilis	Striped bass	5	3	12	1	0	1	22	1.9
Perca flavescens	Yellow perch	7	0	0	0	0	0	7	0.6
Pomatomus saltatrix	Bluefish	0	19	20	11	4	0	54	4.7
Prionotus carolinus	Sea robin (YOY)	0	1	0	0	8	0	9	0.8
Stenotomus chrysops	Scup	0	1	3	1	0	0	5	0.4
Strongylura marina	Atlantic needlefish	0	2	0	0	0	0	2	0.2
Synodus foetens	Inshore lizard fish	0	1	0	0	0	0	1	0.1
P. americanus[1]	Winter flounder	0	0	0	2	3	3	8	0.7
Anguilla rostrata	American eel	0	0	1	0	0	0	1	0.1
Tautog onitis	Tautog	0	0	1	0	0	0	1	0.1
	Total Fish / Estuary	22	90	331	287	94	328	1152	

[1] *Pseudoplueronectes americanus*

Table 2.7. Box trap summary for the 2002-2003 sampling season.

					Range	
River	**# of Traps**	**Start Date**	**End Date**	**Trap Hours / Estuary**	Water Temperature (°C)	Salinity (ppt)
Connecticut	4	25-Jan-03	27-Jan-03	99	0.1 - 0.3	0.1 - 10.1
Mystic	3	19-Jan-03	26-Jan-03	576	-0.1 - 1.1	0.4 - 26.7
Poquonnock	1	19-Jan-03	26-Jan-03	191	0.7 - 2.3	2.7 - 9.8
Quinnipiac	12	28-Nov-02	9-Jan-03	984	n/a	n/a
Total # of Traps	**20**		Total Trap Hours	**1,850**		

Table 2.8. Fish species collected during the 2002-03 box trap sampling season by river system.

		River System					
Species Name	**Common Name**	Connecticut	Mystic	Poquonnock	Qunnipiac	**Total**	**% of Observations**
Fundulus spp.	Killifish	2	0	0	0	2	9.5
Anguilla rostrata	American eel	1	0	0	1	2	9.5
Tautoga onitis	Blackfish	0	0	0	1	1	4.8
Fundulus spp.	Killifish	0	0	0	1	1	4.8
M. aenaeus[2]	Grubby	0	0	8	0	8	38
Brevoortia tyrannus	Menhaden (YOY)	0	0	7	0	7	33
Total Fish / Estuary		3	0	15	3	**21**	

[2] *Myoxocephalus aenaeus*

Table 2.9. Box trap summary for the 2003-2004 sampling season.

River	**# of Traps**	**Start Date**	**End Date**	**Trap Hours / Estuary**
Bride Brook	1	30-Oct-03	31-Dec-03	1488
Connecticut	11	30-Oct-03	8-Jan-04	16201
Mystic	7	2-Nov-03	2-Feb-04	11266
Niantic	2	6-Nov-03	2-Feb-04	4208
Poquonnock	2	2-Nov-03	6-Jan-04	3120
Quinnipiac	7	24-Oct-03	12-Dec-03	5191
Thames	6	27-Nov-03	6-Jan-04	5308
Total # of Traps	**36**		Total Trap Hours	**46,782**

Table 2.10. Fish species collected during the 2003-2004 box trap sampling season by river system.

		River System								
Species Name	**Common Name**	Bride Brook	Connecticut	Mystic	Niantic	Poquonnock	Qunnipiac	Thames	**Total**	**% of Observations**
Anchoa mitchilli	Bay anchovy	0	2	0	0	0	0	0	2	0.13
Anguilla rostrata	American eel	1	3	0	0	5	0	0	9	0.57
Apeltes quadracus	Fourspine stickleback	7	24	1	0	0	1	1	34	2.16
Brevoortia tyrannus	Atlantic menhaden	0	0	1	1	0	0	0	2	0.13
C. variegatus[1]	Sheepshead minnow	169	0	2	0	3	0	0	174	11.05
Cyprinus carpio	Carp (juv)	0	5	0	0	0	0	0	5	0.32
Fundulus spp.	Killifish	76	335	59	0	157	226	23	876	55.62
Gobiosoma bosc	Naked goby	0	1	3	0	1	0	0	5	0.32
Ictalurus punctatus	Channel catfish (juv)	0	3	0	0	0	0	0	3	0.19
Lepomis spp.	Sunfish (YOY)	0	307	6	0	1	0	2	316	20.06
Menidia spp.	Silverside	0	19	0	0	0	0	0	19	1.21
Microgadus tomcod	Atlantic tomcod	0	2	1	0	0	1	1	5	0.32
M. salmoides[2]	Largemouth bass	0	1	0	0	0	0	0	1	0.06
Morone americana	White perch	0	26	0	0	0	0	0	26	1.65
Morone saxatilis	Striped bass	0	1	0	0	0	0	0	1	0.06
M. aenaeus[3]	Grubby	0	1	10	21	0	0	3	35	2.22
Notropis spp.	Shiner	0	0	1	0	0	0	0	1	0.06
Perca flavescens	Yellow perch	0	10	0	0	1	0	3	14	0.89
Pholis gunnellus	Rock gunnel	0	0	1	0	0	0	0	1	0.06
P. nigromaculatus[4]	Black crappie	0	2	0	0	0	0	0	2	0.13
P. americanus[5]	Winter flounder (YOY)	0	11	1	4	0	0	2	18	1.14
Pugnitius pugnitius	Nine spine stickleback	0	0	4	0	0	0	0	4	0.25
Salmo trutta	Brown trout (juv)	0	0	2	0	0	0	0	2	0.13
Tautoga onitis	Blackfish	0	1	2	3	1	9	1	17	1.08
T. adspersus[6]	Cunner	0	0	0	1	0	0	1	2	0.13
unidentified	unidentified	0	0	0	0	0	0	1	1	0.06
	Total Fish / Estuary	**253**	**754**	**94**	**30**	**169**	**237**	**38**	**1575**	

[1] *Cyprinodon variegatus*
[2] *Micropterus salmoides*
[3] *Myoxocephalus aenaeus*
[4] *Pomoxis nigromaculatus*
[5] *Pseudopleuronectes americanus*
[6] *Tautogolabrus adspersus*

Table 2.11. Ichthyoplankton summary for the 2003-2004 sampling season (a).Number of larvae and eggs collected during the 2003-2004 ichthyoplankton sampling season by river system (b).

a.

River / Estuary	Sample Year	# of Samples
Thames	2003	9
	2004	10
Poquonnock	2003	--
	2004	6
New Haven Harbor	2003	25
	2004	2
Mystic	2003	3
	2004	10
Connecticut	2003	--
	2004	8

b.

River / Estuary	# of Tomcod Larvae	# of Other Larvae	# of Eggs
Thames	188	71	116
Poquonnock	19	216	0
New Haven Harbor	0	82	1047
Mystic	2	45	7
Connecticut	2	6969	0

Table 2.12. Seine summary for the 2003 sampling season.

		Range		
Estuary	**Number of Samples**	Water Temperature (°C)	Salinity (ppt)	**Bottom Swept (sq m)**
Alewife Cove	1	16.8 - 17.0	23.5 - 24.3	936
Bride Brook	1	19	21.8	468
Connecticut	3	23.7 - 27.5	0.1 - 4.6	1404
Hammonasset	1	19.1	27.6	468
Mystic	5	14.2-29.2	22.3 - 29.1	1755
Niantic	6	17.9 - 22.0	18.5 - 27.4	2574
Pawcatuck	1	27.5	20.4	468
Poquonnock	4	12.2 - 26.8	2.9 - 29.1	1872
Thames	5	15.4 - 21.8	1.4 - 18.8	2301
Total Number of Samples	**27**		Total Bottom Swept	**12,246**

Table 2.13. Fish species collected during the 2003 seine sampling season by river system.

		River / Estuary System										
Species Name	**Common Name**	Alewife Cove	Bride Brook	Connecticut	Hammonasett	Mystic	Niantic	Pawcatuck	Poquonnock	Thames	**Total**	**% of Observations**
Alosa aestivalus	Blueback Herring	0	0	0	0	0	0	0	0	12	12	0.12
A. psuedoharengus[1]	Alewife	1	0	0	0	0	0	0	0	0	1	0.01
Alosa spp.	Herring	0	0	0	0	0	0	0	0	51	51	0.50
Anguilla rostrata	American eel	0	0	2	0	5	0	0	16	1	24	0.24
Apeltes quadracus	Fourspine stickleback	0	0	4	0	3	39	112	72	72	302	2.99
C. commersoni[2]	White sucker (YOY)	0	0	403	0	0	0	0	0	0	403	3.99
C. variegatus[3]	Sheepshead minnow	0	1	0	0	1	0	0	104	0	106	1.05
Esox lucius	Northern pike	0	0	4	0	0	0	0	0	0	4	0.04
Esox niger	Chain pickerel	0	0	2	0	0	0	0	0	0	2	0.02
Fundulus spp.	Killifish	0	1	66	0	24	7	20	63	50	231	2.28
G. aculeatus[4]	Threespine stickleback	0	0	0	0	0	2	0	0	7	9	0.09
Gobiosoma bosc	Naked goby	0	0	9	0	0	0	0	0	0	9	0.09
Lepomis gibbosus	Pumpkin Seed	0	0	3	0	0	0	0	0	0	3	0.03
Lepomis macrochirus	Bluegill	0	0	5	0	0	0	0	0	0	5	0.05
Lucania parva	Rainwater Killifish	0	0	0	0	0	0	0	2	0	2	0.02
Menidia spp.	Silverside	0	0	0	4	2148	0	268	4522	130	7072	69.95
Microgadus tomcod	Atlantic tomcod	0	2	3	0	16	0	0	3	18	42	0.42
Micropterus salmoides	Large mouth bass	0	0	0	0	0	0	0	1	0	1	0.01
Morone americanus	White perch	0	0	1	0	0	0	0	0	0	1	0.01
Morone saxatilis	Striped bass	0	0	1	0	0	0	0	0	0	1	0.01
Mugil cephalus	Striped mullet	0	0	0	0	3	0	1	0	0	4	0.04
Mugil curema	White mullet	0	0	12	0	0	0	0	0	0	12	0.12
M. aenaeus[5]	Grubby	0	0	0	0	0	9	0	0	1	10	0.10
Notropsis hudsonius	Spottail shiner	0	0	977	0	0	18	0	0	0	995	9.84
Opsanus tau	Toadfish	0	0	0	0	0	0	0	0	1	1	0.01
Perca flavescens	Yellow perch	0	0	10	0	0	0	0	0	0	10	0.10
Pholis gunnellus	Gunnel	0	0	0	0	0	1	0	0	1	2	0.02
P. americanus[6]	Winter Flounder	7	0	16	0	21	28	0	5	52	129	1.28
Pungitius pungitius	Ninespine stickleback	0	0	0	0	1	586	0	32	8	627	6.20
Sygnathus fuscus	Northern Pipefish	0	4	0	0	4	2	8	7	4	29	0.29
Tautoga onitis	Blackfish	0	0	0	0	0	0	0	0	3	3	0.03
T. adspersus[7]	Cunner	0	0	0	0	0	0	0	0	1	1	0.01
Unidentified	Unidentified	0	0	0	0	0	0	0	0	6	6	0.06
Total Fish / Estuary		8	8	1518	4	2226	692	409	4827	418	**10,110**	

[1] *Alosa pseudoharengus*
[2] *Catostomus commersoni*
[3] *Cyprinodon variegatus*
[4] *Gasterosteus aculeatus*
[5] *Myoxocephalus aenaeus*
[6] *Pseudopleuronectes americanus*
[7] *Tautogolabrus adspersus*

Table 2.14. Seine summary for the 2004 sampling season.

Estuary	Number of Samples	Range: Water Temperature (°C)	Range: Salinity (ppt)	Bottom Swept (sq m)
Bride Brook	3	14.7 - 17.7	11.7 - 17.7	1404
Connecticut	15	12.6 - 26.5	0.0 - 11.4	7020
Mumford Cove	1	18.9	25	300
Mystic	31	8.5 - 25.9	4.3 - 29.2	14,760
Niantic	14	11.0 - 24.0	0.0 - 27.5	6552
Poquonnock	17	8.1 - 23.4	1.1 - 26.2	7926
Thames	14	10.0 - 21.8	0.1 - 20.3	5544
Total Number of Samples	**95**		Total Bottom Swept	**43,506**

Table 2.15. Fish species collected during the 2004 seine sampling season by river system.

		Estuary / River System								
Species Name	**Common Name**	Connecticut	Bride Brook	Mumford Cove	Mystic	Niantic	Poguonnock	Thames	**Total Number of Fish**	**% of Observations**
Alosa aestivalus	Blueback Herring	0	0	0	0	0	1	1	2	0.0
A.psuedoharengus[1]	Alewife	6	1	0	0	0	0	0	7	0.0
Alosa spp.	Herring	86	0	0	0	0	0	0	86	0.2
Anchoa mitchilli	Bay anchovy	0	1	0	0	0	0	0	1	0.0
Anguilla rostrata	American eel	0	0	0	16	0	3	5	5	0.0
Apeltes quadracus	Fourspine stickleback	20	0	0	65	9	90	91	275	0.5
Brevoortia tyrannus	Menhaden	19	0	0	6618	0	1500	22,467	30,604	59.2
Caranx hippos	Crevalle jack	0	0	0	0	0	2	0	2	0.0
C. variegatus[2]	Sheepshead minnow	0	0	0	11	0	173	13	197	0.4
Esox niger	Chain pickerel	3	0	0	0	0	0	0	3	0.0
E. olmstedi[3]	Tesselated darter	98	0	0	0	0	0	0	98	0.2
Fundulus spp.	Killifish	184	0	486	847	64	1261	11	2853	5.5
G. aculeatus[4]	Threespine stickleback	1	3	0	5	2	2	0	13	0.0
Gobiosoma bosc	Naked goby	0	0	0	40	0	3	6	49	0.1
L. macrochirus[5]	Bluegill	26	0	0	0	0	0	4	30	0.1
Lucania parva	Rainwater Killifish	0	0	0	43	0	208	0	251	0.5
Menidia spp.	Silverside	104	4	201	5268	173	7400	2269	15419	29.8
Menirhamphus spp.	Halfbeak	0	0	0	0	0	1	0	1	0.0
Microgadus tomcod	**Atlantic tomcod**	**5**	**2**	**0**	**378**	**12**	**0**	**59**	**456**	**0.9**
Morone americanus	White perch	19	0	0	0	0	0	0	19	0.0
Mugil cephalus	Striped mullet	0	0	0	0	0	1	0	1	0.0
M. aenaeus[6]	Grubby	0	0	1	38	23	7	7	76	0.1
Notropsis hudsonius	Spottail shiner	466	0	0	0	0	0	0	466	0.9
Opsanus tau	Toadfish	0	0	0	1	0	1	0	2	0.0
Osmerus mordax	**Rainbow smelt**	**0**	**0**	**0**	**9**	**0**	**0**	**0**	**9**	**0.0**
Perca flavescens	Yellow perch	6	0	0	0	0	0	0	6	0.0
Pholis gunnellus	Gunnel	0	0	0	0	0	1	0	1	0.0
Paralichthys dentatus	Summer flounder	0	0	0	0	0	0	2	2	0.0
Pollachius virens	Pollock (YOY)	0	0	0	0	1	0	0	1	0.0
Pomatomus saltatrix	Bluefish	0	0	0	1	0	0	0	1	0.0
P. americanus[7]	Winter Flounder	1	0	0	57	5	16	20	99	0.2
Pungitius pungitius	Ninespine stickleback	0	3	0	127	148	14	1	293	0.6
Sygnathus fuscus	Northern Pipefish	3	0	2	32	8	23	15	83	0.2
Tautoga onitis	Blackfish	0	0	2	48	1	35	75	161	0.3
T. adspersus[8]	Cunner	0	0	0	58	0	4	12	74	0.1
Trachinotus falcatus	Permit	0	0	0	0	0	3	0	3	0.0
Unidentified	Unidentified	1	0	0	1	0	0	0	2	0.0
	Total Fish / Estuary	1048	14	692	13664	446	10749	25,058	51671	

[1] *Alosa pseudoharengus*
[2] *Cyprinodon variegates*
[3] *Etheostoma olmstedi*
[4] *Gasterosteus aculeatus*
[5] *Lepomis macrochirus*
[6] *Myoxocephalus aenaeus*
[7] *Pseudopleuronectes americanus*
[8] *Tautogolabrus adspersus*

Table 2.16. Fecundity summary statistics for the female adult tomcod collected between winter 2003 and spring 2005.

River / Estuary	Month	Ovary Condition	Total Fish Mass (g)	Ovary Mass (g)	GSI	Fecundity
Niantic	March	resting	45.9	0.1	0.2	16
Niantic	March	resting	142.0	1.3	0.9	251
Niantic	March	resting	158.3	2.9	1.8	240
Niantic	April	resting	160.1	1.3	0.8	433
Niantic	April	resting	168.4	3.4	2.0	297
Niantic	April	resting	365.3	2.4	0.6	614
Latimer Brook	December	mature	165.3	33.3	20.2	54,360
Connecticut	December	mature	151.5	33.4	22.0	53,658
Mystic	December	spent	148.4	15.5	10.5	1,173
Mystic	December	spent	136.6	8.6	6.3	929

Table 2.16a and b. Back calculated hatching dates for the 2003 (a) and 2004 (b) sampling season from examination of YOY tomcod otoliths.

a.

Estuary / River	Number of Samples	Hatch Date Range	Average Coeficient of Variation Between Replicate Counts
Bride Brook	1	4-May	3.72
Connecticut	2	18-May to 24-May	5.13
New Haven	31	7-Apr to 8-May	5.24
Poquonnock	1	27-Apr	13.86
Thames	7	28-Apr to 9-May	4.73

b.

Estuary / River	Number of Samples	Hatch Date Range	Average Coeficient of Variation Between Replicate Counts
Connecticut	2	10-Apr to 12-Apr	4.29
Mystic	41	19-Mar to 15-Apr	5.61
New Haven	1	17-Apr	1.94
Thames	8	6-Apr to 19-Apr	5.35

Fig. 1.1. Total Federal commercial catch statistics for rainbow smelt (*Osmerus mordax*) reported from New England Region, irregularly from 1887 – 1949, and yearly from 1950 – 2003.

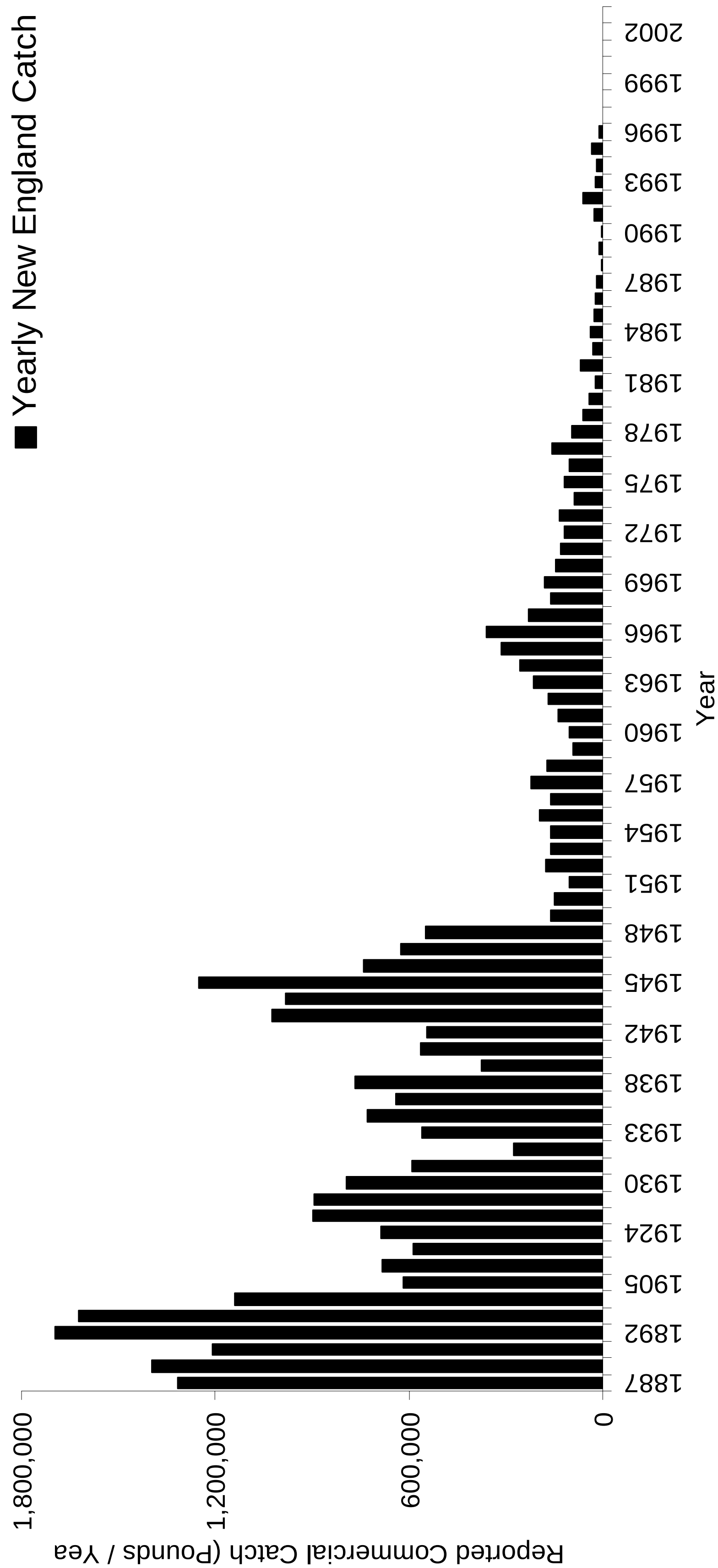

Yearly New England Catch
Reported Commercial Catch (Pounds / Yea
1,800,000
1,200,000
600,000
0
Year
1887
1892
1905
1924
1930
1933
1938
1942
1945
1948
1951
1954
1957
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002

Fig. 1.2. Total Federal commercial catch statistics for rainbow smelt (*Osmerus mordax*) reported from the Mid Atlantic Region, irregularly from 1887 – 1949, and yearly from 1950 – 2003.

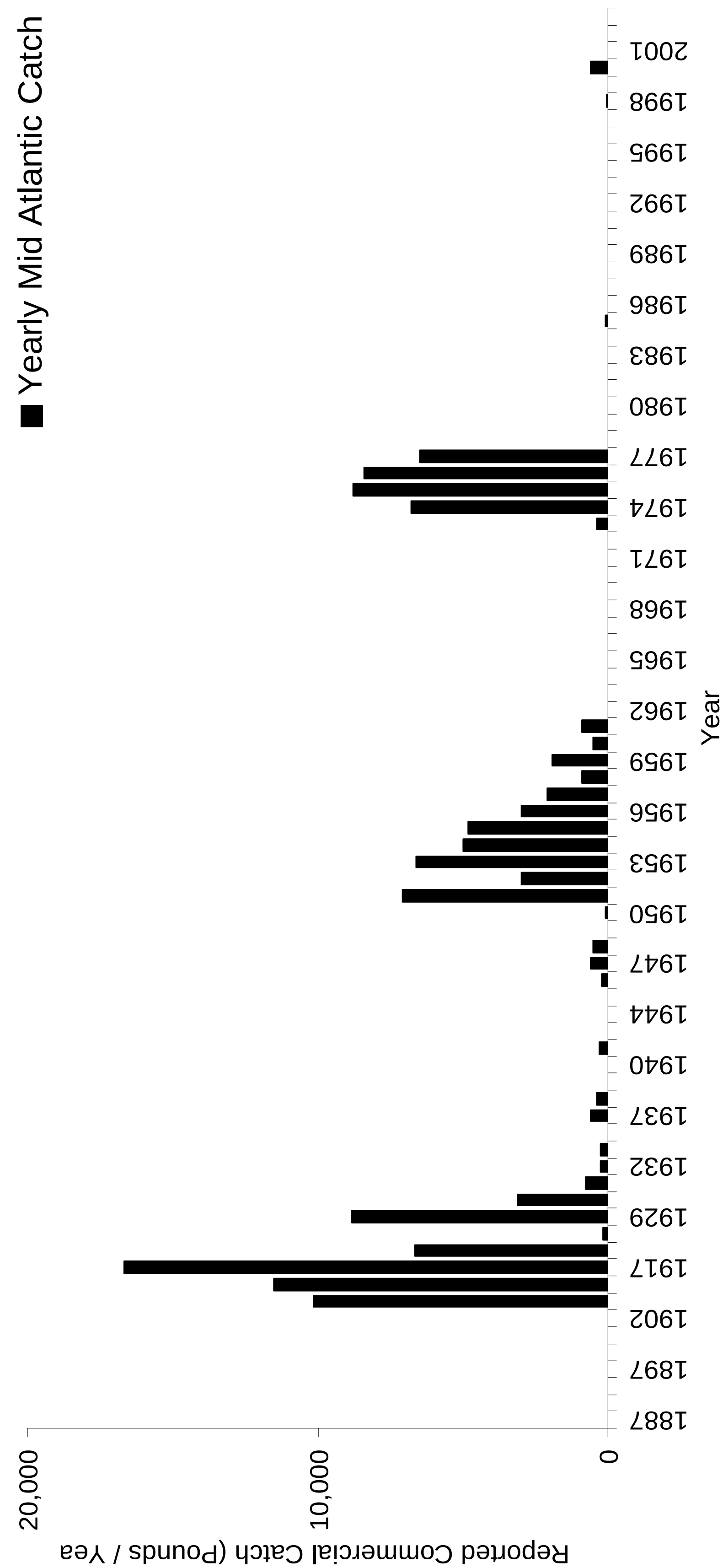

Yearly Mid Atlantic Catch
Reported Commercial Catch (Pounds / Yea
20,000
10,000
0
Year
1887
1897
1902
1917
1929
1932
1937
1940
1944
1947
1950
1953
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001

Fig. 1.3. Total Federal commercial catch statistics for rainbow smelt (*Osmerus mordax*) reported for Maine and New Hampshire, irregularly from 1887 – 1949, and yearly from 1950 – 2003.

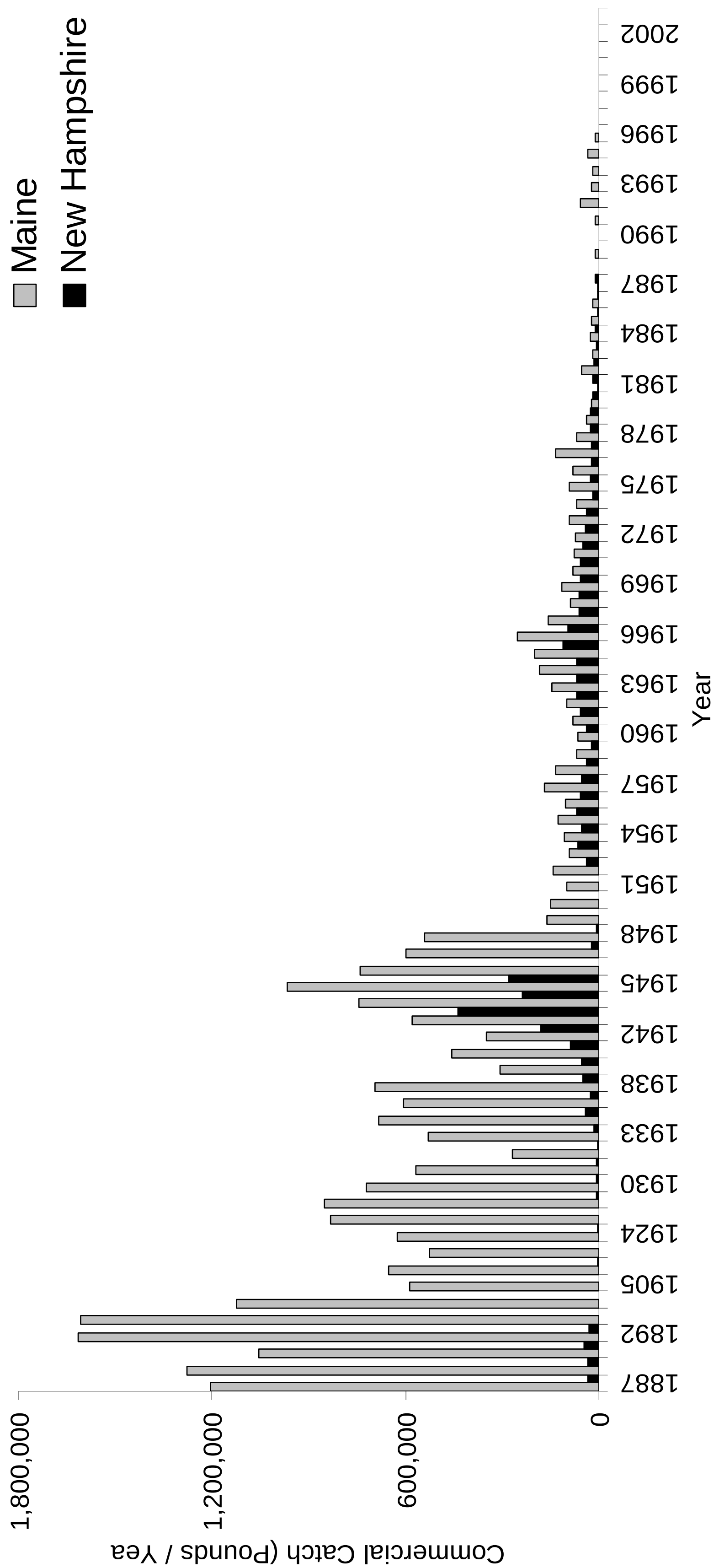

Maine
New Hampshire
Commerical Catch (Pounds / Yea
0
600,000
1,200,000
1,800,000
Year
1887
1892
1905
1924
1930
1933
1938
1942
1945
1948
1951
1954
1957
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002

Fig. 1.4. Total Federal commercial catch statistics for rainbow smelt (*Osmerus mordax*) reported for Massachusetts, irregularly from 1887 – 1949, and yearly from 1950 – 2003.

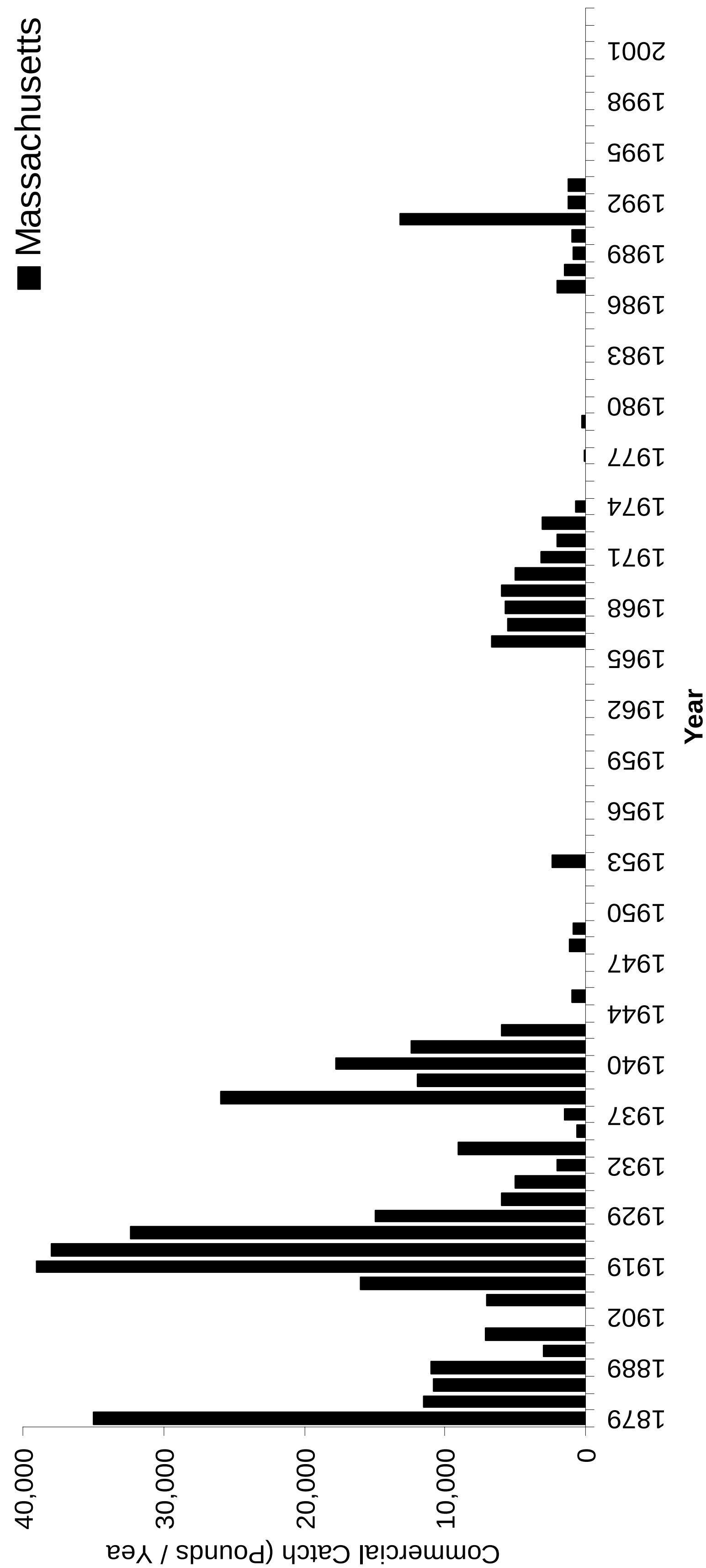

Massachusetts
Year
Commerical Catch (Pounds / Yea
0
10,000
20,000
30,000
40,000
1879
1889
1902
1919
1929
1932
1937
1940
1944
1947
1950
1953
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001

Fig. 1.5. Total Federal commercial catch statistics for rainbow smelt (*Osmerus mordax*) reported for Connecticut and Rhode Island, irregularly from 1887 – 1949, and yearly from 1950 – 2003.

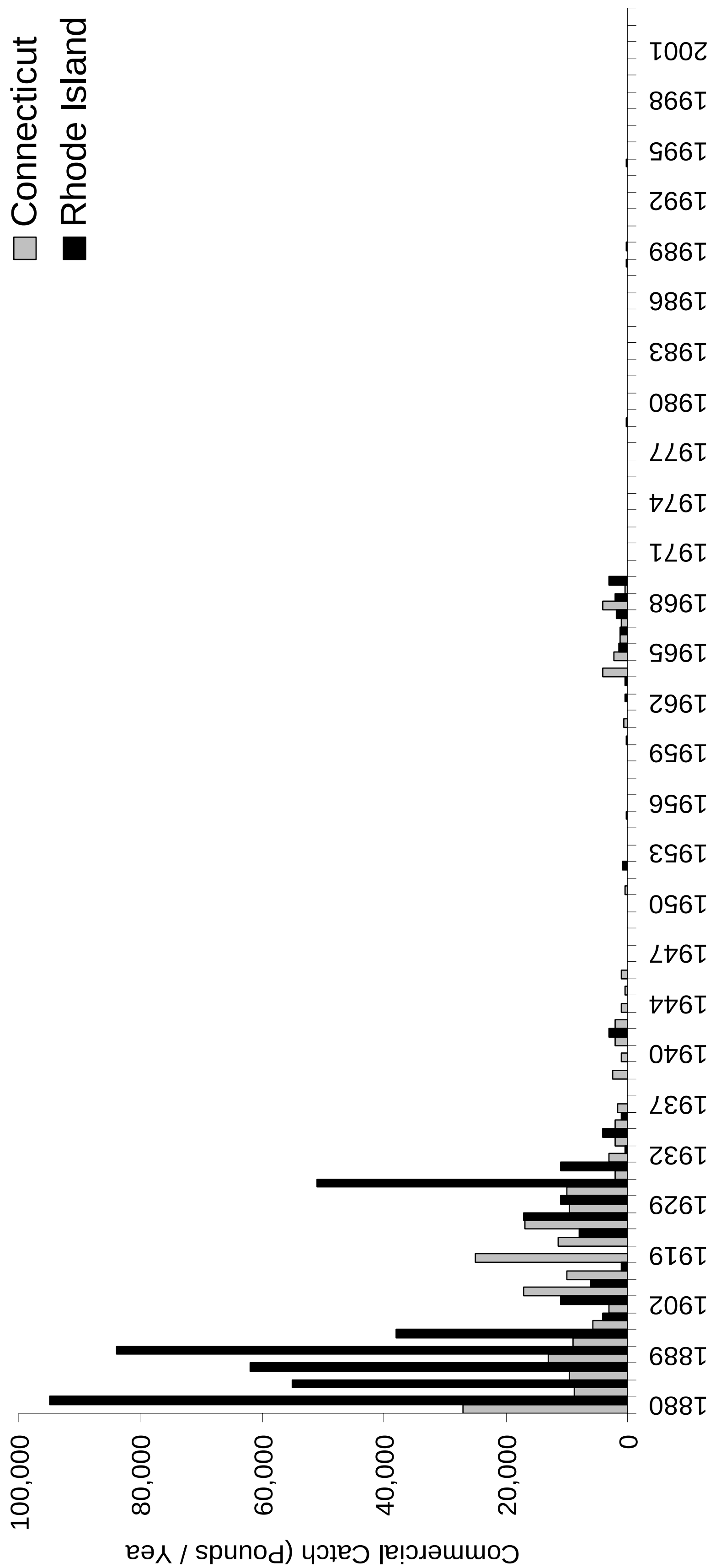

Connecticut
Rhode Island
Commerical Catch (Pounds / Yea
100,000
80,000
60,000
40,000
20,000
0
1880
1889
1902
1919
1929
1932
1937
1940
1944
1947
1950
1953
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001

Fig. 1.6. Total Federal commercial catch statistics for rainbow smelt (*Osmerus mordax*) reported for New York and New Jersey, irregularly from 1887 – 1949, and yearly from 1950 – 2003.

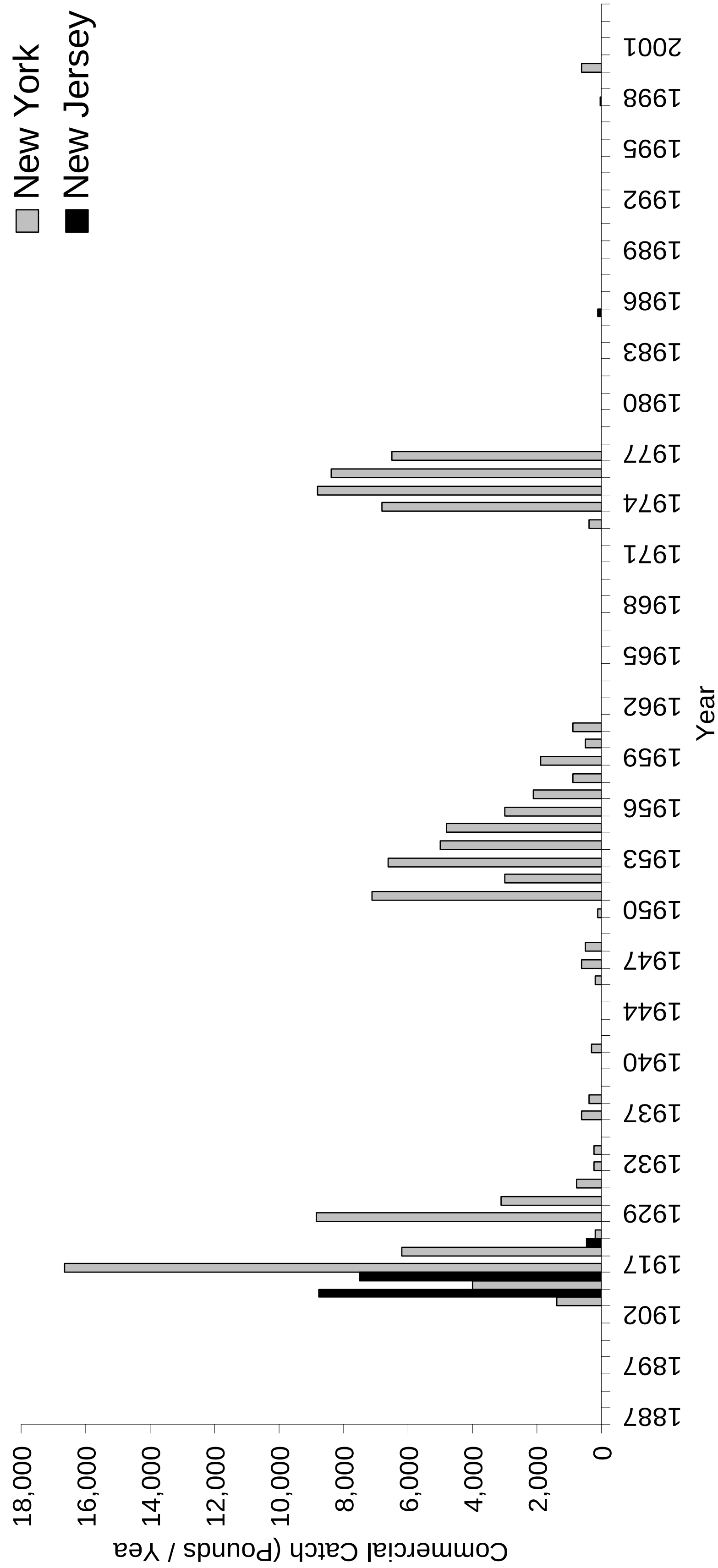

New York
New Jersey
Commerical Catch (Pounds / Yea
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Year
1887
1897
1902
1917
1929
1932
1937
1940
1944
1947
1950
1953
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001

Fig. 1.7. Cumulative commercial catch for rainbow smelt (*Osmerus mordax*) by individual states, as percent.

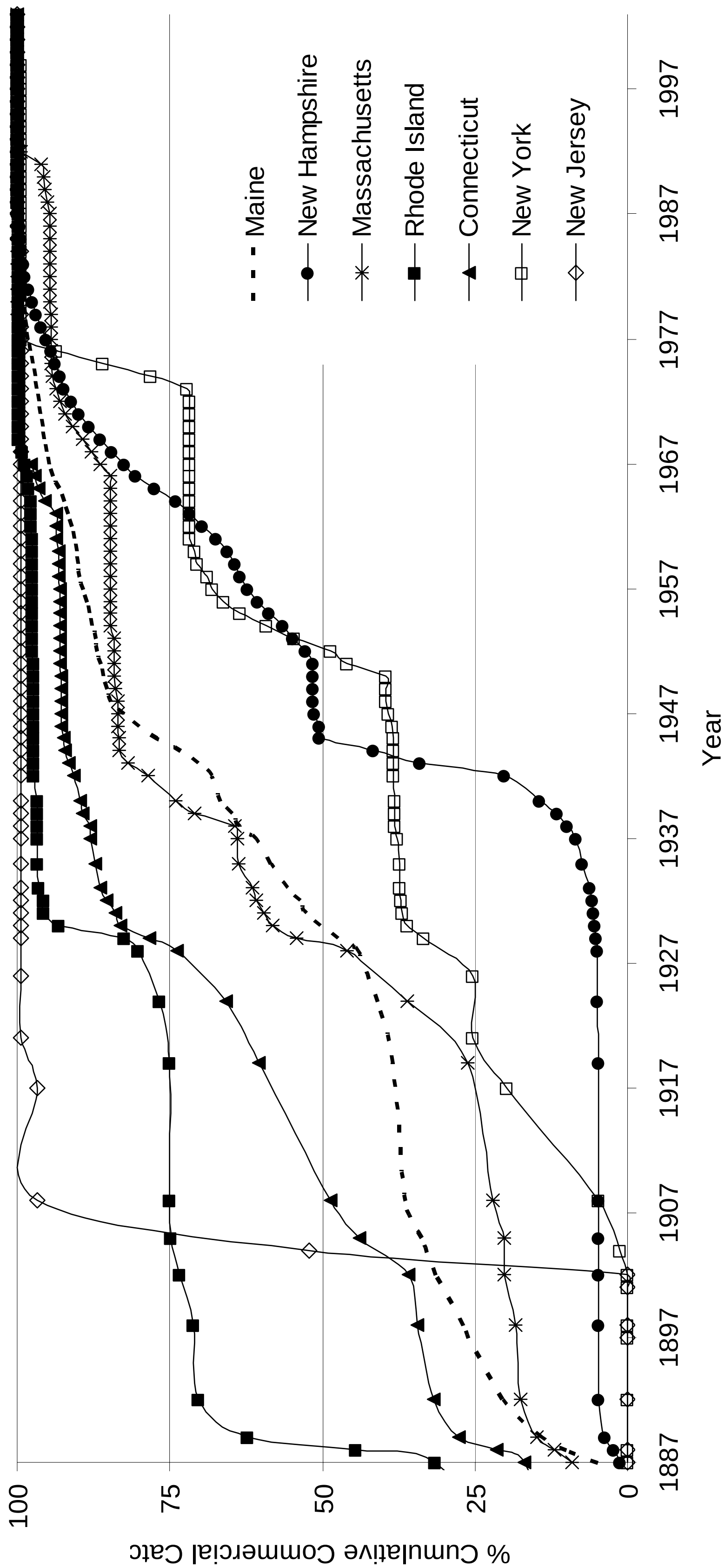

% Cumulative Commercial Catc
100
75
50
25
0
1887
1897
1907
1917
1927
1937
1947
1957
1967
1977
1987
1997
Year
Maine
New Hampshire
Massachusetts
Rhode Island
Connecticut
New York
New Jersey

Fig. 1.8. Total catch (number of individuals) of rainbow smelt (*Osmerus mordax*) reported for Maine, New Hampshire and Massachusetts from 1981 – 2004 by the National Marine Fisheries Service, Marine Recreational Fishery Statistical Survey (http://www.st.nmfs.gov). Catch statistics are based on the total observed harvest (Type A), reported harvest (Type B1), and reported live release (Type B2).

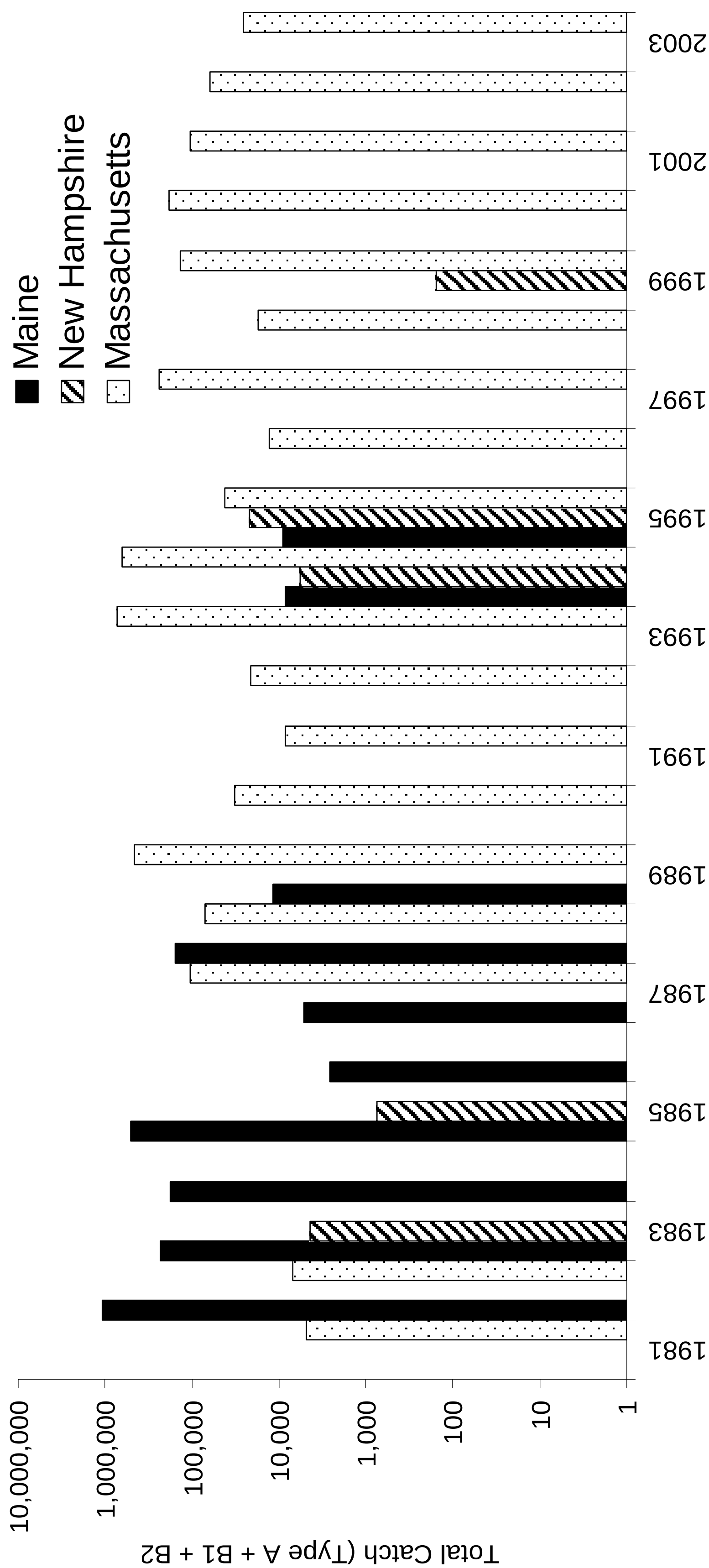

Maine
New Hampshire
Massachusetts
Total Catch (Type A + B1 + B2
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003

Fig. 1.9. Total catch (number of individuals) of rainbow smelt (*Osmerus mordax*) reported for Rhode Island, Connecticut and New York from 1981 – 2004 by the National Marine Fisheries Service, Marine Recreational Fishery Statistical Survey (http://www.st.nmfs.gov). Catch statistics are based on observed harvest (Type A), reported harvest (Type B1), and reported live release (Type B2).

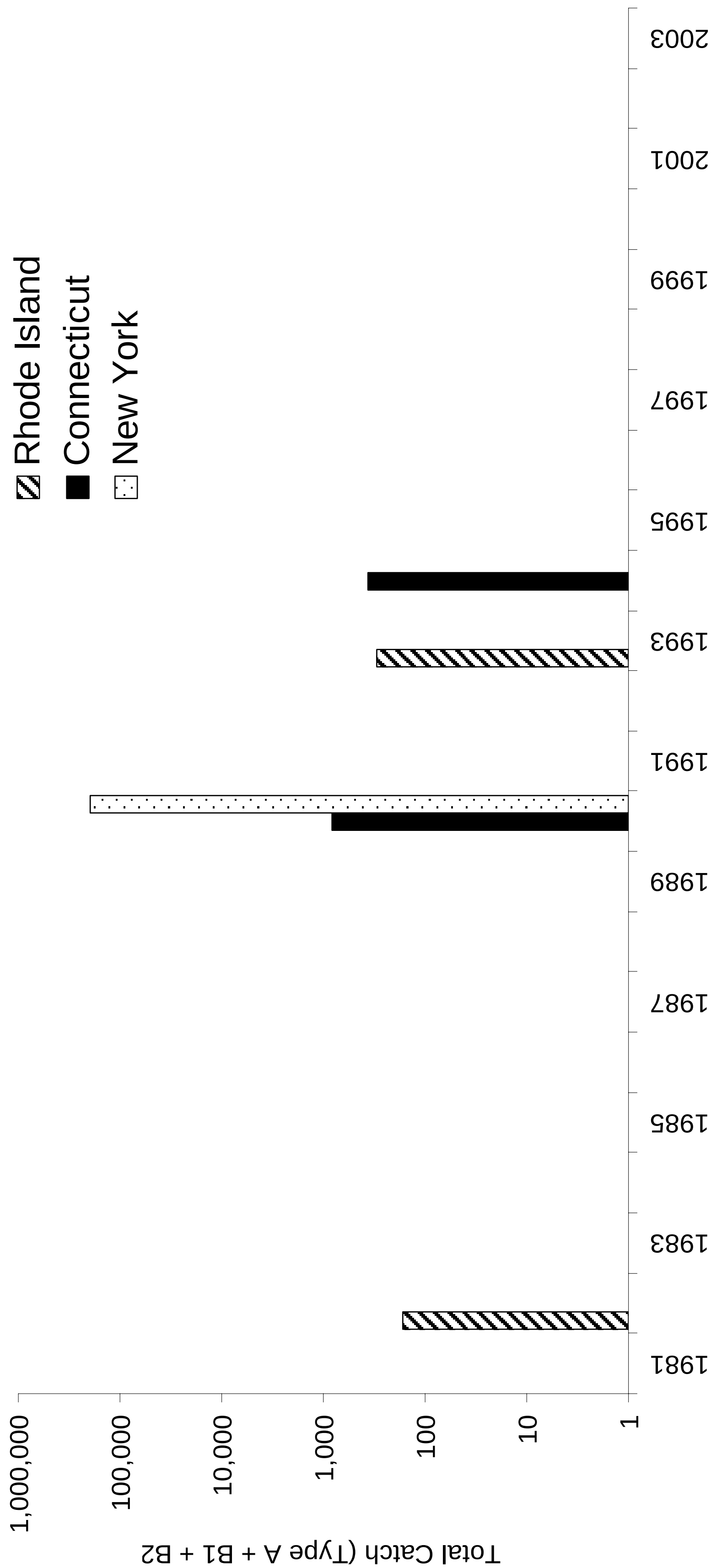

Rhode Island
Connecticut
New York
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
1
10
100
1,000
10,000
100,000
1,000,000
Total Catch (Type A + B1 + B2

Fig. 1.10 . Map of the Millstone Environmental Lab fish ecology trawl monitoring stations. Stations NB (Niantic Bay), BR (Bartletts Reef) and TT (Two Tree Channel) were sampled yearly from 1976 to 1995. Stations JC (Jordan Cove), NR (Niantic River) and IN (Millstone Power Plant Intake) have been sampled yearly since 1976.

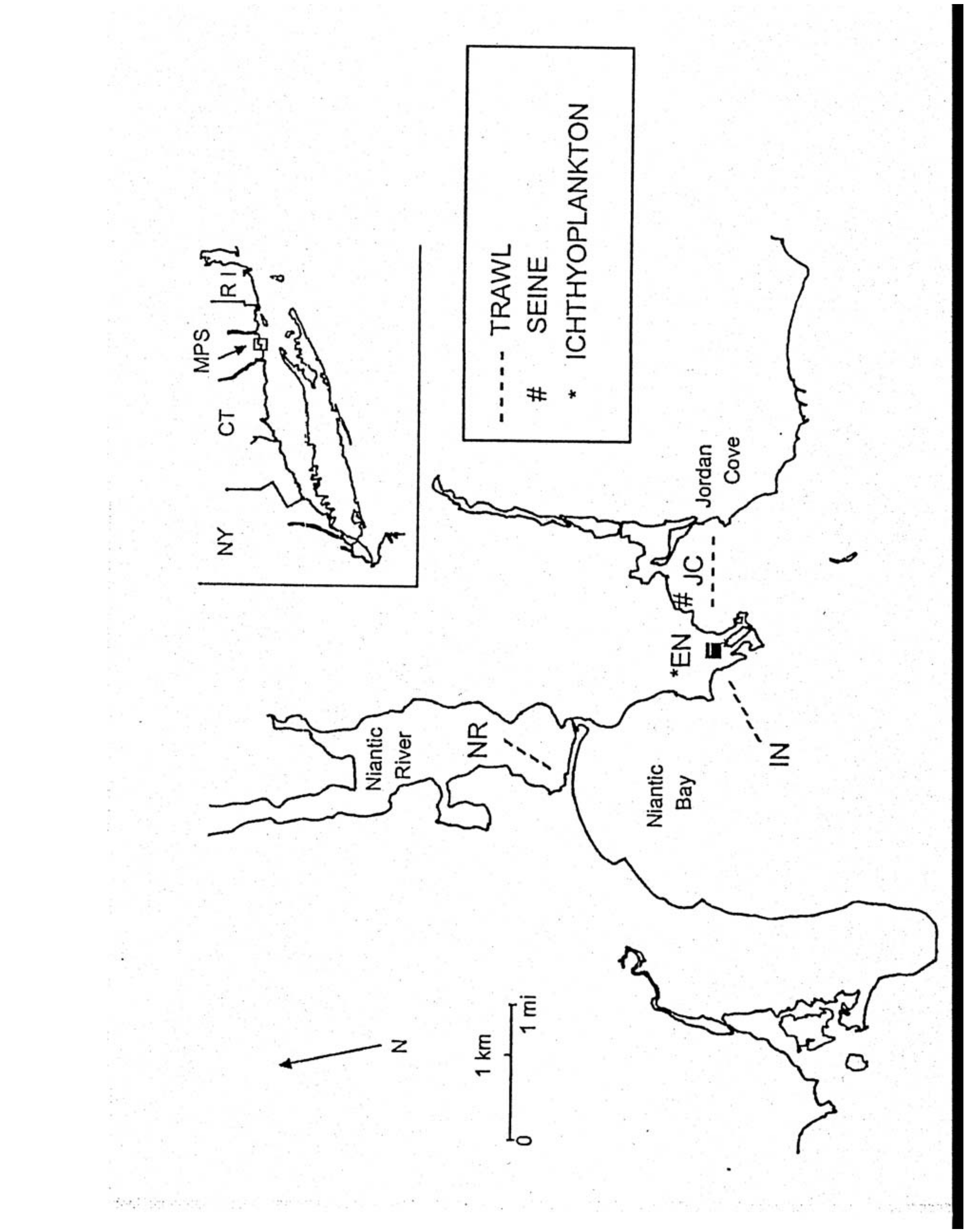

NY
CT
MPS
R I
TRAWL
SEINE
* ICHTHYOPLANKTON
Jordan Cove
JC
#
*EN
IN
Niantic River
NR
Niantic Bay
N
0
1 km
1 mi

Fig.1.11. Total yearly catch of rainbow smelt (*Osmerus mordax*) from all Millstone Environmental Lab fish ecology trawl monitoring stations. Stations NB (Niantic Bay), BR (Bartlett’s Reef) and TT (Two Tree Channel), JC (Jordan Cove), NR (Niantic River) and IN (Millstone Power Plant Intake) were sampled yearly from 1976 to 1995 with a total of 8928 tows. Yearly sampling continued at the JC (Jordan Cove), NR (Niantic River) and IN (Millstone Power Plant Intake) stations from 1995-2003 with a total of 3744 tows.

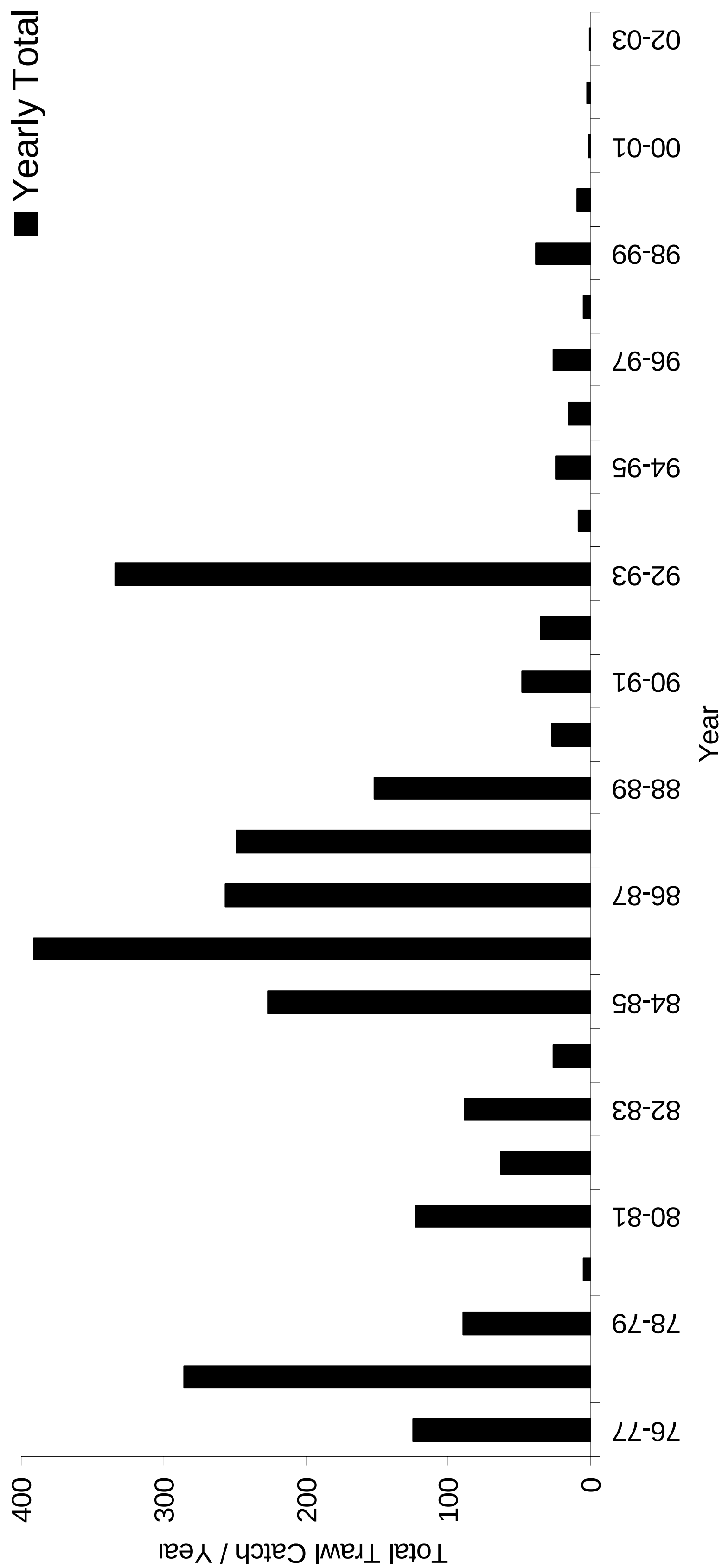

Yearly Total
Total Trawl Catch / Year
0
100
200
300
400
Year
76-77
78-79
80-81
82-83
84-85
86-87
88-89
90-91
92-93
94-95
96-97
98-99
00-01
02-03

Fig. 1.12. Total yearly catch of rainbow smelt (*Osmerus mordax*) by station from all Millstone Environmental Lab fish ecology trawl monitoring stations. Stations NB (Niantic Bay), BR (Bartlett’s Reef) and TT (Two Tree Channel), JC (Jordan Cove), NR (Niantic River) and IN (Millstone Power Plant Intake) were sampled yearly from 1976 to 1995 with a total of 8928 tows. Yearly sampling continued at the JC (Jordan Cove), NR (Niantic River) and IN (Millstone Power Plant Intake) stations from 1995-2003 with a total of 3744 tows.

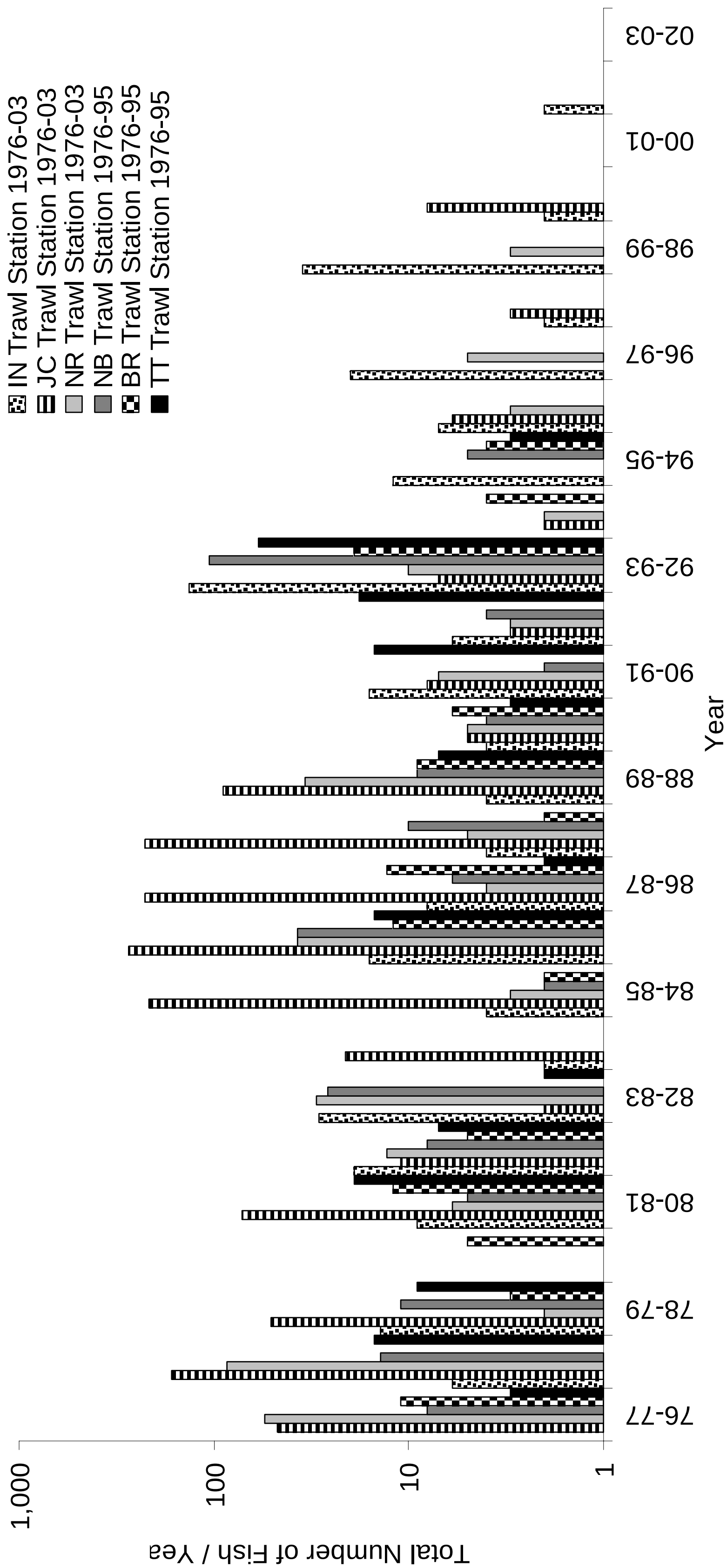

IN Trawl Station 1976-03
JC Trawl Station 1976-03
NR Trawl Station 1976-03
NB Trawl Station 1976-95
BR Trawl Station 1976-95
TT Trawl Station 1976-95
Total Number of Fish / Yea
1,000
100
10
1
Year
76-77
78-79
80-81
82-83
84-85
86-87
88-89
90-91
92-93
94-95
96-97
98-99
00-01
02-03

Fig. 1.13. Location of seine survey stations sampled by the Estuarine Seine Survey Program of the CT-DEP, Bureau of Fisheries, Marine Fisheries Division. Image reproduced from Molnar (2004), pg. 183 with permission of the CT-DEP Bureau of Fisheries.

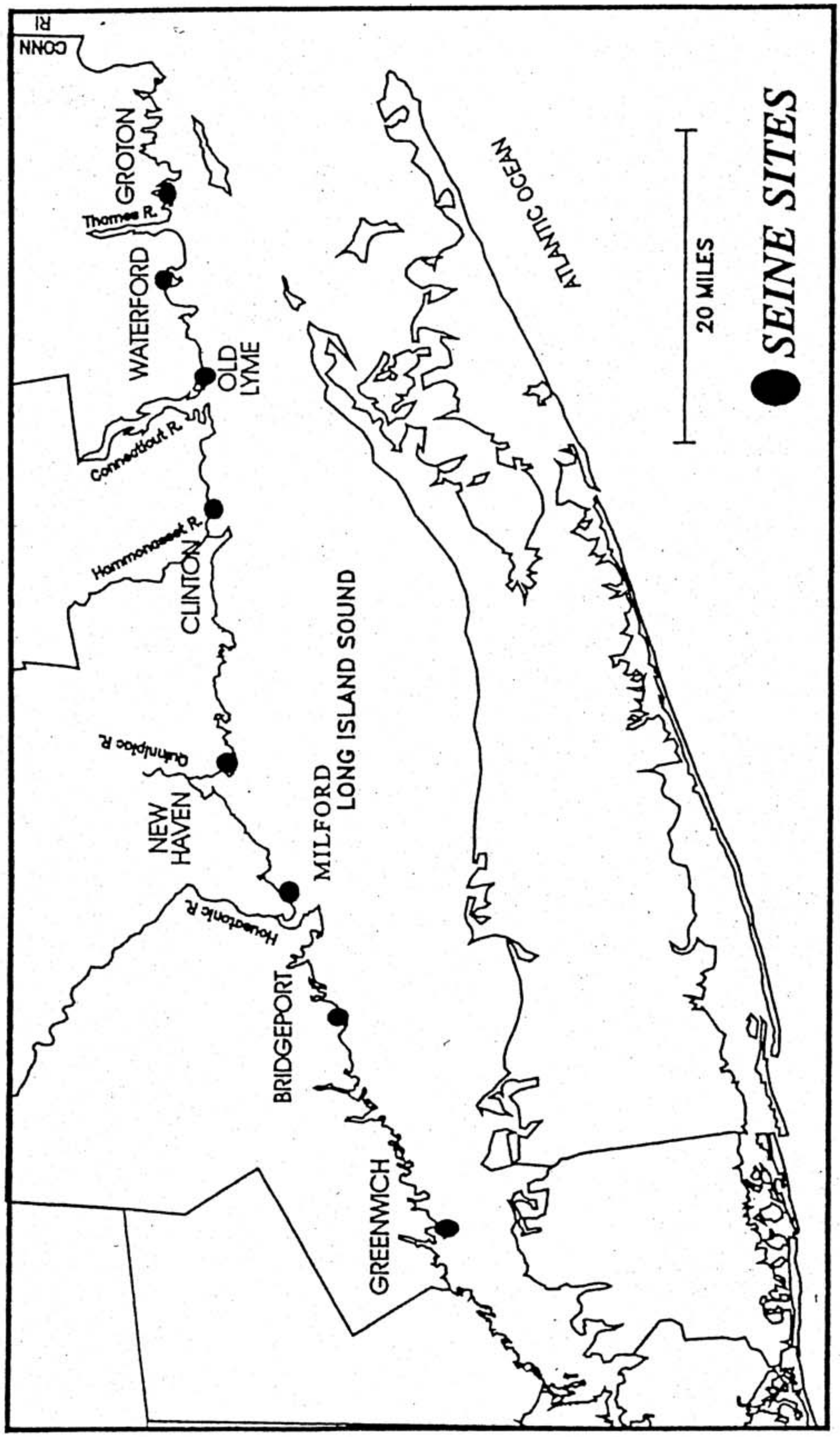

CONN
RI
GROTON
Thames R.
WATERFORD
OLD LYME
Connecticut R.
Hammonasset R.
CLINTON
LONG ISLAND SOUND
Quinnipiac R.
NEW HAVEN
MILFORD
Housatonic R.
BRIDGEPORT
GREENWICH
ATLANTIC OCEAN
20 MILES
SEINE SITES

Fig. 1.14. Rainbow smelt (*Osmerus mordax*) catches by season and location. Catches resulted from 2,859 tows made between 1984-94 as part of the Long Island Sound Trawl Survey. Image is reproduced from Gottschall et al. (2000).

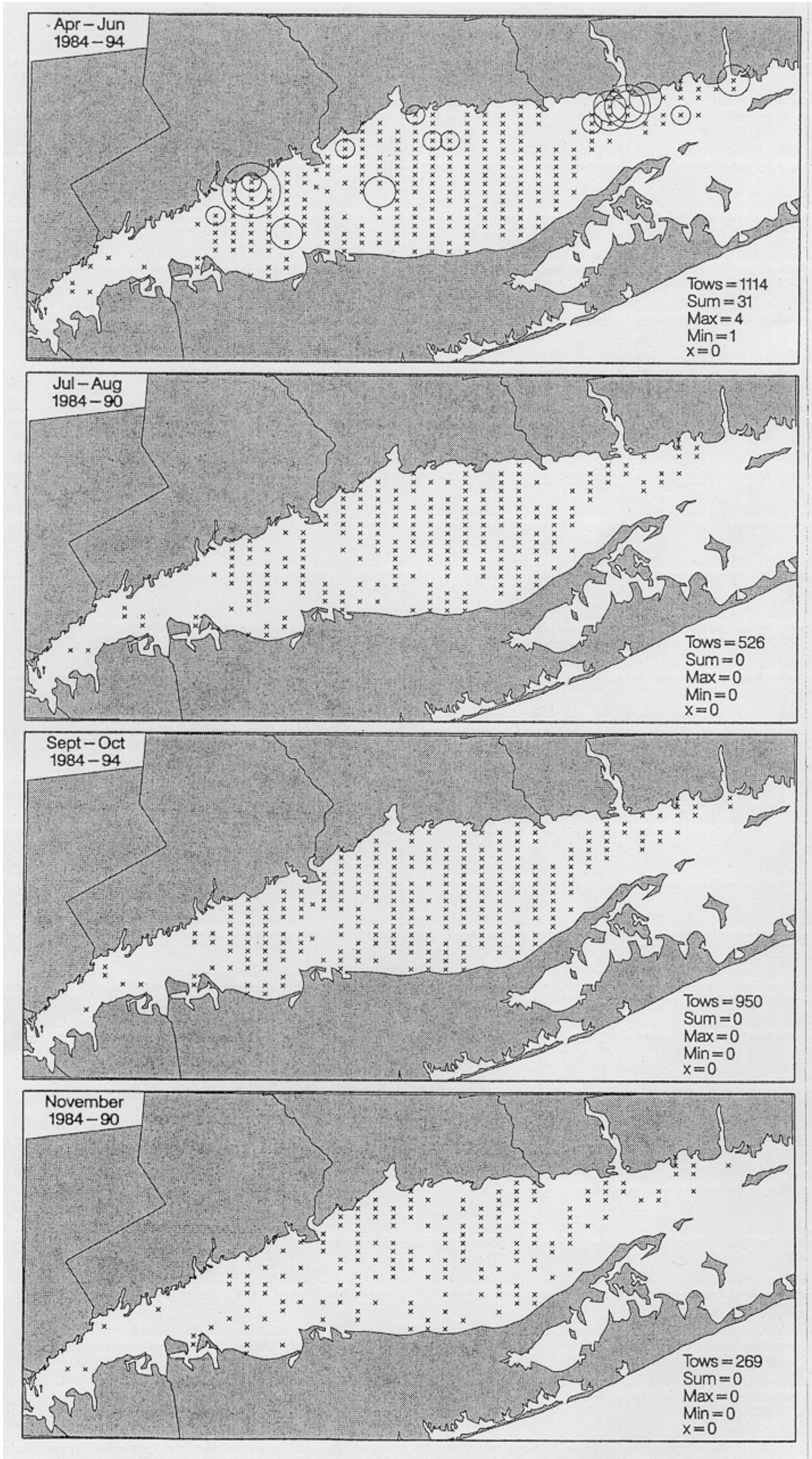

Apr – Jun
1984 – 94
Tows = 1114
Sum = 31
Max = 4
Min = 1
x = 0
Jul – Aug
1984 – 90
Tows = 526
Sum = 0
Max = 0
Min = 0
x = 0
Sept – Oct
1984 – 94
Tows = 950
Sum = 0
Max = 0
Min = 0
x = 0
November
1984 – 90
Tows = 269
Sum = 0
Max = 0
Min = 0
x = 0

Figure. 1.15. Yearly hatchery release of rainbow smelt (*Osmerus mordax*) fry by the State of Connecticut, Board of Fisheries and Game between 1924 and 1938.

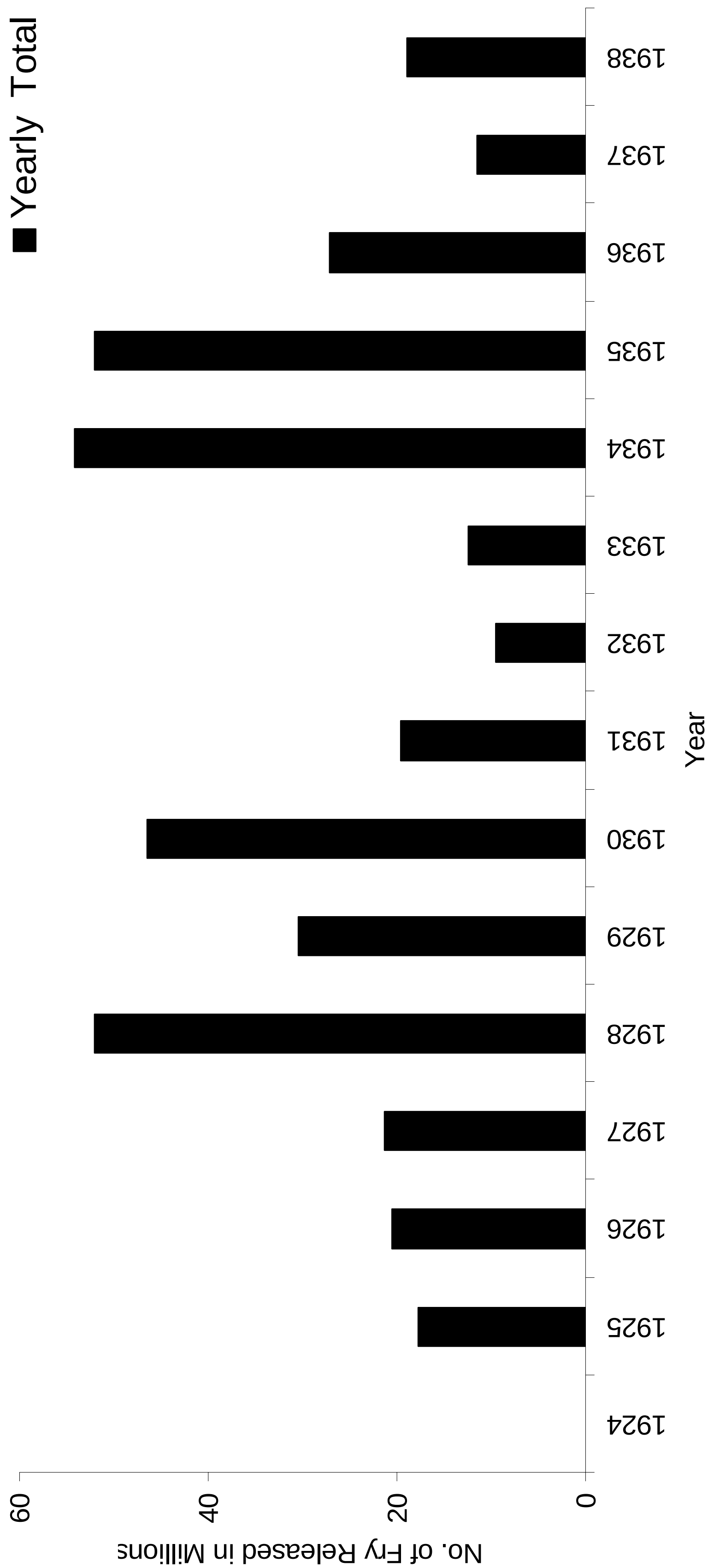

Yearly Total
Year
1924
1925
1926
1927
1928
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
No. of Fry Released in Millions
0
20
40
60

Fig. 1.16. Total Federal commercial catch statistics for Atlantic tomcod (*Microgadus tomcod*) reported from the New England Region, irregularly from 1887 – 1950.

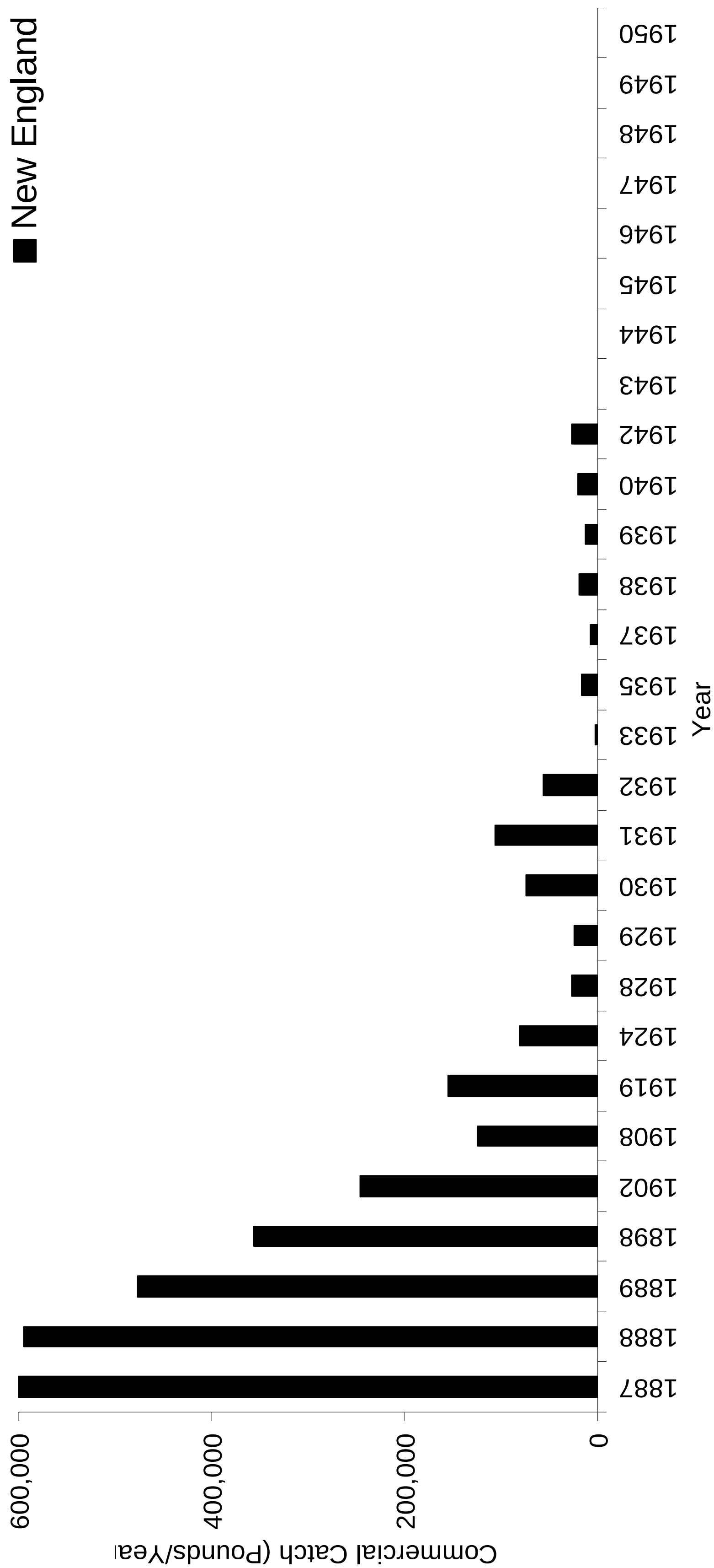

New England
Commerical Catch (Pounds/Year
600,000
400,000
200,000
0
Year
1887
1888
1889
1898
1902
1908
1919
1924
1928
1929
1930
1931
1932
1933
1935
1937
1938
1939
1940
1942
1943
1944
1945
1946
1947
1948
1949
1950

Fig. 1.17. Total Federal commercial catch statistics for Atlantic tomcod (*Microgadus tomcod*) reported from the Mid Atlantic Region, irregularly from 1887 – 1949, and yearly from 1950 – 1990.

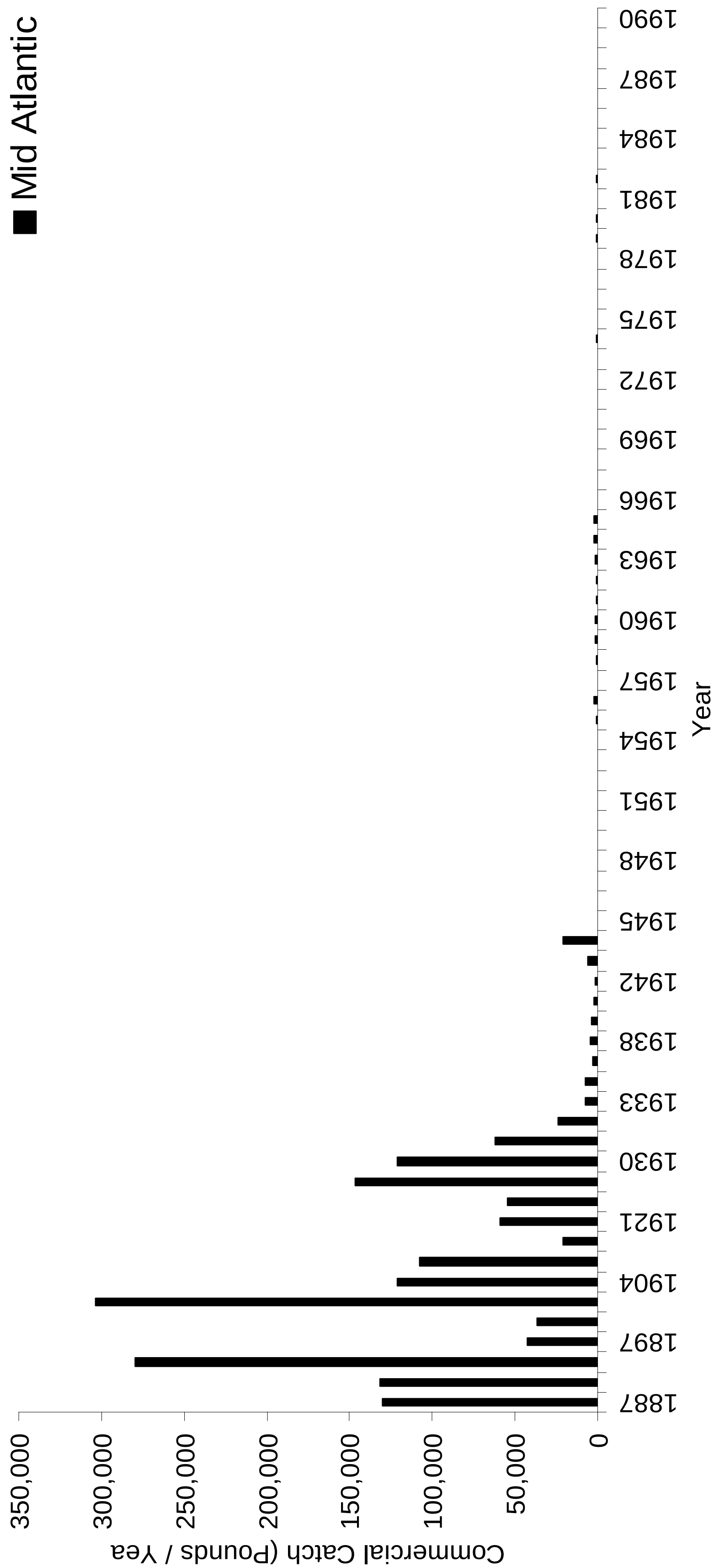

Mid Atlantic
Commerical Catch (Pounds / Yea
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Year
1887
1897
1904
1921
1930
1933
1938
1942
1945
1948
1951
1954
1957
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990

Fig. 1.18. Total Federal commercial catch statistics for Atlantic tomcod (*Microgadus tomcod*) reported irregularly between 1887 – 1950 from the Chesapeake Region.

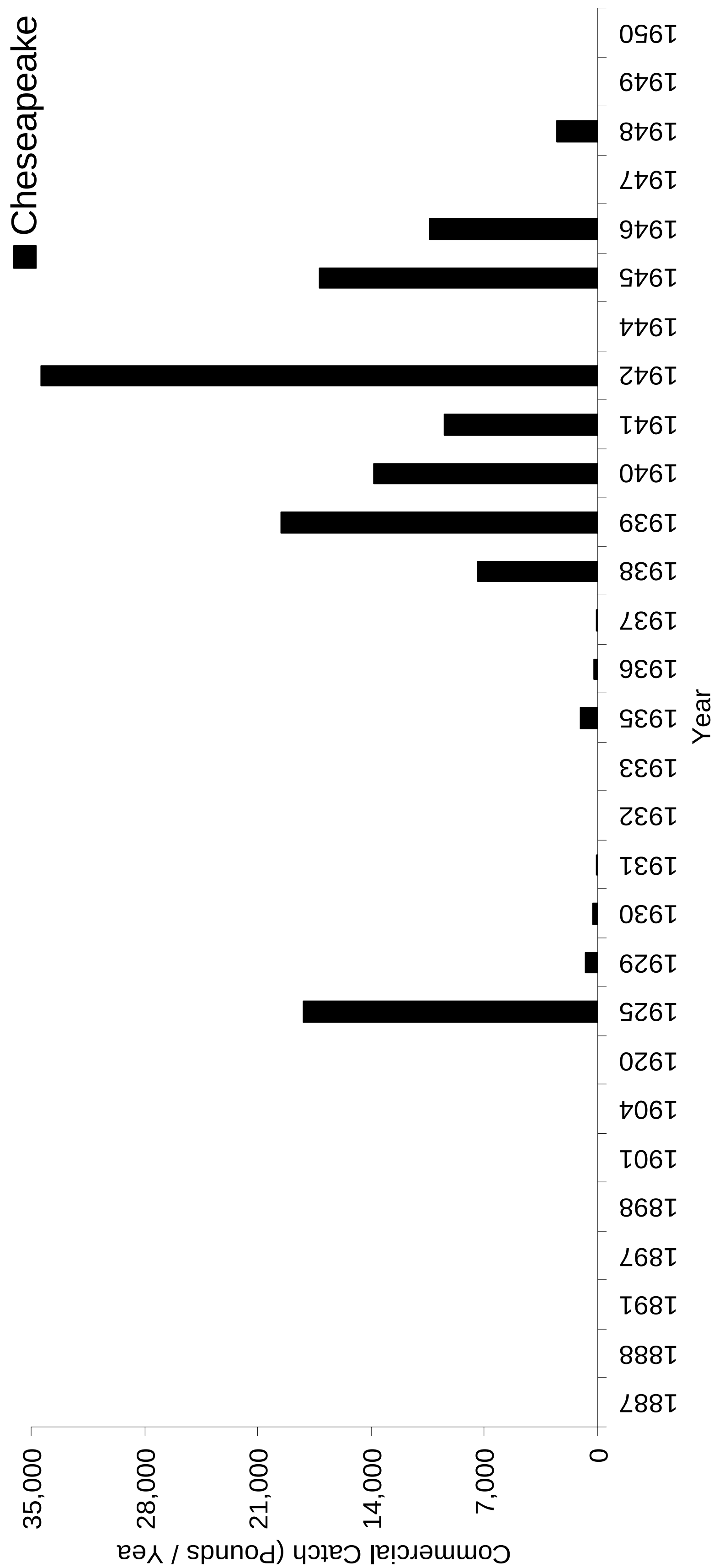

Cheseapeake
Commercial Catch (Pounds / Yea
35,000
28,000
21,000
14,000
7,000
0
Year
1887
1888
1891
1897
1898
1901
1904
1920
1925
1929
1930
1931
1932
1933
1935
1936
1937
1938
1939
1940
1941
1942
1944
1945
1946
1947
1948
1949
1950

Fig. 1.19. Total Federal commercial catch statistics for Atlantic tomcod (*Microgadus tomcod*) reported for Maine and Massachusetts, irregularly from 1887 – 1950.

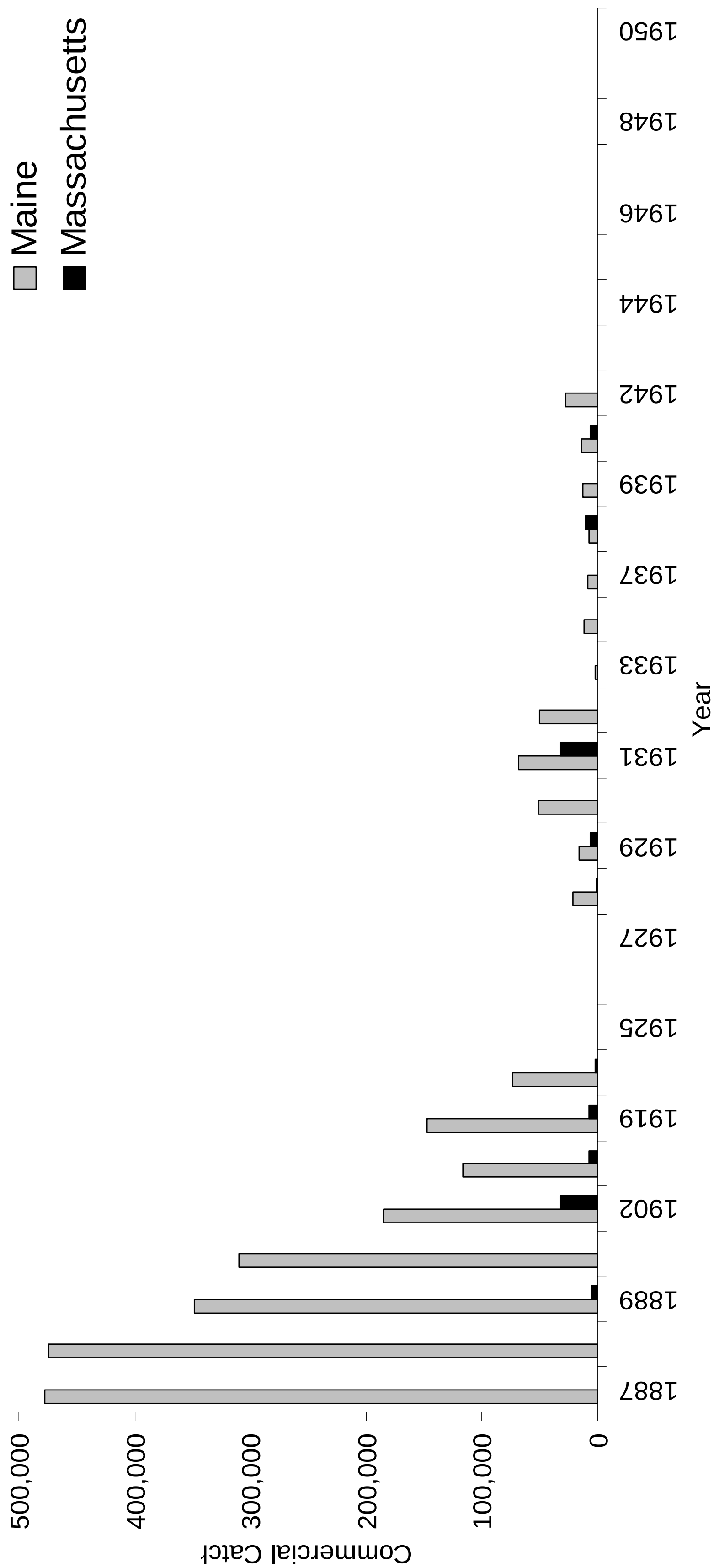

Maine
Massachusetts
Year
Commercial Catc
0
100,000
200,000
300,000
400,000
500,000
1887
1889
1902
1919
1925
1927
1929
1931
1933
1937
1939
1942
1944
1946
1948
1950

Fig. 1.20. Total Federal commercial catch statistics for Atlantic tomcod (*Microgadus tomcod*) reported for Connecticut and Rhode Island, irregularly from 1887 – 1950.

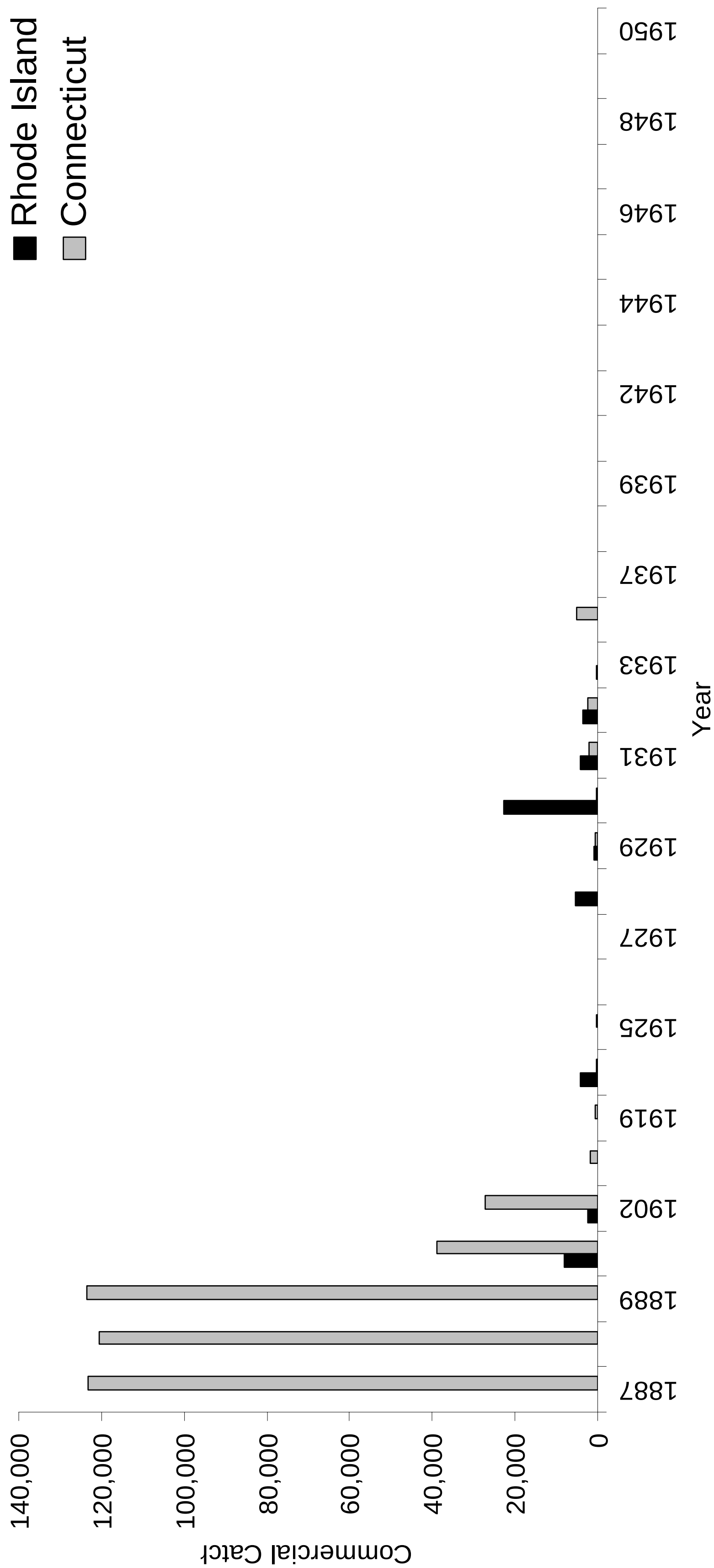

Rhode Island
Connecticut
Year
Commercial Catc
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
1887
1889
1902
1919
1925
1927
1929
1931
1933
1937
1939
1942
1944
1946
1948
1950

Fig. 1.21. Total Federal commercial catch statistics for Atlantic tomcod (*Microgadus tomcod*) reported for New York and New Jersey, irregularly from 1887 – 1949, and yearly from 1950 – 1990.

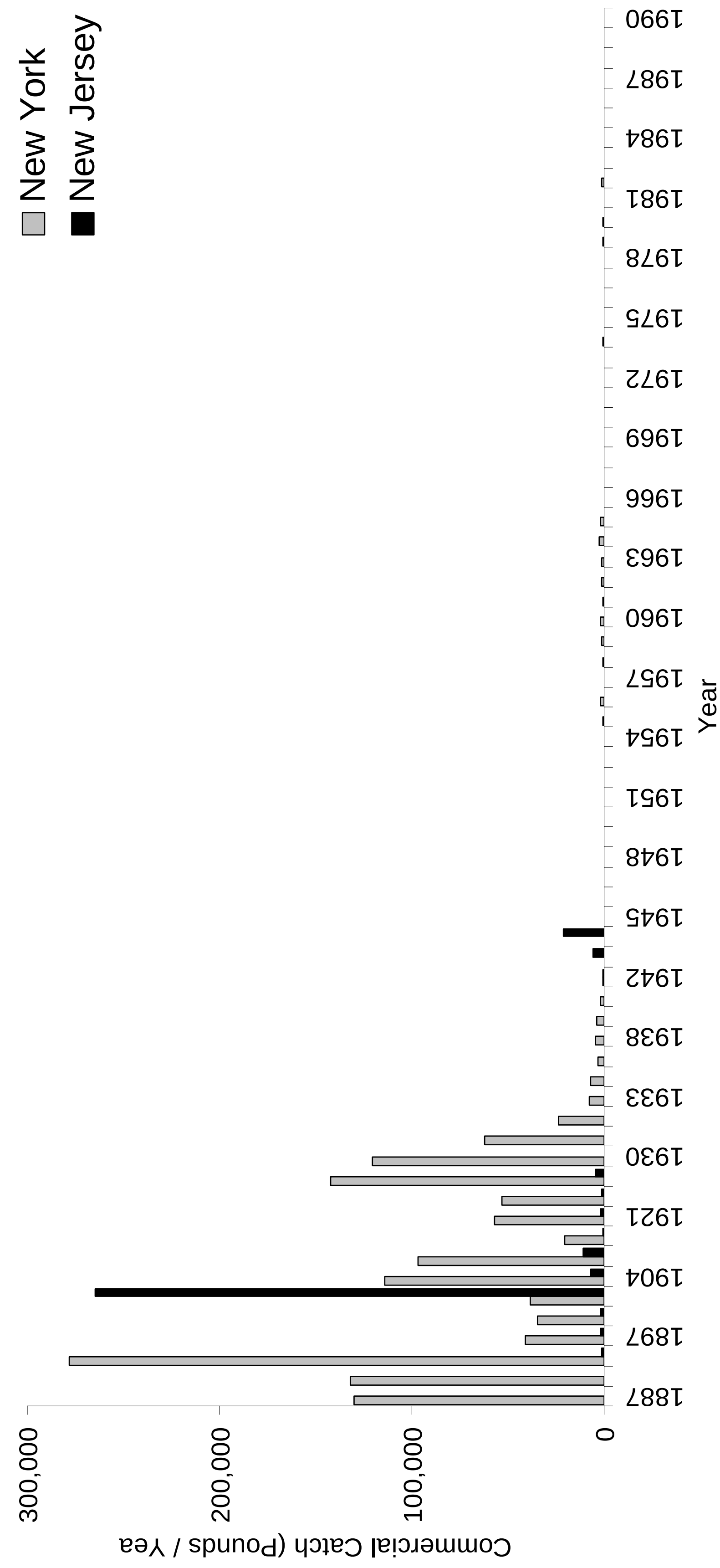

New York
New Jersey
Year
Commerical Catch (Pounds / Yea
300,000
200,000
100,000
0
1887
1897
1904
1921
1930
1933
1938
1942
1945
1948
1951
1954
1957
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990

Fig. 1.22. Total catch (number of individuals) of Atlantic tomcod (*Microgadus tomcod*) reported for Maine, New Hampshire and Massachusetts from 1981 – 2004 by the National Marine Fisheries Service, Marine Recreational Fishery Statistical Survey (http://www.st.nmfs.gov). Catch statistics are based on the total observed harvest (Type A), reported harvest (Type B1), and reported live release (Type B2).

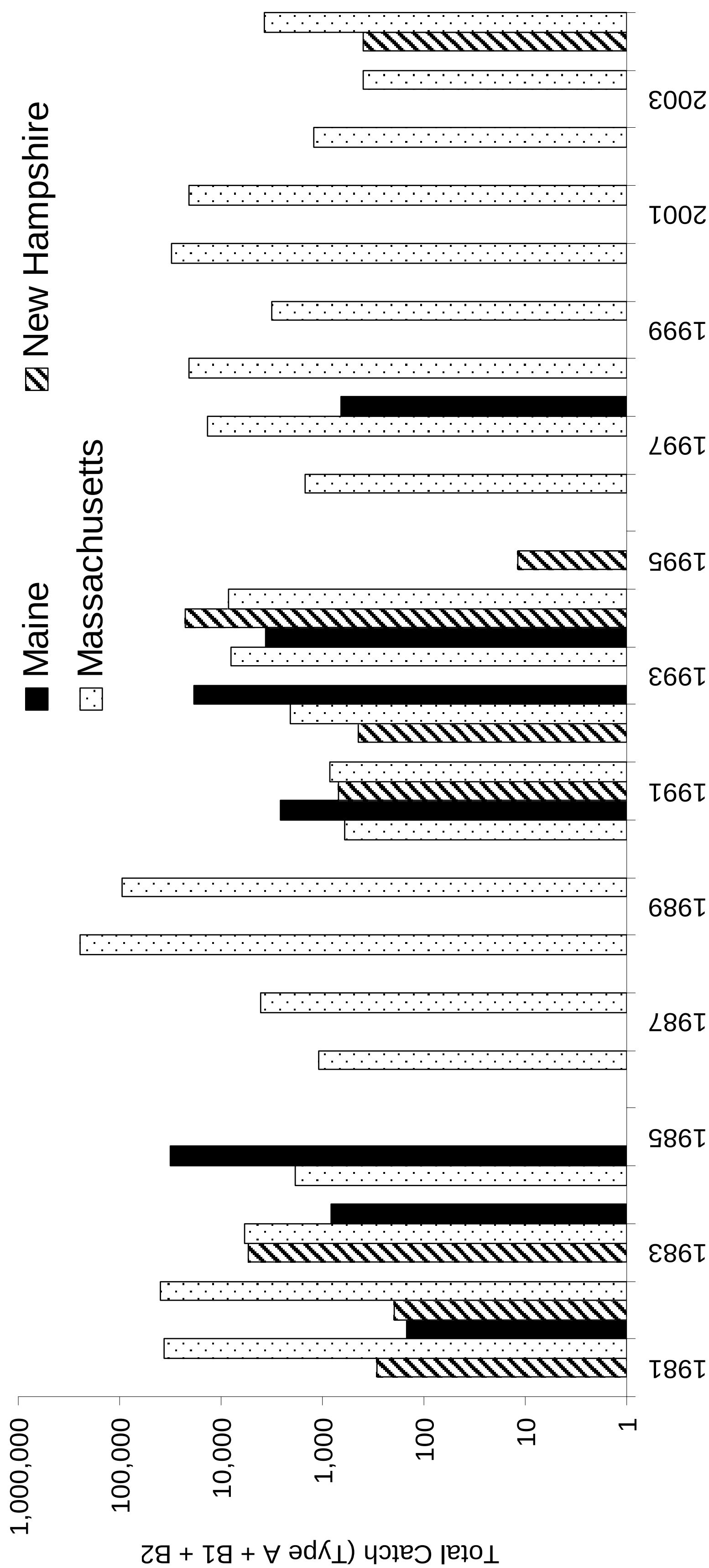

Maine
Massachusetts
New Hampshire
Total Catch (Type A + B1 + B2)
1,000,000
100,000
10,000
1,000
100
10
1
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003

Fig. 1.23. Total catch (number of individuals) of Atlantic tomcod (*Microgadus tomcod*) reported for Rhode Island and Connecticut from 1981 – 2004 by the National Marine Fisheries Service, Marine Recreational Fishery Statistical Survey (http://www.st.nmfs.gov). Catch statistics are based on observed harvest (Type A), reported harvest (Type B1), and reported live release (Type B2).

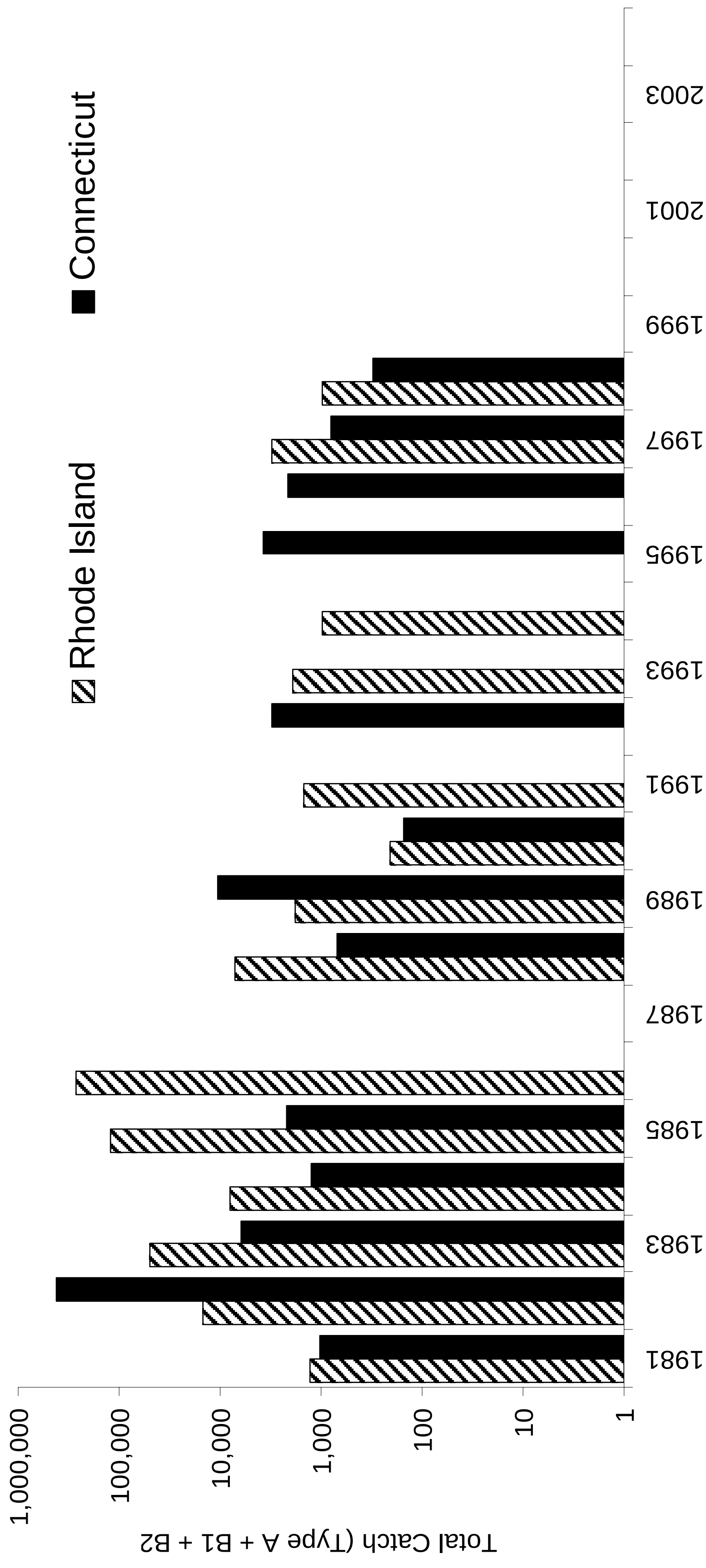

Rhode Island
Connecticut
Total Catch (Type A + B1 + B2
1,000,000
100,000
10,000
1,000
100
10
1
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003

Fig. 1.24. Total catch (number of individuals) of Atlantic tomcod (*Microgadus tomcod*) reported for New York, New Jersey and Delaware from 1981 – 2004 by the National Marine Fisheries Service, Marine Recreational Fishery Statistical Survey (http://www.st.nmfs.gov). Catch statistics are based on observed harvest (Type A), reported harvest (Type B1), and reported live release (Type B2).

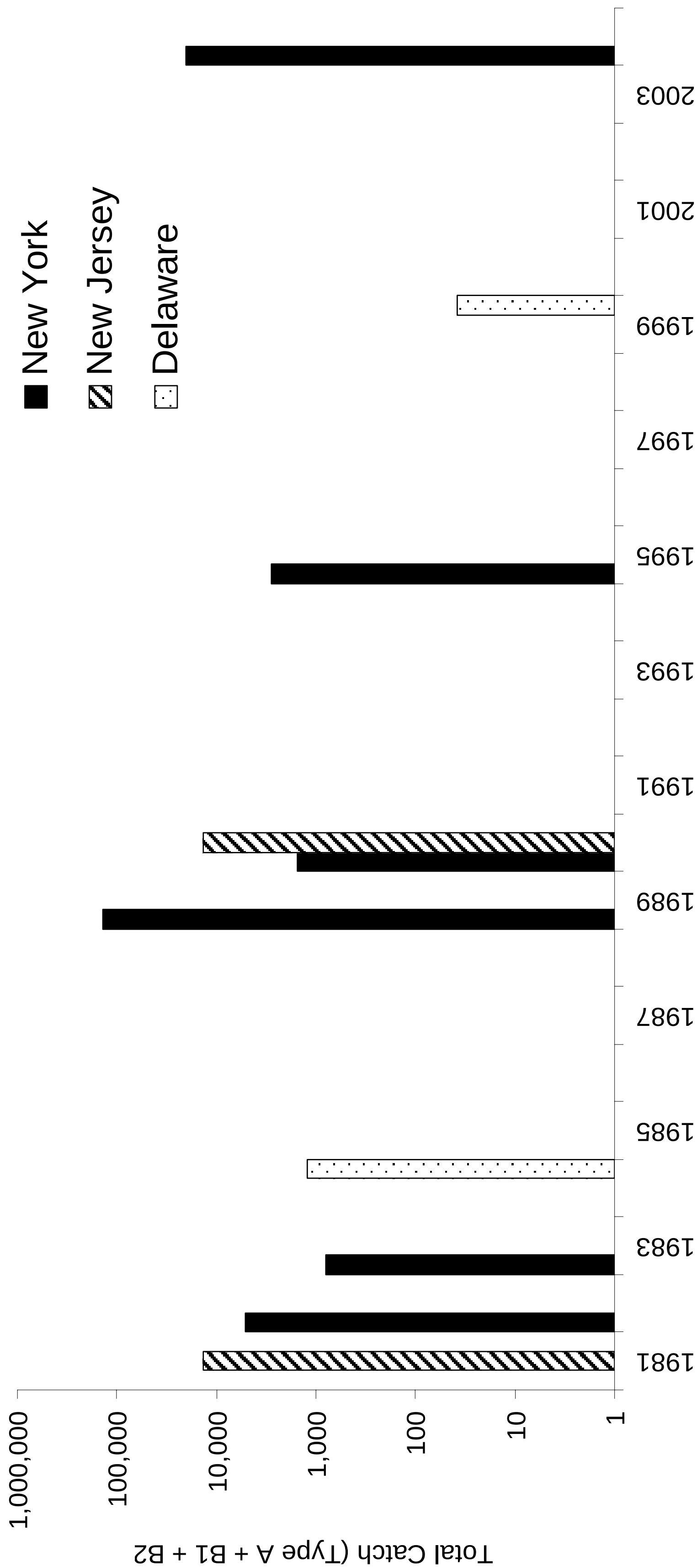

New York
New Jersey
Delaware
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
1
10
100
1,000
10,000
100,000
1,000,000
Total Catch (Type A + B1 + B2

Fig. 1.25. Atlantic tomcod (*Microgadus tomcod*) catches by season and location. Catches resulted from 2,859 tows made between 1984-94 as part of the Long Island Sound Trawl Survey. Image is reproduced from Gottschall et al. (2000).

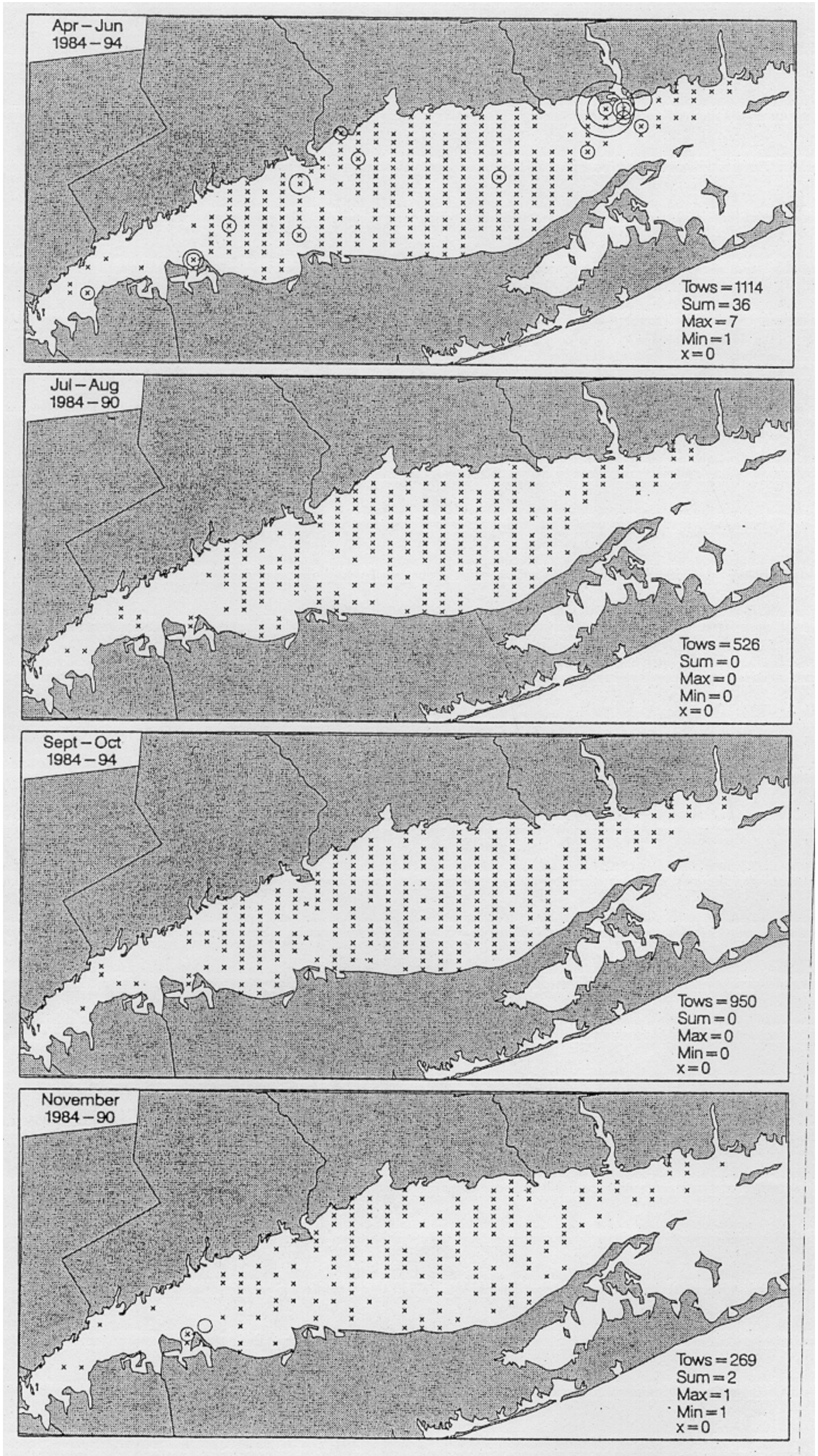

Apr – Jun
1984 – 94
Tows = 1114
Sum = 36
Max = 7
Min = 1
x = 0
Jul – Aug
1984 – 90
Tows = 526
Sum = 0
Max = 0
Min = 0
x = 0
Sept – Oct
1984 – 94
Tows = 950
Sum = 0
Max = 0
Min = 0
x = 0
November
1984 – 90
Tows = 269
Sum = 2
Max = 1
Min = 1
x = 0

Figure 1.26. Total yearly catch of Atlantic tomcod (*Microgadus tomcod*) from all Millstone Environmental Lab fish ecology trawl monitoring stations from 1976-2003.

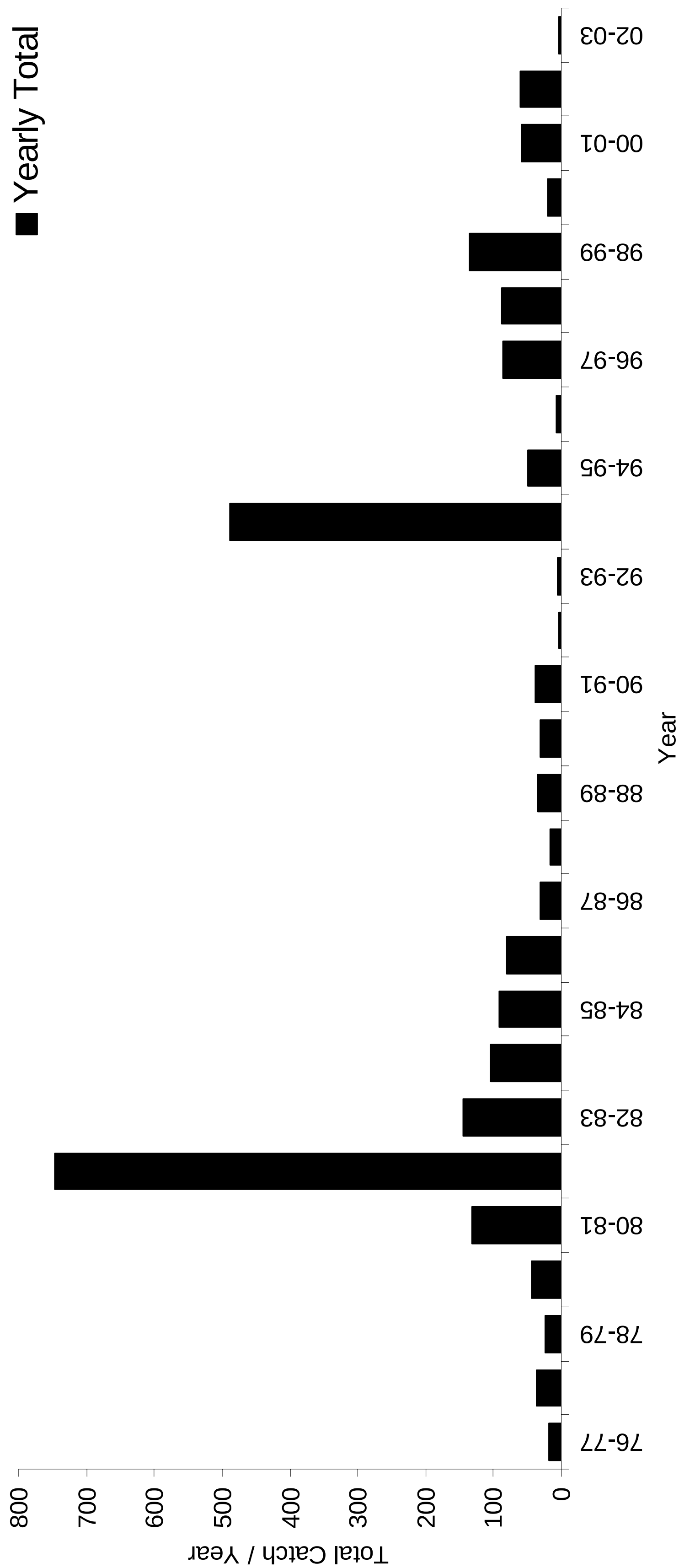

Yearly Total
Total Catch / Year
Year
0
100
200
300
400
500
600
700
800
76-77
78-79
80-81
82-83
84-85
86-87
88-89
90-91
92-93
94-95
96-97
98-99
00-01
02-03

Figure 1.27. Total yearly catch of Atlantic tomcod (*Microgadus tomcod*) by station from all Millstone Environmental Lab fish ecology trawl monitoring stations. JC (Jordan Cove), NR (Niantic River) and IN (Millstone Power Plant Intake) were sampled yearly from 1976 to 2003 with a total of 5634 tows.

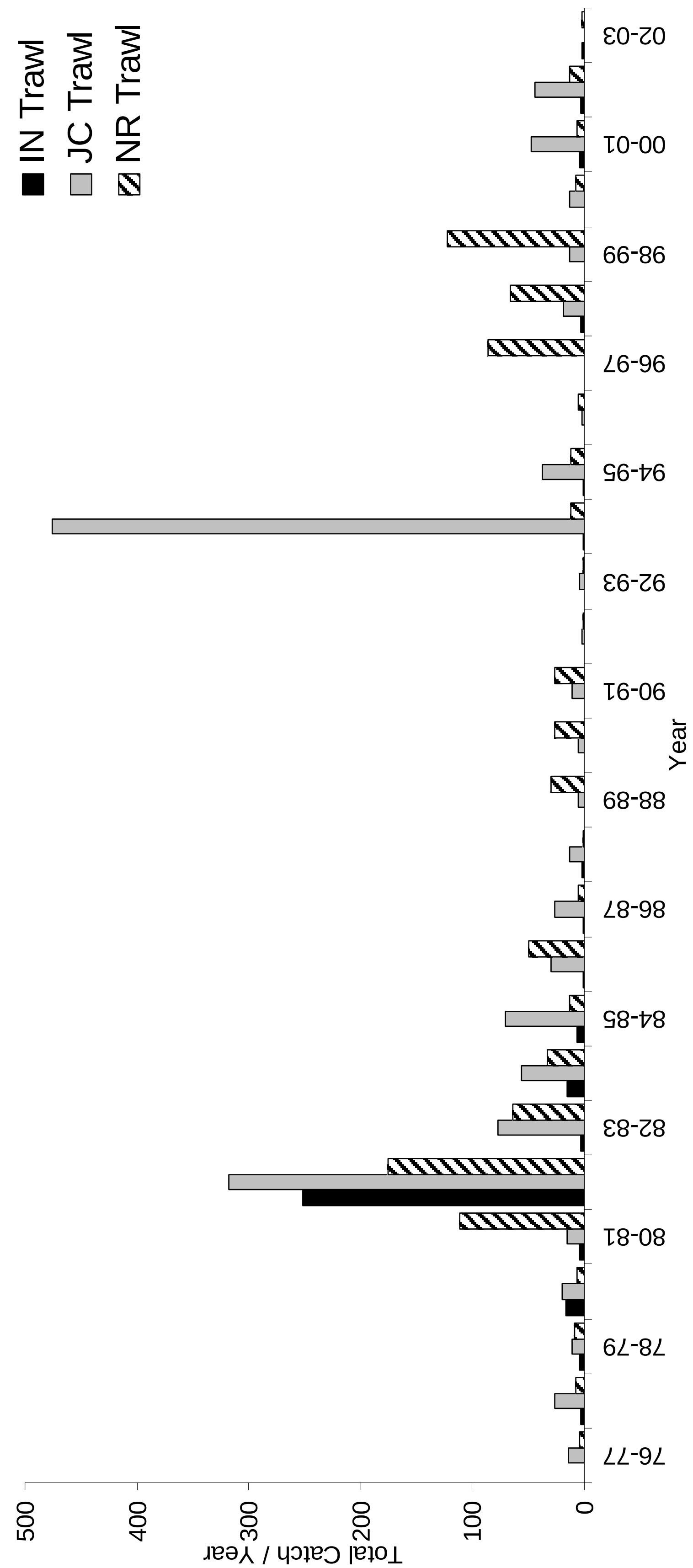

IN Trawl
JC Trawl
NR Trawl
Total Catch / Year
0
100
200
300
400
500
Year
76-77
78-79
80-81
82-83
84-85
86-87
88-89
90-91
92-93
94-95
96-97
98-99
00-01
02-03

Figure 2.1. Length-weight relationship for rainbow smelt (*Osmerus mordax*) collected from the Mystic River during the fall of 2004 and the Niantic River during the spring of 2005.

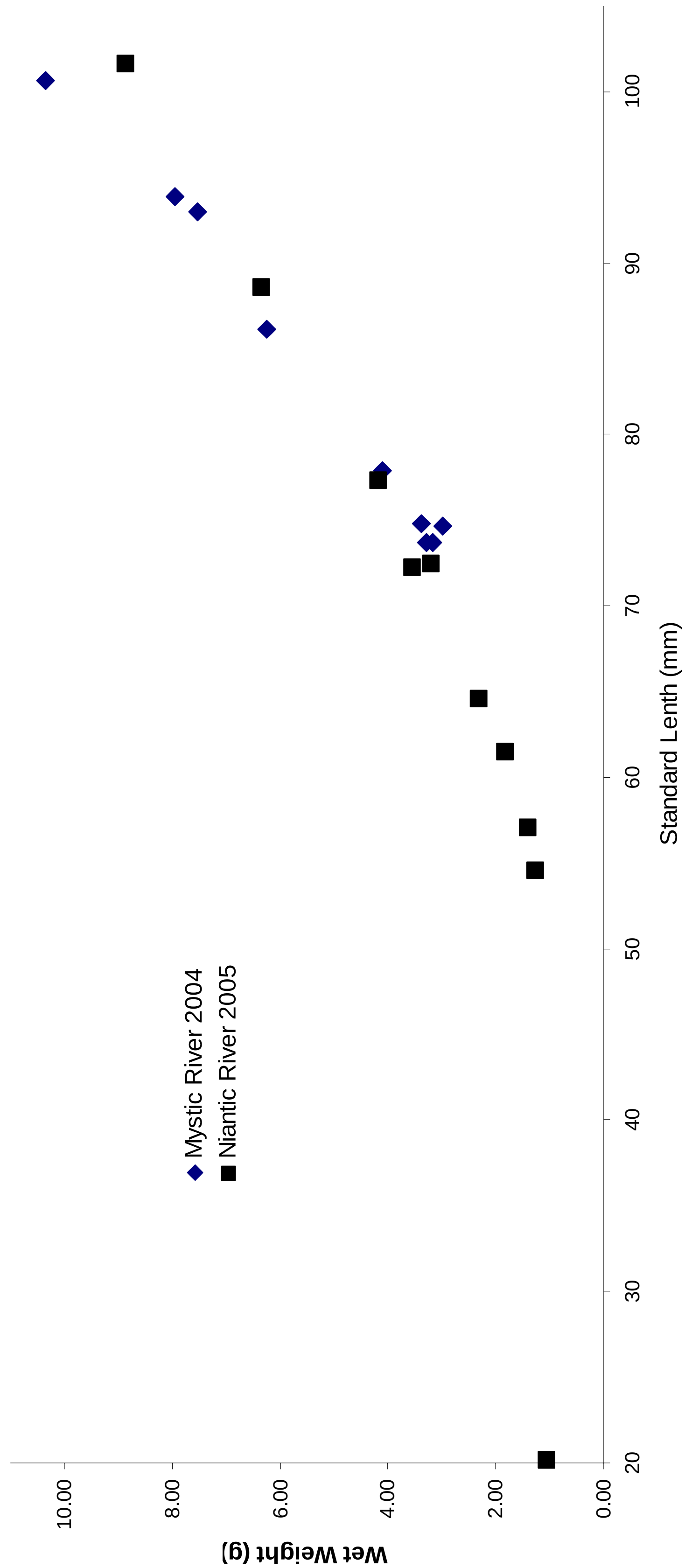

Wet Weight (g)
0.00
2.00
4.00
6.00
8.00
10.00
Standard Lenth (mm)
20
30
40
50
60
70
80
90
100
Mystic River 2004
Niantic River 2005

Figure 2.2. Age class frequency for adult male and female tomcod collected between winter 2003 and spring 2005.

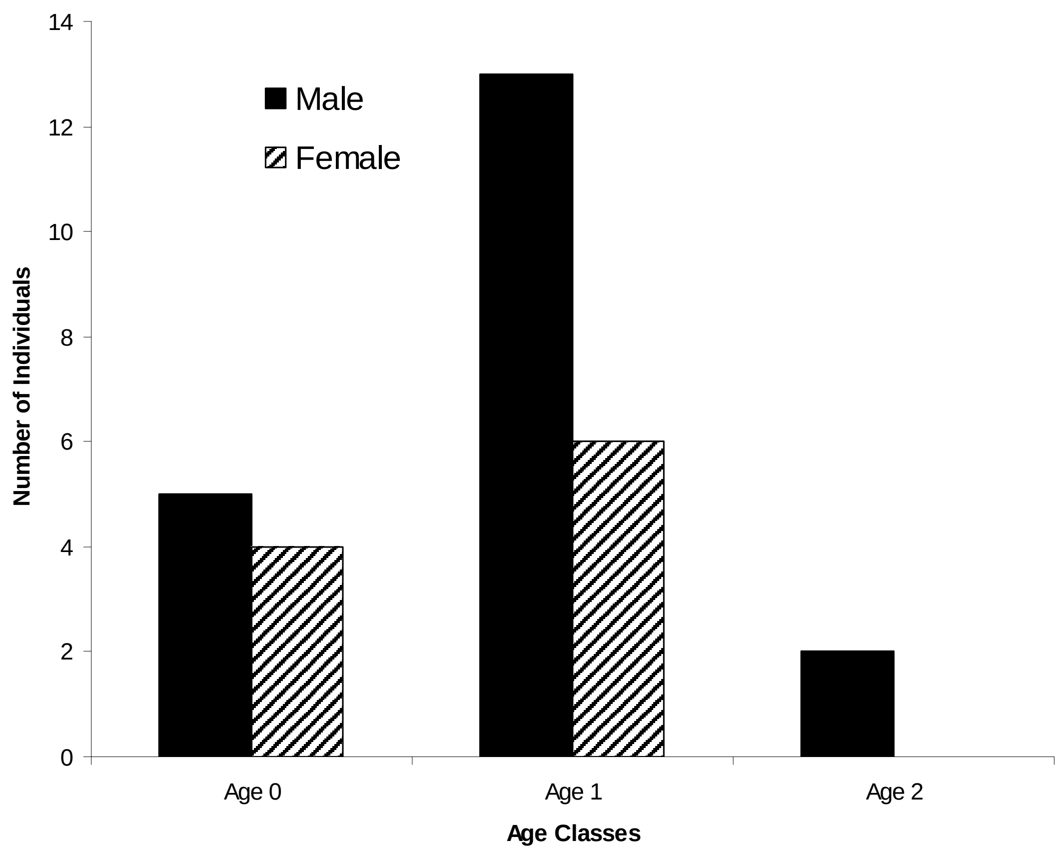

14
12
10
8
6
4
2
0
Number of Individuals
Male
Female
Age 0
Age 1
Age 2
Age Classes

Figure 2.3. Frequency of oocyte diameter in relation to ovary stage. The number of individual fish sampled are given for each stage.

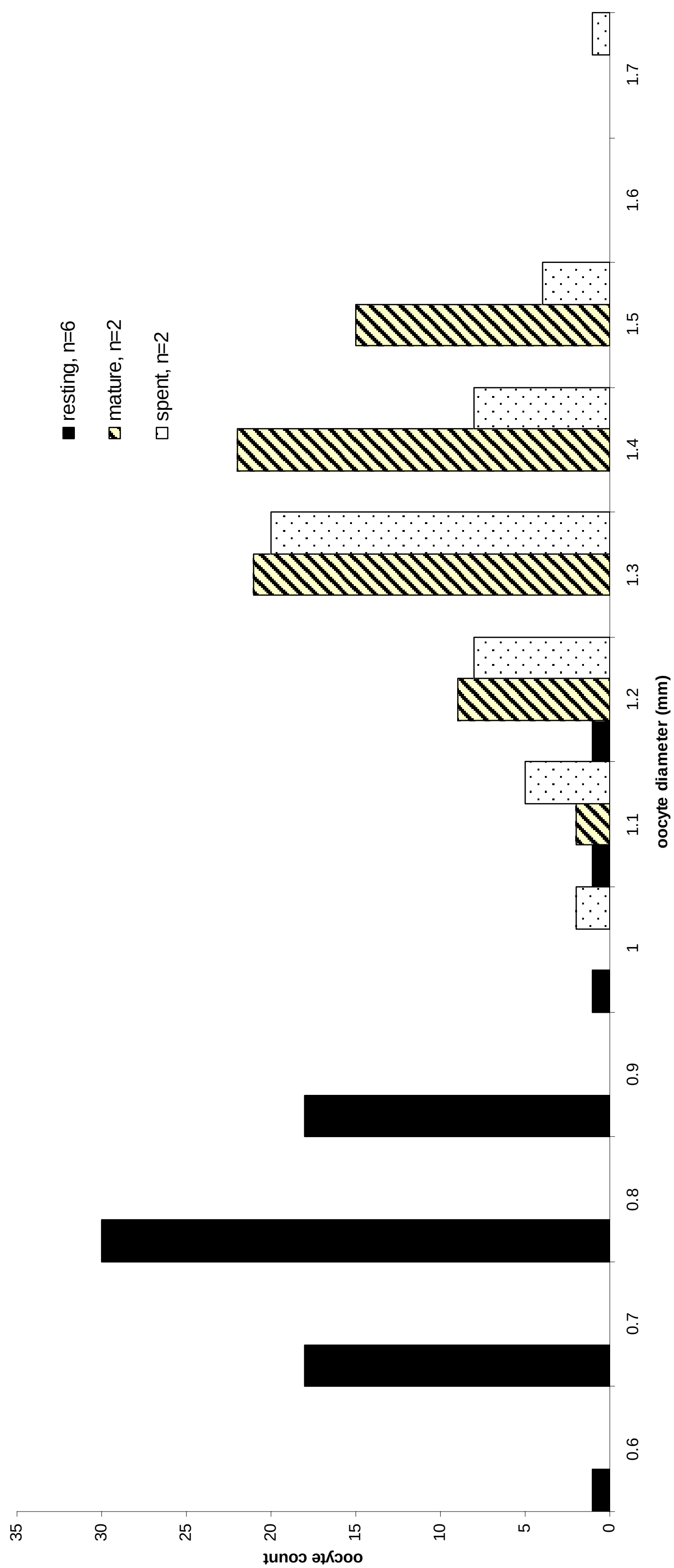

resting, n=6
mature, n=2
spent, n=2
oocyte diameter (mm)
oocyte count
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
0
5
10
15
20
25
30
35

Figure 2.4. Relationship between standard length and sampling date for 2003. Linear regression, equation and R^2 value are given for the New Haven samples.

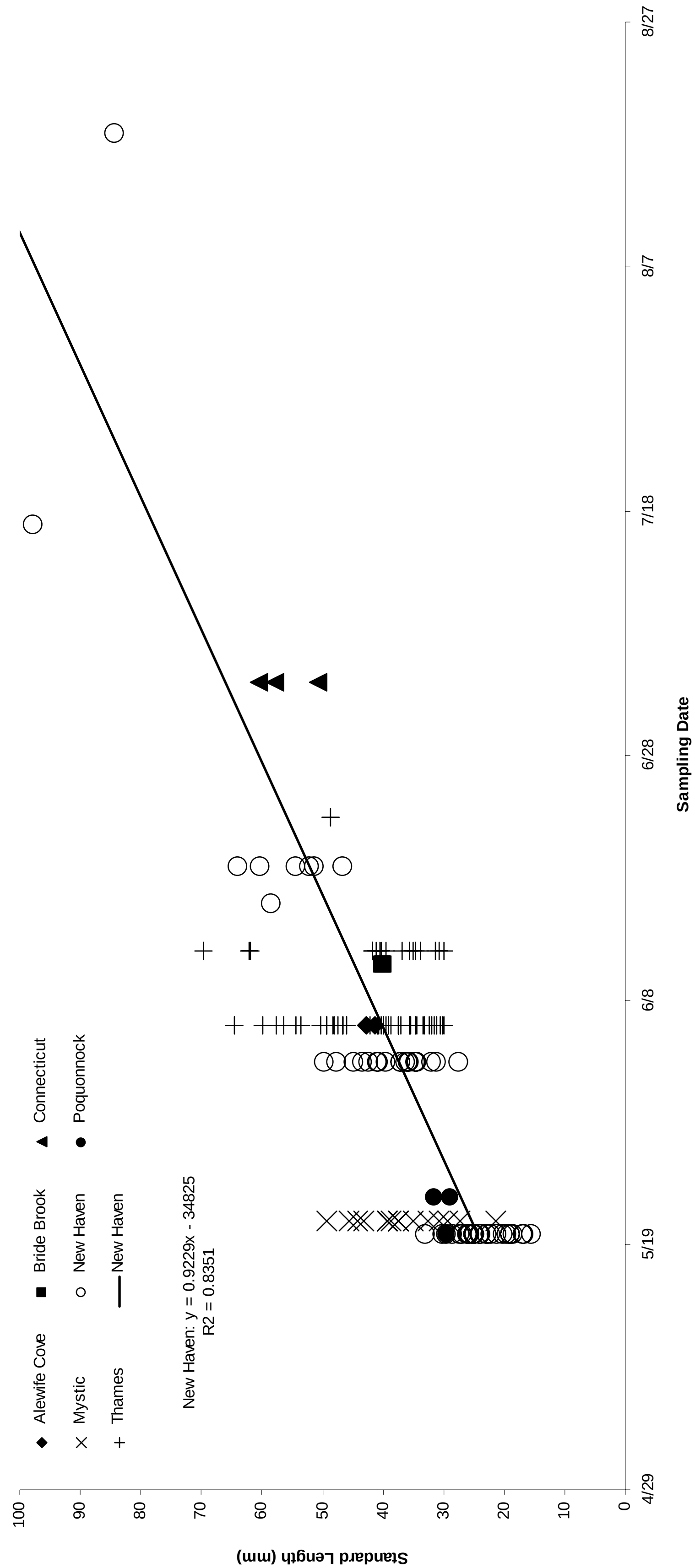
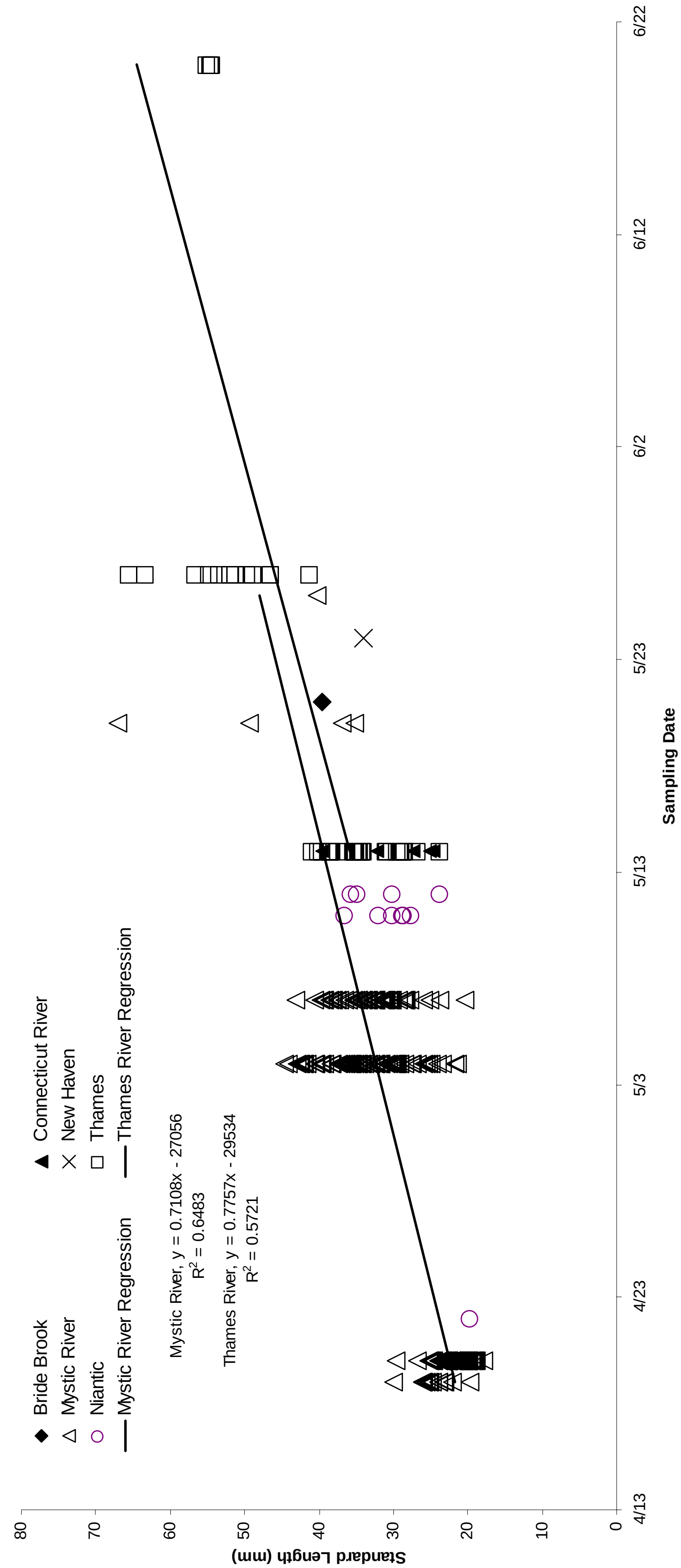

Standard Length (mm)
Sampling Date
100
90
80
70
60
50
40
30
20
10
0
4/29
5/19
6/8
6/28
7/18
8/7
8/27
Alewife Cove
Bride Brook
Connecticut
Mystic
New Haven
Poquonnock
Thames
New Haven
New Haven: y = 0.9229x - 34825
R2 = 0.8351

Figure 2.5. Relationship between standard length and sampling date for 2004. Linear regression, equation and R^2 value are given for the Mystic and Thames River samples.


Bride Brook
Mystic River
Niantic
Mystic River Regression
Connecticut River
New Haven
Thames
Thames River Regression
Mystic River, y = 0.7108x - 27056
R^2 = 0.6483
Thames River, y = 0.7757x - 29534
R^2 = 0.5721
Standard Length (mm)
Sampling Date
0
10
20
30
40
50
60
70
80
4/13
4/23
5/3
5/13
5/23
6/2
6/12
6/22

Appendix A.1. United States Fish Commission reports and bulletins reviewed for fishery statistics and anecdotal information. Reports are arranged in chronological order.

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Smiley, C. W. 1885. The Principal River Fisheries of the United States, with an Estimate of the Catch for 1880. Appendix B. The Fisheries. Part V. In: *Report of the Commissioner for 1883. Part XI. United States Commission of Fish and Fisheries*. Washington, Government Printing Office. pp. 279-301

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United States Commission of Fish and Fisheries. 1896. Report of the Commissioner for the Year Ending June 30, 1895. Part XXI. Washington, Government Printing Office.

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Zawacki, C. S. and P. T. Briggs 1976. Fish investigations in Long Island Sound at a nuclear power station at Shoreham, New York. *N.Y. Fish Game Journal* 23(1): 34-50.

Appendix. D.1. State of Connecticut Fish Commission reports reviewed for fishery statistics and anecdotal information. Reports are arranged in chronological order.

Connecticut Fish Commissioners 1867. *Report of the Commissioners Concerning the Protection of Fish in the Connecticut River, &C. to the General Assembly, May Session, 1867.* Case, Lockwood and Company, Printers, Hartford

Connecticut Fish Commissioners 1868. *Report of the Commissioners on Fisheries, to the General Assembly, May Session, 1868.* Thomas J. Stafford, State Printer, New Haven

Connecticut Fish Commissioners 1870. *Fourth Report of the Commissioners of Fisheries of the State of Connecticut. 1870*. Case, Lockwood & Brainard, Printers, Hartford, Conn.

Connecticut Fish Commissioners 1871. *Fifth Report of the Commissioners of Fisheries of the State of Connecticut, 1871*. Case, Lockwood & Brainard, Printers, Hartford, Conn.

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Connecticut Fish Commissioners 1878. *Twelfth Report of the Commissioners on Fisheries of the State of Connecticut, 1878*. Case, Lockwood & Brainard Company, Hartford, Conn.

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Connecticut Fish Commissioners 1881. *Fifteenth Report of the Fish Commissioners of the State of Connecticut, to the General Assembly, January Session, 1881.* Pelton & King, Printers and Book-Binders, Middletown, Conn.

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Connecticut Fish Commissioners 1881. *Sixteenth Annual Report of the Fish Commissioners and First Report of the Shell Fish Commissioners of the State of Connecticut, to the General Assembly, January Session, 1882.* Case, Lockwood & Brainard Company, Hartford, Conn.

Connecticut Fish Commissioners 1883. *Seventeenth Report of the Fish Commissioners of the State of Connecticut, to the General Assembly, January Session, 1883.* Case, Lockwood & Brainard Company, Hartford, Conn.

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Connecticut Fish Commissioners 1886. *Twenty-First Report of the Fish Commissioners of the State of Connecticut, to the General Assembly, January Session, 1887.* Case, Lockwood & Brainard Company, Hartford

Connecticut Fish Commissioners 1887. *Twenty-Second Report of the Fish Commissioners of the State of Connecticut, to the Governor, January, 1888.* Case, Lockwood & Brainard Company, Hartford

Connecticut Fish Commissioners 1888. *Twenty-Third Report of the Fish Commissioners of the State of Connecticut, to the Governor, January, 1889.* Case, Lockwood & Brainard Company, Hartford

Connecticut Commissioners of Inland Fisheries 1894. *Third Biennial Report and 27th and 28th Annual Reports of the Commissioners of Inland Fisheries to His Excellency the Governor, for the Fiscal Term Ending September 30, 1894.* Fowler & Miller Co., Printers and Binders, Hartford, Connecticut

Connecticut Commissioners of Fisheries and Game 1896. *Report of the State Commissioners of Fisheries and Game for the Years 1895-1896 to His Excellency the Governor, and the General Assembly.* Fowler & Miller Co., Printers and Binders, Hartford, Connecticut

Connecticut Commissioners of Fisheries and Game 1898. *Second Biennial Report of the State Commissioners of Fisheries and Game for the Years 1897-1898 to His Excellency the Governor, and the General Assembly.* R.S. Peck & Co., Printers, Hartford, Connecticut

Connecticut Commissioners of Fisheries and Game 1900. *Third Biennial Report of the State Commissioners of Fisheries and Game for the Years 1899=1900 to His Excellency the Governor, and the General Assembly.* Hartford Printing Company, Hartford, Connecticut

Connecticut Commissioners of Fisheries and Game 1902. *State of Connecticut. Public Document 19. Fourth Biennial Report of the State Commissioners of Fisheries and Game for the Years 1901-1902 to His Excellency the Governor, and the General Assembly.* Hartford Printing Company, Hartford, Connecticut

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Connecticut Commissioners of Fisheries and Game 1912. *State of Connecticut. Public Document 19. Ninth Biennial Report of the State Commissioners of Fisheries and Game for the Years 1911-1912 to His Excellency the Governor and the General Assembly.* State of Connecticut, Hartford, Connecticut

Connecticut Board of Fisheries and Game 1918. *State of Connecticut. Public Document 19. Twelfth Biennial Report of the State Board of Fisheries and Game for the Years 1917-1918 to His Excellency the Governor and the General Assembly.* State of Connecticut, Hartford, Connecticut

Connecticut Board of Fisheries and Game 1920. *State of Connecticut. Public Document 19. Thirteenth Biennial Report of the State Board of Fisheries and Game for the Years 1919-1920 to His Excellency, the Governor, and the General Assembly.* State of Connecticut, Hartford, Connecticut

Connecticut Board of Fisheries and Game 1922. *State of Connecticut. Public Document 19. Thirteenth Biennial Report of the State Board of Fisheries and Game for the Years 1921-1922 to His Excellency, the Governor, and the General Assembly.* State of Connecticut, Hartford, Connecticut

Connecticut Board of Fisheries and Game 1926. *State of Connecticut. Public Document 19. Sixteenth Biennial Report of the State Board of Fisheries and Game for the Years 1924-1926 to His Excellency the Governor and the General Assembly.* State of Connecticut, Hartford, Connecticut

Connecticut Board of Fisheries and Game 1928. *State of Connecticut. Public Document 19. Seventeenth Biennial Report of the State Board of Fisheries and Game for the Fiscal Years July 1, 1926 to June 30, 1928*. State of Connecticut, Hartford, Connecticut

Connecticut Board of Fisheries and Game 1930. *State of Connecticut. Public Document 19. Eighteenth Biennial Report of the State Board of Fisheries and Game for the Fiscal Year Ended June 30, 1930 to His Excellency, the Governor*. State of Connecticut, Hartford, Connecticut

Beck, T. H. 1931. *Report of Fish and Game Conditions in Connecticut and Six Year Program for State Board of Fisheries and Game to Hon. Wilbur L. Cross Governor of Connecticut*. State of Connecticut, Hartford, Connecticut

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Connecticut Board of Fisheries and Game 1936. *State of Connecticut. Public Document 19. Twenty-First Biennial Report of the State Board of Fisheries and Game for the Years 1934-1936 to His Excellency the Governor and the General Assembly*. State of Connecticut, Hartford, Connecticut

Connecticut Board of Fisheries and Game 1938. *State of Connecticut. Public Document 19. Twenty-Second Biennial Report of the State Board of Fisheries and Game for the Years 1936-1938 to His Excellency the Governor and the General Assembly*. State of Connecticut, Hartford, Connecticut

Appendix D.1. Continued.

Connecticut Board of Fisheries and Game 1940. *State of Connecticut. Public Document 19. Twenty-Third Biennial Report of the State Board of Fisheries and Game to His Excellency the Governor and the General Assembly for the Years 1938-1940*. State of Connecticut, Hartford, Connecticut

Connecticut Board of Fisheries and Game 1942. *State of Connecticut. Public Document 19. Twenty-Fourth Biennial Report of the State Board of Fisheries and Game for the Years 1940-1942*. State of Connecticut, Hartford, Connecticut

Connecticut Board of Fisheries and Game 1944. *State of Connecticut. Public Document 19. Twenty-Fifth Biennial Report of the State Board of Fisheries and Game for the Years 1942-1944*. State of Connecticut, Hartford, Connecticut

Appendix E.1. New York Times articles reviewed for information related to rainbow smelt (*Osmerus mordax*) and Atlantic tomcod (*Microgadus tomcod*). Articles were obtained by searching the ProQuest Historical Newspaper Database, *New York Times (1857 – Present*) (visit date March 9, 2004).

Adams, G. 1957. Fishing for all the Family. *New York Times*. Aug. 25, 1957
New York Times. 1854. Fishing. *New York Times*. July 10, 1854
----------------. 1872. Pisciculture. *New York Times*. April 28, 1872
----------------. 1877. Maryland Fisheries. *New York Times*. April 20, 1877
----------------. 1880. Propagating Smelts. *New York Times*. March 10, 1880
----------------. 1881. A Veteran Fisherman. *New York Times*. August 12, 1881
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----------------. 1886. New-York State Fish. *New York Times*. Nov. 1, 1886
----------------. 1888. A Cat Which Went Fishing. *New York Times*. Dec. 26, 1888
----------------. 1889a. In Many Waters. *New York Times*. February 24, 1889
----------------. 1889b. Lots of Fish Caught. *New York Times*. April 22, 1889
----------------. 1889c. Fishing in Barnegat Bay. *New York Times*. Aug. 18, 1889
----------------. 1889d. Big Hauls of Tomcod. *New York Times*. Dec. 20, 1889
----------------. 1890a. Sights at the Hatchery. *New York Times*. Feb. 11, 1890
----------------. 1890b. Work of the Hatcheries. *New York Times*. April 6, 1890
----------------. 1890c. Some Good Fishing Yet. *New York Times*. Sept. 13, 1890
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----------------. 1892. Report of the Fish Commission. *New York Times*. July 20, 1892
----------------. 1893a. Good News for Anglers. *New York Times*. Sept. 12, 1893
----------------. 1893b. Where the fish are biting. *New York Times*. October 27, 1893
----------------. 1894. Eighty Millions of Fish. *New York Times*. Jan. 6, 1894
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----------------. 1894c. Where Fish Are Biting. *New York Times*. May 4, 1894
----------------. 1894d. Cold Spring Harbor Fish Hatchery. *New York Times*. Sept. 21, 1894
----------------. 1895a. Trout may be exterminated. *New York Times*. March 19, 1895
----------------. 1895b. 3,000,000 Smelt Put in the Raritan. *New York Times*. April 26, 1895
----------------. 1895c. Jersey Fish and Game. *New York Times*. Nov. 13, 1895
----------------. 1907. Fish Hatcheries Report Big Output. *New York Times*. Nov. 10, 1907
----------------. 1907. Fishing and Fishermen. *New York Times*. Nov. 19, 1907
----------------. 1910a. State Fish Distribution. *New York Times*. April 25, 1910
----------------. 1910b. Little Fish Biting in Nearby Waters. *New York Times*. Nov. 6, 1910
----------------. 1912. Cold Weather Fishing. *New York Times*. Dec. 22, 1912
----------------. 1913. Nearby New York Lures and Angling Army of 100,000. *New York Times*. Aug. 10, 1913
----------------. 1923. Shad Catch Gains in Hudson River. *New York Times*. May 6, 1923
----------------. 1924. Saving the Fisheries. *New York Times*. April 15, 1924
----------------. 1927. Smelt in Jamaica Bay. *New York Times*. Oct. 5, 1927
----------------. 1982. 192 Species of Fish Abound in City Area of the Hudson. *New York Times*. April 1, 1982
Bryant, N. 1983. Outdoors: The Hudson as a Lure for Fish. *New York Times*. Oct. 10, 1983
Camp, R. R. 1941. Wood, Field and Stream. *New York Times*. Feb. 13, 1941

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Fried, J. P. 1971. Survey Shows 18 Jersey Fish and Wildlife Species Imperiled, Mostly by Man. *New York Times*. Sept. 7, 1971

Greenfield, G. 1936. Wood, Field and Stream. *New York Times*. June 12, 1936

Rendel, J. 1944. New of Wood, Field and Stream. *New York Times*. Feb. 19, 1944

Sutton, G. W., Jr. 1931. The Fishing Boatman Goes Out. *New York Times*. May 10, 1931

Waldman, J. 1984. Outdoors: A Cool Descent Into the Intriguing Croton. *New York Times*. June 25, 1984

Appendix F.1. Historical literature from the Commonwealth of Massachusetts, reviewed for information related to rainbow smelt (*Osmerus mordax*).

Massachusetts Secretary of the Commonwealth. 1887. *Laws relating to Inland Fisheries in Massachusetts. 1623-1886*. Wright & Potter Printing Co., State Printers, Boston, Massachusetts

Massachusetts Commissioners of Fisheries and Game. 1905. Public Document No. 25. Report of the Commissioners of Fisheries and Game for the Year Ending December 31, 1905. Boston, Massachusetts.

Massachusetts Division of Fisheries and Game. 1922. Public Document No. 25. The Commonwealth of Massachusetts. Department of Conservation. Annual Report of the Division of Fisheries and Game for the Year Ending November 30, 1922.

Massachusetts Division of Fisheries and Game. 1923. Public Document No. 25. The Commonwealth of Massachusetts. Department of Conservation. Annual Report of the Division of Fisheries and Game for the Year Ending November 30, 1923.

Massachusetts Division of Fisheries and Game. 1924. Public Document No. 25. The Commonwealth of Massachusetts. Department of Conservation. Annual Report of the Division of Fisheries and Game for the Year Ending November 30, 1924.

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Massachusetts Division of Fisheries and Game. 1932. Public Document No. 25. The Commonwealth of Massachusetts. Department of Conservation. Annual Report of the Division of Fisheries and Game for the Year Ending November 30, 1932.

Massachusetts Division of Fisheries and Game. 1939. Public Document No. 25. The Commonwealth of Massachusetts. Department of Conservation. Annual Report of the Division of Fisheries and Game for the Year Ending November 30, 1939.

Appendix G.1. Current Connecticut General Statutes related to rainbow smelt (*Osmerus mordax*) and Atlantic tomcod (*Microgadus tomcod*) obtained from the website of the Connecticut General Assembly (http://search.cga.state.ct.us/ ; visit date January 4, 2005).

VOL 8, TITLE 26, CHAPTER 490 FISHERIES AND GAME

Secs. 26-144 to 26-148. Nets for taking tomcod or frost fish. Smelt and tomcod; nets, registration and fee. Taking of smelt and tomcod; open season, net specifications, designated time and area, penalty. Eel pots. Shad; nets; penalty. Set nets for taking shad in Connecticut and Farmington Rivers.
Sections 26-144 to 26-148, inclusive, are repealed.
(1949 Rev., S. 4953, 4956—4959; 1949, S. 2537d; March, 1958, P.A. 27, S. 42; 1971, P.A. 872, S. 316—319; P.A. 74-348, S. 5, 6, 10, 11; P.A. 75-567, S. 53, 80; P.A. 80-164, S. 4, 5.)

Sec. 26-171. Taking smelt in Greenwich. No person shall take any smelt in any of the waters of Long Island Sound, or in any river or creek or tributary thereof lying north and east of a line drawn from the southwest end of J. Kennedy Tod's Point to what is known as W. M. Ritch's Dock in Byram Harbor, in the town of Greenwich, otherwise than with a hook and line.
(1949 Rev., S. 4984.)

Sec. 26-177. Mystic River. No person shall draw any seine in the Mystic River north of a line running due east from the lighthouse in Groton, from April fifteenth to November first. No person shall draw or assist in drawing any seine for the purpose of taking fish in said river north of the upper bridge, known as Mystic Bridge, or in the waters of Stonington above the railroad bridge. No person shall catch smelt in said river or its tributaries except with hook and line.
(1949 Rev., S. 4991.)

Sec. 26-179. Taking smelt in Groton. No person shall take or assist in taking or attempt to take any smelt from the waters of Palmer's Cove, Poquonock River or Baker's Cove, or their tributaries, in the town of Groton, by means of a net, seine or trap.
(1949 Rev., S. 4992.)

Appendix A.2. GPS (Magellan - Meridian Platinum) and map coordinates for fyke and weir trap sampling locations. GPS coordinates are given in degrees and decimal minutes.

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Estuary / River	Latitude (N)	Longitude (W)	Source
Thames	41° 20.804'	-072° 02.273'	GPS
Connecticut	41° 30.213'	-072° 29.605'	GPS
Thames	41° 20.804'	-072° 02.273'	GPS
Connecticut	41° 19.499'	-072° 10.572'	GPS

Appendix B.2. GPS (Magellan - Meridian Platinum) and map coordinates for smelt egg sampling locations during 2003 and 2004. GPS coordinates are given in degrees and decimal minutes.

Estuary / River	**Latitude (N)**	**Longitude (W)**	**Source**
Bride Brook	41° 19' 0.1"	-072° 14' 37.6"	Map
Connecticut	41° 23' 41.0"	-072° 21' 0.9"	Map
Connecticut	41° 19.499'	-072° 10.572'	GPS
Connecticut	41° 30.213'	-072° 29.605'	Map
Connecticut	41° 25' 15.4"	-072° 24' 47.7"	Map
Quinnipiac	41° 20' 11.7"	-072° 54' 36.1"	Map
Quinnipiac	41° 25' 56.6"	-072° 51' 2.8"	Map
Quinnipiac	41° 27' 29.0"	-072° 50' 9.0"	Map
Quinnipiac	41° 25' 9.5"	-072° 51' 4.9"	Map
Niantic	41° 22' 22.5"	-072° 11' 30.0"	Map
Thames	41° 24.010'	-072° 06.688'	GPS
Thames	41° 27.166'	-072° 06.340'	GPS
Thames	41° 26.197'	-072° 06.367'	GPS
Thames	41° 29.688'	-072° 05.932'	GPS
Thames	41° 29.211'	-072° 02.619'	GPS

Appendix C.2. Map coordinates for gillnet sampling locations.

Estuary	Latitude (N)	Longitude (W)	Source
CT River	41° 28' 9.2"	-072° 28' 11.2"	Map
CT River	41° 28' 1.1"	-072° 28' 31.1"	Map
CT River	41° 27' 46.9"	-072° 28' 16.0"	Map
CT River	41° 27' 28.7"	-072° 28' 9.6"	Map
CT River	41° 22' 23.6"	-072° 22' 19.2"	Map
CT River	41° 22' 4.3"	-072° 22' 28.3"	Map
CT River	41° 21' 43.1"	-072° 22' 45.0"	Map
CT River	41° 22' 10.0"	-072° 22' 39.8"	Map
Mystic	41° 20' 33.2"	-071° 57' 36.5"	Map
Mystic	41° 20' 49.6"	-071° 57' 40.6"	Map
Mystic	41° 20' 54.8"	-071° 58' 14.1"	Map
Mystic	41° 20' 43.6"	-071° 58' 25.4"	Map
Mystic	41° 22' 9.5"	-071° 57' 58.5"	Map
Mystic	41° 22' 8.1"	-071° 57' 54.8"	Map
Mystic	41° 22' 5.6"	-071° 57' 52.4"	Map
Mystic	41° 22' 2.5"	-071° 57' 52.3"	Map
New Haven	41° 15' 25.5"	-072° 53' 55.5"	Map
New Haven	41° 19' 13.1"	-072° 53' 12.9"	Map
New Haven	41° 19' 26.4"	-072° 53' 25.8"	Map
New Haven	41° 19' 3.6"	-072° 52' 59.3"	Map
Niantic	41° 20' 25.2"	-072° 10' 26.6"	Map
Niantic	41° 20' 50.0"	-072° 11' 0.5"	Map
Niantic	41° 20' 55.4"	-072° 11' 12.0"	Map
Niantic	41° 21' 53.5"	-072° 11' 34.4"	Map
Niantic	41° 20' 47.6"	-072° 11' 23.5"	Map
Niantic	41° 20' 49.3"	-072° 10' 38.3"	Map
Niantic	41° 20' 15.9"	-072° 11' 5.5"	Map
Niantic	41° 19' 54.3"	-072° 10' 57.4"	Map
Poquonnock	41° 19' 40.1"	-072° 3' 18.4"	Map
Poquonnock	41° 19' 4.7"	-072° 3' 9.3"	Map
Poquonnock	41° 19' 13.5"	-072° 3' 0.0"	Map
Poquonnock	41° 19' 12.6"	-072° 2' 56.8"	Map
Poquonnock	41° 19' 35.6"	-072° 2' 32.4"	Map
Poquonnock	41° 19' 42.7"	-072° 2' 18.2"	Map
Poquonnock	41° 19' 55.0"	-072° 2' 10.3"	Map
Poquonnock	41° 20' 2.9"	-072° 2' 10.3"	Map
Thames	41° 29' 38.8"	-072° 5' 0.2"	Map
Thames	41° 27' 59.2"	-072° 4' 0.6"	Map
Thames	41° 27' 31.2"	-072° 4' 29.0"	Map
Thames	41° 29' 58.0"	-072° 5' 1.6"	Map
Thames	41° 26' 20.1"	-072° 5' 33.9"	Map
Thames	41° 26' 19.9"	-072° 5' 47.8"	Map
Thames	41° 27' 5.2"	-072° 5' 7.7"	Map

Appendix D.2. Map coordinates for ichthyoplankton samples collected during the spring of 2003.

Estuary	**Latitude (N)**	**Longitude (W)**	**Source**
Mystic	41° 22' 6.7"	-071° 57' 55.8"	Map
Mystic	41° 21' 54.4"	-071° 57' 53.1"	Map
Mystic	41° 20' 58.6"	-071° 58' 13.6"	Map
New Haven	41° 19' 9.7"	-072° 53' 13.6"	Map
New Haven	41° 18' 6.8"	-072° 53' 35.9"	Map
New Haven	41° 18' 31.1"	-072° 53' 17.2"	Map
New Haven	41° 16' 59.3"	-072° 56' 22.4"	Map
New Haven	41° 17' 57.2"	-072° 54' 11.9"	Map
New Haven	41° 18' 6.8"	-072° 54' 18.1"	Map
Thames	41° 31' 15.5"	-072° 4' 42.9"	Map
Thames	41° 28' 58.3"	-072° 4' 31.8"	Map
Thames	41° 27' 51.6"	-072° 4' 4.3"	Map

Appendix E.2. GPS (Magellan - Meridian Platinum) coordinates for the start location for ichthyoplankton samples collected during the spring of 2004. GPS coordinates are given in degrees and decimal minutes.

Estuary	**Latitude**	**Longitude**	**Source**
Thames	41° 31.007’	-072° 04.697’	GPS
Thames	41° 28.896’	-072° 04.493’	GPS
Thames	41° 27.673’	-072° 04.111’	GPS
Thames	41° 26.682’	-072° 05.001’	GPS
Thames	41° 23.754’	-072° 05.834’	GPS
Poquonnock	41° 18.884’	-072° 03.671’	GPS
Poquonnock	41° 19.213’	-072° 03.986’	GPS
Poquonnock	41° 03.003’	-072° 02.953’	GPS
Poquonnock	41° 19.804’	-072° 02.109’	GPS
Mystic	41° 21.371’	-071° 58.078’	GPS
Mystic	41° 22.189’	-071° 58.014’	GPS
Mystic	41° 23.054’	-071° 57.778’	GPS
Mystic	41° 19.512’	-071° 59.028’	GPS
Mystic	41° 20.970’	-071° 58.216’	GPS
CT River	41° 28.734’	-072° 29.795’	GPS
CT River	41° 28.226’	-072° 28.233’	GPS
CT River	41° 25.666’	-072° 26.085’	GPS
CT River	41° 22.468’	-072° 22.269’	GPS
New Haven	41° 17.157’	-072° 56.436’	GPS

Appendix F.2. GPS (Magellan - Meridian Platinum) and map coordinates for box trap sampling locations. GPS coordinates are given in degrees and decimal minutes.

River/Estuary	Latitude (N)	Longitude (W)	Source
Black Hall River	41° 17.433’	-072° 18.760’	GPS
Bride Brook	41° 18.156’	-072° 14.343’	GPS
Connecticut	41° 31.484’	-072° 04.739’	GPS
Connecticut	41° 19.495’	-072° 20.500’	GPS
Connecticut	41° 19' 8.0"	-072° 21' 1.6"	Map
Hamburg Cove	41° 21.994’	-072° 19.858’	GPS
Lieutenant River	41° 19.494’	-072° 20.503’	GPS
Mystic	41° 22' 16.3"	-071° 58' 0.4"	Map
Mystic	41° 21.354’	-071° 58.023’	GPS
Mystic	41° 22.283’	-071° 58.026’	GPS
Mystic	41° 19.495’	-071° 59.114’	GPS
Mystic	41° 23.107’	-071° 57.455’	GPS
Mystic	41° 23' 11.4"	-071° 57' 45.3"	Map
Niantic	41° 19.499’	-072° 10.572’	GPS
Poquonnock	41° 20.804’	-072° 02.273’	GPS
Poquonnock	41° 20.479’	-072° 02.126’	GPS
Poquonnock	41° 20.104’	-072° 02.135’	GPS
Quinnipiac	41° 16' 52.9"	-072° 56' 18.1"	Map
Quinnipiac	41° 16' 54.7"	-072° 55' 40.6"	Map
Quinnipiac	41° 21' 52.1"	-072° 52' 43.0"	Map
Quinnipiac	41° 17' 56.1"	-072° 54' 14.7"	Map
Quinnipiac	41° 18' 7.0"	-072° 53' 35.1"	Map
Quinnipiac	41° 18' 31.0"	-072° 53' 16.7"	Map
Quinnipiac	41° 19' 14.8"	-072° 53' 20.6"	Map
Quinnipiac	41° 19' 13.3"	-072° 53' 23.2"	Map
Quinnipiac	41° 19' 20.9"	-072° 53' 29.4"	Map
Quinnipiac	41° 18' 10.0"	-072° 53' 32.8"	Map
Thames	41° 21.819’	-072° 05.082’	GPS
Thames	41° 29' 6.6"	-072° 4' 33.2"	map
Thames	41° 31' 30.6"	-072° 4' 56.8"	Map
Whitford Brook	41° 23.691’	-071° 57.643’	GPS
Whitford Brook	41° 23.691’	-071° 57.643’	GPS

Appendix G.2. GPS (Magellan - Meridian Platinum) and map coordinates for seine sampling locations. GPS coordinates are given in degrees and decimal minutes.

River/Estuary	Latitude (N)	Longitude (W)	Source
Alewife Cove	41° 18' 21.9"	-072° 6' 11.2"	Map
Alewife Cove	41° 18' 18.9"	-072° 6' 9.1"	Map
Bride Brook	41° 18' 0.3"	-072° 14' 7.7"	Map
Connecticut	41° 28.871’	-072°30.370’	GPS
Connecticut	41° 18.877’	-072° 20.681’	GPS
Connecticut	41° 22.363’	-072° 22.327’	GPS
Connecticut	41° 19.784’	-072° 20.783’	GPS
Connecticut	41° 28.452’	-072° 29.129’	GPS
Connecticut	41° 28.518’	-072° 29.114’	GPS
Connecticut	41° 20' 46.6"	-072° 22' 3.2"	Map
Connecticut	41° 21' 27.6"	-072° 22' 54.5"	Map
Hammonasset	41° 15' 11.8"	-072° 32' 12.5"	Map
Mumford Cove	41° 19' 15.3"	-072° 1' 12.8"	Map
Mystic	41° 22.457’	-071° 57.948’	GPS
Mystic	41° 22.442’	-071° 57.959’	GPS
Mystic	41° 20.740’	-071° 57.605’	GPS
Mystic	41° 22.159’	-071° 57.899’	GPS
Mystic	41° 20.404’	-071° 57.577’	GPS
Mystic	41° 19' 45.7"	-071° 59' 21.7"	Map
Mystic	41° 19' 58.8"	-071° 58' 41.3"	Map
Mystic	41° 19' 44.1"	-071° 58' 41.0"	Map
Mystic	41° 19' 5.2"	-071° 58' 34.6"	Map
Niantic	41° 19.370’	-072° 10.687’	GPS
Niantic	41° 19.582’	-072° 10.500’	GPS
Niantic	41° 20.203‘	-072° 10.479’	GPS
Niantic	41° 21.625’	-072° 11.528’	GPS
Niantic	41° 19' 3.8"	-072° 11' 52.0"	Map
Niantic	41° 22' 15.3"	-072° 11' 34.1"	Map
Pawcatuck	41° 20' 10.4"	-071° 52' 13.2"	Map
Poquonnock	41° 20.404’	-072° 02.027’	GPS
Poquonnock	41° 20.098’	-072° 02.000’	GPS
Poquonnock	41° 19' 6.3"	-072° 3' 5.0"	Map
Poquonnock	41° 18' 54.3"	-072° 3' 18.4"	Map
Poquonnock	41° 19' 17.1"	-072° 2' 57.6"	Map
Poquonnock	41° 19' 11.7"	-072° 2' 55.1"	Map
Poquonnock	41° 19' 46.6"	-072° 2' 13.1"	Map
Poquonnock	41° 20' 47.3"	-072° 2' 16.6"	Map
Poquonnock	41° 19' 11.7"	-072° 2' 38.4"	Map
Thames	41° 28.562’	-072° 04.593’	GPS
Thames	41° 24.081’	-072° 05.958’	GPS
Thames	41° 28' 16.2"	-072° 3' 35.3"	Map
Thames	41° 22' 3.1"	-072° 5' 42.3"	Map
Thames	41° 23' 46.1"	-072° 6' 4.4"	Map
Thames	41° 26' 17.3"	-072° 5' 50.3"	Map