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of the

ATLANTIC STATES MARINE FISHERIES COMMISSION

Fishery Management Plan for Inshore Stocks of Winter Flounder

May 1992

FISHERY MANAGEMENT PLAN
FOR
INSHORE STOCKS OF
WINTER FLOUNDER
Pleuronectes americanus

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Part One Page

INTERSTATE MANAGEMENT PLAN FOR INSHORE STOCKS OF WINTER FLOUNDER

SUMMARY

Effective management of winter flounder *(Pleuronectes americanus)* at stock sizes which can sustain stable, productive fisheries over the long term will require restraints on fishing mortality as well as on indirect mortality due to loss of productive habitat. This document outlines management actions to reduce both mortality sources. The purpose of the plan is to conserve and manage winter flounder stocks for the utilization of current and future generations of the fishing and non–fishing public.

Winter flounder is a common estuarine flatfish found in almost all shoal water habitats along the northwest Atlantic coast. Genetically identifiable flounder stocks are numerous, with individual estuaries providing winter spawning grounds. Stock groups consist of an assemblage of adjacent estuarine spawning units. These fish return to natal spawning areas after relatively limited seasonal migrations offshore. At least one offshore stock, on Georges Bank, has been identified. All of these flounder populations vary among themselves in growth rate, longevity, and female maturation schedule. Recognizing the range of variability in this species, as well as current and historical exploitation patterns, this plan identifies three stock units, from Maine to Delaware inclusive, where growth, seasonal movement, and female maturity schedules are similar enough to be modeled as one biological unit. Georges Bank flounder could be considered a fourth stock unit under the jurisdiction of the New England Fishery Management Council and not addressed here.

For all three stock units, current fishing rates are above target levels (F_{40}), a rate which would preserve the spawning stock at 40% of its maximum spawning potential (MSP) after fishing. MSP is defined as the maximum stock biomass of spawning females in the absence of fishing. Current fishing mortality on some populations exceeds that which will preserve 25% of MSP (F_{25}). Stock decline is believed to be probable when fishing mortality exceeds F_{25}.

Commercial landings have generally declined from a peak in 1980–82 (average 29.1 million lbs.) to an average of 14.5 million lbs. in 1986–88. During the same period (1979–89), recreational catches averaged 12.5 million lbs., with the lowest catches in 1987–89. Significant downward trends in catch were seen in the northern (north Cape Cod and inshore Gulf of Maine) and central (east Cape Cod to eastern Long Island Sound) stock units.

The management strategy proposed in this plan is to initially reduce fishing mortality to prevent overfishing (current F less than F_{25}), and secondly to approach or achieve target levels (F_{40}). For the mid–Atlantic stock, F_{25} can be achieved with a 10" length limit for all fisheries, with a 4.5" codend mesh size (diamond), and existing area closures. For the southern New England and the Gulf of Maine stocks, F_{25} can be achieved with a 12" length limit for all fisheries, with a 5.5" codend mesh size (diamond), and area closures existing prior to July 1991. Alternatives to these recommended measures which would achieve the same objectives could include larger minimum length limits and mesh sizes, more restrictive creel limits, or more extensive area closures. However, comparable management actions are required in the Exclusive Economic Zone in order to achieve effective management of inshore stocks. Minimum action would be a 12" length limit and 5.5" codend mesh size (diamond) to postpone fishing mortality to mature age groups.

A variety of management measures, in addition to those listed above, are recommended to meet F_{30}, as an intermediate step, and F_{40}. Additional measures could include additional area, season, or time–of–day closures; restrictions on vessel characteristics or use, creel limits, or other effort reductions.

This plan also recognizes the crucial role shallow water habitats play in determining the ultimate productivity of these stocks. A relationship between stock size and spawning area is demonstrated here. Three anthropogenic mortality factors exerting long-term deleterious effects on winter flounder habitat quality are detailed: toxic compounds, habitat loss and alteration, and power plant entrainment and impingement. Specific effects are quantified as much as possible, but further study incorporating these mortality factors into fishery yield models is needed. Recommended actions include minimizing sewage discharge, or increasing waste treatment level, in spawning and nursery areas subject to hypoxia; placing exclusionary time frames on permitted dredging within or bracketing a core time period from January 15 to May 15 to prevent egg and larval mortality; standardization of power plant impact assessment so that losses due to entrainment include separate mortality values for planktonic and benthic larval stages in computation of adult equivalent losses; and avoidance of the upper reaches (retention areas) of known spawning grounds when siting new power plants.

An introductory economic analysis is provided. The recreational fishery produces much greater economic values ($16–48 million in 1988) than the commercial fishery ($3–6 million). However, the commercial fishery produces greater economic impact (mean sales impact estimate of $72 million; household income $36 million; employment 2960 people) than the recreational fishery (mean sales $28 million; household income $15 million; employment 635 people). Although commercial landings have generally declined over the last decade, nominal ex-vessel prices per pound have nearly tripled. Landing values have increased somewhat, reaching a high of $17.9 million in 1988. Real ex-vessel prices (adjusted by the Consumer Price Index) approximately doubled between 1979 and 1988.

PART 1: STATUS OF WINTER FLOUNDER HABITAT

A. Anthropogenic Activities and Habitat Quality

The effects of habitat modification on local fish stocks are often indirect, gradual, and unquantifiable. They are also additive and interactive. A single physical modification can be perceived as insignificant merely by relating it to a large geographic area, length of time, or array of habitat elements within which the modification is described (Burns 1991). Each modification may then be regarded as of little consequence to a given population because the extent of impact in time and space cannot be separated from other actions. However, this problem of scale is more one of perception than measurement. Even without application of quantitative techniques, individual small-scale effects on fish habitat clearly have cumulative effects on regional fisheries (Burns 1991).

For these reasons, habitat issues usually present an intractable problem for management of marine fish stocks. Habitat quality is of particular importance to winter flounder because the geographic location of its spawning grounds, and limited seasonal movements, make this species particularly susceptible to habitat degradation. Nursery habitat includes littoral and sublittoral saltwater coves, coastal salt ponds, estuaries, and protected embayments (see *Species Profile*). The proximity of these habitats to many human activities expose winter flounder to the effects of habitat loss and alteration, effects of toxic contaminants, and entrainment and impingement in power plant coolant systems. The result can be an insidious loss of reproductive and growth potential.

In recent decades, there has been a considerable alteration of nearshore habitat, primarily due to human activities. Three-quarters of all estuaries nationwide were classified as moderately or severely degraded in the National Estuary Study completed in 1970 (Gusey 1978, 1981). Along with exogenous contaminant addition to the nearshore environment, loss of nearshore shallow habitat due to filling, or dredging, is detrimental to winter flounder production. Off Atlantic coastal states, loss of shallow water acreage averaged 4% by state from 1954-68 (Gusey 1978, 1981). However, the average loss for Massachusetts to New Jersey, the center of flounder population abundance, was 6-15%. Other than a few limited restoration projects, this loss has been permanent. Specific recommendations for mitigation are discussed in Part 3B.

B. Habitat Quantity and Population Size

In order to better address the importance of habitat size to the abundance of associated winter flounder populations, a current hypothesis (Sinclair 1988) which relates a species' population richness, or number of populations, to the number of geographic settings within which the species life cycle is capable of closure (retention areas) was applied to flounder populations. The hypothesis makes the logical extension that the absolute or mean size of each population is scaled to the size of these retention areas. Geographic areas whose physical features lead to larval retention, thereby enhancing spawning success and stock cohesion, have been identified for several species (Sinclair 1988). Estimates for flounder populations, giving population size and production (retention) area, were extracted from the published literature (Gibson 1991a, Table 1.1). Production area was defined as the inshore embayment, estuary, salt pond, or offshore bank where spawning aggregations occur. Standing stock numbers are either direct adult population estimates from tagging studies on spawning grounds, or indirect adult estimates from known catch divided by estimated exploitation rate for that stock. Log population size was significantly correlated to the log of habitat area for twelve flounder populations (Figure 1.1). Although the level of precision of this

Table 1.1: Winter flounder population size and associated habitat area.

Stock Location	Method	Estimated Habitat Area	Population Size
Georges Bank (NMFS 1989, Lux 1973)	2	11,580,366	11,954,248
St. Marys Bay NS (Dickie and McCracken 1955)	2	134,400	1,821,039
Narragansett Bay RI (Gibson 1989b, 1990)	1	84,063	6,385,057
Great S.Bay NY (Lobell 1939, Briggs 1965, Poole 1966)	2	81,920	2,458,171
Barnegat Bay NJ (P.Scarlett pers.comm., Gibson 1991a)	2	72,593	4,013,937
Peconic Bay NY (Lobell 1939, Briggs 1965, Poole 1966)	2	14,515	285,300
Moriches Bay NY (Lobell 1939, Briggs 1965, Poole 1966)	2	8,687	1,513,489
Pt. Judith Pd. RI (Grove 1982)	1	1,576	38,700
Ninnigret Pd. RI (Saila 1961b)	1	1,560	137,800
Ninnigret Pd. RI (Worobec 1982)	1	1,560	38,000
Waquoit Bay, MA (Howe et al. 1976)	1	1,211	51,845
Niantic R. CT (NUSCo. 1990)	1	721	62,998
Green Hill Pd., RI (Saila 1961a)	1	475	11,320
Upper Narragansett Bay (Gibson 1989b, 1990)	1	336	21,936

1 Tagging method
2 Exploitation method

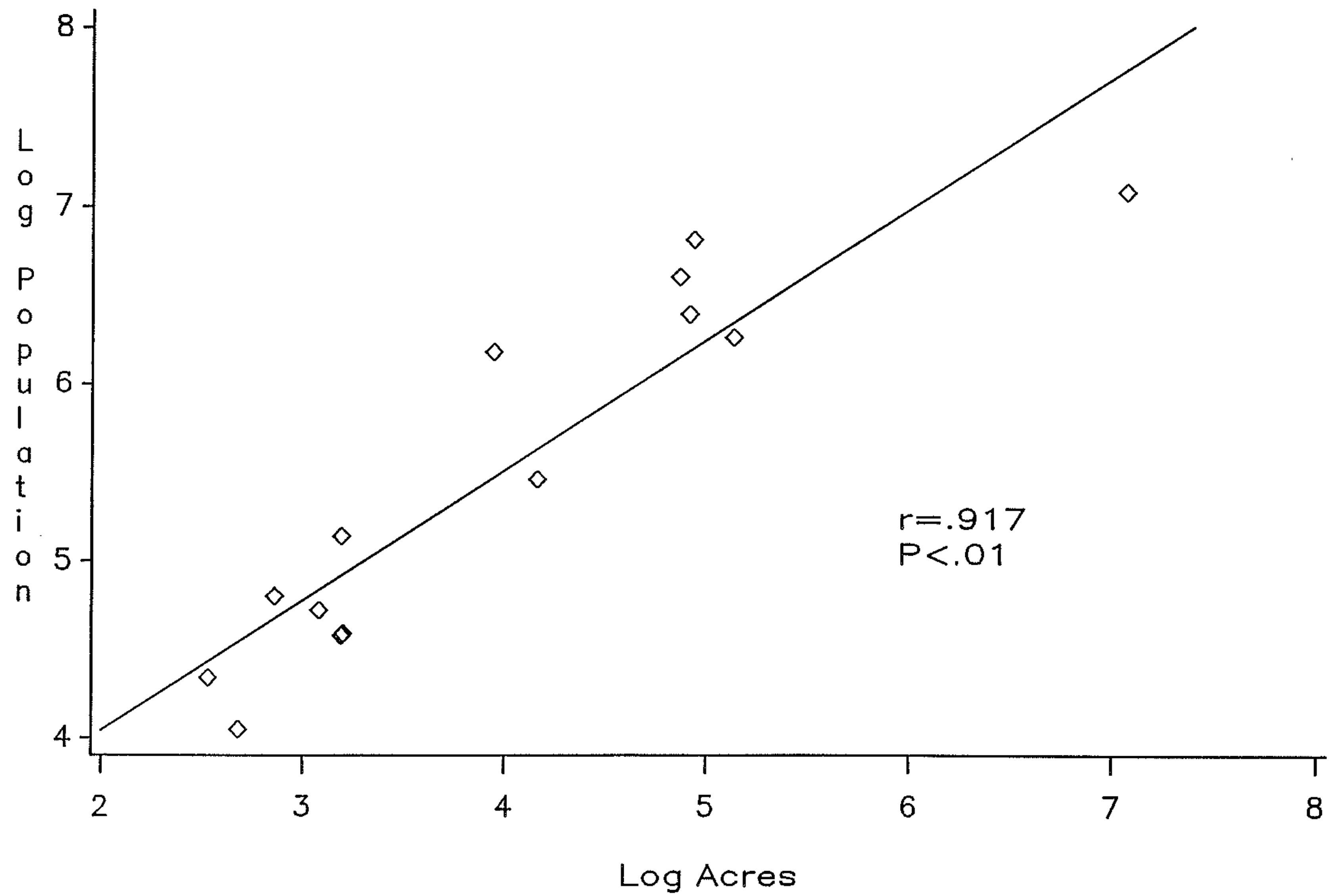

Figure: 1.1 Winter Flounder Stock Size vs. Habitat Area relationship is sufficient only to make estimates as an order of magnitude, it clearly shows that there is a consistent pattern in the population density across many winter flounder habitats. Large flounder populations are associated with large physical structures which promote larval retention such as bays and offshore banks. Small populations are associated with structures such as coastal ponds and estuaries. It logically follows that degradation or loss of habitat will reduce standing stock size. More importantly, the relationship between population and area is not constant from small to large sizes, reflecting the fact that production per unit area decreases with total area. This functional form suggests that changes in habitat area will be most influential over stock size in small populations where the slope of the curve is steepest when taken out of a log scale. Many flounder spawning groups have been found to have a limited range of movement, with juvenile movement equally limited. It is possible then for each of these spawning populations, especially smaller ones, to gradually diminish from localized mortality factors without any obvious cause.

C. Temporal Habitat Alteration

In addition to permanent habitat loss, temporary impacts to coastal estuaries are a concern. Coastal development and land use patterns make mechanical dredging and dredged material disposal a common occurrence. Many of these dredging projects are performed in the vicinity of winter flounder spawning and nursery grounds during the period when early life stages are most vulnerable to the effects of sediment resuspension.

Data linking dredging impacts and reduced winter flounder recruitment were obtained recently when a dredging event took place in Milford Harbor, CT, during a three-year study of winter flounder reproductive success (Rusanowsky *et al. in press*). Commencing on March 5, 1988 and for nearly three months thereafter, at least one clamshell dredge and barge removed 97,000 cubic yards of silty clay sediment that had accumulated in the navigational channel and adjacent dockage areas. Contaminant assays performed by the US Army Corps of Engineers showed that, with the exception of cadmium, harbor sediments contained low to moderate contaminant levels. Fine sediment fractions, resuspended by the dredging operation, were dispersed in a plume that engulfed much of the harbor. Some of those particles were entrained in seawater that was pumped into the NMFS Milford Laboratory and subsequently drawn through a sand filtering system that removed all but the finest sediment fractions. This water was used in experiment tanks containing winter flounder embryos from six Long Island Sound and two Boston Harbor sites.

As a consequence of their exposure to the effected seawater and suspended sediment, normal larval development and behavior were adversely affected. Significantly diminished hatchability and yolk metabolism measured in winter flounder embryos and larvae that survived indicated that dredging had a catastrophic impact on larval survival. This conclusion was drawn after comparison of cultures exposed to the dredged sediment to cultures from the same sites which developed just prior to the onset of dredging (N=98 cultures of 200 embryos each) and in previous years (Rusanowsky *et al. in press*). Total hatchability of embryos exposed to dredging conditions prior to attaining tail–bud stage declined approximately fourfold over cultures that had been monitored prior to commencement of the dredging. Percent viable hatch declined from a mean of 29% (SD=16.7, N=39 cultures) to 6% (SD=10.3, N=59 cultures, P=0.0001) for larvae exposed to dredged material prior to attaining that stage. This net reduction, in conjunction with other recruitment parameters measured in the study, reflects an increase in all forms of embryonic death.

Among larvae that managed to hatch successfully, yolk utilization was reduced as much as threefold. Compared with cultures from previous years, the yolk–sac volumes of larvae exposed to dredging were up to 40% larger than expected. The most serious behavioral impact observed in exposed larvae was a complete failure to exhibit positive phototropism. Larval ability to influence their position in the water column and remain in the nursery area, depends upon that particular attribute (Klein-McPhee 1978; NUSCo 1989). These observations collectively demonstrate that the laboratory's larval population samples were decimated by the dredging activity.

The effect of dredging operations on the distribution of adult shore-zone fishes over naturally vegetated and dredged sand-filled bottoms was investigated in Great South Bay, NY (Briggs and O'Connor 1971). Paired sites sampled within the bay showed that winter flounder occurred in both habitat types, but were significantly more abundant in the naturally vegetated bottom.

Winter flounder spawning sites occur within hydrodynamically conservative basins which facilitate larval retention (Pearcy 1962; Crawford and Carey 1985). Conflicts can arise when nearshore habitat must be managed for multiple use as nursery ground, harvest area and human recreation (Crawford 1990). The relationship between hydrodynamics and the quality of nursery habitat should be considered when dredging activities are contemplated.

Seasonal habitat losses also appear to be occurring in shallow coastal lagoons and salt ponds through high nutrient loading and growth of marine macroalgae. Burgeoning residential development and attendant leaching of sewage and fertilizer have been major sources of nitrogen to groundwater and to tidal waters in the northeastern coastal plain over the last 40 years. Macroalgae (*Ulva, Enteromorpha, Cladophora,* and *Gracilaria*) has increased significantly, out-competing seagrasses (*Ruppia, Zostera*) and threatening the quality of salt ponds for spawning and nursery grounds (Lee and Olsen 1985). In Cape Cod's Waquoit Bay, high density macroalgae blanket the bottom in summer, thereby restricting light, oxygen, and juvenile fish movements. Associated biological oxygen demand has contributed to recent anoxic events and several flounder kills (Deegan, pers. comm.). Substantial research, regulatory and educational effort is needed to understand the relationship between nutrient loading and flounder production, and reduce loadings to estuarine spawning and nursery grounds, and public water supplies.

D. Disease and Toxic Contaminants

Even when habitat is not permanently lost it can be degraded in such a way to greatly reduce the size and health of the flounder population it can support. Diseases and biological anomalies in winter flounder have been increasingly linked to the presence of contaminants in the marine environment. Winter flounder are particularly susceptible to the effects of annual or periodic contaminant exposure because of their physical contact with polluted sediments, and their ingestion of contaminated sediment and/or benthic organisms.

Recent review of the status of all U.S. estuaries (NOAA 1990a) showed that the greatest number of pollution point sources were in the Gulf Coast and the mid-Atlantic (defined as south of Cape Cod to Chesapeake Bay inclusive) regions (Tables 1.2–1.3). As a measure of non-point pollution sources, enumeration of the percent of urbanized land showed the mid-Atlantic was again highly impacted. A second measure of non-point source pollution, pesticide usage per square mile of estuary, was also high in the mid-Atlantic. When all these factors are taken together, it is not surprising that the greatest percentage of contaminated sites were also found in the mid-Atlantic region (Tables 1.2–1.3). The lower percentage in the North Atlantic region masks a high number of contaminated sites surrounding metropolitan Boston. This area, from Boston

Table 1.2: Impacts to U.S. estuarine drainage areas (EDA) by region. (Data source: NOAA 1990a)

Region	POINT SOURCES Industrial and Municipal Sewage	NON-POINT SOURCES Urban Land (% EDA)	Pesticide Usage (lbs/sq.mi. cropland)
N. Atlantic (ME–N. MA)	300	7	276
M. Atlantic (S. MA–VA)	2700	19	1148
S. Atlantic (NC–E. FL)	1200	4	1170
Gulf of Mexico (W. FL–TX)	3300	5	366
Pacific (WA–CA)	1000	12	250

===

Table 1.3: Percentage of highly contaminated sites by state in the coastal U.S. Highly contaminated sites are those with concentrations of more than five contaminants ranking in the top 20 of 211 sites examined nationwide (Data Source: NOAA 1988b).

State	Number Sites Examined	Number Contaminated Sites	Percent Contaminated Sites
Atlantic Coast			
ME	6	0	0
MA	12	5	42
RI	5	0	0
CT–NY (LI Sound)	11	2	18
NJ	9	6	67
DE	5	0	0
MD–VA (Chesapeake)	11	0	0
NC–SC–GA	10	0	0
Gulf Coast			
FL–AL–MS–LA–TX	68	0	0
Pacific Coast			
CA	45	3	7
OR–WA	21	1	5
AK	6	0	0
HI	2	0	0
TOTAL SITES	211	17	8

to Chesapeake, encompasses the core of the winter flounder's range. The NOAA review (NOAA 1990a) concluded that estuaries in the mid–Atlantic region are most susceptible to pollutant retention because of their relatively large volumes, moderate to low freshwater inflow, and low tidal exchange: the very retention characteristics that winter flounder exploit to enhance spawning success (Pearcy 1962).

A variety of fish diseases, many initially observed in winter flounder, has been associated with deteriorating coastal water quality. The disease that has received the most research attention is fin erosion or fin rot, a syndrome characterized by fin necrosis, dermal ulceration, and hemorrhaging. Fin rot may be associated with physiological failure of calcium deposition. Depressed red blood cell levels, an additional indicator of stress, is also associated with this disease. Of unknown etiology, fin rot is associated with degraded estuarine and coastal environments and is regarded as the best external pathology for studies of disease prevalence and a marker signifying compromised fish health (Mahoney *et al.* 1973, Ziskowski and Murchelano 1975, O'Connor *et al.* 1987, Murchelano 1990). A 1979–83 survey of fish diseases in coastal and offshore waters noted the incidence of fin rot in winter flounder was highest (1.4%) in the Gulf of Maine (Ziskowski *et al.* 1987), but similar prevalence was detected in coastal areas adjacent to Boston and New York population centers. Also, bent fin rays were significantly more prevalent on Stellwagon Bank (0.5%) and in Massachusetts Bay (0.3%) than elsewhere. Fin rot was significantly lower in southern New England coastal and offshore waters.

In contrast, the non–lethal infectious viral disease lymphocystis was significantly more prevalent (4.5%) in offshore waters of the Middle Atlantic Bight than other offshore or coastal areas (Ziskowski *et al.* 1987). A blister–like viral disease, similar in appearance to lymphocystis, has been documented in winter flounder from a sewage and hydrocarbon polluted estuary of coastal Newfoundland (Emerson *et al.* 1985). The bacterial disease, vibriosis, has also been shown to affect winter flounder in Narragansett Bay (Levin *et al.* 1972). The pathogenicity of *Vibrio anguillarum* has been established under laboratory conditions (Watkins *et al.* 1981), and another *Vibrio* bacterium has been implicated in causing ulcerative lesions (Robohm and Brown 1978).

With external pathology information indicating flounder health was compromised in degraded waters, research attention focused on the liver for effects of environmental carcinogens, usually in the form of hepatic neoplasia. Flounder collected on Deer Island Flats near the Deer Island Sewage Treatment Plant's discharge outfall revealed an 8% (N=200) and 15% (N=325) prevalence of liver cancers and a variety of possible precursor and other lesions (Murchelano and Wolke 1985, and *in press*). The epizootic nature of the lesions and their histopathology was interpreted as extreme response to contaminants of human origin (Murchelano 1988). Another study within greater Boston Harbor (Quincy Bay) noted a 23% prevalence (N=100, Gardner and Pruell 1988). However, an ongoing study at Boston's Deer Island Flats has suggested decreased prevalence and extent of neoplastic and precursor lesions since 1984 and from 1987–90 (Moore and Stegeman, unpub.). A number of possible reasons for the decline have been advanced, including reduced toxic discharges to the harbor over the six year period. Flounder taken near urban harbors, such as New Bedford and Plymouth, appeared to have higher prevalence of hepatic disorders than other populations along the Massachusetts coast (Sass and Murchelano 1988), and less contaminated sites in Massachusetts Bay (Dawe 1986) and Narragansett Bay (Lee *et al.* 1988).

With the exception of Great Bay (NJ), the presence of hepatic neoplasms in flounder from Boston Harbor–Quincy Bay, Merrimack River (MA), Salem Harbor (MA), Buzzards Bay (MA), Narragansett Bay (RI), Western Long Island Sound, and Raritan Bay (NJ) were correlated with high levels of sediment contaminants (NOAA 1987, 1990b). Flounder displaying the highest prevalence of pathological conditions had elevated levels of liver contamination and were from waters receiving large inputs of waste from urban–industrialized communities – Boston Harbor, Quincy Bay, western Long Island Sound, and Hudson/Raritan Bay – sites of high sediment contamination (Daniels and Gardner 1989, Gardner *et al.* 1989, Table 1.3).

Although liver cancers are unlikely to cause extensive winter flounder mortality, they suggest the presence of environmental chemicals that may be exerting effects at sub–chronic levels. Polynuclear aromatic hydrocarbons (PAHs), especially benzo[a]pyrene, are implicated as the most likely causative agent of flatfish carcinomas (Malins *et al.* 1984). PAHs originate from petroleum and/or combustion sources, and occur in various commercial products. Major pathways to the marine ecosystem include surface runoff, atmospheric fallout and sewage outfalls (Zdanowicz *et al.* 1986). Appearing in sediment cores in the early 1800's, PAHs increased from the 1900's to the 1970's (NOAA 1990c).

Petroleum hydrocarbons, and associated PAHs, have been implicated as pollutants which significantly impact biological processes from the cellular to the whole community level. Oil pollution sources in order of significance include urban and rural surface runoff, sewage discharges, industrial and refinery discharges, accidental oil spills (Connell 1981). Spilled oil undergoes a wide variety of natural fates including dispersion, evaporation, emulsion formation, degradation by microorganisms in the water and surface sediments, and eventual deposition into deep sediments (Mackay and McAuliffe 1988). Toxicity to fish is largely determined by the pollution event's magnitude and environmental conditions rather than oil characteristics (McIntyre 1982, Teal and Howarth 1984). Adult fish kills are less damaging to fish populations than the less conspicuous increase in egg and larval mortality, and localized ecosystem alterations. A pollution event occurring during the winter and early spring period may be particularly stressful to winter flounder. Enhanced vulnerability arises from the diversion of energy to gonadal development at a time when flounder are fasting or negligibly feeding. Studies examining normal seasonal changes in blood constituents, as well as differences noted when flounder were exposed to stress, indicate that the spawning period is naturally stressful (Fletcher 1975, Bridges *et al.* 1976) thereby potentially heightening pollutant sensitivity.

Oil spill studies have shown that some hydrocarbons remain associated with sediments for years, thus benthic flatfish species are susceptible to chronic contaminate exposure. Laboratory studies of flatfish, including winter flounder, showed physiological effects from exposure to oiled sediment at sublethal levels. English sole (*Paraphrys vetulus*) exhibited greater stress than non–exposed fish as petroleum alkanes and aromatics accumulated in the skin, muscle, and liver tissues (McCain *et al.* 1978). Weight loss, induction of mixed–function oxygenase (MFO) enzymes, and severe liver abnormalities resulting from increased lipid synthesis were observed concurrent with high tissue aromatic concentration. However, after one month of continuous exposure, hydrocarbon concentrations were only detectable in the liver.

Decreasing tissue hydrocarbon concentrations over time reflect efficient biotransformation and detoxification systems. Although the skin, gills, and gastrointestinal tract are primary areas for uptake and release of hydrocarbons and their metabolites (Haensly *et al.* 1982), the liver is the primary organ for their accumulation and detoxification utilizing hepatic MFO enzymes (Payne 1977). The MFO system's primary function of regulating hormone levels may be compromised when detoxification rates are elevated. Exposure to relatively low hydrocarbon levels commonly observed in coastal waters (~1.0 ppm) has induced MFO enzymes in winter flounder (Payne *et al.* 1988). Monitoring MFO activity in flounder livers has served as an indicator of environmental contamination for some populations (Foureman *et al.* 1983, Stegeman *et al.* 1987, Elskus *et al.* 1989).

MFO induction in winter flounder exposed to oil contaminated sediments was accompanied by liver enlargement, increases in lipid-like components, and decreases in liver protein, DNA, and minerals (Fletcher *et al.* 1981, 1982). Longer exposure resulted in reduced food intake and liver shrinkage as stored lipids and certain fatty acids were metabolized under sustained demands of MFO enzymes (Dey *et al.* 1983, Haensly *et al.* 1982). As an energy reserve, lipids play an important role in gonad maturation while fatty acids maintain biomembrane structure and function. Consequently, a pollution event that interferes with lipid metabolism affects gonadal development (Khan 1991).

Chronic toxicity of petroleum hydrocarbons has been expressed in a variety of degenerative changes in winter flounder exposed to oil in the laboratory. These include: reduced food intake and lower condition factor (Fletcher *et al.* 1981, Khan 1991); altered swimming behavior (Khan 1987); lower juvenile growth rate (Fletcher *et al.* 1981); excessive mucus secretion from skin and gills (Burton and Idler 1984, Khan 1987, 1991); alteration of blood plasma, hematocrit and hemoglobin levels (Payne and Penrose 1975); anemia (Khan 1991); enlarged gall bladder and altered bile chemistry (Fletcher *et al.* 1981, Kiceniuk and Khan 1983, Dey *et al.* 1983, Khan 1987, 1991); fin and tail necrosis (Khan 1987, 1991); reduced enteric parasite burden (Khan and Kiceniuk 1983); reduced testes size (Fletcher and King 1978, Fletcher *et al.* 1982); and increased pathology of a protozoan parasite (Khan 1987, 1991).

Direct effects on winter flounder reproductive success have been demonstrated in the laboratory (Kuhnhold *et al.* 1979). Exposing eggs to low levels (100 ppb) of No. 2 fuel oil significantly reduced viable hatch (19%). Although exposure during fertilization and embryonic development resulted in a low incidence (4%) of obvious larval abnormalities, hatching was delayed 3–9 days, a subtle effect potentially reducing survival in the wild due to increased predation. Progeny of adults exposed to 10 or 100 ppb fuel oil during gametogenesis showed reduced larval survival and growth.

Other environmental pollutants, such as PCBs and chlorinated pesticides, may be bioaccumulated and move upward through trophic levels by being adsorbed to sediments and detritus then ingested by zooplankton, epibenthic and infaunal invertebrates, which in turn are eaten by bottom-feeding fish. PAHs in winter flounder stomach contents appear to be more sediment derived; they are generally lower in concentration in stomach contents than in sediment suggesting that they may also be metabolized by the flounder's prey (Zdanowicz *et al.* 1986). Winter flounder exposed to chemically contaminated sediment from Black Rock Harbor (Bridgeport, CT), had proliferative lesions in external, oral, and esophageal epithelial surfaces, renal vascular and nephroblastic elements, and pancreatic islets (Gardner and Yevich 1988), as well as an 18% incidence of hepatic neoplastic lesions (Daniels and Gardner 1989). Flounder fed mussels that had been exposed to the sediment also had enhanced pathologies (Gardner and Yevich 1988).

Significant differences in specialized cells called macrophages, which accumulate natural and foreign material for destruction and detoxification in the liver and spleen in all fish, were found to be a useful index of stress in flounder taken from sites with demonstrated contamination gradients (Wolke *et al.* 1985a and 1985b, Wolke and Reckseik *in press*). Payne and Fancey (1989) noted a stepwise decrease in numbers of macrophages after chronic exposure to PAH contaminated sediments (25–50+ ppm) suggesting that the fish's immune response, phagocytosis, was impaired in heavily polluted areas.

Although compounds may be more easily eliminated by biliary excretion, some also may be metabolized to more cytotoxic, mutagenic, or carcinogenic derivatives. For certain carcinogens, binding of the reactive metabolites with nucleic acid (DNA) appears to precede postulated hepatocyte cell death and/or pathological disorders and eventual tumorigenesis in the winter flounder liver (Bodammer and Murchelano 1990, Murchelano and Wolke *in press*). Exposure to some toxic compounds may also damage genetic material. DNA damage has been detected in winter flounder from contaminated sites in Boston Harbor (Varanasi *et al.* 1989) and Long Island Sound (Stein *et al.* 1989, Gronlund *et al. in press*) and correlated with concentrations of PAHs in sediment.

1. Population Effects

The relationship of stock abundance to anthropogenic versus natural environmental variables has been a subject of much conjecture. Correlations have been sought between 50-year reconstructions of stock abundance of 24 species, climate, and pollution conditions in five major northeastern estuaries, each subjected to multiple pollutant discharges (Summers *et al.* 1987). This study found that long-term variation in winter flounder stock abundance has been strongly associated with climatic variables in Hudson/Raritan and Narragansett Bays. Stock size was also positively related to dissolved oxygen (D.O.) in Hudson/Raritan Bay, but there was no clear connection with specific causes of low D.O. In Narragansett Bay, stock size was positively related to a monotonic-trend variable aggregating human population and sewage loading. The authors suggested that this could mean increased organic loading to the Bay has enhanced flounder survival by increasing benthic prey populations. Increased nutrient input can increase productivity in some marine species, however interactions with contaminants associated with sewage and other environmental variables are not well understood, thereby obscuring the net effect of sewage discharge on flounder populations. For example, winter water temperature alone has been shown to be very important to the winter flounder recruitment process in Narragansett Bay (Gibson 1991b , Jefferies and Terceiro 1985) and elsewhere (NUSCo 1989). Human influences other than fishing appear to have affected stock size, but historical pollution records are insufficient to show a clear causal mechanism.

Reproductive consequences from exposure to specific contaminants has been demonstrated and may be involved in stock declines. Chlorinated hydrocarbons, such as DDT, DDE, heptachlor, and dieldrin, can accumulate in ovarian tissue of adult female winter flounder and result in mortalities of developing eggs and larvae (Smith and Cole 1973). High juvenile mortality has been associated with chlorinated hydrocarbon insecticides formerly applied on cranberry bogs within the watershed of the Weweantic River estuary, MA. Seasonal differences in concentration among juveniles appeared related to spring runoff and the leaching of pesticides from cranberry bogs in the watershed. Fertilization and survival of flounder eggs and larvae decreased with increased exposure to DDT and dieldrin residues; vertebral deformities also tended to be dose-dependent (Smith and Cole 1973).

Recent studies have related contaminant burdens in adult fish to reproductive failures. Comparison of winter flounder eggs, embryos, and larvae from contaminated sites in Long Island Sound (LIS) and Boston Harbor showed higher early embryo mortality for fish from contaminated sites than for those from sites which were considered relatively clean (NOAA 1990d). This study estimated that one-fifth of the LIS winter flounder egg production may be lost by early embryogenesis and three-fifths by time of hatching. Larvae from contaminated sites (New Haven CT, Hempstead NY) in LIS had large yolk-sac volumes, possibly contaminant-induced metabolic disturbance inhibiting yolk utilization. Further study of large (>30cm) flounder from two degraded LIS sites showed impaired yolk production (Pereira *et al. in press*) which may cause eggs to be resorbed rather than spawned.

Gross embryo malformations at all developmental stages were higher for Boston's Deer Island site than any of LIS sites. Boston Harbor fish produced small eggs and small, active larvae with small yolk-sacs. Similarly, flounder eggs from New Bedford Harbor, noted for its PCB contamination (see below), had significantly higher levels of PCBs, and hatchlings were significantly smaller in length and weight, than larvae from a Narragansett Bay reference site (Black *et al.* 1988). Reduced larval size is associated with increased probability of larval mortality (Anderson 1988, Chambers *et al.* 1988). Small larvae with little energy reserve have been found to have higher metabolic demands during the transition to normal feeding (Laurence 1977).

A number of heavy metals may accumulate in harbor and nearshore sediments: silver (Ag), cadmium (Cd), chromium (Cr), copper (Cu), and zinc (Zn), which are associated with industrial discharges and waste water effluent; lead (Pb), which is more often related to use of lead additives in gasoline, now banned; and mercury (Hg) from both atmospheric fallout and industrial inputs. Bioconcentration of most metals is initiated at low levels. Embryos and larvae are most susceptible, with survival and growth adversely affected (Voyer *et al.* 1982, Klein-MacPhee *et al.* 1984).

Winter flounder exposed to mercury (5–10 ppb for 60 days) exhibited elevated gill-tissue respiration rates and differences in blood characteristics (Calabrese *et al.* 1975). Exposure of female flounder to cadmium (25–50 ppb for 70 days) showed that this metal interferes with normal yolk production (Pereira *et al.* 1991). Laboratory exposure of winter flounder to copper poisoning resulted in liver and kidney disorders and gross changes in gill structure (Baker 1969). Lead exposure (50 ppb for 60 days) induced metabolic damage to kidney and liver functions, as did silver (10 ppb for 60 days) and cadmium (5–10 ppb for 60–150 days) exposure (Calabrese *et al.* 1982).

The implications of these metal-induced sublethal stresses are that added demand is placed on the animal's energy reserves which greatly impairs its capacity to respond and survive in a naturally changing environment (Calabrese *et al.* 1982). In addition to draining energy reserves normally used for growth and reproduction, such stressed populations may be more susceptible to injury and death by environmental factors such as abrupt changes in salinity or temperature, injury from fishing nets and hooks, or disease.

Although environmental toxins always have some negative effect on marine populations, one study gives evidence of metabolic adaptation in flounder populations from impacted areas. Enzyme bioassay of adult flounder from the New York Bight showed greatest toxic effects from cadmium, with less pervasive effects from mercury and silver (Calabrese *et al.* 1982). The authors concluded that these adults had apparently acquired a physical tolerance for mercury and silver, such as a sequestering mechanism, which was lacking in juveniles, and permitted normal tissue metabolism despite large body burdens. Exposure to such toxic compounds spans more than a century for flounder populations in this region (NOAA 1989a).

The recent worldwide increase in phytoplankton blooms called red tides, which appear to be exacerbated by chronic eutrofication of coastal waters from human development, were generally thought to be toxic to shellfish but nontoxic to fish and people. However, winter flounder and other fish such as cod and Atlantic herring have been found to be sensitive to even low laboratory doses of "paralytic shellfish toxins" extracted from Bay of Fundy *Gonyaulax excavata (tamarensis)* cells (White 1981). Classic symptoms included loss of equilibrium within 15 minutes, followed by immobilization and weak, irregular respiration; death occurred within 20–60 minutes (LD_{50} = 400–750 micrograms saxitoxin equivalent/ kg). Because toxins were undetectable in muscle tissue following lethal dosage in the laboratory, blooms of *G. tamarenis* may cause significant unmeasured local mortality.

Table 1.4: Concentrations of selected heavy metals and organic contaminants found in sediments and flounder tissues. Units given: sediments = ug/g dry weight, flounder tissue = ppm wet weight.

HEAVY METALS

AREA/STATE (n=# of sites)	ME (n=25)	MA (n=75)	RI (n=25)	L.I. SOUND (n=68)	NJ (n=26)
Cd–Sed	0.09–0.55	0.02–9.79	0.07–0.82	0.04–2.63	0.16–3.77
Tis	0.24	0.00–0.88	0.127–0.268	0.02–0.06	
Hg–Sed	0.01–53.99	0.01–1.68	0.1–0.9	0.01–4.31	0.1–3.41
Tis	147.04	0.016–0.54	0.115–0.197	0.01–0.12	
Pb–Sed	28.16–29.36	12–210.1	31–102.02	9.13–250.6	13–279.69
Tis	133	0–0.59	0.45–0.75	0.16–0.44	
Cr–Sed	96.35–39.23	20.6–3373.9	34.73–165.47	12.33–252.7	34–363.87
Tis		0.02–0.38		0.0–0.8	
Cu–Sed	16.29–	4.72–256.13	19–125.50	8.58–204.09	7.8–238.27
Tis		0.04–2.2		0.08–3.60	
Zn–Sed	84–	27–452	98–235	31–522	32–566
Tis		4.55–12.5		3.90–19.0	
Ni–Sed	0.82	4.71–65.28	14–51.21	9.77–61.01	3.7–57.57
Tis				0.06–0.22	

(Data source: NOAA (1988b), Hall *et al.* (1978), Reid *et al.* (1982), Dustin *et al.* (1990), Gardner and Pruell (1988), Lee *et al.* (1988).)

ORGANIC CONTAMINANTS

AREA/STATE (n=# of sites)	ME (n=25)	MA (n=75)	RI (n=25)	L.I. SOUND (n=68)	NJ (n=26)
DDT–Sed	0.38–9.6	0.6–62.39	1.99–11.41	0.06–87.74	0.56–71.15
Tis	0.11	0.002–1.07			
PCB–Sed	9.87–99.02	12.39–2,069.63	34.37–319.1	1.13–749.28	8.18–755.17
Tis		0.002–5.9	0.102–0.397	0.06–0.56	
PAH–Sed	362–6,690	68–57,778	384–7,547	67–35,669	95–8,868
Tis		1–10			

(Data source: Sediment data from NOAA (1988b), fish tissue data from Boehm and Hirtzer (1982), Boehm *et al.* (1984) Gardner and Pruell(1988), Lee *et al.*(1988), Pritchard *et al.* (1973), Reid *et al.* (1982), Smith and Cole (1970).)

With evidence of chemically degraded nearshore habitats and diminished ability of winter flounder to reproduce in certain areas, there is a need to better understand how pollution interacts with natural dynamics to effect overall population levels. Population declines have been presumed to be caused by over-harvesting as well as natural mortality from predation or disease rather than other competing anthropogenic mortalities including pollution and habitat alteration/loss. Enhanced mortality at any stage in the life cycle ultimately reduces fish available for harvest. Almeida and Fogarty (1989) have begun to construct a life history model for identifying and merging recent and future quantitative research results on potential yield.

2. *Tissue Burdens and Risk Assessment*

In addition to threatening the reproductive potential and health of local flounder stocks, another serious potential consequence of estuarine and coastal pollution is the threat to human health through consumption of contaminated fish tissue. To address this health issue, a comprehensive survey of 15 trace elements in fish tissues was undertaken from sites throughout the coastal US (Hall *et al.* 1978). Results showed that body burdens of winter flounder from clean offshore sites on Georges Bank were somewhat lower but of comparable range to tissue burdens in flounder from the New York Bight, Long Island Sound and coastal Massachusetts (Greig and Wenzloff 1977, Reid *et al.* 1982, Dustin *et al.* 1990, Table 1.4). Flounder tissues from seven locations within Long Island Sound analyzed more recently for selected heavy metals (CT DEP 1989) showed generally low concentrations, within the published range of values for fish from uncontaminated environments. Examination of flounder muscle tissue from Boston Harbor and Salem Harbor locations showed that, in most instances, metal burdens did not reflect reported sediment concentration from either urban location, each among the most metals-polluted harbors in the country (Dustin *et al.* 1990). Furthermore, mean concentrations for harbor flounder were lower than coastal flounder for all metals except mercury in Boston Harbor and chromium in Salem Harbor. Somewhat higher tissue burdens were reported for Quincy Bay (Gardner and Pruell 1988) and upper Narragansett Bay (Lee *et al.* 1988, Table 1.5).

Accumulating principally in fish fatty tissue, chlorinated hydrocarbons, such as PCBs and DDT, display extreme persistence in the marine environment. DDT pesticides were banned from use in 1972 and PCB production halted in 1979. PCBs' high volatility property and use in anti-fouling marine paints have resulted in their being more abundant in the marine environment than DDT. According to NOAA (1990c), both contaminants reached their maximum concentration in marine sediments in the late 1960's followed by a slow decline.

The only study yielding unacceptably high PCB tissue burdens in flounder was in New Bedford Harbor and the Acushnet River (Kolek and Ceurvels 1981), where flounder sampled from 1976–80 in the inner harbor, closest to the original discharge sites, had PCB levels up to 13 ppm. Winter flounder from the outer harbor had levels ranging from 0.2–5.9 ppm (mean 1.6 $\pm$ 0.50 ppm), resulting in the MA Department of Public Health closure of both areas to the taking of all bottom feeding finfish in 1979. The FDA tolerance level was lowered from 5 to 2 ppm in 1984, and the closures remain in effect.

More recent PCB monitoring of flounder from various locations have resulted in tissue burdens well below the new more stringent FDA limit of 2 ppm: Salem Harbor, Boston Harbor (Boehm *et al.* 1984, Schwartz 1987, Schwartz *et al.* 1991), Quincy Bay (Gardner and Pruell 1988), Buzzards Bay (Schwartz 1988), coastal Massachusetts

Table 1.5: Concentrations of contaminants found in sediments and fish tissues in Quincy and Narragansett Bays. Units given: sediments = ug/g dry weight fish tissue = ppm wet weight.

	QUINCY BAY		NARRAGANSETT BAY	
	TIS	SED	TIS	SED
PAH	0.0002–0.000	345–57778	---	384–7547
PCB	0.06–0.7	36.09–319.1	0.102–0.397	12.39–1128.76
DDT	0.002–0.032	1.99–11.41	---	0.38–62.39
Cd	0.001–0.009	0.15–3.24	0.127–0.268	0.31–0.82
Cr	0–0.38	34–419.32	---	53–165.47
Cu	0.04–2.2	11–256.13	---	19–125.51
Hg	0.006–0.009	0.03–0.33	0.115–0.197	0.1–0.9
Pb	0–0.04	20–207.37	0.453–0.750	31–102.02
As	---	2.59–16.98	0.012–0.027	6.9–21.83

Data source: Sediment data for Boston Harbor and Narragansett Bay from NOAA (1988b), Narragansett Bay fish tissue data from Lee et al (in press), Quincy Bay fish tissue data from Gardner and Pruell (1988).

(Schwartz *et al.* 1991), the New York Bight and Long Island Sound (Reid *et al.* 1982, CT DEP 1989). PCBs were also found in the tissues of offshore flounder taken from Georges Bank and the mid–Atlantic shelf, although at very low concentrations (0.002–0.031 ppm, Boehm and Hirtzer 1982).

Observed total DDT concentrations in winter flounder flesh samples range from low values in offshore samples (mid–Atlantic Bight shelf and Georges Bank, 0.002–0.075 ppm; Boehm and Hirtzer 1982), to higher values from inshore northern sites (0.01–0.03 ppm coastal New Brunswick, Sprague and Duffy 1971; 0.11 off Mount Desert Island, ME, Pritchard *et al.* 1973), to inshore southern sites (0.18–1.07 Weweantic River estuary, MA, Smith and Cole 1970). Tissue concentrations of other pesticide and volatile hydrocarbon residues – chlordane, toluene, PAHs – from Boston Harbor and an adjacent nearshore locations (Boehm *et al.* 1984), Quincy Bay (Gardner and Pruell 1988), and Long Island Sound (CTDEP 1989) were all very low, and less than the FDA's 0.3 ppm action level for chlordane.

In summary, with the exception of New Bedford Harbor, reported contaminant body burdens in winter flounder edible tissues are well under U.S. Food and Drug Administration Tolerance and Action Levels. Even flounder from the most degraded nearshore habitats generally have body burdens below FDA Action Levels, in part because many contaminants, notably PAHs, are metabolized by the flounder's liver and eliminated by biliary excretion. Samples from clean offshore and coastal sites nearly always have trace amounts of contaminants, indicating the ubiquity of these compounds in the marine ecosystem and their bioaccumulative nature.

Although many urban embayments in the U.S. are impacted by past and present human activities, the Northeast Atlantic coast has the greatest number of sites with the highest concentrations of contaminants (Table 1.3). The geographic range of these highly contaminated sites, from Massachusetts to New Jersey, encompasses a large proportion of the entire range of winter flounder, though biological effects appear to be restricted to specific locals (NOAA 1990c). Formal human health risk assessments have been completed for flounder from Quincy Bay, MA (USEPA 1989), and Narragansett Bay, RI (Kipp 1990). The results suggest that average consumers of flounder taken from contaminated locations have little increased theoretical risk of developing a cancer due to that consumption, while maximum consumers (132 lbs/year) of fish from contaminated locations may be exposed to levels of risk deemed "unacceptable" by public health professionals. In short, while concern over the wholesomeness of flounder fillets taken from clean coastal and offshore waters is unwarranted, extremely avid consumers eating flounder from polluted areas may be doing so at some risk.

E. Power Plant Entrainment and Impingement

Winter flounder larvae are particularly susceptible to entrainment mortality by power plant intakes during and after metamorphosis because they are weak swimmers (Pearcy 1962) and their benthic habit places them near intake pipes designed to draw bottom water. Mechanical forces, elevated temperatures, and chlorination cause nearly complete mortality of all fish larvae and most fish eggs drawn into the coolant water stream of power plants (Marine Research 1989).

The relatively large volume of seawater required to cool multiple–unit power plants makes entrainment mortality from the operation of these plants a major concern. For example, the three–unit nuclear station at Millstone Point (Waterford, CT) draws an average of 2.7 billion gallons per day from Long Island Sound. Full operation entrains an estimated 79–192 million winter flounder larvae annually. The four–unit fossil fuel station at Brayton Point (Somerset, MA) entrains an estimated 266–686 million winter flounder larvae annually (Marine Research 1982). In comparison, the smaller Pilgrim nuclear power station (Plymouth, MA) entrains an estimated 15 million flounder larvae annually (Marine Research 1989), comparable to an older fossil fuel plant, United Illuminating in New Haven, CT, which entrains an estimated 18 million flounder larvae annually (Normandeau Associates, 1979).

The ultimate effect of entrainment mortality (adult equivalent losses, see Horst 1975) can easily be underestimated if entrainment numbers are not examined by larval age group. Because entrained larvae are often disproportionately older metamorphosing stages (stage 3–4, NUSCo 1987), this additional mortality targets the small percentage of larvae which have survived the very high natural mortality rates experienced by younger planktonic stages (stage 1–2, Z=2.25; stage 3–4, Z=0.66; Crecco and Howell 1990).

Extensive study at the Millstone plant (NUSCo 1990, Crecco and Howell 1990) has shown that, on average, 75% of entrained larvae are late stage (pre and post–metamorphic, stage 3–4). Although there is uncertainty concerning the stock origin of entrained larvae, the conditional mortality due to entrainment could be as much as 35% if all entrainment is from the local Niantic River stock (Crecco and Howell 1990). Such mortality factors, added to high fishing pressure, may severely erode the spawning stock, resulting in recruitment failure.

A second concern related to power plant removals is impingement of juveniles and adults on intake screens. Impingement losses can be substantial if plant intakes are located in nursery grounds, as impinged fish are usually YOY or yearling fish unable to escape intake currents (Turnpenny 1988). For example, a relatively small plant near spawning flats in upper New Haven harbor, CT, impinges 27,000 juvenile flounder annually (Normandeau Associates 1979). Annual impingement by larger power stations at Brayton Point and Millstone Point remove 6,000 (Marine Research 1982) and 16,700 (NUSCo 1988b) flounder, respectively. Retrofitting plants located near spawning areas with fish return systems would reduce this unnecessary mortality. For example, return systems added to two of three units at the Millstone Power Station, Waterford, CT, reduced impingement mortality of winter flounder by more than half (NUSCo 1988b).

F. Habitat Quality Versus Fishing Mortality

In order to compare the effectiveness of enhancing flounder populations through improving habitat quality versus reducing fishing mortality, lifetime egg production from a single Age 1 female recruit was calculated under scenarios of reduced early life–stage mortality (greater YOY production) versus reduced adult fishing mortality (Boreman 1991). This analysis followed methods developed for restoration and regulation of striped bass populations in Chesapeake Bay (Boreman and Goodyear 1984) and Rhode Island (Prager *et al.* 1987). In this case, flounder populations in western Long Island Sound, Rhode Island, and Massachusetts, were modeled using growth and maturity data for each population (see *Species Profile*) converted to fecundity–at–age estimates using a length–fecundity relationship developed for winter flounder in Niantic Bay, CT, by NUSCo (1987) and Narragansett Bay, RI (Saila 1961b). The analysis showed that egg production is concentrated in the first few spawning ages in all three flounder populations under current mortality conditions (Figure 1.2), but that older ages contribute more to total egg production as fishing mortality is reduced. Additionally, fishing mortality reduces the population's total egg production. At current fishing mortality, egg production is at or below 20% of egg production for an unfished

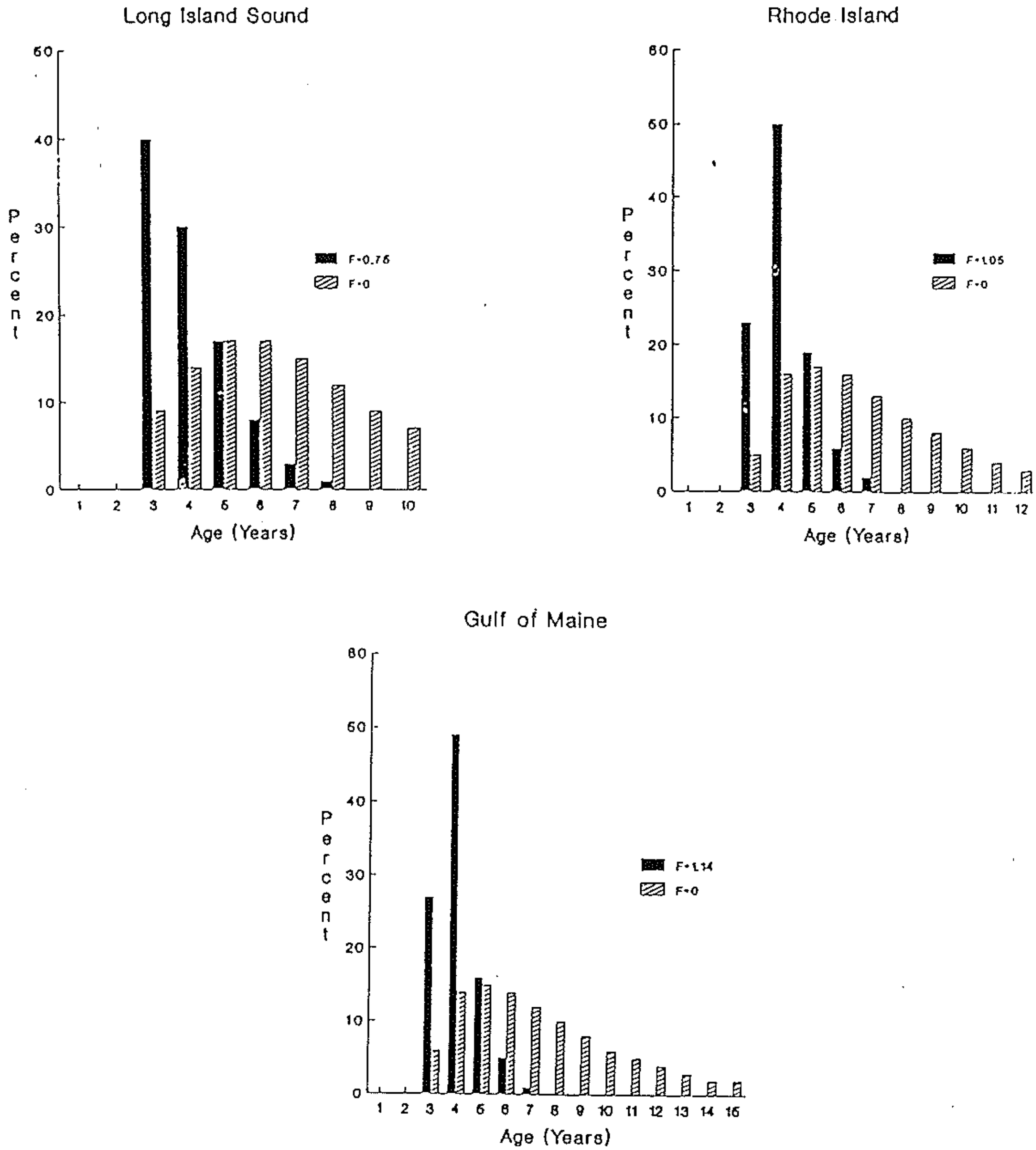

Figure 1.2: Relative distributions of egg production by age for a single Age 1 female from three populations with and without fishing mortality.

population. Although the percent egg production level where recruitment failure occurs remains unknown, the risk of failure increases as egg production declines. Early life stage losses become more critical when fishing mortality is high. Under present levels of fishing mortality, an increase (due to habitat restoration) or decrease (due to habitat loss) in flounder YOY survival is roughly equivalent to the same relative change in fishing mortality rate in terms of its effect on lifetime egg production. That is, a 20% increase in YOY mortality results in a 17–30% loss in fishing opportunity on the adult stock. Conversely, a 50% decrease in YOY mortality is equivalent to decreasing the fishing mortality by 45–60%. The largest change was seen in the Rhode Island and Massachusetts populations, the smallest change was seen in the western Long Island Sound population.

The relationship between habitat quality and YOY production is not well understood and has not been quantified. Managers do not know what kind of habitat changes result in a 20–50% change in flounder production. Enhancing flounder populations by reducing fishing mortality via more conservative regulations is more straightforward, and therefore presents less risk to managers than undertaking habitat restoration programs. However, these analyses indicate that investing in habitat restoration programs which increase YOY production would result in longer–term benefits and allow managers to gradually increase fishery yield from these populations.

PART TWO: STATUS OF WINTER FLOUNDER STOCKS

Detailed examination of winter flounder life history characteristics are discussed in the *Species Profile*. One salient feature which emerges from examination of the biology of this species is the relatively large variability among stocks along the northwest Atlantic coast. This variability in biology, as well as current and historical exploitation patterns, necessitate the delineation of the flounder's range into stock units where growth, seasonal movement, and female maturity schedules are similar enough to be modeled as one group. Based on these criteria, inshore flounder populations were split into three stock units for management purposes (Figure 2.0). Georges Bank flounder could be considered a fourth stock unit under the jurisdiction of the New England Fishery Management Council.

A. Identification of Stock Units

1. Gulf of Maine

This unit encompasses coastal Maine, New Hampshire, and Massachusetts north of Cape Cod, exclusive of Georges Bank. Flounder populations here show relatively moderate growth rates, and 50% of females mature between age three and four or about 30 cm. Flounder in this unit exhibit limited seasonal movements inshore.

2. Southern New England

This unit is comprised of coastal Massachusetts east and south of Cape Cod including Nantucket Sound, Vineyard Sound, Buzzards Bay, Narragansett Bay, Block Island Sound, Rhode Island Sound, Rhode Island coastal ponds, and eastern Long Island Sound to the Connecticut River including Fishers Island Sound, NY. Flounder populations here show relatively fast growth rates, and 50% of females mature at age three or 27–30 cm. Flounder in this unit may undertake extensive seasonal migrations.

3. Mid–Atlantic

This unit includes Long Island Sound west of the Connecticut River to Montauk Point, NY, including Gardiners and Peconic Bays, coastal Long Island, NY, coastal New Jersey and Delaware. Flounder populations here are at the southern extent of their range and exhibit a relatively slower growth rate. Size at 50% maturity is 25 cm for females, or between age two and three years. Seasonal movements are generally less extensive than for northern populations but may extend offshore in a northeasterly direction.

By comparison, the Georges Bank stock exhibits extremely fast growth, probably reflecting a more stable environment on offshore banks. Size at 50% maturity is 32 cm for females, or age two and one–half. It appears that this age represents a physiological minimum, expressed by populations with the fastest and slowest growth rates at greatly differing sizes (Georges Bank, 32 cm versus mid–Atlantic, 25 cm ; see Gibson 1989c).

B. Fishery–Independent Abundance Indices

Several fishery independent data sets on winter flounder abundance are available from trawl surveys of marine waters within state and federal jurisdiction. All surveys are designed as random stratified sampling schemes. The length of each time–series varies from seven years (CT) to 22 years (NMFS).

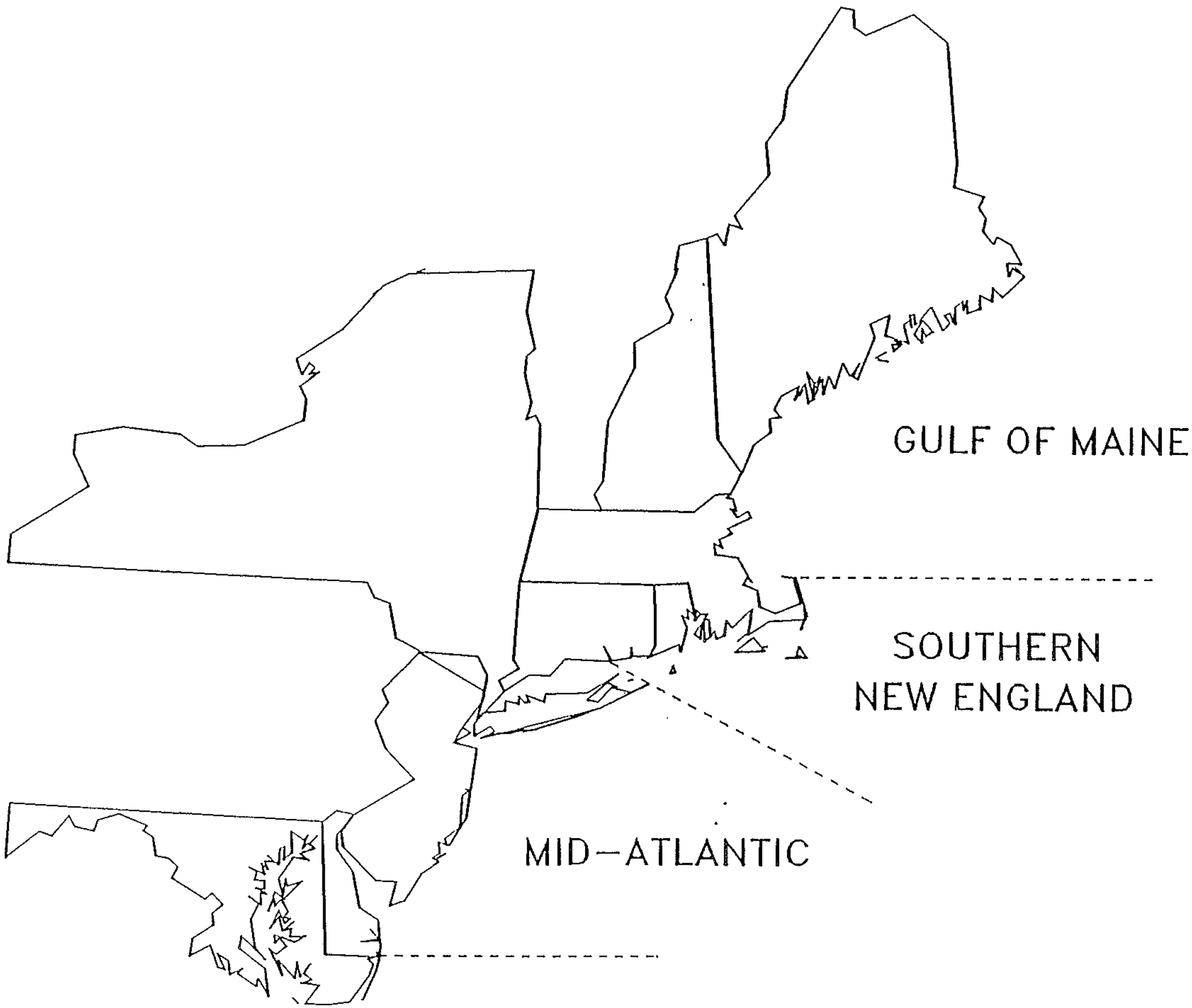

FIGURE 2.0: WINTER FLOUNDER STOCK UNITS

1. Gulf of Maine

Abundances of winter flounder in the Gulf of Maine are provided by Massachusetts DMF and NEFC/NMFS bottom trawl surveys. The MDMF spring trawl surveys have been conducted in state territorial waters since 1978. Trends in MDMF survey indices (stratified mean weight per tow) for flounder north of Cape Cod show a 54% decline in abundance from 28.5 kg/tow in 1983 to 13.0 kg/tow in 1990; however no trend beyond two years has been evident (Figure 2.1).

Recent NEFC/NMFS spring trawl surveys, 1982–1988, from inshore and offshore waters in the Gulf of Maine (Figure 2.2) show a general decline in flounder abundance inshore from 1982 (11.6 kg/tow) to 1986 (2.6 kg/tow), followed by an increase in 1987–88 (14.9 kg/tow). Offshore data show very low flounder abundance with no apparent trend. It should be noted that winter flounder are not entirely available to the NEFC/NMFS sampling gear until Age 3, when the highest number per tow of any age group was observed. Additionally, changes in abundance are age (size) related; abundance of Ages 1–3 have fluctuated and even increased, whereas for Ages 4 and older catch per tow indices have generally declined. These ages (>30cm) are fully recruited to both the commercial and recreational fishery in this region.

2. Southern New England

Abundance indices for winter flounder in this region are provided by Massachusetts DMF, Rhode Island DFW, and NEFC/NMFS bottom trawl surveys. The MDMF survey south and east of Cape Cod showed relatively stable abundances from 1978–1983, averaging 16.2 kg/tow, followed by a 68% decline to 5.38 kg/tow in 1990 (Figure 2.3).

The DFW survey of Narragansett Bay and Rhode Island Sound showed large decreases in flounder abundance during 1979–1990 (Figure 2.4). Abundance indices declined from 1979 (169 fish/ tow) to 1982 (32 fish/tow), gradually increasing through 1988 (73 fish/tow), and then declining to low levels in 1989–90 (19 fish/tow).

3. Mid-Atlantic

Winter flounder abundance indices for this region are provided by Connecticut DEP bottom trawl surveys of Long Island Sound, April–May 1984–89. CTDEP survey data show a decrease in abundance from 1984 (21 fish/tow) to 1985 (11 fish/tow), followed by a continuous increase in abundance through 1989 (45 fish/tow) and 1990 (87 fish/tow, Figure 2.5). Although New Jersey began a monthly statewide trawl survey in 1988, a longer time-series will be needed to discern trends in abundance. Earlier trawl surveys of the Indian River and Wamouth Bay, DE, (Seagraves, pers. comm.) showed an order of magnitude drop in relative abundance from December 1966–70 (catch/standard tow 1.03–11.18 flounder) to December 1980–81 (catch/standard tow 0.12–0.15 flounder). Recent research trawl surveys of Rehoboth Bay, DE, have caught no winter flounder (Seagraves, pers. comm.).

The NEFC/NMFS spring trawl survey flounder catch in southern New England–middle Atlantic waters peaked in 1981 and has fluctuated at lower levels in recent years (Figure 2.6). Some of the variability in this survey is a reflection of the fact that the index is a composite of the central stock, which has shown large declines recently, and the southern stock, which has varied without any clear trend.

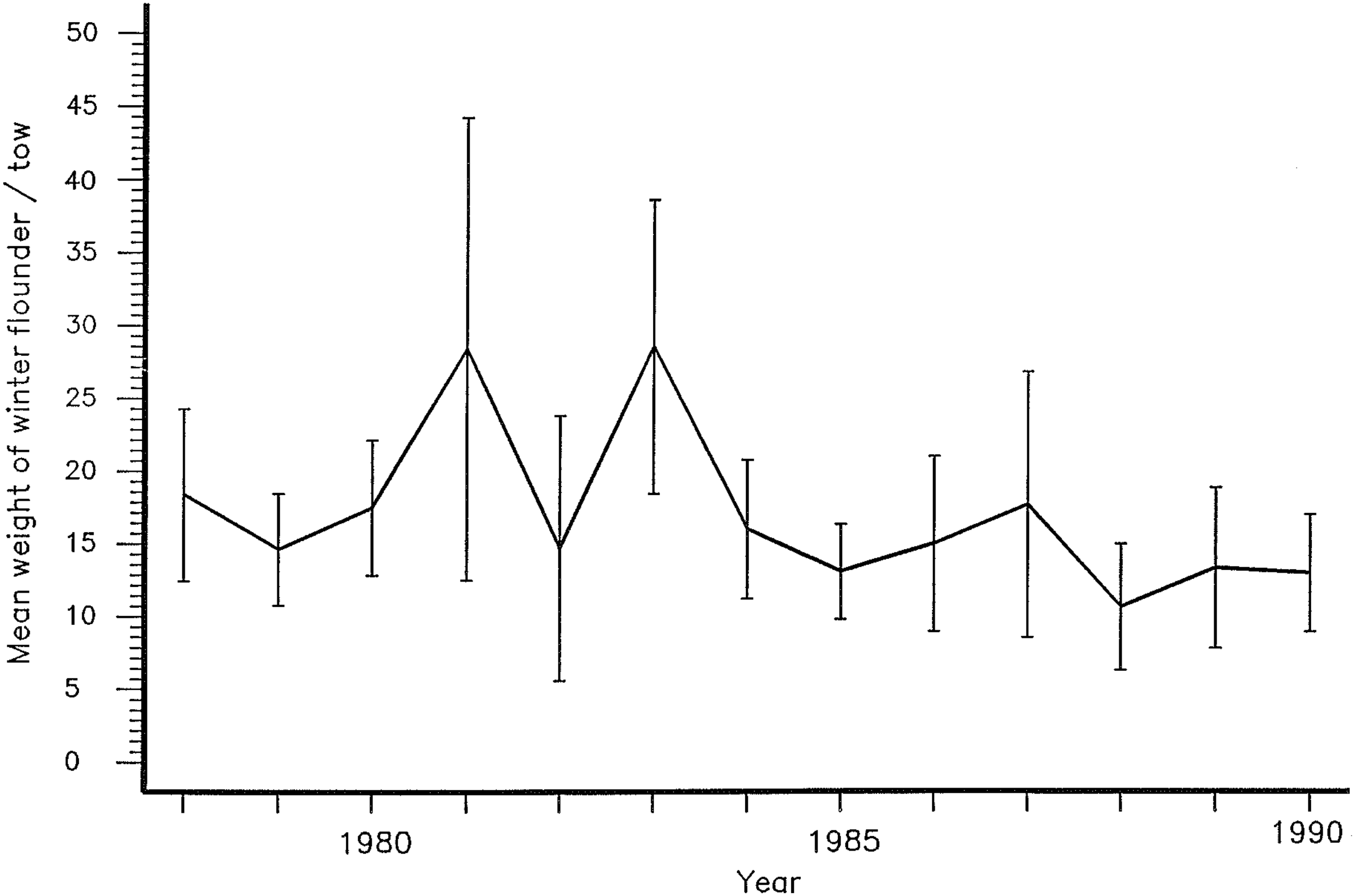

Figure 2.1 Relative abundance (Mean +/− 95% Confidence Interval) of winter flounder in Massachusetts, north of Cape Cod, for 1978 to 1990 (Witherell et al. 1990)

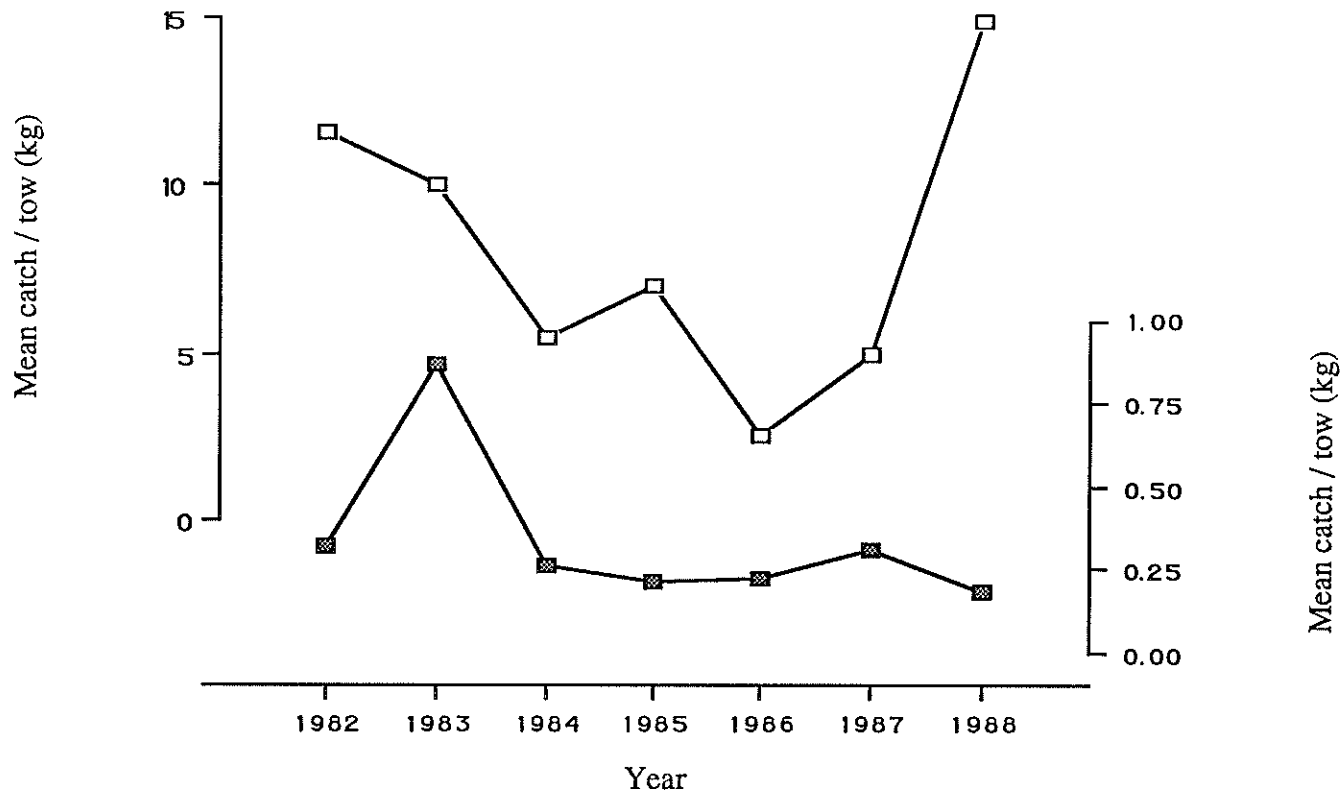

Figure 2.2. Stratified mean catch per tow in weight (kg) of winter flounder in NEFC/NMFS inshore (open symbols) and offshore (solid symbols) spring bottom trawl surveys in the Gulf of Maine area, 1982-1988.

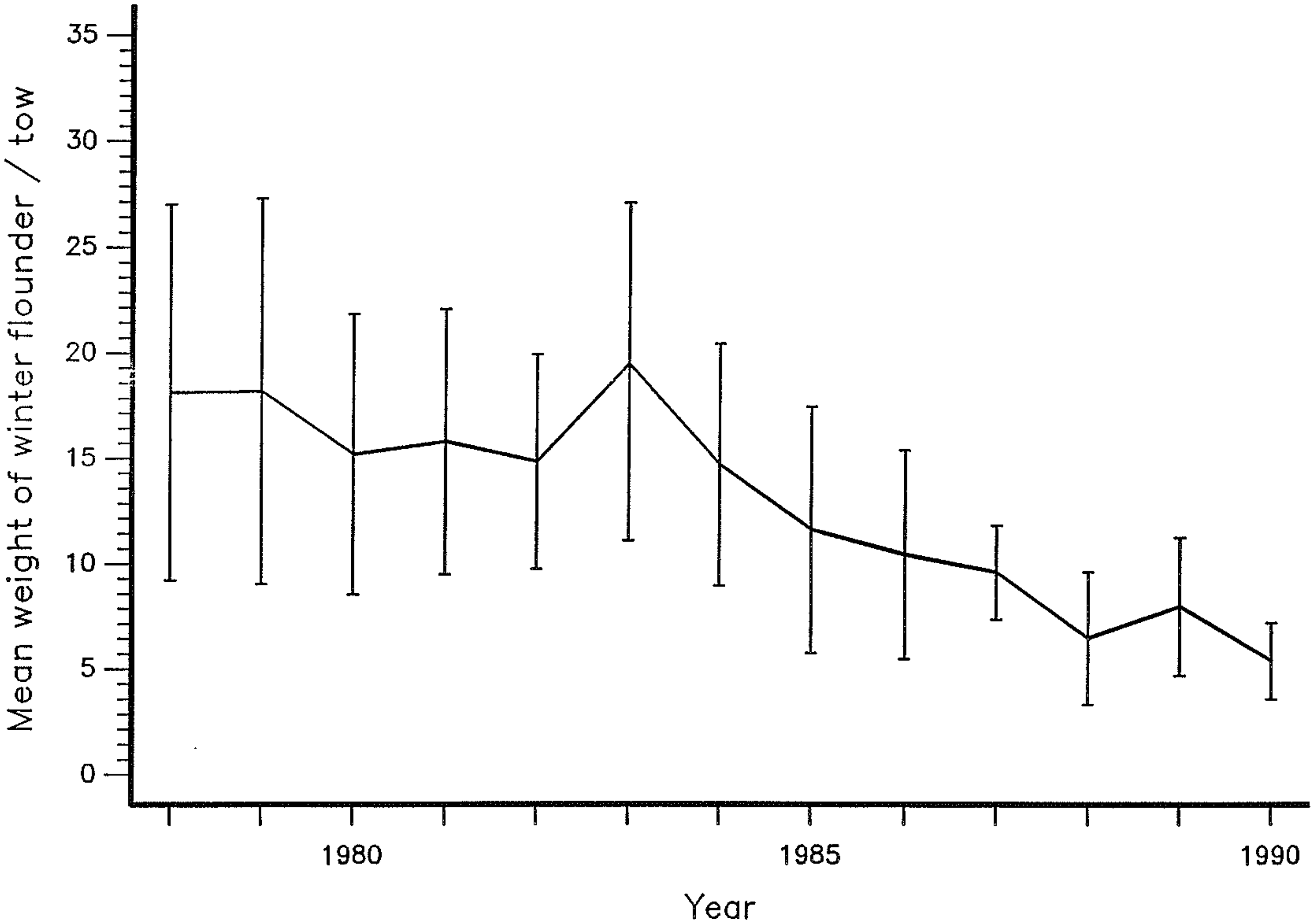

Figure 2.3 Relative abundance (Mean +/– 95% Confidence Interval) of winter flounder in Massachusetts, south and east of Cape Cod, for 1978 to 1990 (Witherell et al. 1990)

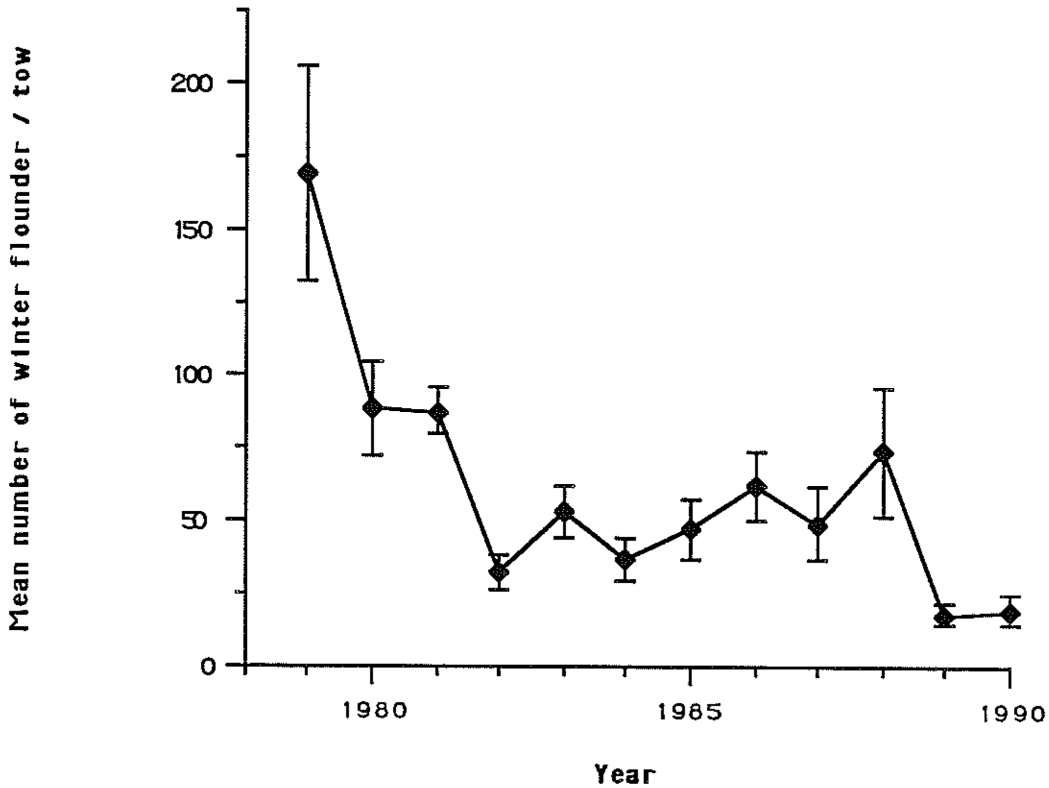

Figure 2.4. Relative abundance (MEAN ± SE) of winter flounder in Rhode Island for 1979 to 1990 (modified from Gibson 1987).

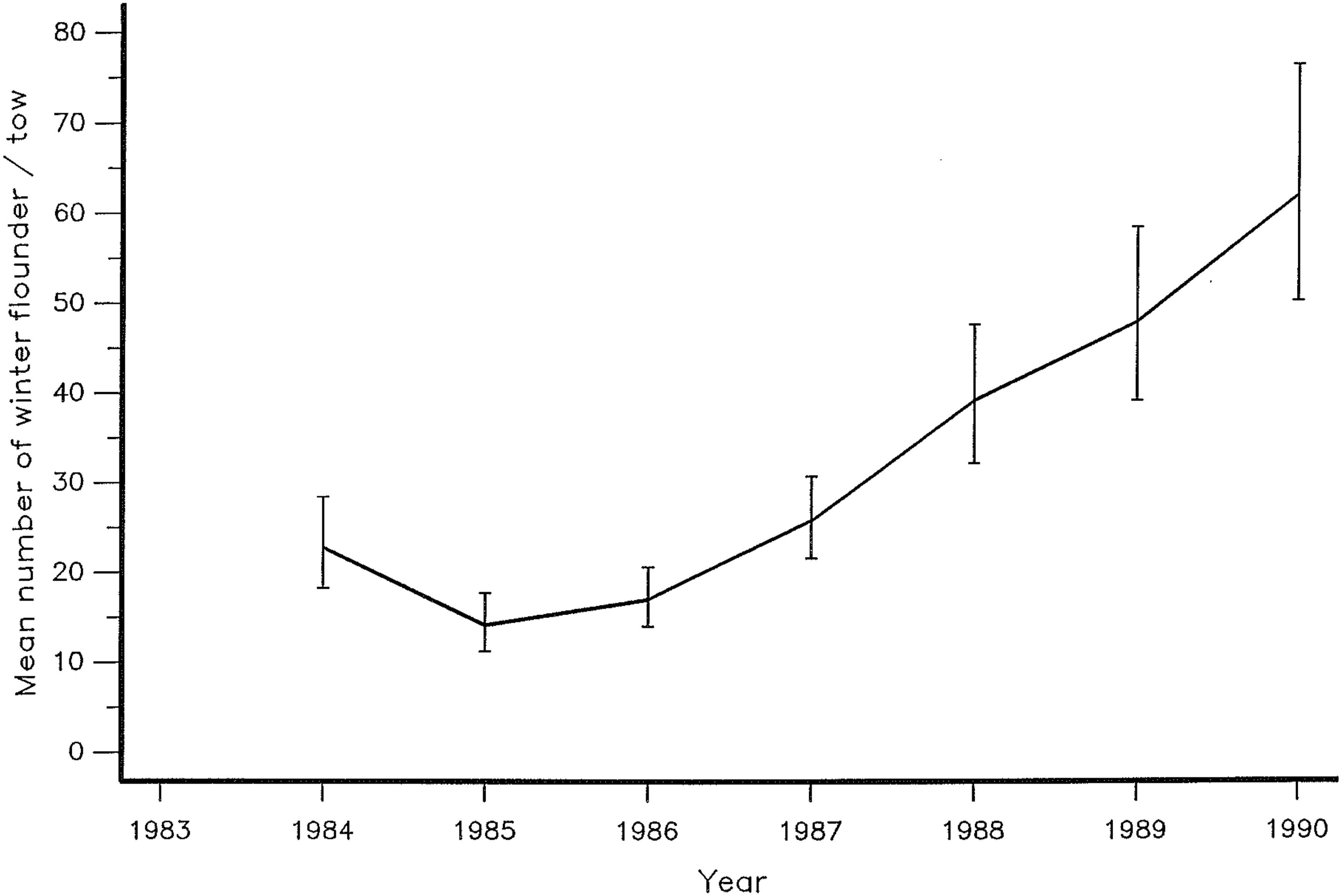

Figure 2.5 Relative abundance (Mean +/− 95% Confidence Interval) of winter flounder in Connecticut, Long Island Sound, from 1984 to 1990 (from CT D.E.P. 1990)

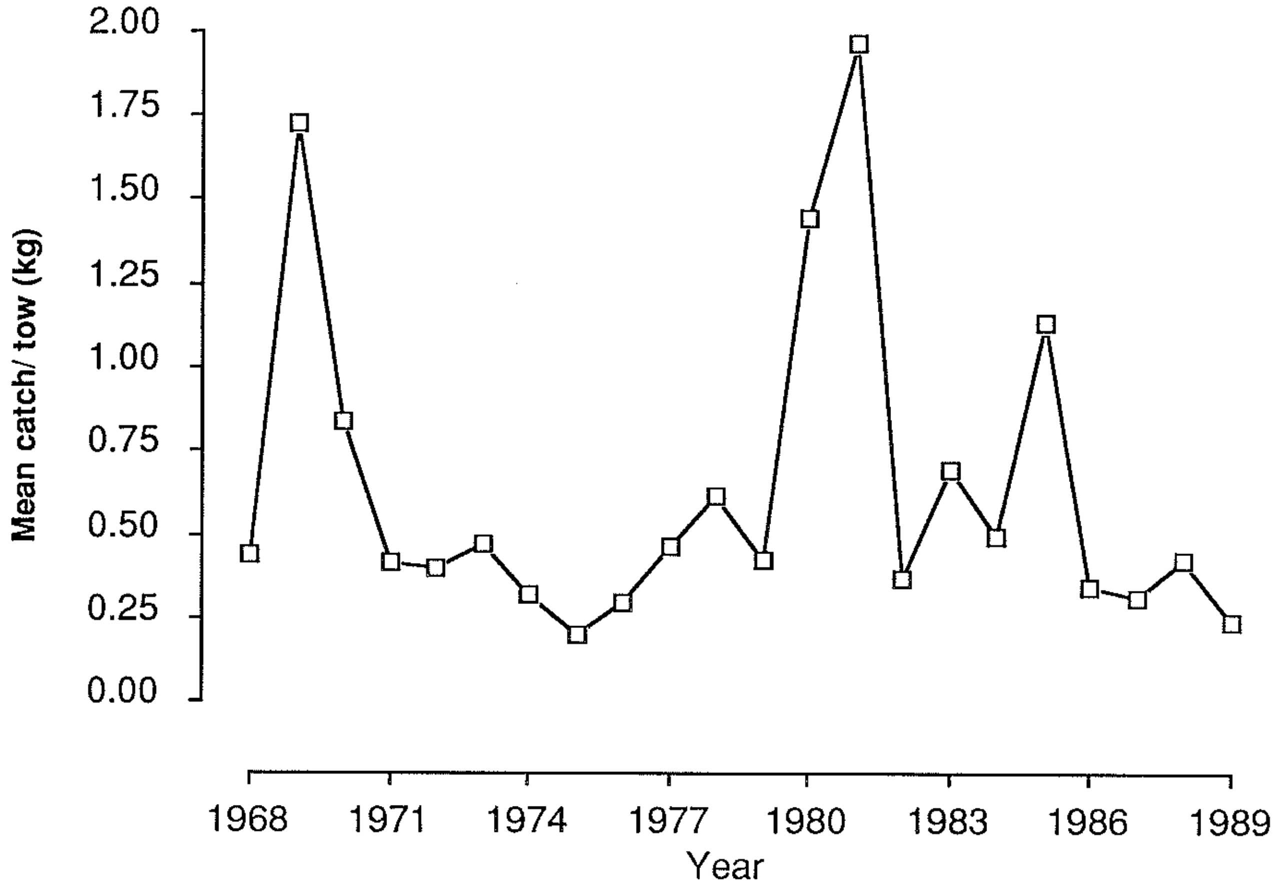

Figure 2.6. Stratified mean catch per tow in weight (kg) of winter flounder in NEFC/NMFS spring bottom trawl surveys New England-Middle Atlantic waters (strata 1-12, 25, 61-76), 1968-1989.

C. Mortality Estimation

1. Total mortality

Total instantaneous mortality (Z) and its annual equivalent was calculated for each stock unit using two methods: analysis of returns from several tagging studies which spanned 58 years from 1931–1989 (Table 2.1); and catch curve analysis of four aging studies which spanned 29 years from 1961–90 (Table 2.2). A third method estimating relative fishing mortality (U) was applied to the southern New England stock where total mortality is driven principally by the commercial fishery. Therefore, a long time-series of commercial catch data could be used to generate a measure of relative exploitation (Table 2.3). These three methodologies are discussed in detail in the *Species Profile.*

a. Tagging Study Results

The Gulf of Maine stock unit had the fewest tagging studies of the three units, with none later than 1969. The results of these studies suggest that relatively high total mortality rates existed in the 1930's and early 1940's. Mortality may have declined during World War II, as was the case for North Sea plaice (Beverton and Holt 1957). Royce *et al.* (1959) also noted that effort was shifted away from winter flounder to yellowtail flounder during this time period. Mortality was considerably lower during the 1960s (Mean 0.92, SE 0.05).

Changes in mortality through time are less apparent for the Southern New England stock. Estimates are high across the time line, although there is again a decline in the 1960s and the most recent estimates for Narragansett Bay are the highest. Numerous mortality estimates for the southern stock unit over the time period show an upward trend beginning in the 1930s. Overall, the available estimates indicate that average total mortality rates currently are higher than they were in 1940, although not exceptionally so.

b. Age Based Studies

Estimates for the northern stock (Gulf of Maine) from MDMF spring trawl survey data indicate that instantaneous total mortality (Z) has remained high for the past 13 years (1978–90, mean=1.35), with the highest mortality during 1986–88. Values for 1989–90 dropped to pre-1986 levels (Table 2.2). A catch curve generated for Georges Bank fish from 1963–66 (from Lux 1973) gave a much lower mortality estimate (Z =0.70).

Total mortality estimates in the central stock (Southern New England), were estimated from Massachusetts, Rhode Island, and Connecticut survey data. MDMF spring surveys south and east of Cape Cod indicate mortality is high (Z >1.0) and has increased during the 1978–90 time series (Table 2.2). Total mortality averaged 1.03 from 1978–83, increasing to a mean of 1.42 in recent years (1984–90). Lower mortality estimates are evident from catch curves in Rhode Island and eastern Connecticut (RIDFW spring survey, 1.20 for 1986–90; CTDEP spring survey, 1.01 for 1985–90).

Catch curve analysis resulted in similarly high mortality estimates for the southern stock unit in western Long Island Sound, New York, and New Jersey. In the early 1960's, total mortality in Great South Bay, NY, averaged 1.13. More recent estimates from Long Island Sound are similar. CTDEP spring survey data indicate mortality greater than 1.0 during the late 1980's (Table 2.2).

Table 2.1 Instantaneous total mortality estimates (Z) for winter flounder derived from tagging data. Standard errors (SE) of the estimates and probability (P) of a greater chi-square are also given. The data are arranged by date within stock unit (Gibson 1990, 1991c).

Tagging Area	Year	Z	SE	P>X2
Gulf of Maine				
St. Johns Bay, ME	1940–1942	1.54	0.82	0.33
Mary's Bay, NS	1949–1950	1.00	0.70	0.69
Boston Harbor, MA	1960–1963	1.19	0.19	0.21
Merr. R. Ipswich Bay,MA	1964–1969	0.75	0.07	0.34
Beverly–Salem, MA	1964–1969	1.00	0.08	0.90
Quincy Bay	1964–1969	0.87	0.06	0.10
Plymouth Outer Harbor	1965–1969	0.94	0.16	0.20
Billingsgate Shoals	1964–1969	0.77	0.07	0.07
Southern New England				
Waquoit Bay, MA	1931–1936	0.90	0.05	0.11
Narragansett Bay,RI	1937–1942	0.89	0.23	0.27
Mystic River, CT	1938–1942	1.19	0.15	0.71
Pt. Judith Pd., RI	1937–1942	0.89	0.09	0.11
RI Sound, RI	1940–1942	0.45	0.11	0.92
Watch Hill, RI	1940–1942	1.15	0.18	0.26
Green Hill Pd.,RI	1956–1958	0.97	0.15	0.22
Narragansett Bay,RI	1958–1959	1.11	0.15	0.15
Hedgefence Shoal, MA	1964–1969	0.76	0.06	0.17
Tarpaulin Cove, MA	1964–1969	0.73	0.06	0.69
Tuckernuck Shoal, MA	1967–1969	1.01	0.13	0.55
Great Point,	1964–1969	0.60	0.04	0.17
Rodgers Shoal	1964–1969	0.62	0.04	0.37
Pendelton Wreck	1964–1969	0.69	0.11	0.09
Highland Light	1964–1969	0.80	0.08	0.40
Nantucket, MA	1964–1968	0.73	0.04	0.26
Provincetown	1964–1968	1.03	0.10	0.32
Waquoit Bay, MA	1970–1971	0.66	0.03	0.29
Niantic, CT	1983–1989	0.80	0.03	0.18
Narragansett Bay, RI	1986–1989	1.48	0.14	0.06
Mid–Atlantic				
Great South Bay, NY	1937–1941	1.46	0.12	0.62
Great Peconic Bay, LIS, NY	1938–1942	1.02	0.11	0.79
Gardiners Bay, LIS, NY	1938–1942	1.16	0.23	0.29
Port Jefferson, NY	1938–1942	1.21	0.14	0.74

(continued next page)

Table 2.1 continued:

Tagging Area	Year	Z	SE	P>X2
Great South Bay, NY	1964–1968	1.29	0.08	0.13
Barnegat Bay, NJ	1978–1979	1.80	0.11	0.19
Oyster Bay,LIS, NY	1981–1983	1.36	0.27	0.20
Huntington Bay,LIS, NY	1981–1983	1.14	0.41	0.57
Shark River, NJ	1982–1985	1.95	0.48	0.10
Manasquan River, NJ	1982–1985	1.95	0.29	0.20
Barnegat Bay, NJ	1986–1987	1.86	0.46	0.07
Sandy Hook Bay, NJ	1986–1989	1.23	0.17	0.13
Offshore				
E.NE. Nantucket	1965–1969	0.69	0.13	0.09
W. Nantucket Shoals	1964–1969	0.61	0.07	0.24
Nantucket Shoals	1965–1969	0.78	0.06	0.07
Georges Bank	1967–1973	0.57	0.04	0.46

Table 2.2 Estimates of instantaneous mortality rates (Z) on winter flounder calculated from catch curve data by state and year.

Area	Years	Z	SE(SD)	Data Source
GULF OF MAINE				
MA	1978–1983 Ages 4–7	1.28	0.15 (SD)	Witherell *et al.* 1990
	1984–1990 Ages 4–7	1.42	0.15 (SD)	Witherell *et al.* 1990
Georges Bank	1963–1966 Ages 7–12	0.70	0.09	Gibson (pers. comm.),from Lux 1973
SOUTHERN NEW ENGLAND				
MA	1978–1983 Ages 4–7	1.03	0.25 (SD)	Witherell *et al.* 1990
MA	1984–1990 Ages 4–7	1.42	0.13 (SD)	Witherell *et al.* 1990
RI				
RIDFW Spring	1986–1990	1.20	0.27	Gibson 1989b; 1990
RIDFW Winter	1986–1990 Ages 3–8	1.17	0.83	
URIGSO Winter	1986–1990 Ages 3–8	1.10	0.73	Gibson 1989b; 1990
MRC Winter	1986–1990 Ages 3–8	1.18	0.10	Gibson 1989b; 1990
E. Long Island Sound	1978–1983 Ages 3–9	0.72		NUSCo 1987
MID–ATLANTIC				
Great South Bay	1961–1963 Ages 3–6	1.13	0.16	Castaneda (pers. comm.) from Poole 1966
Long Island Sound				
	1984–1988	0.99	0.06	CTDEP 1991
sound–wide	1989–1991 Ages 4–8	1.26	0.06	
western	1988–1989 Ages 4–7	1.20	0.06	Castaneda (pers. comm.) NY DEC

Table 2.3. Relative rates of exploitation for Narragansett Bay, RI
(Taken from Gibson 1990).

Year	539 Catch[1] lbs*10^6	NMFS Survey lbs/tow	Relative Fishing Rate (U)	Scaled Z
1963	2.51	1.36	1.85	1.10
1964	3.50	1.49	2.35	1.40
1965	2.46	1.56	1.58	0.94
1966	3.56	1.36	2.62	1.56
1967	2.90	1.21	2.40	1.43
1968	2.80	1.44	1.95	1.16
1969	2.20	1.60	1.37	0.81
1970	1.89	1.42	1.33	0.79
1971	1.48	1.17	1.27	0.75
1972	0.97	1.03	0.94	0.56
1973	1.15	0.94	1.22	0.73
1974	0.86	0.84	1.02	0.61
1975	0.79	0.79	1.01	0.60
1976	0.84	0.86	0.97	0.58
1977	1.06	1.01	1.05	0.62
1978	1.45	1.19	1.22	0.72
1979	1.81	1.34	1.34	0.80
1980	2.81	1.67	1.68	1.00
1981	2.42	1.75	1.38	0.82
1982	2.91	1.45	2.02	1.20
1983	2.71	1.39	1.94	1.15
1984	2.84	1.28	2.22	1.32
1985	2.56	1.25	2.04	1.22
1986	1.88	1.02	1.84	1.09
1987	1.37	0.89	1.54	0.92
1988	1.11	0.83	1.34	0.80
1989	1.47	0.76	1.93	1.15
1990	1.00	0.59	1.70	1.01

[1]NMFS Statistical Landing Area 539 encompassing Block Island and Rhode Island Sounds.

c. Relative exploitation study

Estimates of relative fishing mortality using a third method applied to data from Narragansett Bay, RI, showed a significant (P=0.025) negative exponential relationship between fishing rates and stock abundance lagged seven years or one generation. Low flounder abundance in the next generation was associated with fishing rates ranging from 1.0–1.4 on the parent stock. Lower fishing rates ranging from 0.6–0.8 were associated with higher stock abundance. This time series also showed that fishing mortality was significantly lower in 1969–78 (mean F=0.68 SE=0.03) than in 1963–68 (mean F=1.27, SE=0.10) and 1979–90 (mean F=1.04, SE=0.05; Table 2.3).

In summary, when all methods are considered, three time periods with similar mortality levels are evident: 1930 to the late 1950s or early 1960s, 1969–78, and 1979 to the present. From 1931–42, mortality was high (Z>1.0), especially where commercial fishing was concentrated principally inshore such as on inner fishing grounds in the Gulf of Maine and Great South Bay, NY. The tagging data indicate a respite in mortality began in 1956 and continued through the 1970s. The time series of relative exploitation for Rhode Island indicated that a low point in fishing effort lasted from 1969–78. The popularity of offshore species during the late 1960s and early 1970s are likely reasons for subsequent declining mortality. From 1954–66, small vessels were replaced by medium and large tonnage trawlers (Gibson 1990). These larger vessels increasingly abandoned inshore flounder in favor of more lucrative offshore groundfishes. The resulting low point in flounder mortality was probably instrumental in the ability of present stocks to sustain high fishing mortality in recent years. Current declines in abundance may be a lag response to the increasing fishing mortality rates which probably began in 1977 after implementation of the Magnuson Act. Real fishing effort in New England actually doubled from 1977–1987 due to increasing size, number, and technology of vessels (Anthony 1990). High historical estimates of mortality should not be taken as evidence that flounder stocks can withstand such mortality indefinitely. Although many fish stocks have persisted in the face of high fishing rates, extreme variability in recruitment may be the end product of reduced stock size (Shepherd and Cushing 1990).

2. Fishing Mortality

Estimates of instantaneous fishing mortality (F) can be derived directly from estimates of total instantaneous mortality (Z) by subtraction of the fraction of mortality (M) attributed to natural causes. Although natural mortality rates are difficult to calculate for populations which concurrently experience substantial mortality from fishing, two methods were employed which gave fairly comparable results. These methods examined maximum age and tag return data, and are detailed in the *Species Profile*. The even more difficult task of estimating increases in M due to non-fishing anthropogenic sources is not addressed here (see Part One, and Almeida and Fogarty 1989).

Using recapture rates of marked fish (Ricker 1975) from three tagging studies, estimates of instantaneous natural mortality (M) ranged from 0.35 for stocks south of Cape Cod; 0.36 for Narragansett Bay, RI; and 0.90 for Great South Bay, NY. Although Poole (1966) discusses reasons for a very high natural mortality on the Great South Bay population, a more moderate value seems more reasonable. A value of M=0.35 was chosen. Subtracting the natural component from current estimates (1982–90) of total mortality for each stock unit (Table 2.2) gives the following estimates of fishing mortality:

Gulf of Maine:	**F=1.07 (median Z=1.42)**
S. New England:	**F=0.84 (median Z=1.19)**
Mid–Atlantic:	**F=1.01 (median Z=1.36)**

D. Status of the Fisheries

1. Commercial Landings and Catch-Effort Trends

Since 1939 NMFS records of commercial landings have varied from 13 to 38 million pounds. Coastwide, 69% of flounder landed in the U.S. in the last decade were taken by commercial gear, almost exclusively (95%) by otter trawl. A steady increase in landings occurred between 1939–1950, followed by an historic low in 1955 (13.2 million lbs.). Landings rose in the late 1950's only to decline through the mid- 1970's then increased in the early 1980's. Landings peaked during the early 1980's (38.1 million lbs.). Recently, landings have continuously declined with 1989 (14.7 million lbs.) close to the previous time series low in 1955 (Figure 2.7).

During the last decade, 58% of commercial catches were taken in the Southern New England unit, compared to 15% in the Gulf of Maine, 7% in the mid-Atlantic, and 19% on Georges Bank (Table 2.4). For the northern two stock units, the trend in landings in state waters over the last decade has been decidedly negative (Table 2.4; regression of landings vs years, $P<0.001$). Landings taken in the Exclusive Economic Zone (EEZ) in these two units have also shown a negative trend since 1979 (Table 2.4, $P=0.04$; Georges Bank, $P=0.08$). Landings in the mid-Atlantic have shown no clear trend during the same years (state waters: $P=0.75$; EEZ: $P=0.10$).

To further examine the relationship between commercial fishing and fish abundance, catch-per-unit-effort (CPUE) data from commercial fisheries was examined as fishery dependent information on fish abundance and exploitation. Recent declines in CPUE of otter trawls have been observed in the northern two stock units. Of trips landing 50% winter flounder or more, CPUE of Class 2 vessels (5–50 GRT) in the Gulf of Maine has declined almost continuously since the late 1960's, when these vessels landed more than three metric tons per day fished (mt/df; Figure 2.8). Recent CPUE remains low, averaging 0.91 mt/df (1987–89). The effort of these vessels has increased since 1976 from low levels during the 1960s to a peak in 1981, and has since declined somewhat. Of trips landings 50% or more winter flounder with Class 3 vessels (50–150 GRT), CPUE in the southern New England area (defined by NMFS as East Cape Cod to New Jersey) remained relatively stable from 1964–1980, then declined 77% from 3.4 mt/df in 1980 to 0.77 mt/df in 1989 (Figure 2.9). Effort levels in this class also rose substantially after 1976. Recent declines in CPUE are due to an increase in effort, as well as a decline in landings.

A long-term abundance trend (catch-effort) was constructed to examine changes in flounder abundance with respect to total mortality rates. The Rhode Island commercial catch-effort data from 1947–1990 (NOAA NMFS Fisheries Statistics of the US and recent vessel and weighout data, Gibson 1990) is particularly instructive because the data predates any research abundance series and is representative of abundance trends in the center of the species' range. A nominal measure of effort was calculated as the total trawling tonnage divided by 50 to give the number of 50 ton units. Long-term flounder abundance was estimated as the ratio of catch to the number of trawling units. For years after 1967, the long-term trend was compared to a more precise estimate of abundance, the NMFS spring trawl survey catch-effort in southern New England waters (NMFS strata 1–12, 25, 61–76, smoothed estimates, Almeida pers. comm.). Correlation of the two time series was significant ($r=0.64$, $P<0.01$, Figure 2.10), suggesting that the longer commercial series is a good reflection of past flounder abundance. The trend shows abundance increased from 1947 to 1957 and was stable until 1970. A decade of decline followed, with only modest gains to the 1980s. Recent estimates are at record low levels.

Table 2.4. Winter flounder commercial landings (thousands of pounds) by year and stock unit. (Data source: NMFS weighout data).

	------State Waters------				-----Exclusive Economic Zone---				
YR	Gulf ME	S.New Engl.	Mid-Atl.	**Total**	Gulf ME	S.New Engl.	Mid-Atl.	Geo. Bank	**Total**
1979	951	4052	842	5846	2992	9776	891	5231	18690
1980	841	4504	1104	6451	4849	17023	700	7016	29588
1981	1095	4752	1397	7244	4985	17706	1122	7145	30958
1982	802	4293	1013	6108	5010	15160	1099	5299	26568
1983	719	3832	991	5542	4307	14242	813	7788	27150
1984	524	3835	1081	5440	3679	13719	497	7842	25737
1985	400	3295	746	4441	2797	10990	1040	4159	18986
1986	257	2440	808	3505	2209	7373	515	3495	13592
1987	269	2065	886	3220	2118	8105	591	5281	16095
1988	229	1872	1275	3376	3075	8706	547	2438	14766
1989	175	1097	595	1867	2670	8000	809	1756	13235
MEAN:	569	3276	985	4822	3517	11891	784	4924	21397
%Total:				18%					82%
1979-88 10-YR TREND:	Neg.	Neg.	Neg.		Neg.	Neg.	Neg.	Neg.	
	***	***			**	**	*	*	

Note: Trend = Slope of regression: landings versus years where
* = 0.05<P<0.10; ** = 0.01<P<0.05; *** = P<0.01

----PERCENTAGE OF COMMERCIAL LANDINGS----

GULF OF MAINE:	16%
S. NEW ENGLAND:	58%
MID-ATLANTIC:	7%
GEORGES BANK:	19%

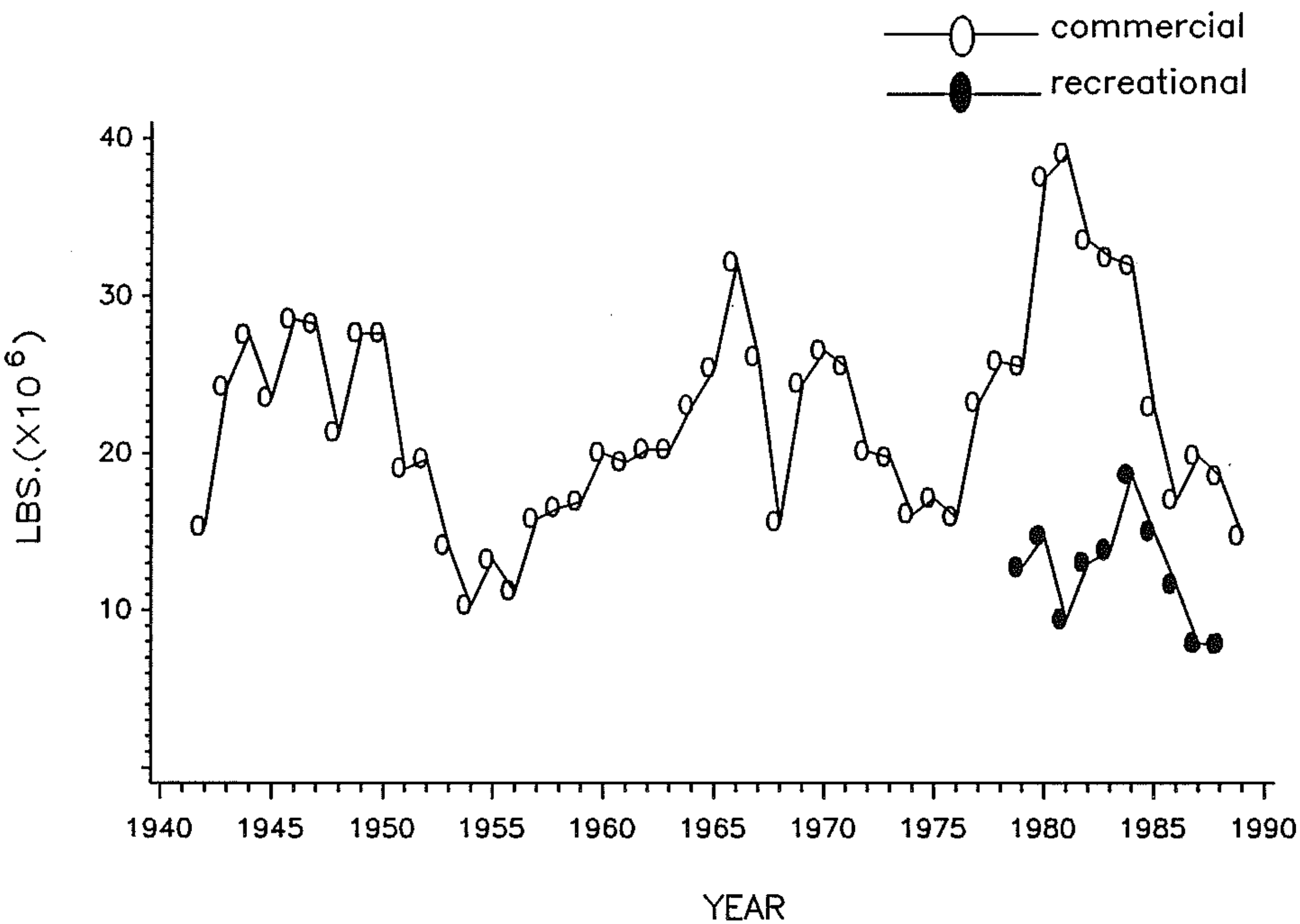

Figure 2.7. Total U.S. landings of winter flounder.

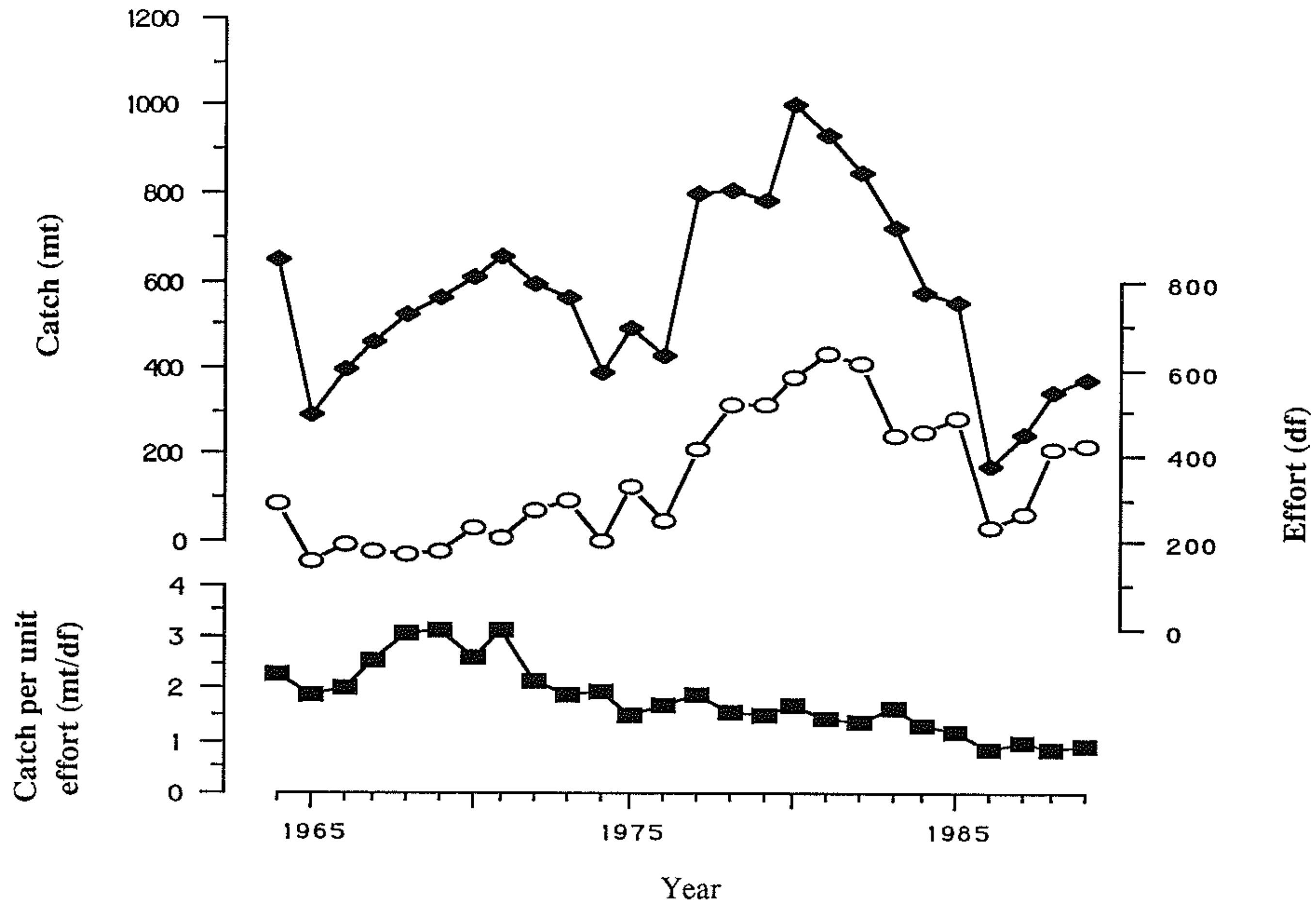

Figure 2.8 Catch (◆metric tons, mt), effort (○days fished, df), and catch per unit effort (■CPUEm mt/df) from the Gulf of Maine area in which landings consisted of greater than or equal to 50% winter flounder.

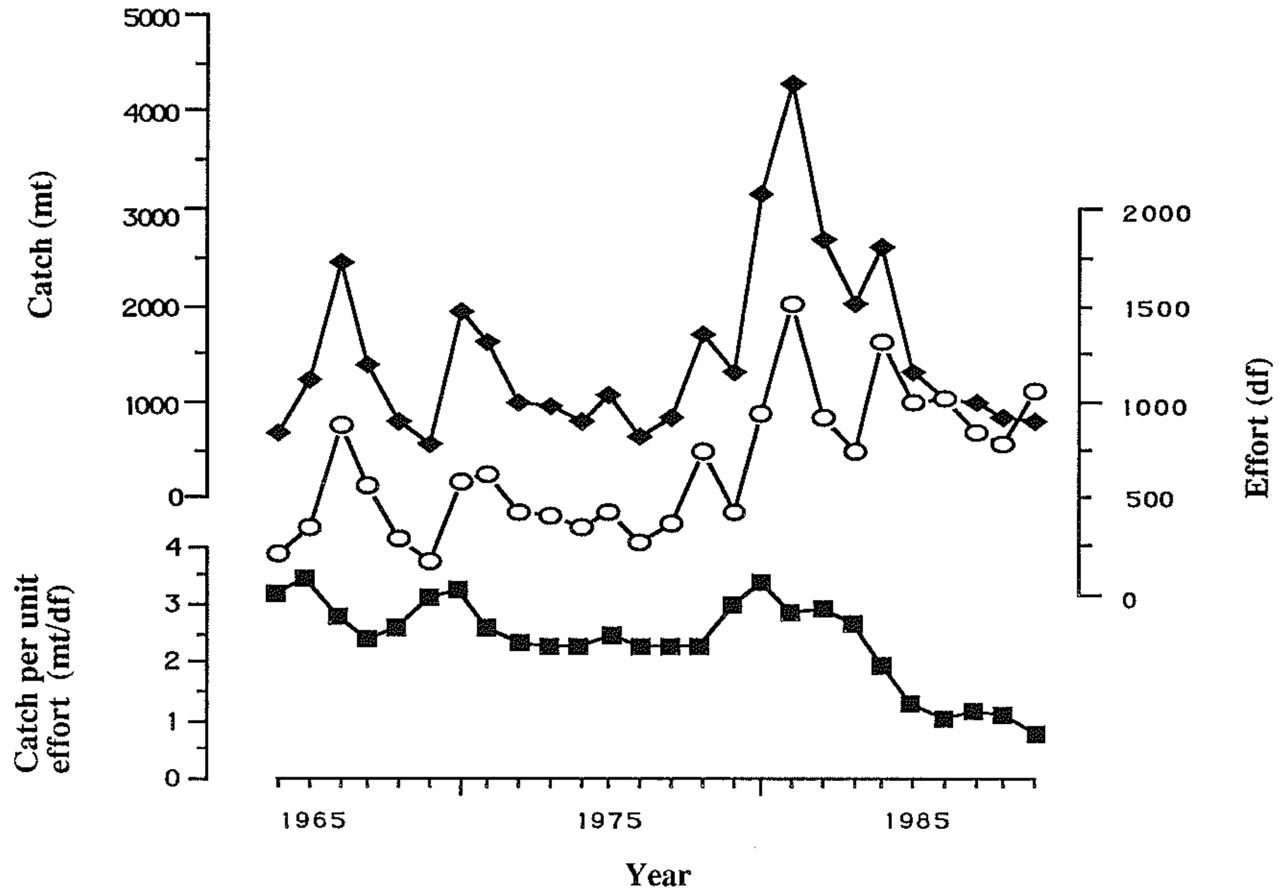

Figure 2.9. Catch (◆metric tons, mt), effort (○days fished, df), and catch per unit effort (■ CPUE, mt/df) from the southern New England area in which landings consisted of greater than or equal to 50% winter flounder.

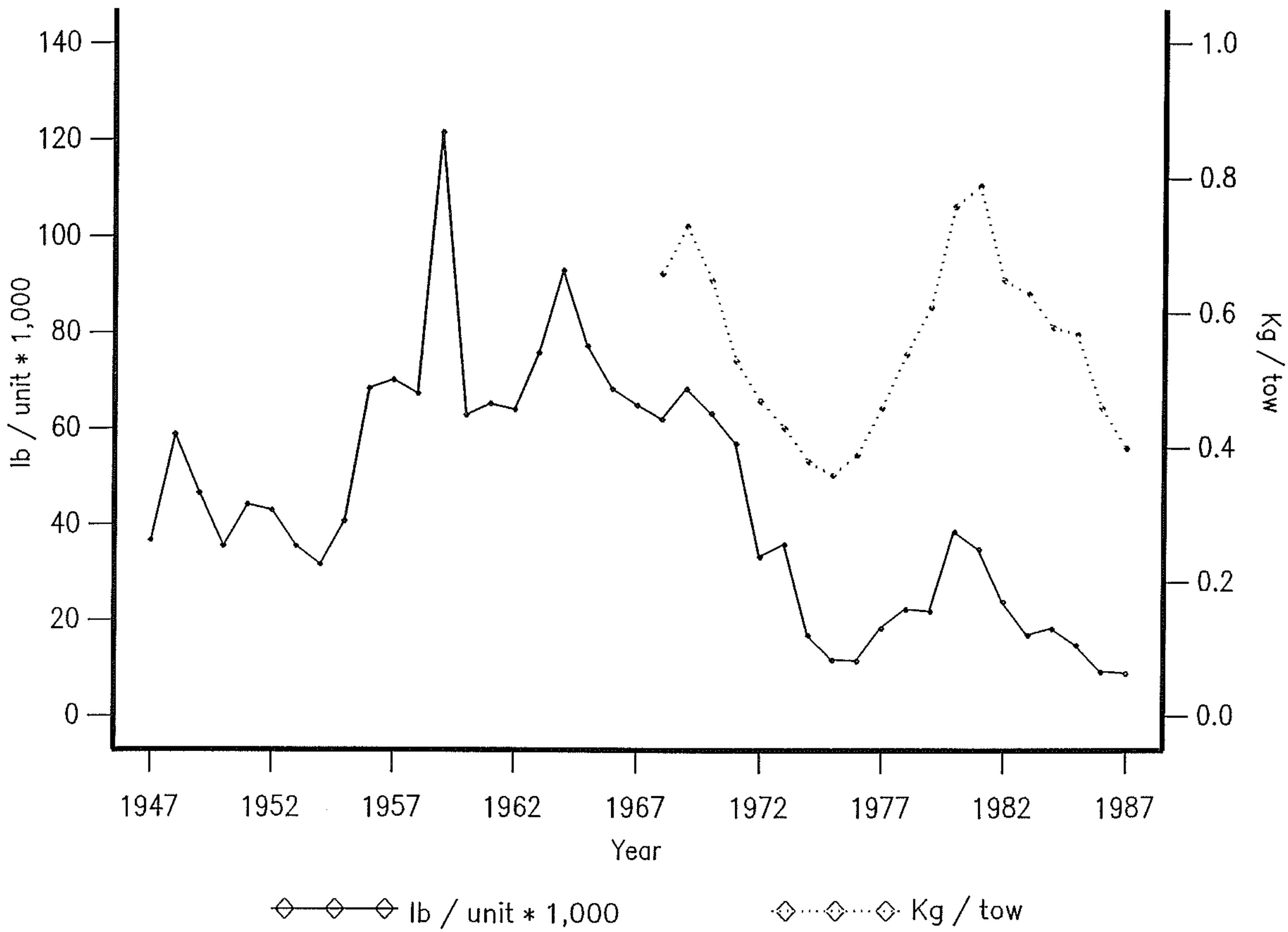

Figure 2.10: Winter flounder abundance trends by two methods in Southern New England, 1947 – 1990

2. Recreational Landings and Catch-Effort

Recreational landings have only been tallied coastwide since 1979, and have ranged from 3 to 18 million pounds. Recreational catch of winter flounder was derived from the Marine Recreational Fisheries Statistics Survey (MRFSS) catch and effort data base for the North Atlantic and mid-Atlantic regions of the Survey. A detailed description of methods used to extrapolate total catch is given in the Methods Appendix of the *Species Profile*.

During the last ten years, 62% of the recreational catch was taken in the mid-Atlantic stock unit, while 24% was taken in the Gulf of Maine, and 14% in Southern New England (Table 2.5). In the southern states, there was no clear trend in catch over this time period (regression of year versus catch, P=0.98). However, a negative trend in catch was recorded for the central unit (P=0.01), and northern unit (P=0.03). The same results were obtained when the number of successful flounder trips, as a percent of total trips, was regressed against year (Mid-Atlantic: positive, P=0.41; S. New England: negative, P=0.06; Gulf of Maine: negative, P=0.13).

Recent trends in total catch from both commercial and sport fisheries for each stock unit are similar to sport trends alone: Total catch since 1979 shows a significant downward trend (regression of landings vs years: negative slope, P=0.01) for the two northern units, while landings in the southern unit show no apparent trend. Georges Bank commercial landings show a significant downward slope which is comparable to the Gulf of Maine and Southern New England units.

In summary, one of three (31%) flounder landed in the U.S. in the last decade were taken by recreational fishermen (Table 2.6). The remaining two-thirds were taken by commercial gear, almost exclusively by otter trawl. The pattern of exploitation by the sport and commercial fisheries differs considerably by stock unit. Flounder in the Gulf of Maine are equally exploited by the sport (48%) and commercial (52%) fisheries. Inclusion of the Georges Bank commercial fishery would increase the commercial portion by about 10%. Exploitation ratios for the other two stock units are heavily skewed toward the commercial fishery (89%) in Southern New England, and toward the sport fishery (79%) in the Mid-Atlantic.

Commercial catch from all state waters represents an average of 13% of total landings, while the exclusive economic zone (EEZ), including Georges Bank, represent **more than half** (56%) of total winter flounder landings during the last decade. Total catch from both fisheries divided by stock unit (Table 2.6) show that by far the largest fishery is in Southern New England waters in the EEZ, followed by Gulf of Maine federal waters.

Table 2.5. Winter flounder recreational catch (thousands of fish) by year and stock unit. (Data source: MRFSS positive intercept catch rates)

CATCH by STOCK UNIT

Year	Gulf of Maine Thousands Fish	Gulf of Maine Thousands Pounds	Southern New England Thousands Fish	Southern New England Thousands Pounds	Mid-Atlantic Thousands Fish	Mid-Atlantic Thousands Pounds	Total Catch Thousands
1979	3112	3112	2597	2597	7975	7018	12727
1980	5674	5220	3019	2777	7941	6670	14680
1981	3633	3960	1566	1707	4293	3778	9445
1982	4286	4072	2455	2332	6572	6572	12976
1983	3425	3117	1591	1448	9376	9282	13847
1984	1946	2218	1231	1403	15910	14955	18577
1985	3041	3467	1726	1968	11117	9561	14995
1986	2346	2557	1540	1679	8006	7366	11601
1987	1698	2360	1086	1510	4185	4059	7929
1988	1684	2235	773	850	3767	3531	6233
1989	1113	1225	538	592	1768	1537	3354
Mean		2905		1647		7355	12455
(SE)		(403)		(233)		(1194)	(1072)
% Total		24%		14%		62%	

11 Year Trend:	Gulf of Maine	Southern New England	Mid-Atlantic
	Negative**	Negative**	No trend

** slope of regression: landings versus years P<=0.01

Table 2.6. Ten year mean of commercial and recreational landings by state and stock unit, 1979–1988.

Location	(Thousands of pounds) Recreational	Commercial State	Commercial EEZ	Commercial GB	Ratio R:C	% Total
State						
ME	521	81	961	12	33:67	3.9
NH	280	2	151	1	64:36	1.1
MA	3035	2077	9877	4895	15:85	49.8
RI	1070	1514	4371	307	14:86	18.2
CT	1221	458	501	0	55:45	5.5
NY	2970	912	554	23	67:33	11.2
NJ	3338	106	196	0	90:10	9.1
DE	469	6	32	3	91: 9	1.3
STOCK UNIT						
Gulf of Maine	3232	609	3602		44:56	21.7
S. New England	1845	3494	12280		11:89	51.4
Mid–Atlantic	7377	1024	782		79:21	26.8
All Areas	12455 (31%)	5127 (13%)	16664 (42%)	5241 (14%)	31:69	39851 (100%)

STATE = state waters <=3 mi
EEZ = > 3 mi exclusive of Georges Bank
GB = Georges Bank

MEAN LANDINGS AS A PERCENT OF TOTAL ANNUAL MEAN OF 39 MILLION POUNDS

Stock Unit	Recreational	Commercial State	Commercial EEZ	Commercial GB	Total	10 Year Trend *
Gulf of Maine	8%	2%	9%	13%	32%	Neg **
S. New England	5%	9%	31%	1%	46%	Neg **
Mid–Atlantic	17%	3%	2%	<1%	22%	No Trend
TOTAL	30%	14%	42%	14%		

* slope of regression: landings vs years, excluding Georges Bank
** P<0.01

PART THREE: MANAGEMENT OF WINTER FLOUNDER STOCKS

The purpose of managing winter flounder stocks is to ensure that the winter flounder resource can be utilized throughout its range by current and future generations of the fishing and non–fishing public. Effective management will require controls on mortality due to both fishing and habitat degradation. The analyses outlined below are tools designed to facilitate the management process. As new data become available and new assessments are completed, planners and users of the winter flounder resource should anticipate that estimates of fishing mortality and resultant management activities will be adjusted accordingly.

A. Management of the Fisheries

1. Yield per Recruit and Surplus Production Analyses

To examine the relationship between long–term yield and fishing mortality, growth and maturity estimates for winter flounder were used to calculate yield–per–recruit with a Thompson–Bell model (Ricker 1975, Witherell 1990). The model was run using parameters from six populations under a range of fishing mortalities and recruitment regimes. Details of the model are discussed in the Methods Appendix of the *Species Profile.*

Each model run calculated the total biomass of spawning females surviving after fishing. This biomass is expressed as a percentage of the biomass of spawning females in the absence of fishing, or maximum spawning potential (%MSP). The fishing rate at which biomass falls below 25% of the maximum is given as a reference point (F_{25}) where stock maintenance is questionable and the stock is overfished. Because uncertainty in calculating maximum spawning potential tends to underestimate the true maximum, this reference point should be considered as a critical threshold below which the spawning stock is seriously eroded over time. Experience with haddock and yellowtail flounder stocks has shown that fishing rates which preserve less than 25% MSP do not achieve replacement stock levels (Gabriel 1986, Gabriel *et al.* 1989), making stock decline probable.

A more desirable reference fishing rate preserves 40% of the maximum spawning potential (F_{40}) and provides a maximized range in yield to the fishery. Fishing mortalities that preserve approximately 36% MSP were found to maximize the minimum yield among several possible spawner–recruit relationships examined for six species of New England groundfish, including Georges Bank winter flounder (Clark 1991). In this plan, this reference point is considered a target fishing rate which will allow presently depleted stocks to rebuild. Although large reductions in mortality would be required to meet this target, management actions which reduce fishing to near this target will begin to rebuild stocks which are presently overfished. Details of the data sets and methods used to generate F_{25}, F_{40}, and an intermediate value of F_{30} are discussed in the Methods Appendix of the *Species Profile.*

In terms of these reference fishing rates, current fishing rates are above target (F_{40}) levels for all three stock units (Table 3.1) under present length and net mesh regulations. Moreover, some estimates of current fishing mortality exceed fishing levels where stocks maintenance is in jeopardy (F_{25}). Current fishing mortality rates are preserving 24% MSP of populations in the Gulf of Maine, 18–22% MSP in Southern New England, and 23–29% MSP of in the mid–Atlantic after newly instituted length limits.

Table 3.1 Fishery reference points for winter flounder by stock unit for various size limits and codend mesh sizes (diamond). See text for description of reference fishing rates. Current limits are listed first for each area.

Location	Size Limit	Mesh Limit	Current Fishing F (%MSP)	Reference Fishing Rates F_{25}	F_{30}	F_{40}
--GULF OF MAINE--						
N. Cape Cod	12"	5.5"	1.07 (24)	1.00	0.78	0.49
--SOUTHERN NEW ENGLAND--						
S. Cape Cod	12"	5.5"	1.07 (25)	1.09	0.80	0.50
Rhode Island	*11"	3.5"	1.03 (20)	0.58	0.47	0.32
	12"	3.5"		0.71	0.58	0.38
	12"	4.5"		0.79	0.62	0.41
	12"	5.5"	(31)	0.97	0.72	0.46
Eastern Long Island Sound	10"	3.5"	0.91 (19)	0.67	0.53	0.37
	10"	4.5"	(22)	0.78	0.61	0.41
	10"	5.0"		0.84	0.67	0.43
	11"	4.5"	(25)	0.90	0.70	0.45
	12"	5.0"		1.25	0.92	0.57
	12"	5.5"	(34)	1.61	1.15	0.68
--MID-ATLANTIC--						
Western Long Island Sound	**10"	3.5"	0.91 (26)	0.95	0.72	0.47
	10"	4.5"	(29)	1.16	0.88	0.53
	10"	5.0"		1.27	0.92	0.57
	11"	3.5"	(30)	1.18	0.90	0.58
	11"	4.5"	(33)	1.49	1.10	0.67
	12"	5.0"		2.01	1.50	0.89
	12"	5.5"	(42)	>2.0	1.79	1.01
New Jersey /New York Bight	**10"	3.5"	1.20 (23)	1.08	0.81	0.52
	10"	4.5"		1.13	0.85	0.54
	11"	4.5"		1.74	1.29	0.75

*As of June 1991, minimum length limit 12", minimum mesh 5" with exemptions.

**Current sport fishing practices in NJ reflect an 8" minimum length (data source: MRFSS Survey) although no legal limit was in place prior to 1991, NY 8" prior to 1991; 3.5" mesh size was considered the minimum size currently in use although no legal limit is in place.

2. Recommended Actions

Management recommendations to postpone and reduce fishing mortality are tailored to the characteristics of populations in each of the three stock units. The management strategy reflects a two-step process of initially preventing overfishing by reducing F to below F_{25} values, and secondly reducing F to approach F_{40}. It is not inconsistent with this plan for states encompassing two stock units to consider all alternatives given for both units in seeking an effective strategy to accomplish these reductions in fishing mortality.

Mid-Atlantic

Fishing mortality in the mid-Atlantic states is predominantly from the recreational fishery. Limited data showing abundance and landings trends have been variable for the last decade, but show large declines from the 1960s to 1980-81 in southern estuaries. Minimum legal length limits are low or nonexistent (Table 3.2). However, the states of New Jersey and New York have extensive area restrictions on mobile commercial fishing gear and both states have recently increased their minimum legal length limits to ten inches. A ten inch limit is recommended for the recreational and commercial fisheries in all states in this stock unit. Such a minimum length limit postpones fishing mortality to mature age groups (>Age 3) over the range of the management area. Achieving F_{25}, and other reference rates, will require either further postmonement of fishing mortality with larger length limits or reduction of mortality. Reduction in catch could be accomplished through creel limits (Table 3.3), commercial mesh size restrictions, additional area or season closures, or restrictions on commercial vessels or gear such as fyke nets often fished in nursery grounds.

Southern New England

Fishing mortality in the center of the flounder's range is predominately from the commercial otter trawl fishery. In recent years, abundance indices have declined, and mortality has risen substantially on most populations. Present minimum length limits and commercial mesh size limits are relatively restrictive (Table 3.2). A 12" length limit, with 5.5" mesh, preserves spawning stocks at 25-34 %MSP (Table 3.1), meeting or exceeding the 25% minimum criterion.

Achieving F_{40} will require approximately a 25-50% reduction in F in addition to a 12" length limit. For the Narragansett Bay, (RI) stock, a year-round closure of Narragansett Bay achieves F_{40}. Alternatives to this closure could include other area or season closures, or restrictions on vessel characteristics or use.

Recreational fishing contributes approximately 20% of the total regional catch taken in this stock unit. Therefore, creel limits would reduce total exploitation somewhat but could not easily meet target fishing levels. For example, for the stock unit as a whole, a creel limit of six fish, with a 12" length limit, would reduce the sport catch by 22-35% (Table 3.4). Total exploitation would be reduced by only 10% or less (35% of 20% = 7%).

For populations south of Cape Cod, MA, and east of Narragansett Bay, RI, present fishing rates approach estimates where stock decline is probable. Effort reduction in both the sport and commercial fishery is the only way to prevent continued overfishing and allow stock rebuilding. Postponing fishing mortality by extending length limits to meet this criterion could be accomplished only with unreasonably large length and mesh sizes. Target fishing levels can be reached with area closures, but they would need to encompass a large portion of seasonal movements of individual populations if a 50% reduction in F is to be achieved. For example, a model of monthly flounder movements within the 20 fathom line in southern New England waters from south of Cape Cod to Long Island was developed to assess the effect of permanently closing various sub-

Table 3.2 Current minimum length and gear regulations by state.

MAINE	
Minimum length:	11"
Mesh size:	5.5", except Jan-Mar shrimp fishery 1.75"
Seasonal closures:	Sheepscot Bay
NEW HAMPSHIRE	
Minimum length:	11"
Mesh size:	None (5.5" required to take,transport, or possess Cod, Haddock, or Yellowtail flounder)
Gear Restrictions:	No mobile gear in state waters Apr 16-Dec 14 No mobile gear in Great Bay Estuary system
MASSACHUSETTS	
Minimum length:	12"
Mesh size:	5.5"
Area closures:	North of Cape Cod: 1 mile from shore, Feb 1-May 31, commercial gear and sport pole/hook limit; Mobile gear closure to November South of Cape Cod: mesh limit 3.5", 5.5" seasonally, and exemptions; Buzzards Bay year round closure, all gear
RHODE ISLAND	
Minimum length:	12" as of June 1991
Mesh size:	5" with area and species exemptions
Area closures:	Narragansett Bay and coastal ponds year round as of June 1991
CONNECTICUT	
Minimum length:	11" commercial/ 10" sport
Mesh size:	4.5" mesh Nov. 15 - May 14. 3" remaining months except exempted squid fishery May 15-July 14
Area closures:	Commercial gear shoreward of a trawl line; all gears in Niantic River
NEW YORK	
Minimum length:	10"commercial/9" sport as of Jan 1991 increases to 11"commercial/10" sport Jan 1992
Mesh size:	None
Area closure:	Trawl gear in western Long Island Sound west of Eatons Neck Apr 1- Nov 1, and in Peconic Bays Apr 15- first Mon in Oct; Trawl gear prohibited in western Long Island Sound Bays and Long Island south shore Bays year round
NEW JERSEY	
Minimum length:	10" as of 1991
Area closure:	Trawl gear prohibited 2 miles from shore
DELAWARE	
Minimum length:	None
EXCLUSIVE ECONOMIC ZONE	
Minimum length:	11"
Mesh size:	Mesh limits vary by area

Table 3.3 Mid–Atlantic Stock Unit: The effect of various size and possession limits on 1985–89 combined winter flounder recreational landings (MRFSS Type A fish). The table contains the percent reduction in the number of winter flounder killed by anglers. Reductions were calculated assuming a post–release mortality of 15%.

	Size Limit (TL inches)					
Possession Limit	NO	8	9	10	11	12
NO	–	0.8	3.3	11.8	28.8	49.5
1	64.5	65.3	67.4	75.2	89.5	101.9
2	50.2	51.0	53.2	61.6	76.9	91.6
3	40.1	40.9	43.1	51.8	67.5	83.6
4	33.0	33.7	35.9	44.7	60.5	77.6
5	27.4	28.2	30.4	39.3	55.3	73.1
6	23.2	24.1	26.2	34.9	51.1	69.5
7	19.7	20.4	22.6	31.4	47.8	66.5
8	16.6	17.4	19.6	28.3	44.8	63.9
9	14.1	14.8	17.0	25.8	42.4	61.8
10	11.7	12.4	14.7	23.5	40.3	60.0
11	10.2	10.9	13.2	22.0	38.7	58.5
12	8.8	9.6	11.8	20.5	37.3	57.2
13	7.6	8.3	10.6	19.3	36.0	56.2
14	6.5	7.2	9.5	18.2	35.0	55.2
15	5.5	6.2	8.5	17.2	34.0	54.4
16	4.7	5.5	7.7	16.4	33.3	53.7
17	4.0	4.7	7.0	15.7	32.6	53.1
18	3.4	4.1	6.4	15.1	32.0	52.6
19	2.9	3.6	5.9	14.6	31.5	52.2
20	2.4	3.2	5.4	14.2	31.1	51.8

Note: Stock unit separation based on state and county of landing.

Table 3.4: Southern New England stock unit: The effect of various size and possession limits on 1985–89 combined winter flounder recreational landings (MRFSS Type A fish). The table contains the percent reduction in the number of winter flounder killed by anglers. Reductions were calculated assuming a post-release mortality of 15%.

	Size Limit (TL inches)						
Possession Limit	NO	9	10	11	12	13	14
NO	–	1.0	2.9	5.9	16.8	34.5	
1	59.5	60.6	61.9	64.3	74.2	88.7	100.7
2	43.9	45.0	46.4	49.0	59.7	75.3	90.1
3	34.0	35.1	36.6	39.2	50.2	66.5	83.1
4	27.5	28.6	30.2	32.9	43.8	60.3	78.0
5	22.6	23.7	25.4	28.1	38.9	55.8	74.3
6	19.0	20.1	21.7	24.6	35.4	52.4	71.3
7	16.3	17.4	19.1	22.0	32.9	49.9	69.3
8	14.2	15.2	16.9	19.9	30.6	47.7	67.5
9	12.2	13.2	15.0	18.0	28.8	45.9	66.1
10	10.6	11.6	13.4	16.4	27.2	44.5	64.9
11	9.5	10.5	12.4	15.3	26.2	43.5	64.0
12	8.5	9.6	11.4	14.3	25.2	42.5	63.2
13	7.6	8.6	10.4	13.3	24.2	41.6	62.4
14	6.6	7.6	9.5	12.4	23.2	40.6	61.6
15	5.6	6.7	8.5	11.4	22.4	39.8	61.4
16	5.0	6.0	7.9	10.8	21.7	39.1	60.4
17	4.4	5.4	7.3	10.2	21.1	38.5	60.0
18	3.8	4.8	6.7	9.6	20.5	38.0	59.6
19	3.2	4.3	6.1	9.1	20.0	37.6	59.3
20	2.8	3.8	5.7	8.7	19.7	37.3	59.0

Note: Stock Unit separation based on state and county of landing.

areas to flounder fishing (Gibson 1991d). Initial model runs showed that limited closures simply transfer fishing effort to adjacent areas or times. However, a scenario which closed all inshore waters from eastern Long Island Sound to south of Cape Cod permanently resulted in a 72% reduction in annual fishing mortality, but required the assumption of no fish migration or effort transfer. Known migration patterns and effort transfer make such conditions quite unrealistic. A second more realistic scenario allowed seasonal migration of fish and effort transfer. This simulation assumed that when an area was closed to the possession of flounder, one third of the effort was eliminated (sport and commercial fishermen not able to move), one third was uniformly distributed into open areas, and one third remained in the closed area where it was represented as a 20% release mortality, or one half of present release mortality. This scenario resulted in a 22% reduction in an initial F=1.0. The combination of seasonal fish movement out of closed areas, release mortality, and transferred fishing effort to open areas dampened the effectiveness of these refugia to reduce overall fishing mortality by a factor of three.

Seasonal inshore closures in Massachusetts waters may have forestalled stock collapse by reducing mortality during the spawn, but have not substantially reduced fishing mortality rates owing to the movement of fish out of state waters into the offshore fishery. Some area and/or seasonal closure is recommended for southern Massachusetts waters as a means of reducing fishing mortality to target F_{40} levels so that stock rebuilding can occur. Alternatives for achieving F_{40} include time-of-day closures or restrictions on vessel characteristics or use.

In order for actions by Massachusetts to be effective, stringent measures to reduce commercial fishing effort in the Exclusive Economic Zone at a comparable rate (at least a 25% reduction) will also be required. The effectiveness of management measures in state waters will be greatly undermined if no further action is taken by the New England Fishery Council.

Gulf of Maine

Fishing mortality north of Cape Cod is equally divided between the recreational fishery and the commercial trawl fishery. Later female maturity and longer life span of flounder in this region make large length limits effective here, and all state and federal waters have an 11-12 inch (~Age 4) minimum length limit (Table 3.2). Current commercial mesh size limits are equally effective in postponing fishing mortality to a later recruitment age. Recent survey data show that while abundance of fish Age 4 and older has declined, abundance of flounder Age 1-3 has remained relatively stable. However, sea-sampling on commercial vessels in Cape Cod Bay (Pierce and McKiernan 1990) indicated diminished returns from larger legal size limits as discard of fish just under legal size can be high (>50%).

Recent ASMFC requirements for the Gulf of Maine shrimp fishery mandate separator trawls designed to reduce the catch of pre-recruit flounder in small mesh shrimp nets. Recent studies (Howell and Langan, pers. comm.) suggest that although there is discard of winter flounder in various northeast fisheries, it is relatively small (18% by weight) compared to other groundfish species. These authors speculate that the low discard rate is due to the fact that young flounder are typically inshore while the winter/spring shrimp fishery occurs primarily offshore in deeper water. However, NMFS sea sampling (Power, pers. comm.) of the shrimp fishery in 1989-91 showed a large amount of variability in the winter flounder discard (48-130%), although mean weights-per-tow were low (0.9-5.3 lbs., N=316 tows). Discard of winter flounder was found to be low (5% by weight) during sea sampling in the Gulf of Maine large mesh fishery (Howell and Langon 1987). Earlier examination of the Georges Bank mixed trawl fishery (Mayo *et al.* 1981) estimated a 47% discard by weight of winter flounder, but no discard in the New England squid and scup fisheries.

Large length limits and mesh restrictions, as well as the Massachusetts spawning closure, have enabled northern flounder stocks to withstand extremely high fishing mortalities for many years. Current fishing pressure leaves the present spawning stock at approximately 24% MSP. As with populations of the southern New England stock, larger length limits alone will have diminished effectiveness.

Meeting F_{40} levels would require approximately a 50% reduction in present exploitation. Reductions in both recreational and commercial effort could be accomplished through additional area, season, or time–of–day closures, or creel limits (Table 3.5). Sheepscot Bay, ME, and Cape Cod Bay, MA, are already subject to limited closures. Extending the present spawning closure in Cape Cod Bay to include all recreational fishing and extending the closure in Sheepscot Bay both geographically, to include the sand/gravel bottom to the west of Sequin Island, and temporally, to include the peak spawning period in April, would reduce current fishing mortality. Analysis of larger closures encompassing the inshore areas of the Gulf of Maine, as well as quantifying other alternatives, is recommended.

3. Management of the Fisheries after Adoption of the Plan

This plan calls for reductions in fishing mortality on winter flounder and allows states flexibility to achieve recommended reductions. Implementation of the plan will require the interaction of state fishery management agencies, the New England Fishery Management Council, the National Marine Fisheries Service, and ASMFC over a seven–year period. Therefore, the following institutional arrangements will be maintained following adoption of the plan:

1. The ASMFC Winter Flounder Management Board will continue in existence and will include all states with a declared interest in managing winter flounder. The Board will make management decisions germane to implementation of the plan. Board findings and decisions will be reported to ASMFC's Interstate Fisheries Management Program Policy Board which will have final authority for judging non–compliance with measures contained in the plan.

2. ASMFC's Winter Flounder S&S Committee will be maintained to collect data and conduct analyses necessary for the implementation and monitoring of the plan. The S&S Committee will be comprised of fisheries scientists from states that declare an interest in managing winter flounder.

3. Participating states are encouraged to establish fishery advisory committees if necessary to promote implementation of the plan.

Table 3.5: Gulf of Maine Stock unit: The effect of various size and possession limits on 1985–89 combined winter flounder recreational landings (MRFSS Type A fish). The table contains the percent reduction in the number of winter flounder killed by anglers. Reductions were calculated assuming a post-release mortality of 15%.

	Size Limit (TL inches)				
Possession Limit	NO	11	12	13	14
NO	–	0.6	1.9	6.9	17.1
1	64.3	68.3	74.0	85.7	99.7
2	51.1	55.3	61.1	73.7	89.2
3	42.8	47.0	52.8	65.7	82.4
4	36.7	41.0	46.7	60.1	77.4
5	32.2	36.4	42.1	56.0	73.5
6	28.6	32.8	38.6	52.5	70.4
7	25.6	29.8	35.6	49.5	67.9
8	22.9	27.1	32.9	46.8	65.5
9	20.6	24.7	30.7	44.5	63.4
10	18.4	22.5	28.7	42.7	61.6
11	17.0	21.2	27.3	41.2	60.3
12	15.7	19.9	25.9	40.1	59.1
13	14.5	18.7	24.7	38.9	58.1
14	13.3	17.5	23.5	37.7	57.1
15	12.1	16.4	22.4	36.6	56.1
16	11.2	15.4	21.4	35.6	56.1
17	10.3	14.6	20.6	34.9	54.6
18	9.5	13.7	19.8	34.1	53.9
19	8.7	13.0	19.0	33.5	53.3
20	8.0	12.3	18.3	32.8	52.8

Note: Stock unit separation based on state and county of landing.

B. Management of the Habitat

Part 1, Status of the Habitat, identified three human activities exerting long term deleterious effects on winter flounder habitat quality: sediment dredging during spawning, degradation of nearshore waters by nutrient enrichment and toxic compounds, and power plant impacts. Each can exert potentially large scale losses, either through acute mortality or chronic decline in production. Throughout the geographic range of winter flounder, some level of contamination from human activities has been identified, both in harbors and offshore. However, the greatest contaminant levels in U.S. marine waters have been found in the core of this species' range, namely sites off the Atlantic coast from Massachusetts to New Jersey. Areas especially impacted by urban development include the greater Boston Harbor area, upper Narragansett Bay, western Long Island Sound, the Hudison–Raritan estuary and the New York Bight.

1. Recommended Actions

Introduction of toxic substances from single sources into estuarine and coastal waters is presently regulated to minimize mortality to marine organisms. However, the synergistic effects of multiple discharges should be more closely scrutinized and controlled. To alleviate local mortality and growth effects, sewage discharge should be minimized or wastewater treatment levels increased in critical inshore spawning and nursery areas subject to chronic summer hypoxia. Enforcement activities should be strengthened and penalties made severe for treatment plant violations and inadequate individual subsurface sewage disposal systems. Sewage and toxic compound discharges from boats are lesser in magnitude relative to land–based discharges, but are direct sources of contamination in nearshore flounder nursery areas and should be eliminated. Although such discharges are illegal under the Clean Water Act (Section 312), these regulations have not been rigorously enforced due, in part, to wholly inadequate pump–out facilities coastwide. For example, a survey of Chesapeake Bay showed there was less than one facility per six marinas (Report to Congress, 10/15/91).

Physical alteration of known nursery habitat, such as sediment removal by dredging, bulk–heading, and channelization, should be considered in terms of their impacts to winter flounder production. Permits for such activities should be issued so as to avoid mortality of egg and larval stages in areas where winter flounder are known to congregate to spawn. Time frames when dredging should be prohibited are recommended within or encompassing the period January 15 to May 15, depending on local spawning activity.

Larval stage assessments should be incorporated into entrainment studies required by power plants withdrawing coolant water from shallow water marine habitats. Separate mortality values for planktonic and benthic larval stages should be used in computation of equivalent adult losses. Such losses should be evaluated in terms of impacts on local spawning populations as well as regional stocks. Existing plants sited in such areas should be retrofitted with the best available technology to minimize plant–induced mortality (*e.g.* state–of–the–art fish return systems to minimize impingement mortality).

In summary, state fishery agencies should actively intervene to the extent of their authority to ensure that federal, state and local permitting agents are aware of the loss in winter flounder productivity associated with water quality degradation and habitat loss and give full consideration to the following recommendations:

1. Assure that Clean Water Act (Section 319) Non–Point Source Plans and Coastal Non–point Pollution Control Plans are developed and implemented such that adverse impacts of non–point source pollutants on winter flounder are minimized. These plans should include measures such as:

   a) protective land use practices (*e.g.* establishment of substantial buffer zones around productive coastal nursery grounds);

   b) reduction of non–point toxic contamination of ground water and nearshore coastal habitats by redirecting stormwater runoff into catch basins;

   c) evaluation of the cumulative effects of in–water structures on habitat quality;

2. Strengthen enforcement of sewage discharge, or PDES (Pollution Discharge Elimination System), permit effluent limits from centralized treatment plants, and ensure proper maintenance and operation of domestic septic systems.

3. Implement effective oil and toxic chemical spill prevention and control programs to prevent accidental release, and prioritize cleanup plans to protect areas where winter flounder are known to concentrate for spawning.

4. Establish and enforce no–vessel–discharge zones, and promote education of recreational boaters to reduce their contamination of inshore waters from chronic vessel fuel spills and waste disposal.

5. Establish time frames when sediment dredge activities should be prohibited or minimized in areas where winter flounder are known to concentrate for spawning.

6. Assist industrial siting councils in siting new power plants so that areas where winter flounder are known to concentrate for spawning are avoided, and assess cooling water entrainment mortality from existing plants (Clean Water Act, Section 316) on a stage–specific basis for both local and regional flounder populations.

7. Identify sediments sufficiently contaminated to impose documentable acute or chronic impacts on winter flounder resources including the benthic communities upon which they depend, and develop remediation plans or active sediment pollution prevention programs for such areas.

2. Research Needs

Further study of flounder populations in impacted areas is required to fully quantify physiological adaptation to habitat alteration, and interactive effects, on an individual and population level. Assessment of each population's exposure to inshore habitat degradation will require delineation of the population's spawning and nursery areas. States should identify and prioritize these areas so that essential spawning and nursery grounds can be protected from municipal and industrial discharges, sediment dredging during the spawning period, and any additional shoreline alterations which increase non–point source pollution.

Research studies should also be designed to provide reliable estimates of anthropogenic mortality (M_R) from sources other than fishing. Both mortality sources should then be incorporated into fisheries yield/recruit models to simultaneously evaluate these dual mortality factors. For example, ongoing studies by NMFS at the Milford, CT, laboratory (Goldberg, pers. comm.), will incorporate early life–stage mortality rates from spawning stocks subjected to differing contaminant loads and habitat alteration but similar adult fishing pressure.

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SPECIES PROFILE OF WINTER FLOUNDER

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A. Species Taxonomy and Morphology

1. ***Nomenclature*** *Pleuronectes americanus* (Sakamoto 1984, Robins *et al.* 1991)

Synonymy (after Norman 1934 and Robins *et al.* 1991):
Pleuronectes. Schoepf 1788. Schrift. Ges. Nat. Freunde Berlin, VIII, p. 148.
Pleuronectes americanus Walbaum 1792. Artedi Ichth. (3), ed. 2, p.113.
Pleuronectes planus Mitchill 1814. Rep. Fishes New York, p.8.
Platessa plana. Storer 1893. Boston J. Nat. Hist., ii, p. 475; Rep. Ichth. Mass., p.140.
Platessa pusilla De Kay 1842. Nat. Hist., New York (Fish), p. 296, pl. xivll; fig.153 (New York).
Pseudopleuronectes planus. Bleeker 1862. Versl. Akad. Wet. Amsterdam, xiii, p.428
Pseudopleuronectes americanus. Gill 1864. Proc. Acad. Nat. Sci. Phil., xvi, p. 26.
Pseudopleuronectes dignabilis Kendall 1912. Bull. U.S. Bur. Fish., xxx, (1910), p.392, pl. lvii.

Taxonomy:
Phylum–Chordata
  Subphylum–Vertebrata
    Class–Osteichthyes
      Order–Pleuronectiformes
        Family–Pleuronectidae
          Subfamily–Pleuronectinae

Common Names:
Blackback; Georges Bank Flounder; Sole; Rough Flounder; Mud Dab; Lemon Sole; Black Flounder; Flatfish; Carrelet

2. ***Morphology and Morphological Variation***

The winter flounder is a laterally compressed right–handed (viscera on the right side) species. Eyes on the right–side are set relatively far apart and separated by a rough scaled region. The upper eye is near the edge of the head. The body is oval–shaped and approximately two and one–fourth times as long to the base of the caudal fin, as it is wide. The mouth is small, not reaching back to the eye, with thick, fleshy lips. The left (under) side of each jaw contains one series of close–set incisor–like teeth, the right (upper) side has a few teeth on either side of the jaw. The dental formula is:

$$\frac{0\text{–}2 + 10\text{–}15}{0\text{–}2 + 10\text{–}15} \begin{array}{l}\text{(ocular side + blind side– upper jaw)}\\ \text{(ocular side + blind side– lower jaw)}\end{array}$$

The dorsal fin has 60–76 rays and originates opposite the anterior margin of the upper eye, and is of nearly equal height throughout its length. All rays are simple. The anal fin (45–58 rays) is longest midway, and is preceded by the tip of the first interhaemal spine. The pectoral fin is usually larger on the ocular side than the blind side, with 10–11 rays; five to seven are branched. The caudal peduncle is moderate in length and broad. The caudal fin has 13–14 branched rays. The scales are small, ctenoid or cycloid. The lateral line is nearly straight except for a bowed area above the pectoral fin. Several color variants have been observed. Winter flounder may be reddish–brown, olive green, dark slate or black on top and white to nearly translucent on the blind side. The lower side of the caudal peduncle is sometimes yellowish. Mottling varies from smaller to larger spots of increasing intensity (Norman 1934, Bigelow and Schroeder 1953, Klein–MacPhee 1978, Burton 1978, 1980). Reproductive males develop a signinficantly thicker blind side epidermis during the pre-spawning period.(Burton and Fletcher 1983, Burton and Burton 1989a, 1989b).

Based on meristic counts of fin rays, growth rates, and coloration, several authors have distinguished races or stocks of winter flounder. Kendall (1912) recognized the Georges Bank flounder as a distinct species, *Pseudopleuronectes dignabilis*. Diagnostic characteristics listed by Kendall were a greater number of fin rays, different coloration, and length. Perlmutter (1947) compared dorsal, anal, and pectoral fin counts from populations north and south of Cape Cod, and Georges Bank. His results indicated a statistically significant difference for each meristic trait between inshore fish and Georges Bank, suggesting restricted migration and mixing. Comparison of specimens from Georges Bank with other offshore groups led Bigelow and Schroeder (1953) to consider the Georges Bank population a local race. Currently, this is the pervasive view.

Lux et al. (1970) concluded that Georges Bank fish had a greater number of fin rays and grew to a larger size than either of the more nearshore stocks because of the warmer annual average water temperature. In addition, two other groups were identified off Massachusetts along the coast north of Cape Cod and along the coast east and south of Cape Cod. Pierce and Howe (1977) confirmed the existence of these groups by fin ray count and determined that individual estuaries did not constitute separate groups.

3. *Population Genetics*

A species may occur over a large geographic range, with a distribution that may or may not be continuous. Regional subareas may contain reproductively discrete populations or stocks. Biologically, discrete populations or stocks are the preferred unit for management. The biological significance of the stock concept is that separation during reproduction isolates populations, and may effectively generate phenotypic and genotypic divergence from other stocks.

Numerous genetically identifiable stocks of winter flounder may exist. For example, Schenck and Saila (1982) examined the population structure of winter flounder near Millstone Point, Connecticut as well as nearby eastern Connecticut and Rhode Island locations by iso-electric focusing of eye lens tissue. The results indicated that a local stock, ranging a few nautical miles, is found near Millstone Point during spawning. Intermixing with substocks in adjacent bays is greatest during the summer; lesser mixing occurs between Millstone area flounder and more distal populations. Pierce and Howe (1977) concluded an extensive meristic study of estuarine caught YOY by stating that estuarine units do not constitute separate genetic or biological units, but that distinct groups consist of an assemblage of adjacent estuarine spawning units.

B. **Spatial and Seasonal Distribution by Life Stage**

1. Distribution by age

The geographic distribution of winter flounder includes nearshore habitats to offshore fishing banks along the Atlantic coast of North America. The northernmost geographic limit is Ungava Bay, Labrador (Kendall 1909, Liem and Scott 1966), the southern record is Georgia (Hildebrand and Schroeder 1928). Winter flounder are one of the most common demersal fishes in inshore regions from the northern shore of the Gulf of St. Lawrence, and south to New Jersey. Smaller populations extend to Chesapeake Bay (Bigelow and Schroeder 1953). Egg, larval, juvenile, and adult winter flounder populations have been mapped in several estuaries along the Atlantic coastline (Table 1.1).

2. Inshore-offshore movements

Adult winter flounder seasonal movements consist of two phases; an autumn estuarine immigration prior to spawning, and a late spring/summer movement to either deeper, cooler portions of estuaries or to more offshore areas (Merriman and Warfel 1948, Bigelow and Schroeder 1953, Saila 1961, McCracken 1963, Howe and Coates 1975). This pattern of seasonal distribution may change in the northern extent of the flounder's range. Data from the flounder fishery in Passamaquoddy Bay and St. Mary's Bay in the upper Bay of Fundy indicate that winter flounder leave shoal areas in winter for deeper water (McCracken 1963). In cold-water areas, winter flounder are abundant in shallow water in summer; however in warmer areas, such as Northumberland Strait and Pubnico Harbor regions, flounder migrate from warm shoal areas to cooler, deeper water in the summer.

Historical tagging studies (Lobell 1939, Perlmutter 1947, Saila 1961, Kennedy and Steele 1971, and Howe and Coates 1975) and recent tagging studies (Weber and Zawacki 1983a, Scarlett 1988a, NUSCo 1987, Powell 1989) provide evidence that winter flounder make short distance excursions from shallow embayments during the summer and return to the same estuaries, or nearby ones, to spawn the following winter. These movements may be a response to increasing water temperature, and are more pronounced in the southern portion of the range and off southern New England where summer temperatures in shoal waters can reach 20^{0}C or greater.

The monthly catch of winter flounder in Passamaquoddy Bay indicated that YOY and Age 1 fish move from depths less than nine meters into deeper water by November (McCracken 1963). Older immature fish were found at this depth continuously. During early winter, Age 1-2 immature fish were most abundant between 10-30 meters, while Age 3 and older were deeper. During spawning, mature fish migrated onto the shallows (less than nine meters) and remained there throughout the summer.

A ten year mark-recapture study of 12,151 winter flounder by the MA Division of Marine Fisheries (Howe and Coates 1975) yielded a recapture rate of 36.5%. Fish were tagged at 21 locations. Post-spawning migrations north of Cape Cod were localized, and for the most part restricted to inshore waters. The average movement was 3.2 miles (range 0.5- 8.9). Flounder tagged east of Cape Cod showed mean travel distance of 7.7 miles (range 6.0-10.1). South of Cape Cod, post-spawned flounder dispersed southeastward from estuarine and coastal tagging sites to beyond the territorial limit. These flounder moved an average of 22.0 miles (range 6.3 - 38.0). Movements appeared to be related to water temperature; flounder moved back into shoal areas during the fall when temperatures dropped below 15^{0} C.

Saila (1962) studied winter flounder movements within Narragansett Bay, RI, using a transplantation experiment between Mt. Hope Bay and the Sakonnet River. Flounder transferred between tagging sites demonstrated a 36% (Sakonnet River) and 25% (Mt. Hope Bay) recapture rate from the original release site, indicating that winter flounder were fairly constrained in their migration. In Green Hill Pond, RI, data from marked and recaptured flounder were analyzed utilizing a random search model, where fish are bounded by a depth contour (for example the 15 mile isobath) and the coastline which retains the fish (Saila 1962). The model assumes that upon reaching the shoreline flounder will search randomly until an inlet is located. Saila concluded that migration with no assumption of orientation from outside stimuli, is a reasonable explanation for the flounder's ingress to shore.

Table 1.1 Summary of studies concerned with various life history phases of the winter flounder, *Pleuronectes americanus* (from north to south).

Location	Life History Stage *	Authority
Conception Bay, N.S.	A	Van Guelpen and Davis 1979; Kennedy and Steele 1971
Passamaquoddy Bay, N.S. St. Mary's Bay Pubnico Harbor Northumberland Strait	J,A	McCracken 1963; Dunn 1967
Passamaquoddy Bay, N.S.	A	Tyler 1971a
Gulf of Maine	All stages	Bigelow and Schroeder 1953
Massachusetts	J,A	Howe and Coates 1975; Howe *et al.* 1976
Plymouth Harbor, MA	L	Radtke and Scherer 1982
Weweantic River, MA	J	Topp 1967
Waquoit Bay, MA	J	Saucerman 1990
	J	Howe *et al.* 1976
Narragansett Bay, RI	A	Jeffries and Johnson 1974; Oviatt and Nixon 1973;
	J,A	Powell 1988
Point Judith Pond, RI Potter's Pond, RI	L,J	Grove 1982
Green Hill, RI	A	Saila 1961a
Charleston Pond, RI	A	Berry *et al.* 1965
Block Island Sound	All stages	Merriman and Warfel 1948
Mystic River, CT	J	Pearcy 1962; Pearcy and Richards 1962
Niantic River, CT	All stages	NUSCo 1987
Morris Cove, CT	A	Warfel and Merriman 1948
CT/NY waters	A	Perlmutter 1947
Long Island Sound	L	Wheatland 1956
south shore of Long Island	J,A	Poole 1966a & b
Sandy Hook, NJ	E,L,J	Croker 1965;
southern NJ	A	Danila 1978, 1980
Manasquan River, NJ Shark River, NJ	E,L,J,A	Scarlett 1988a & b
Rehoboth and Indian River, DE	A	Derickson and Price 1973

* E = egg, L = larvae, J = juvenile, A = adult

Two tagging studies (NUSCo unpub. data; Weber and Zawacki 1983a) examined winter flounder movements in Long Island Sound. Between 1980–1983, 2,303 flounder were tagged in eastern Long Island Sound (NUSCo, unpub. data). Three thousand flounder were tagged in Huntington and Oyster Bays, western Long Island Sound from 1981–1983 (Weber and Zawacki 1983a). The percent tag returns by season and area indicated limited movement from the original tagging location. During spring and summer periods, tagged fish from both release areas tended to move eastward. The recapture pattern was similar to movements noted in a 1940's study (Lobell 1939). Less than 20% of recaptured fish were caught outside of Long Island Sound, and only eight fish were taken beyond Block Island Sound (Weber and Zawacki 1983a).

A three year tagging study was conducted in the Sandy Hook–Raritan Bay area and sludge dumpsite offshore (Phelan, B. in press); of 7,346 flounder tagged (3,245 dumpsite fish; 4,101 bay fish) 193 tags (2.6%) were recovered. A large proportion of fish were recaptured within 10 km of the tagging sites, indicating limited movement from natal estuaries. However, some flounder tagged at the 12–mile sludge dumpsite exhibited considerable movement extending into Long Island Sound, off Montauk Point, Long Island, Block Island Sound, Fire Island, and Nantucket Shoals. Valdes suggested that both intermixing and distance migrations reduce the chance of genetic isolation.

Danila (1980) reported on 971 winter flounder tagged between December 1978 and February 1979 in Barnegat Bay, New Jersey. A total of 108 tagged fish were returned, principally from Barnegat Bay during the spring post–spawning emigration. Later in the season, fish were captured from the Barnegat Inlet and the Intracoastal Waterway. Flounder appeared to move in a northeast direction during the summer. During the winters of 1982–1987, Scarlett (1988a) conducted a tagging of 14,820 winter flounder in the Shark River, Manasquan River, and Barnegat Bay estuarine system. A total of 885 tagged fish were recaptured. Generally, during summer months, flounder were encountered in the Atlantic in an area north and east of the tagging sites. In the fall, flounder moved inshore, many returning to the same estuaries as the year before, and remained until May. Offshore movement began in May and was completed by June. The northeasterly movement of these fish from estuarine areas provides additional evidence of a general migratory pattern for flounder in southern regions.

Based on observations of abundance, tagging studies and feeding ecology, Van Guelpen and Davis (1979) formed a general hypothesis of winter flounder movements throughout their range. They suggested that during summer months, adults remain in shoal areas where temperature is not excessive and food is abundant. McCracken (1963) suggested that summer distribution was related to a temperature preference of 12–15^{o}C. With gonad maturation in the fall and early winter, winter flounder move in or remain in the shallow inshore areas. Spawning commences in the winter in southern locales, or spring in northern locales. In northern regions, winter flounder remain inshore in protected sites during the winter but will migrate offshore to avoid turbulence and drifting ice flows. Milder winter water temperature and earlier spawning time in more southerly regions may explain the persistence of flounder in shallow waters. Initiation of migration appears to be cued by spring and fall water temperature stratification.

3. Spawning and Nursery Areas

The annual spawning period for winter flounder varies over its geographic range (Table 1.2). Although spawning periods overlap considerably, peak spawning times are earlier in southern locations. Nursery habitat for winter flounder larvae and juveniles includes littoral and sublittoral saltwater coves (Poole 1966b, Briggs and O'Connor 1971), coastal salt ponds (Saila 1961b, Crawford and Carey 1985), estuaries (Pearcy

Table 1.2: Dates of winter flounder spawning at different geographic locations from north to south (from Klein–McPhee 1978).

Dates	Peak	Area	Investigator
Mar.–June	--	Long Pond, Conception Bay, Newfoundland	Kennedy and Steele 1971
May–June	--	Canadian Waters	Fletcher and King 1978, Earles and Fletcher 1982
Mar.–May	Apr.	Boothbay Harbor, Maine	Hahn (pers. comm. in Bigelow and Schroeder 1953)
Feb.–May	--	Eel Pond, Woods Hole Massachusetts	Sherwood and Edwards 1901
Jan.–May	Feb.–Mar.	South of Cape Cod and Massachusetts Bay	Bigelow and Schroeder 1953
Mid Feb.–Apr.	Mar.	Mystic River estuary, CT; Niantic River, CT	Pearcy 1962 NUSCo 1987
Dec.–May	Varies with water temp	Southern New England–New York	Perlmutter 1947
Jan.–March		Manasquan River	Scarlett and Allen 1989
Nov.–Apr.	--	Indian River Bay, Del.	Fairbanks et al. 1971

1962, Saucerman 1990), and protected embayments (McCracken 1963, Kennedy and Steele 1971). Larvae and juveniles have also been found in open ocean areas such as Georges Bank and Nantucket shoals

Winter flounder spawn during winter and early spring producing demersal adhesive eggs (Wheatland 1956, Pearcy 1962, and Pearcy and Richards 1962, Scarlett 1989). Based on coastal New Jersey ichthyoplankton surveys (Scarlett 1989), winter flounder spawning occurs from January–March when bottom water temperature range from 1–10^0 C and bottom salinities range from 14–32 ppt. These values are within reported ranges of salinity (1–28 ppt surface, 18–26 ppt bottom) and temperature (8.7–15.5^{0}C. surface, 8.8–15.0^0 C bottom) noted in New England where spawning may occur into May (Bigelow and Schroeder 1953, Pearcy 1962). The demersal and adhesive quality of winter flounder eggs facilitates retention within spawning grounds (Pearcy 1962, Crawford and Carey 1985).

Underwater observations on Narragansett Bay spawning grounds found flounder eggs were only deposited among the filaments of certain mat–formed diatoms (Anonymous 1972). The most abundant of these was *Melosira nummeloides* with lesser amounts of *Melosira juergensi* and *Amphipleura rutilous*. No eggs were found in adjacent bare sandy or muddy areas, or among eelgrass *(Zostera marina)*, sea lettuce *(Ulva lactuca)* or *Enteromorpha intestinalis*. The diatoms associated with flounder eggs are present from mid–November through May, encompassing the spawning season. The report suggested that diatom mats prevent considerable egg clumping after fertilization, thereby reducing mortality of eggs in the center of a clump.

Larvae are predominately found in the upper reaches of natal estuaries in early spring, moving into the lower estuary later in the season (Topp 1967, NUSCo 1987). Larval distribution is vertically stratified: larvae are more abundant near the substrate than in the water column (Pearcy 1962, Croker 1965, Topp 1967). Diel variation in abundance was observed in two studies (Pearcy 1962, Croker 1965) but not in a third (Topp 1967).

Several biotic and abiotic factors, such as wind and tidal exchange in spawning areas, affects larval distribution (Perlmutter 1947). Late stage benthic larvae may maintain their position in the estuary by taking advantage of the density current system which increases the potential for retention (Pearcy 1962, Crawford and Carey 1985).

Exudates from sea lettuce, or its bacterial flora, were found to be toxic to larval winter flounder, killing all larvae in 22 days (McPhee 1987). However, when sea lettuce and two other algae, *Gracilaria tikvahiae*, a red macroalga; and *Dunaliella tertiolecta*, a green phytoplankter, were used as biological water conditioners in juvenile winter flounder cultures, there was no difference in survival, fish length, or dry weight between treatments. These results indicate sea lettuce may affect larvae and juvenile flounder differentially, and may explain the lack of egg deposition on sea lettuce beds.

Light and temperature–salinity factors influence size and/or age–specific differences in seasonal depth distribution (Pearcy 1962, McCracken 1963, Frame 1973a, Casterlin and Reynolds 1982). Underyearling or YOY juveniles (6–9cm) inhabit shallow cove nursery areas because they orientate to light (photopositive): light intensity may influence daily movements. Marking experiments during the summer months have indicated that YOY movements are very limited, on the order of 100m (Saucerman and Deegan 1991). As the shallow waters cool (< 8 C) in late autumn, YOY move into deeper estuarine areas. Yearlings (12–18cm) reside in deeper estuarine areas because they are photophobic (avoid light). Yearlings and older immature winter flounder are nocturnally active and exhibit more extensive intra–estuarine movements than YOY in order to avoid sublethal effects such as when water temperatures approach 25^{o}C (Frame 1973b; Casterlin and Reynolds 1982). On the basis of field observations and laboratory studies that showed up to a 50% decrease in metabolic rate (i.e., oxygen consumed) at salinities of 10 and 20%, versus the high salinity of 30%. Frame (1973b) hypothesized that (juvenile) survival depends on "their ability to move gradually into favorable temperature-salinity" regimes.

Investigations of the distribution of shore-zone fishes over naturally vegetated and sand-filled bottoms in Great South Bay, NY, found winter flounder in both habitat types, but they were significantly more abundant in the naturally vegetated bottom (Briggs and O'Connor 1971). Similarly, juveniles were most abundant in upper Narragansett Bay and the Sakonnet River at sites with sandy-mud bottom, regularly interspersed with vegetation, and protected from prevailing winds (Powell 1988). Both attached and floating algae, predominantly sea lettuce and *Codium* spp., are found at these sites.

Saucerman (1990) examined distribution and movement of post-metamorphic YOY winter flounder in different habitat types in Eel Pond, MA, by mark and recapture. The majority of flounder were originally captured near eelgrass beds and were recaptured near these same eelgrass areas. Ninety-eight percent of recoveries were recaptured within 100 M of the release site, with only 1% straying more than 200 M from the release site. Cross channel exchange was negligible (0.73%).

While most winter flounder populations are primarily found in estuarine and nearshore habitats, they also utilize offshore waters. The clearest example of this situation is the self-sustaining Georges Bank stock. Larval surveys in the coastal waters off the mid-Atlantic Bight suggest spawning may occur in offshore southern waters. Trawl surveys conducted in coastal waters within state jurisdiction in Massachusetts and Connecticut routinely capture YOY winter flounder, although whether or not spawning occurs offshore is uncertain. Although it is difficult to define such peripheral nursery habitats, the limited information from these surveys demonstrate that YOY flounder utilize deeper water habitats to some extent, primarily 30-60 ft. but extending to greater than 90ft.

C. Environmental Requirements

1. Temperature

Temperature may be the single most important environmental factor regulating the metabolism, growth and distribution of winter flounder. Temperature preference and tolerance of juvenile and adult winter flounder have been observed in the field (Pearcy 1962, Olla *et al.* 1969) and experimentally (Huntsman and Sparks 1924, Battle 1926, Hoff and Westman 1966, Casterlin and Reynolds 1982).

In the laboratory, growth and metabolism from hatching through metamorphosis was chiefly influenced by temperature (Laurence 1975). Flounder eggs incubated over a range of conditions had highest hatch viabilities at 3^{0}C over a salinity range of 15-35 ppm (Rogers 1976). Eggs hatch into normal larvae even after sustained exposure (two months) to very low temperature (-1.8^{0}C and 35ppt, Williams 1975).

A field study in the Mystic River estuary, CT, showed both juveniles and older flounder are eurythermal, as flounder were found in the estuary at all seasons, from 0 to 25^{0}C. (Pearcy 1962). Supplementary laboratory experiments indicated a minimum lethal temperature in the winter between -1.0 and -1.5^{0}C The production of antifreeze polypeptides enhances survival in ice-laden seawater (Fletcher *et al.* 1985). This freezing point was later lowered to about -0.70^{0}C. to -0.80^{0}C. (Umminger and Mahoney 1972).

Hoff and Westman (1966) explored the survival of juvenile winter flounder (<120 mm) at various temperatures. The upper and lower median tolerance limits (the temperature at which 50% of the experimental fish could no longer live for the exposure period) were estimated by interpolation from the known number of survivors. The percent survival of winter flounder acclimated at 7, 14, 21, and 28^{0}C and exposed to low test temperature (1, 2, 4, 6, and 7^{0}C) indicated high survival rates at all temperatures except for acclimation temperatures of 21^{0}C and 28^{0}C, and test temperatures of 4 and 1^{0}C, respectively. These values are in agreement with the range of upper lethal temperatures (29.1–30.4^{0}C for 100 mm fish) reported by Huntsman and Sparks (1924) and Casterlin and Reynolds (1972). These authors reported 'death points' for flounder exposed to high temperature which were related to size: 27.8–29^{0}C for 300 mm fish, and 29.1–30.4^{0}C for 100 mm fish. Another study of the relationship between acclimation temperature and upper lethal temperature indicated that, at acclimation temperatures of 4 and 20^{0}C, 50% of adult flounder could tolerate 19 and 26.5^{0}C, respectively (McCracken 1963). The higher tolerance of small flounder was also observed by Battle (1926) who reported that the tissues of juveniles could withstand 1.0–1.7^{0}C higher temperatures than larger fish. Adult flounder also have a disproportionately greater oxygen demand at high temperatures than juveniles (Voyer and Morrison, 1971)

2. Salinity

Laboratory studies (Rogers 1976) indicate that salinity was a significant factor influencing the time of embryo mortality. Salinities of 35–45 ppt caused mortalities at gastrulation and abnormal development of embryos, at all temperatures. At lower salinities (5–10 ppt), development appeared normal but larvae died prior to hatching. Pearcy (1962) collected various life stages in salinities ranging from 4–30 ppt.

3. Dissolved Oxygen

Juvenile winter flounder are sensitive to reduced levels of dissolved oxygen (D.O.), an important factor determining their distribution during warm summer months in shallow estuarine waters which periodically may become hypoxic. Low oxygen conditions, sometimes followed by fish kills, have been documented in Narragansett Bay (Powell, pers. comm.), Waquoit Bay, MA (Fiske , pers. comm.; Ayvazian, pers. comm.), and western Long Island Sound (CTDEP 1991) in recent years.

To test the effect of low D.O. on local winter flounder abundance, on–board readings of bottom D.O. were paired with concurrent research survey catch information taken throughout western Long Island Sound during the summer of 1989 (CTDEP 1990). Flounder catches were significantly lower at deep mud (>60ft) sites with D.O. between 2–3 mg/l (median catch 55 fish/tow) compared with deep mud sites with D.O. >3 mg/l (median catch 97 fish/tow). At shallow mud sites with D.O. <1.4 mg/l, no flounder were captured, significantly less than the median catch of 74 fish/tow at shallow sites with D.O. >3 mg/l. The relative distribution of flounder abundance and D.O. indicated that areas with bottom D.O. above 2 mg/l, which are adjacent to sites with lower oxygen concentration, may become holding areas for fish either moving out of hypoxic areas or blocked from continuing normal seasonal movements. Such herding results in a threshold effect at D.O. levels between 2–3 mg/l, where average–to–large catches occur above this level, and catches of virtually no fish below this level (CTDEP 1991). Laboratory studies of prolonged exposure to low oxygen (11–12 wks, 2.2 mg/l) showed that growth of YOY flounder was diminished by half compared to high oxygen (6.7 mg/l) conditions (Bejda *et al. in press).* Conditions fluctuating daily between high and low D.O. showed intermediate growth depression.

D. *Feeding and Growth*

1. *Feeding and food habits*

Winter flounder juveniles and adults are sight–feeders, and feed during daylight. The highest percentage gut fullness occurs during early to mid–morning, (Pearcy 1962, Olla *et al.* 1969, Frame 1972, Huebner and Langton 1982, Worobec 1984, Bailey 1989). Feeding activity during the day is accompanied by a visual search posture characterized by a raised head directed at individual moving prey. When prey is 2–3 cm from the mouth, a lunge secures the item. At night, fish rest on the bottom (Olla *et al.* 1969, MacDonald 1982). Age 1 and older winter flounder consume less during winter and on cloudy days (Frame 1972).

Both juvenile and adult winter flounder make diurnal migrations into the intertidal zone to feed (Tyler 1971b). Two principal prey items, maldanid polychaete, and soft–shelled clams, occur throughout much of the flounder's geographic range and are restricted to the intertidal zone. There is also evidence that winter flounder may be attracted to specific amino acids (Sutterlin 1975).

In Passamaquoddy Bay, N.B. and in Newfoundland coves, winter flounder do not eat during winter months and are usually found in deeper areas buried up to 12–15cm in sediments that are up to 0.4C warmer than seawater (Fletcher 1977; Earles and Fletcher 1982). The annual fast which begins by the end of October and may extend to May, decreases condition factor and reduces fat content in liver (75%) and muscle (24%). Muscle water content (2.4%) increases with the resumption of spring feeding (McCleese and Moon 1989).

The quantity of food in the stomach increased from first spring feeding in April, peaking in May, then decreasing during summer and fall (Tyler 1971c). In experiments involving meal frequency in relation to ration, growth, and organ condition, Tyler and Dunn (1976) hypothesized an adaptive reproductive strategy. With food scarcity, winter flounder sacrificed egg production to maintain body weight. Abundant food resources prompted the development of a larger ovary resulting in increased fecundity.

In a southern New England salt pond, daily food consumption was highest during the warmest months (2.84% dry body weight June and 3.31% September) and lower for cooler periods (1.27% April, Worobec 1984). Additionally, food was retained in the stomach during the evening at cooler temperatures, retarding the return of hunger. Adult gastric evacuation, calculated from the rate of hunger return at 6^{0} C, was exponential (Huebner and Langton 1982). Juvenile and adult flounder remaining in shoal waters during summer may have to increase their rate of feeding to compensate for a faster gut evacuation time.

Stomach evacuation rates for laboratory fed juveniles is inverse to their length (Pearcy 1962). Huebner and Langton (1982) estimated daily food consumption to be 2.4% of body weight on average for all but the largest fish, where it decreased to 1.8% of body weight. Stomach volume was correlated to both fish length and weight. Stomach content (% initial meal) decreased exponentially with time, however the data were highly variable.

The first foods of flounder larvae, following yolk absorption up to three weeks of age, are diatoms, followed by small crustaceans (Sullivan 1915). Spring field collection of larvae 2.6–8.0 mm TL (Marine Resources, Inc. 1980), showed they fed predominantly on rotifers until approximately 4.0 mm TL, when polychaetes, nauplii, and tintinnids increased in abundance in stomach contents. Although flounder mouth gape differs insignificantly over the size range examined, rotifers may be captured more easily than nauplii due to their slow movement. Polychaete larvae are also relatively slow swimmers but their large size and low densities may reduce their dietary importance to larval flounder. Larval survival rates based on prey availability were studied by Laurence (1977) using a bioenergetics model. Summing over the total larval phase, the critical minimum prey densities ranged from 0.3 to 0.8 nauplius/ml.

Juvenile winter flounder are omnivorous. One study identified 77 organisms from seven phyla, although the fish demonstrated food selectivity at certain times of the year

(Pearcy 1962). Another study of seasonal food preferences showed that planktonic copepods were more abundant in spring; bivalves, amphipods, and polychaetes predominated the diet in summer and fall (Frame 1974). Species diversity overlap values between stomach contents and Petersen grab samples taken at various locations suggest that young flounder are more selective in the spring as postlarvae than later in the season when they are benthic. The juvenile diet is comprised primarily of crustaceans, polychaetes, annelids, mollusks and bivalves, with various studies emphasizing one or two groups over others (Pearcy 1962, Mulkana 1966, Frame 1972, 1974, Bailey 1989). The composition of the diet appears to be related to age and size of the juvenile flounder (Figure 1.1), as well as availability of prey items.

Like juveniles, adult winter flounder are opportunistic, omnivorous, benthic feeders. Although euryphagous, prey selectivity may result from seasonal cycles of prey abundance and catchability. Polychaete worms, mollusks, amphipods, and isopod crustaceans provide main food items (Linton 1921, Pearcy 1962, Richards 1963, Mulkana 1966, MacPhee 1969, Kennedy and Steele 1971, Frame 1972, Langton and Bowman 1981, Scarlett 1988a, Langton and Watling 1990) found a size-related shift in prey species, i.e., decreased importance of certain crustaceans and increased importance of cerianthods polychaetes as food for larger fish. The hydroid, *Obelia geniculata*, is a major food item in the Cape Cod Canal where flounder have been observed tearing it from kelp (Fairbanks *et al.* 1971). Off eastern Newfoundland, prey appear to be selected according to maximum consumable size rather than abundance; predation may be significant enough on sea anemone, *Metridium senile*, and tortoise-shell limpet, *Acmaea testudinalis* to influence their abundance (Keats 1990). Various plant material is regularly present in stomachs (Fairbanks *et al.* 1971, Wells *et al.* 1973) and apparently can be utilized - this includes *Desmarestia* (Keats 1990), a benthic brown algae noted for its acidity. Briggs (1977) noted that canned kernel corn, used as an attractant or chum by recreational anglers, was consumed and apparently without harm to the fish.

MacPhee (1969) linked the diet of winter flounder to substrate type. Winter flounder living on a coarse, rocky bottom had a more variable diet than those on a soft mud bottom. A regional analysis of prey items (Langton and Bowman 1981) showed that over 52.8% of winter flounder collected from the Middle Atlantic shelf contained Cnidarians (hydroids). Annelids were important prey items across all regions, comprising 15 to 60% of the diet. The relative percent of annelids in the diet varied geographically, decreasing from Middle Atlantic to Georges Bank. Based on dietary overlap, three other fish species, scup (*Stenotomus chrysops*), sea robin (*Prionotus carolinus*), and smallmouth flounder (*Etropus microstomus*), compete for food resources in southern New England (Richards 1963). Kennedy and Steele (1971) found that winter flounder from Conception Bay, Newfoundland, commonly fed on fish eggs, their own and capelin. Selective consumption of capelin eggs contributed significantly to recovery of body condition by postspawning flounder and was estimated to result in 23% of annual growth of the fish (Frank and Leggett 1984).

2. ***Growth: Larval and Juvenile***

Mean growth rates of wild winter flounder larvae collected from four stations in Cape Cod Bay, MA, ranged from 0.38 to 0.63 mm/day after yolk-sac absorption. Estimates of growth were 0.10 mm/day at day 1, 0.65 mm/day at day 5 and 0.23 mm/day at day 25 (Radtke and Scherer 1982). Laurence (1979) calculated a larval length-weight relationship and in an earlier study Laurence (1975) demonstrated a strong positive relationship between rearing temperature and growth. Regression analysis of growth rates at

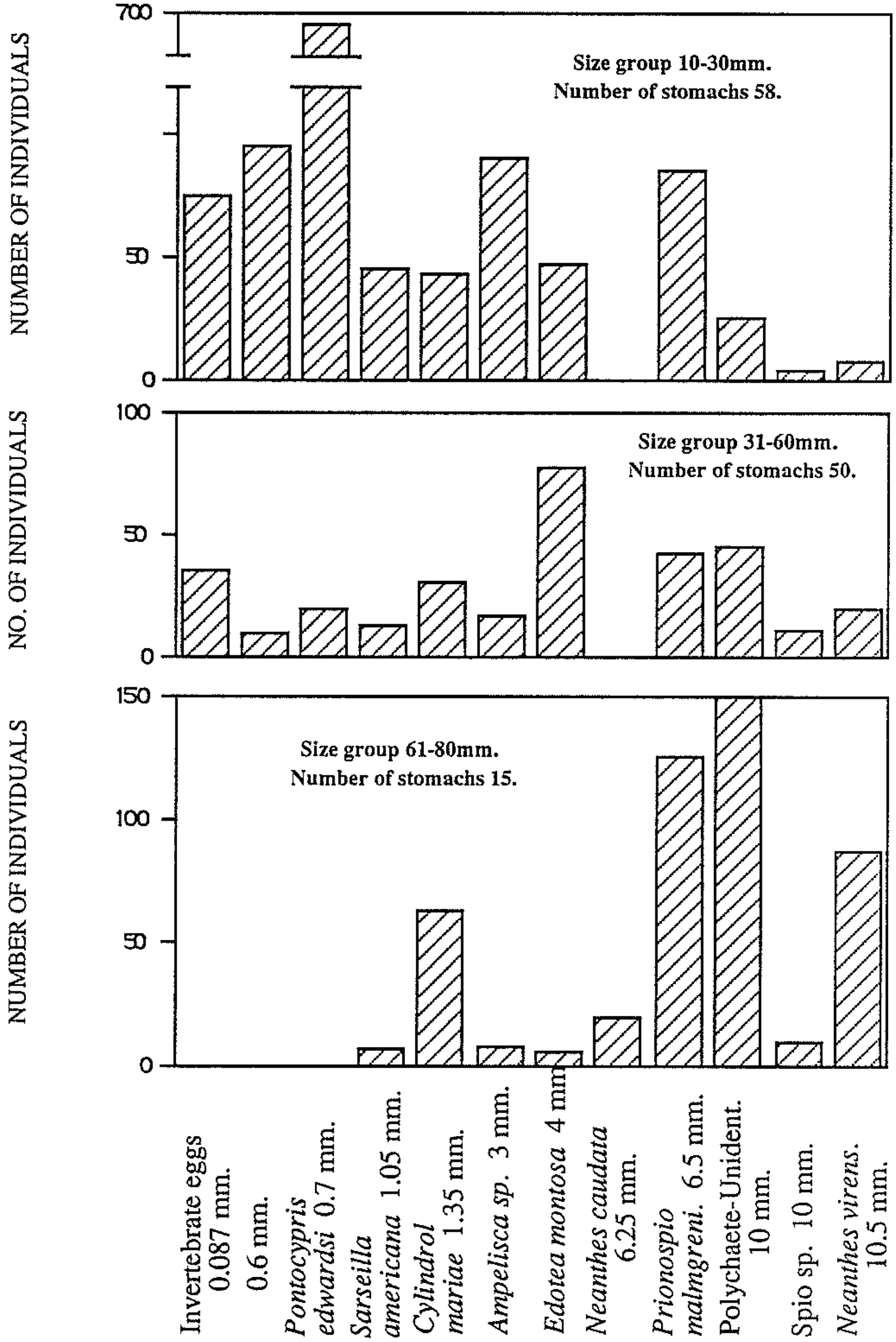

Figure 1.1. Variations between different size groups of juvenile *Pseudopleuronectes americanus* and size of the prey organisms collected from the lower Pettaquamscutt River (from Mulkana 1966).

different temperatures indicated that growth was strongly influenced by temperature (Figure 1.2). Mean daily specific growth rates (weight) were 10.1%/day at 8° C, 5.8%/day at 5° C, and 2.6%/day at 2° C. Metamorphosis occurred in 49 days for larvae reared at 8° C and 80 days at 5° C; larvae did not survive to metamorphose at 2° C.

For winter flounder collected from Conception Bay, Newfoundland (Chambers and Leggett 1987), average length at hatch was 3.83 mm total length (TL) for eggs incubated at 5° C; growth rate from hatch to metamorphosis averaged 0.07 mm/day. The mean age at metamorphosis was 59.5 days post hatching at 6.6 – 10.1 mm TL. A positive relationship between length and age at metamorphosis indicated that fish which metamorphosed at an older age (longer larval stage) were larger in size.

Variation in larval size at hatching may result from the interaction of acclimation temperature prior to spawning and incubation temperature of eggs (Buckley et al. 1990). Larger larval size enhanced survival, food capture, and reduced risk of predation by size–dependent predators. Low adult acclimation temperature (2° C) and egg incubation temperature (4° C) produced the largest larvae, both in terms of length and RNA/DNA content. Winter flounder adults migrate into estuaries to spawn during the coldest winter months. Eggs also incubate at a low temperature. Between hatching and metamorphosis, larvae are exposed to increasing spring water temperatures which promotes rapid growth. This reproductive strategy appears to exploit the changing spring water temperatures, not only to increase the size and survival of larvae, but also minimize competition with other estuarine fishes for spawning locations, nursery areas or foraging sites.

Growth rates for YOY and juvenile winter flounder have been established from field collections (Pearcy 1962; Mulkana 1966) and manipulative experiments (Sogard 1989; Saucerman 1990). Growth curves for YOY and Age 1 flounder (Pearcy 1962) showed rapid growth during spring and summer, followed by depressed growth during winter. The growth rate of juvenile (15–56 mm TL) winter flounder from two estuaries in Rhode Island was 10.5 mm/month, from July–October (Mulkana 1966). Under experimental conditions Age 1 flounder had significantly higher growth efficiencies than Age 2 fish (Chesney and Estevez 1976)

3. Growth variability by habitat

The effect of habitat types on juvenile winter flounder growth rate has been examined in two recent studies. Growth rates were measured in vegetated and unvegetated substrates at four locations in southern New Jersey (Sogard 1989). Two sites were chosen in natural eelgrass and two on sand flats with mats of sea lettuce. Ten and fifteen day caging experiments demonstrated that YOY flounder grew faster on bare sand substrate at sea lettuce sites than at eelgrass sites. Significantly higher water temperatures in eelgrass beds versus sea lettuce were negatively correlated with observed patterns of growth. Although shading from vegetation may be important to juvenile growth in the southern range of this species where temperature may be limiting, Sogard (1989) suggested that differences in site location within an estuary may be more critical in determining habitat quality than vegetation cover. Smaller fish exhibited rapid growth at the time of initial settlement, and larger fish demonstrated decreasing growth (length in mm), regardless of habitat.

Saucerman (1990) sampled YOY winter flounder from different substrates based on both textural classification and organic content in a Massachusetts estuary. Growth rates varied inconsistently with respect to substrate type and sediment organic content among mud, silt, and sand sites over two years. Although density was highest on mud

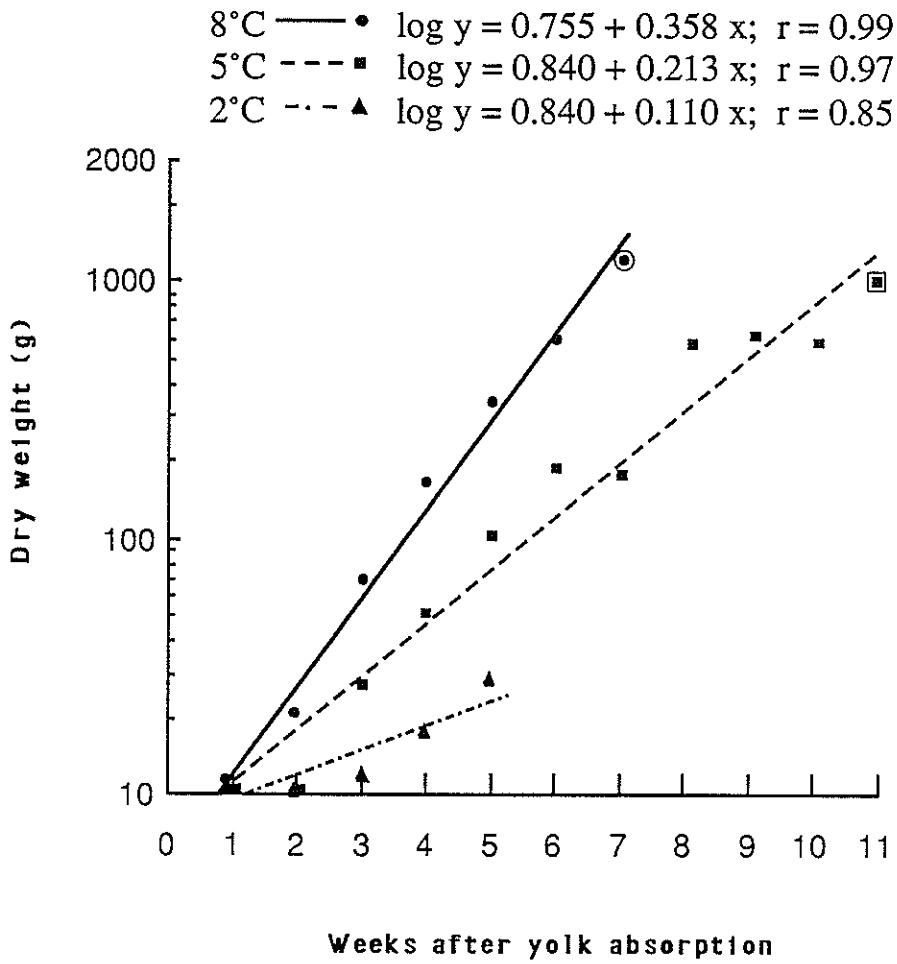

Figure 1.2. *Pseudopleuronectes americanus.* Growth of winter flounder larvae at 3 temperatures. Bordered data points indicate metamorphosis (from Laurence 1975).

bottoms, growth (total length) was lowest. This may be due to food limitation as warm mud habitats become oxygen deficient. Conversely, high abundance may signal a density dependent mechanism regulating growth. These two studies indicate that where temperature, oxygen, or other physical factors vary widely, these habitat characteristics can limit juvenile growth.

4. *Growth: Adults*

Several studies have examined growth rates for adult winter flounder populations along the Atlantic coast (Berry et al. 1965, Poole 1966a, Kennedy and Steele 1971, Lux 1973, Howe and Coates 1975, Gibson 1989a, NUSCo 1987, Scarlett 1988a, CTDEP 1990, Witherell *et al.* 1990). Growth rates as measured by length–at–age vary over the species geographic range (Tables 1.3–1.4, Figure 1.3).

The growth rate of flounder on Georges Bank was greater than inshore stocks for both sexes (Howe and Coates 1975). Mean length–at–age of females south of Cape Cod was intermediate between those from Georges Bank and those north of Cape Cod. Females grew faster than males south of Cape Cod, but not on Georges Bank.

Length and age data from Niantic River, CT, for 1977–1983 (NUSCo 1987) showed relatively fast growth during the first several years of life with declining growth rates after age four. Growth rates were greater for females than males, as reported in other studies (Berry, *et al.* 1965, Poole 1966; Lux 1973, Scarlett 1988a and b).

Utilizing otolith measurement techniques, Poole (1966) determined that the age composition of the population and length–at–age was significantly different between south shore bays of Long Island, NY. Generally, larger–sized fish were found in more eastern bays. In contrast, comparison of flounder sizes from Charleston Pond and Narragansett Bay, RI, detected no differences in growth between the two areas (Berry *et al.* 1965).

In summary, examination of winter flounder length–at–age over a wide geographic range indicated maximum size occurred at the center of their range. Adult winter flounder attain the largest ultimate size on Georges Bank and off the Massachusetts coast east and south of Cape Cod. Maximum size decreases to the north and south of this geographic focus as well as within partially enclosed embayments, such as western Long Island Sound (CTDEP 1990).

E. Community Interactions

Throughout most of their geographic range winter flounder are an essential component of estuarine assemblages. Estuarine habitats provide spawning areas for adults, juvenile nursery habitat, and juvenile and adult foraging area. Although adults may leave the estuary during warm summer months, YOY and juveniles are residents. Therefore, predatory and competitive interactions may occur with other estuarine Sheepscot Bay, Maine, where fish abundance was highest on a gravel/sand bottom compared to mud bottom. Six species, including winter flounder, longhorn sculpin (*Myoxocephalus octodecimspinosus*), little skate (*Raja erinacea*), American plaice (*Hippoglossoides platessoides*), and ocean pout (*Macrozoarces americanus*) comprised 87% of the total number of fish. Similarly, on the Scotian Shelf winter flounder exhibited a broad preference for sand and sand–mud bottoms (Scott 1982).

The demersal fish community in Narragansett Bay consisted of 99 species, with winter flounder being most abundant (36% of the total catch by number and 39% by weight, Oviatt and Nixon 1973). The study concluded that the three most important factors influencing flounder distribution were temperature, depth, and organic content of the sediment. Increasing temperature was also found to be influential to flounder catch

Table 1.3 Age and average length (cm) of Winter flounder.

Location	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
(1)St. Mary's Bay, N.S.												
A.		17.5	26.5	31.4	34.9							
B.					35.0	37.2	39.5	41.5	42.7			
(1)Anapolis Bay		15.3	22.5	29.1	33.0	35.6	38.0	40.2				
(1)Passamaquoddy Bay	7.9	11.8	18.7	23.5	25.7	28.2	31.0	32.4				
(1)Pubnico Bay	8.8	13.3	19.1	22.9	26.0	30.0	35.7					
(1)Northumberland Strait			19.5	22.9	28.7	29.6	32.4	34.3				
(5)North of Cape Cod, MA												
Females			29.0	34.1	37.6	40.1	41.8	43.0	43.8	44.3	44.7	45.0
(5)South of Cape Cod, MA												
Males			25.2	30.1	34.0	37.0	39.3	41.1	42.5	43.6	44.5	45.2
Females			29.4	35.0	39.0	41.8	43.8	45.2	46.2	46.9	47.4	47.8
(2)Narragansett Bay	8.0	19.2	26.6	31.3	34.4	36.5	37.8	38.6	39.2	39.8	39.8	39.9
(3)Charleston Pond, RI												
Males	12.5	18.8	23.6	27.2	29.3	30.6	37.2	38.0	38.5	38.9	39.1	39.3
Females	13.5	21.5	27.4	31.5	34.2	36.0	37.2	38.0	38.5	38.9	39.1	39.3
(6)Long Island Sound												
(9)Peconic and Gardiner's Bay,Eastern,NY		27.9	29.2	34.6	37.2	39.1	40.6	48.2				
Eastern, CT												
Males	11.3	18.9	24.9	28.6								
Females	11.3	20.4	27.5	32.1	35.1	36.4	37.8					
Western												
Males	10.1	16.0	20.0	23.1								
Females	10.1	16.6	21.7	25.8	31.5	33.1	35.6					
(7)Western LIS												
Males	14.0	19.5	23.7	23.6								
Females	14.5	20.6	24.0	25.0								

Table 1.3 continued. Age and average length (cm) of winter flounder.

Location	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Tom's River and Metedeconk River, NJ(10)												
Males	14.8	20.9	25.5	29.1	31.1	34.2						
Females	15.2	21.9	27.0	29.1	32.3	33.9	38.5	35.0				
Barnegat Bay (10)												
Males	21.3	25.2	27.7	29.2	31.5							
Females				28.2	31.5	31.2						
Barnegat Bay (4)												
Males	15.0	21.6	24.9	25.2	25.9							
Females	17.5	24.1	26.9	28.7								
Little Egg Inlet (4)												
Males	14.5	22.1	25.4	26.4	28.7	30.2						
Females	14.7	23.6	26.4	29.2	30.5	33.8						
Shark River (10)												
Males	17.1	23.3	25.4	26.5	28.6	30.3						
Females	19.7	23.6	26.5	29.3	30.5	33.8						
Manasquan River (10)												
Males	19.6	22.1	25.3	28.1	29.7	32.2						
Females	19.7	23.2	26.9	30.1	32.4	34.2						
Eastern George's Bank(8)												
Males	29.8	38.7	46.6	46.9	48.5	48.7	54.7					
Females	34.3	37.1	45.6	50.7	52.3	55.4	58.8					

(A) sample from a small weir
(B) sample from commercial landings

1 McCracken (1963)
2 Gibson (1987)
3 Berry et al. (1965)
4 Danilla (1978)
5 Howe and Coates (1975)
6 CTDEP (1990)
7 Weber and Zawacki (1983b)
8 Lux (1973)
9 Perlmutter (1947)
10 Scarlett (1988a)

Table 1.4 Growth model parameter estimates.

Location	K	L max (cm)	Reference
MA			
north Cape Cod	0.37	45.5	Witherell *et al.* 1990
south Cape Cod	0.34	48.7	
Georges Bank	0.37	55.0 male	Lux 1973
	0.31	63.0 female	
RI			
Narragansett Bay	0.44	41.0	Gibson 1989b
CT			
eastern Long Island	0.39	40.0	CT DEP 1990
Sound	0.43	40.0	NUSCo 1987
western Long Island Sound	0.25	38.	CT DEP 1990
NJ	0.35	35.3	Scarlett 1988a

in Narragansett Bay from 1966 through 1973 (Jeffries and Johnson 1974), a period of decline documented in Jeffries and Terceiro's (1985) analysis of 17 years of winter flounder abundance in the Bay. During flounder declines, scup (*Stenotomus chrysops*) residents (Jeffries and Johnson 1976, Jeffries and Terceiro 1985). Both temporal and spatial variation in community composition of estuarine fishes has been examined in several studies (Merriman and Warfel 1948, Massman 1962, Richards 1963, Tyler 1971a, Oviatt and Nixon 1973, Langton *et al.* 1989, Targett and McCleave 1974).

Winter flounder occur in both the Acadian and Virginian Biogeographical Regions, and the communities in which winter flounder live and interact depends on their geographic location. The Acadian Region includes the Gulf of Maine, with its southern border at Cape Cod, MA. Winter flounder collected in this region belong to a boreal, cold water fish assemblage, characterized by many estuarine resident species. Winter flounder in the Virginian Region, located south of Cape Cod and along the southern Atlantic coast, are components of a warmer water community characterized by large numbers of seasonal migrants during summer months.

Tyler (1971a) examined the relative abundance of fishes in Passamaquoddy Bay, New Brunswick, a cold-temperate community. During the 16 month sampling period there were 13 resident species, four summer periodics, four winter periodics, and 18 occasionals. To elucidate patterns of latitudinal variation, Tyler compared the Passamaquoddy assemblage to similar studies in Block Island (Merriman and Warfel 1948), Long Island Sound (Richards 1963) and Chesapeake Bay (Massman 1962). Generally, instability in the temperature regime, resulting from greater annual temperature fluctuations in the south, corresponds to a smaller resident component.

Two studies of nearshore habitats in Maine showed winter flounder to be among the top six and or seven species in abundance. Targett and McCleave (1974) found winter flounder occurring with smooth flounder, *Liopsetta putnami*, Atlantic herring, *Clupea harengus*, alewives, *Alsoa spp.*, and Atlantic tomcod, *Microgadus tomcod*, in the Back River estuary, ME. Winter flounder ranked seventh in abundance, however, they

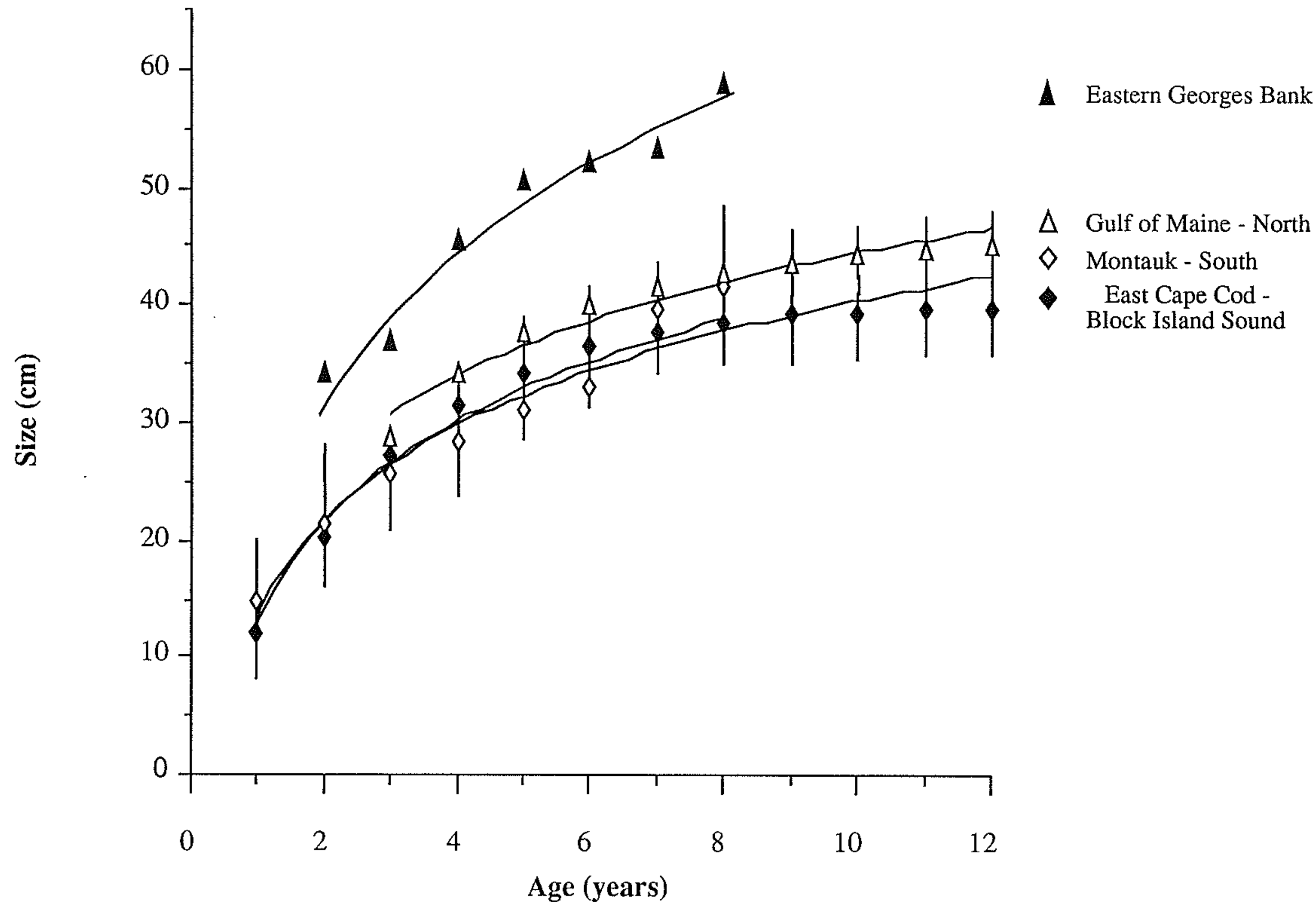

Figure 1.3. Size (median with range) at age for winter flounder by management unit.
Data points from Table 1.1.

comprised less than 1% of the total catch by number and weight. Langton and Watling (1990) documented the occurrence and distribution of YOY and older groundfish in abundance increased 25-fold in the Bay. In Block Island Sound, winter flounder abundances also peaked and declined, however this cycle was time lagged compared to the Bay. During the flounder's decline, abundance increased for three species, red hake, *Urophycis chuss*, ocean pout, *Macrozoarces americanus*, and silver hake, *Merluccius bilinearis*. These fish species may have first been attracted to the Sound due to warmer summers and secondarily by abundant food reserves. Winter flounder were also the most abundant demersal fish (67% by weight, 45% by number) of 37 species collected in Long Island Sound (Richards 1963). Primary resident species were winter flounder, windowpane flounder, *Scophthalmus aquosus* and red hake, *U. chuss*. Scup, *S. chrysops*, was the chief migrant species. Winter flounder were among the five most abundant of 46 species taken by beach seine and trawl Rehoboth and Indian River Bays, DE (Derickson and Price 1973). Flounder constituted over 88% of the total number of fish collected during the winter in shallow water, occurring with striped killifish, *Fundulus majalis*, Atlantic silverside, *Menidia menidia*, mummichog, *Fundulus heteroclitus*, and bay anchovy, *Anchoa mitchilli*. Adult winter flounder abundance was not related to substrate type, vegetation or current velocity; however water depth and temperature were important determinants of distribution and abundance.

F. *Longevity*

Maximum age appears to decline from north to south over the winter flounder's range. Kennedy and Steele (1971) found flounder up to 15 years of age in Newfoundland. Maximum scale age of a small sample of 1964 tagged fish was Age 15 for fish released north and south of Cape Cod and Age 15+ for Georges Bank (Howe and Coates 1975). Additionally, flounder scale samples taken during Massachusetts DMF 1983-1989 trawl surveys have shown a maximum age of 16 south of Cape Cod and 15 north of Cape Cod (Witherell , pers. comm.). Bigelow and Schroeder (1953) recorded a 570 mm TL winter flounder, which they believed was older than 12 years. Saila *et al.* (1965) computed age-length tables from coastal ponds in Rhode Island with the oldest fish estimated to be 12 years old. Poole (1966A) reported flounder longevity of seven years in western Long Island Sound. A current aging study (CTDEP 1990) indicated a maximum age of ten years in western Long Island Sound. Danila (1978) reported a maximum age of seven years in New Jersey populations. More recently, Scarlett (1988a) reported an maximum age of eleven from New Jersey.

G. *Maturation age and length*

Maturity is a variable life history trait which is confounded by both age, size and nutritional status. The significance of this variability appears to be a compromise between somatic growth and reproductive effort. While variation exists in the size at maturity, a minimum size at maturity has been observed. A 3 year maturation time is required for oocyte spawning according to micro-anatomy studies of ovarian tissue (Dunn and Tyler 1969, Dunn 1970, Burton and Idler 1984). Gibson (1989b) used a logistic regression model to compare size-age maturity rates as percent mature at length for female flounder from different stocks (Table 1.5):

$$P = 1/\{1+\exp\{-r^*(L-L_{50})\}$$

where: P = fraction of mature fish at length;
r = rate parameter determining curve steepness;
L = length interval;
L_{50} = length at 50% maturity.

The length at which 50% of females are mature varied from 22.5 cm in western Long Island Sound to 31.5 cm on Georges Bank. (Table 1.5). There were no statistical differences among L_{50} estimates from New Jersey, Connecticut, southern New England, and Newfoundland; however maturity lengths (L_{50}) from western Long Island Sound and Georges Bank were significantly smaller and larger, respectively. The L_{50} for fish collected southeast (28.1 cm) and north (29.7 cm) of Cape Cod, MA, was intermediate between Georges Bank and locations to the north and south (Witherell *et al.* 1990).

Ages at 50% maturity (A_{50}) ranged from 2.5 years on Georges Bank to 5.0 years in Newfoundland (Table 1.5). Burton and Idler (1984) also found Newfoundland females were immature until age 5.

NUSCo (1989) reported complete maturity by Age 6 for Niantic River, CT, females (A_{50} between Age 3 and 4) using a method combining observed proportions of mature fish at age and expected age structure based on mortality estimates. This analysis resulted in a maturity schedule older than other studies reported for the areas.

In summary, Georges Bank stocks, which demonstrated a high growth rate, are the youngest and largest females to reach maturity. Newfoundland females mature at an older age and intermediate size; while western Long Island Sound stocks exhibit the smallest size at maturity with corresponding young age. Coefficients of variation suggest that size appears to regulate maturation rates more than age (Gibson 1989b). When coupled with data on longevity, it appears that western Long Island Sound females compensate for a shortened life span by maturing at the smallest size and youngest age; while long-lived but slow-growing Newfoundland populations reserve maturation until an older age.

H. **Sources of Natural Mortality**

Causes of natural mortality can be partitioned into predation, parasites and disease, and competition.

1. ***Predation***

Larval winter flounder are preyed upon by the medusae *Sarsia tubulosa* (Pearcy 1962; NUSCo 1987). The distribution and peak abundance of *Sarsia* often coincides with the appearance of larvae. Pearcy suggested that the smallest larvae are selected differentially and sustain the highest mortality rates. Common predators of juvenile flounder include summer flounder *(P. dentatus*), toadfish *(Opsanus tau)*, bluefish *(Pomatomus saltatrix*) and striped bass, *Morone saxatilis* and cormorants *(Phalocrocorax auritus*; Pearcy 1962, Derickson and Price 1973). Predators on adult flounder in Canadian waters include monkfish *(Lophius americanus*), spiny dogfish *(Squalus acanthias*) and sea raven *(Hemitripterus americanus*; Dickie and McCracken 1955). The harbor seal, *Phoca vitulina concolor*, has been implicated as competitors with fishermen for commercially important fish like winter flounder since the late 1800's. More recent vilification especially on Cape Cod has been occasioned by their increasing abundance since being afforded federal protection and people's observations and/or perception of their food habits. A 1979–83 analysis of stomach content from 63 stranded seals in southern New England found that three contained winter flounder remains (Selzer *et al* 1986). The study recognized biases in methodology. Payne and Selzer's (1989) more recent examination of scat samples (N= 234) from three winter-haulout sites on Cape Cod (1984–87) found that the percent composition of the flounder group (five species including winter flounder) constituted less than 10% of the diet. The study concluded that seals feed opportunistically on species which are seasonally abundant, with a preference for small, schooling fish particularly American sandlance (minimum 55% of total prey species).

Table 1.5 Maturity parameters for female winter flounder estimated from logistic model and growth rates. Regression analysis from Gibson 1989b. Original data sources given in parentheses.

Stock	L50	A50	r	99% CI on L50
New Jersey (Danilla 1978)	268	3.2	0.0383	254.0 – 282.2
West L.I. Sound (Weber and Zawacki 1983a)	225	2.8	0.0519	214.4 – 236.5
East L.I. Sound (NUSCo 1987)	268	3.0	0.0402	254.3 – 282.5
Southern New England (NMFS 1988)	259	2.8	0.0368	245.1 – 272.4
Massachusetts				
S. Cape Cod	281			
N. Cape Cod (Witherell *et al.* 1990)	297			
Georges Bank (Morse 1979)	315	2.5	0.0268	298.4 – 331.6
Newfoundland (Kennedy and Steele 1971)	262	5.0	0.0392	250.1 – 274.1

2. ***Parasites and Disease***

Parasites of winter flounder have been investigated extensively by Linton (1901, 1924, 1933, 1941) and Ronald (1957, 1958a, 1958b). A total of 52 taxon have been reported from winter flounder (Pellegrino 1973, Table 1.6) A prevalent microsporidian, *Glugea stephani*, infecting the digestive tract of winter flounder, was first described by Linton (1901). Prevalence rates of 3.5% to 54.8% were reported from embayments in the Woods Hole, MA, region with no seasonal or sexual differences (Stunkard and Lux 1965). Georges Bank fish showed no sign of infection. However, monthly prevalence for flounder from the New York – New Jersey Lower Bay Complex ranged from 0.63% in October to 25% in August, coinciding with high water temperatures (Takvorian and Cali 1984). Annual prevalence rate estimates increased from 4.8% in 1978 to 10.6% in 1980. High rates of infection for smaller fish may be a result of residence in shoal waters during the first year of life. *Glugea* induced mortality was investigated for YOY and adult winter flounder from seven sites along the southern coast of Connecticut between July, 1985, and November, 1987 (CTDEP 1988). Although *G. stephani* was prevalent among all age groups, the greatest impact was among Age 1–3. Estimated mortality resulting from infection ranged from 2–11% depending on the assumptions involved translating prevalence into mortality rates. The study concluded that mortality from this parasite is inconsequential on a population level.

Prevalence of *G. stephani* in YOY winter flounder from upper Narragansett Bay (Buckley and Caldarone 1987) approached 30% in October. The seasonal distribution and infection rate were similar to that reported for Long Island Sound and New York–New Jersey (CT DEP 1988, Takvorian and Cali 1984). This study also reported `pigment spots' or `black spots' observed primarily on the fins. This spotting is a host response to cercarial invasion by the trematode *Cryptocotyle lingua* (Creplin). The incidence of `black spot' was highest from fish taken in the lower bay, and did not vary with collecting month.

Examination of adult (>15cm) flounder from Long Island to Block Island Sounds (Pellegrino 1973) found Trematoda and Nematoda ubiquitous among sampling sites, while Acanthocephala showed distinct inshore – offshore trends. Protozoa were found mostly inshore, and Cestoda were least encountered. Trematode infestation increased with age. The occurrence and distribution of external disease in winter flounder was documented for geographic areas off northeastern coastal states for the period 1979–83 (Ziskowski *et al.* 1987). Disease prevalence rates were; finrot, 0.09–1.39%; lymphocystis, 0.05–4.46%; ulcer, 0.04–0.19%; ambicoloration, 0–0.89%; bent fin rays, 0–0.54%; and axial skeletal anomalies, 0–0.18%. Contaminant induced diseases are detailed in the Habitat Section (Part 1 of the Management Plan).

Table 1.6 Some parasites of winter flounder (taken from Klein-MacPhee 1978, and Pellegrino, 1973).

Parasite	Site of infestation	Reference
Protozoa		
Glugea microsporsa stephani	intestine wall	Stunkard & Lux 1965
Nosema stephani	intestinal wall, pyloric caeca	Pellegrino 1973
Trichodinid	gills	
Platyhelminthes		Lom & Laird 1969
Trematoda		
Derogenes varicus	stomach & intestine	Ronald 1960
Distomum appendiculatum	stomach & intestine	Linton 1901
D. grandiparum	stomach & intestine	Linton 1901
D. globeparum	stomach & intestine	Linton 1901
D. vitellosum	stomach & intestine	Linton 1901
D. aerolatum	stomach & intestine	Linton 1901
Steringophorous furciger	stomach & intestine	Ronald 1960
Homalometron pallidum	intestine	Pellegrino 1973
Podocotyle atomon	intestine, stomach pyloric caeca	
P. alssoni	intestine	Pellegrino 1973
P. reflexa	intestine	Pellegrino 1973
Podocotyle sp.	intestine	Pellegrino 1973
Plagioporus varia	intestine & pyloric caeca	Pellegrino 1973
Plagioporus sp.	intestine & pyloric caeca	Pellegrino 1973
Hemiurus sp.	intestine(stomach)	Ronald 1960
Hemiurus appendiculatus	stomach & intestine	Pellegrino 1973
H. levinseni	stomach & intestine	Pellegrino 1973
Parahemiurus merus	intestine	Pellegrino 1973
Cryptocotyle lingua	skin, fins	Pellegrino 1973
Fellodistomum furciger	intestine	Pellegrino 1973
Cestoda		
Bothrimonus intermedius	intestine	Cooper 1918
Diplocotyle olrikii	intestine	Ronald 1958b
Bothriocephalus claviceps	intestine	Ronald 1958b
B. scorpii		Leidy 1855
Tetrarhynchus bisculcatus	stomach wall	Linton 1901
Tetrarhynchus sp.	peritoneum	Linton 1901
Aschelminthes		
Nematoda	stomach	
Ascaris	muscle intestine	Linton 1901

Table 1.6 continued:

Parasite	Site of infestation	Reference
C. gadi	intestine, body walls	Ronald 1963
Grillotia erinaceus		Linton 1924
Lacistorhynchus tenius		Linton 1924
Scolex pleuronectis		Linton 1924
Terranova sp.	axial musculature, body cavity exterior or pyloric caecae and intestine	
Stomachinae larvae	musculature, body cavity, surface external organs	Ronald 1963
Acanthocephala		
Echinorhynchus laurentianus	digestive tract	Ronald 1957
E. acus	intestine	Linton 1901
E. gadi		Linton 1933
Cucullanus heterochrous	intestine	Ronald 1963
Corynosoma sp.	intestinal mesentries	Pellegrino 1973
Branchiura		
Argulus megalops	skin body surface	Ronald 1958a
A. m. spinosus	skin body surface	Ronald 1958a
A. laticaudata	not given	Rathbun 1885
Acanthochondria cornuta	not given	Stock 1915
A. depressus	not given	Wilson 1932
Nematoda		
Contracaecum spiculigerum	intestinal mesentries	Pellegrino 1973
Copepoda		
Calious rapax	not given	Wilson 1905
Argulus sp.	body surface	Pellegrino 1973
Hirudinea		
Atlanticobdella bursata	body surface	Pellegrino 1973

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PART TWO: ECONOMIC ANALYSIS OF FISHING FOR WINTER FLOUNDER

A. Approach

The following section is an excerpt from a larger report (Storey 1991) on the economics of the winter flounder fisheries in the Northeastern U.S. The main focus of this introductory report is on information useful in evaluating alternative regulatory or management techniques under consideration in the Atlantic States Marine Fisheries Commission's Winter Flounder Management Plan.

Two types of economic measures are examined: economic value and economic impact. The economic value of an activity is the amount it contributes to the value of society's output. Economic impact, on the other hand, describes how sales, incomes and employment in a region are related to the level of output of a good. Impact assesments partially overlap with value assessments. Both types of analysis are useful, but for different purposes. Economic values are used to determine whether the benefits of an activity exceed its costs. Economic impacts show the consequences of an activity in terms of jobs, salaries and wages, taxes, and the like.

Although commercial landings have generally declined from a peak in 1980–82 (average 29.1 million lbs) to an average of 14.5 million lbs. in 1986–88, nominal ex-vessel prices per pound have nearly tripled during the ten year period. Landing values have increased somewhat, reaching a high of $17.9 million in 1988. Real ex-vessel prices (adjusted by the Consumer Price Index) approximately doubled between 1979 and 1988.

During the 1979–88 period, distributions of annual commercial landings recorded in the NMFS weigh out system by weight and values among states indicated no major changes in relative shares. Commercial catches within state waters accounted for a consistent fraction of the total (55%) during the same period. It is assumed that the recreational catches detailed in the MRFSS Survey all occurred inshore of Georges Bank. Thus, while recreational landings comprised 26% of the combined commercial and recreational catch for all areas, they represented 31% of the catch in all areas except Georges Bank during the last decade.

B. Economic Value of Recreational Fishing for Winter Flounder

Ideally an estimate would be obtained for the supply and demand of winter flounder angler days in each region for each time period. However, with available data, the best that can be done is to assemble some estimates of gross values and expenses per day fished, for recreational fisheries roughly comparable to winter flounder, and estimates of the number of days spent fishing for flounder, as a basis for estimating the overall net economic value of the fishery. The year 1988 will be the principal focus of the analysis.

The percentage of intercept interview fishermen who were successful in catching flounder was used as a basis for estimating the number of flounder fishing trips (see Methods Appendix, section B). Estimates of net value per fishing day are available from the literature (Table 2.1) for activities similar to flounder fishing, namely shore or bay fishing. Since recreational fishing is a non-marketed activity, values estimates are not precise. However, research economists have devoted considerable research effort to this issue, so the estimates should not be considered grossly inaccurate. After adjustment to 1988 price levels, the estimates ranged from $8.91 per day to $121.63, with a mean value of $39.67. Most of the studies cited were not species specific, but McConnell's 1978 Rhode Island study did focus on winter flounder. The winter flounder values, $63.28 to $121.63 per fishing day, seem very high in comparison to the results of the other studies which averaged $27.95 per day when flounder results were

Table 2.1. Summary of estimated values per recreational fishing day for activities similar to winter flounder fishing,(various research studies).

State	Year	Valuation Method[a]	Species/Mode	1985 Study Value Per day[b]	1988 Adjusted Value Per day[c]
California	1983	CVM	All/Shore	$ 8.10	$ 8.91
California	1983	CVM	All/Rental boat	16.20	17.82
California	1983	CVM	All/Private boat	32.39	35.63
Delaware	1982	TCM	All/Canal	8.59	9.45
Delaware	1982	TCM	All/Beach	41.76	45.94
Delaware	1982	TCM	All/Bays	31.76	34.94
Florida	1981	TCM	All/Shore	13.90	15.29
Rhode Island	1978	Hedonic	Winter Flounder/All	110.58	121.63
Rhode Island	1978	TCM	Winter Flounder/All	57.53	63.28
U.S.	1975	CVM	All/Bays(boat)	43.97	48.37
U.S.	1975	CVM	All/Pier,jetty	31.98	35.18

Data Source: Reily, 1988.

[a]CVM = Contingent Valuation Method.
TCM = Travel Cost Method.
[b]Lavin adjusted all study results to a standardized 1985 value per fishing day, using the CPI.
[c]Lavin's 1985 values adjusted to 1988 price levels, using the CPI.

removed from the average. McConnell considered his results "suggestive rather than final" (McConnell 1979).

Picking the upper limit of a plausible range is problematic, but in the author's judgement $30 dollars seems a reasonable figure. Thus, a range of $10 to $30 will be used for the net economic value of a winter flounder fishing trip (a day spent fishing primarily for winter flounder). The two net values for per–trip estimates were combined with the fishing trip estimates discussed previously (see Methods Appendix, section B) to derive six total net economic value estimates for the two regions (Table 2.2). The net value of winter flounder recreational fisheries was estimated to range from $16 to 48 million in 1988. It is difficult to assign probabilities to figures within the range, although numbers towards the lower end of the range seem more plausible.

Accepting a net value of $15.00 per winter flounder trip, as a roughly accurate measure of the average value of the recreational fishery does not necessarily mean that the marginal value – the gain or loss from added or decreased numbers of trips is $15.00 per trip. From a conceptual viewpoint, the average valuation represents the upper limit for the marginal valuation at current levels of activity. The marginal valuation, which is likely different for different levels of activity, is probably less than the average valuation for relatively small changes in activity away from current levels.

C. Economic Value of Commercial Fishing for Winter Flounder

Conceptually, the information needed to estimate economic values for the commercial fishery is the same as for the recreational fishery: estimates of the characteristics of the demand and supply functions. In this case, the net value can be divided into two components: consumer surplus and producer surplus. Consumer surplus is the difference between what consumers are willing to pay, as indicated by the demand function, and what they actually pay, the consumer expenditures for fish.

Table 2.2 Estimated total 1988 net value of winter flounder recreational fishing trips for a range of net value per trip estimates

Region	Successful Trips[a] (thousands)	Estimated Total Net Value (thousands of dollars) — Net Value per Fishing Trip[b]: Minimum Estimate ($10)	Maximum Estimate ($30)
New England	770	7,700	23,100
Mid–Atlantic	839	8,390	25,170
Both Regions	1,609	16,090	48,270

[a]See Methods Appendix, part b for explanation of trip estimating procedures.
[b]See text for explanation of net value per trip estimates.

Producer surplus is the difference between revenues to the owners of commercial fishing vessels, these revenues being the same as consumer expenditure, and the costs of operating their vessels. The sum of consumer surplus and producer surplus equals the net economic value of the commercial fishery. As previously indicated, a change in either supply or demand would change the net economic value of the commercial fishery. The task of estimating net economic value is easier in one respect at least, for the commercial fishery compared to the recreational fishery. There is a market for food fish. Therefore producer revenues, also known as landings level consumer expenditures, are known with certainty.

Using 1988 as the focus year again, we know that 15.7 million pounds worth $17.9 million ($1.14 per pound on average) were landed from all areas except Georges Bank (Table 2.3). Nearly 92% of the landings value occurred in the New England states in 1988. Studies by the National Marine Fisheries Service's Gloucester office provide some clues about producer surplus earned in the winter flounder fishery. Their analysis identified net income to vessel owners, as well as net crew shares, for small, medium and large otter trawls in New England for the period 1976 to 1986 (Table 2.4). Recall that over 95% of winter flounder commercial landings during 1979 –1988, and 93% for the specific year 1988, were by otter trawl vessels, and less than 5% by other gear types. The NMFS studies indicated generally declining net incomes to otter trawl vessels during the 1976 to 1986 period in nominal dollars, so the declines would be even greater in inflation adjusted dollar terms. Unfortunatly their studies ended in 1986.

Stanley Wang of NMFS provided unpublished data for the most recent year, 1986, on costs and net incomes in relation to gross incomes. While a single year is not a broad foundation for estimation, the most recent year studied is preferable to an average which includes years further in the past and not representative of the recent

Table 2.3 Winter flounder commercial landings: weight, value and price, 1979–1988, in all areas except Georges Bank.

Year	Thousands of pounds	Thousands of dollars	Nominal Ex–Vessel Price in Dollars Per Pound	Real Ex–Vessel Price in 1988 Dollars Per Pound[a]
1979	19,308	7,140	0.37	0.60
1980	29,027	9,731	0.34	0.49
1981	30,927	12,226	0.40	0.52
1982	27,389	11,524	0.42	0.52
1983	24,907	11,128	0.45	0.53
1984	23,340	14,190	0.61	0.70
1985	19,272	14,565	0.76	0.84
1986	13,606	11,803	0.87	0.94
1987	14,038	14,825	1.06	1.10
1988	15,710	17,936	1.14	1.14
Mean	21,752	12,507		

[a]Adjusted using the Consumer Price Index

Table 2.4. Average net income and net crew share by tonnage class New England otter trawl vessels, 1976–1986.

Year	Average net income by vessel class[a] I	II	III	Average individual net crew share by vessel class[b] I	II	III
1976	21,991	31,381	36,713	13,552	18,028	16,240
1977	30,120	45,987	56,020	16,710	22,192	20,417
1978	41,102	55,606	81,456	24,898	25,027	27,269
1979	29,703	47,632	71,522	20,028	26,220	27,604
1980	22,246	17,664	45,540	17,317	20,560	23,518
1981	22,902	23,348	66,140	20,324	21,774	27,417
1982	17,144	36,474	62,136	17,672	25,988	28,326
1983	18,050	27,993	57,943	18.020	25,962	28,397
1984	8,517	13,871	39,107	17,258	24,506	30,272
1985	8,494	–2,063	22,032	17,322	22,161	30,471
1986	9,502	15,379	54,000	18,265	25,933	35,908

SOURCE: U.S. Department of Commerce, National Marine Fisheries Service, 1988. Chart and Statistical Book of the U.S. Northeast Fisheries. Gloucester, MA: Analytical Services Branch, Research Document No: NER88.1

Class I = 5–50 GRT; Class II = 51–150 GRT; Class III = 151+ GRT

[a] Net income to vessel owner before depreciation, taxes, and miscellaneous costs.
[b] Not including captains' share.representative of the recent situation.

situation. Overall, for 279 otter trawlers studied in seven major ports, the net income to vessel owners represented 6.1% of gross incomes (Wang 1990). This figure is equivalent to the producer surplus. If the 6.1% is multiplied by the $17.9 million gross value landings of winter flounder in 1988, the resulting 1988 producer surplus estimate is $1.1 million. This is a crude estimate, but it is probably correct to conclude that producer surplus is a fairly small proportion of gross landings value. Therefore, it is estimated that producers surplus in 1988 was $1.1 million, with an error range of 50 percent or $550,000 to $1,650,000.

A review of the literature indicates that there have been no studies of the market demand for winter flounder separate from other flounder or groundfish. Representative studies of the demand for ground fish include Wang (1984) and Felixson *et al.* (1987). Wang studied seven groundfish species groupings, one of which was flounders other than yellowtail flounder. Econometric analysis of 1974–1982 data indicated a short-run price–landing flexibility of –0.40 for the "other flounders" group and short-run price–import (fresh flounder import) flexibility of –0.06, with both measures computed at sample means. Felixson *et al.* (1987) grouped flounder with cod, haddock and ocean perch. Econometric analysis of 1970–1982 data indicated a rather similar short-run price–landing flexibility of –0.38 for groundfish.

Using Wang's linear model estimate for "other flounder," we can estimate that the consumer surplus, when ex–vessel price is $1.14 and landings are 15.7 million pounds, is approximately $3.5 million. Of course there may have been demand changes since the 1974–1982 period, and winter flounder may have a demand different from that of all flounders except yellowtail flounder grouped together. But a consumer surplus estimate range of $2.5 to $4.5 million is probably fairly accurate.

Putting the consumer and surplus estimates together, we conclude that the net economic value of the winter flounder commercial fisheries in 1988 was between $3.05 million and $6.15 million, with $4.6 million representing the best single estimate (Table 2.5).

The same caveats apply here as in the case of recreational fisheries. An average net value estimate of $0.293 per pound of flounder landed commercially in 1988 ($4.6 million divided by 15.7 million pounds) does not necessarily mean that the marginal net value from an increased or decreased catch would be the same for each new pound of landings lost or gained. Assuming normal short–run demand and supply curves, the marginal net value of a small change in landings is probably less than average value.

Table 2.5 Estimated 1988 net value of winter flounder commercial fishery (excluding Georges Bank) for a range of producer surplus and consumer surplus estimates.

	Estimated Net Economic Value of Commercial Fisheries (in millions of dollars)		
	Consumer Surplus Estimate		
Producer Surplus Estimate	2.5	3.5	4.5
0.55	3.05	4.05	5.05
1.10	3.6	4.6	5.6
1.65	4.15	5.15	6.15

NOTE: the above estimates exclude Georges Bank.

D. Economic Impact of Recreational Fishing for Winter Flounder

Economic impact analysis shows the effect of an activity on the regional economy: on business sales, on wages and other components of value added, and on employment. For the recreational fishery, the focus is on how the various measures change as angler expenditures change. The first piece of information needed is how much is spent on the typical winter flounder recreational fishing trip. In the absence of information specific to the winter flounder fishery, we again turn to more general studies conducted in recent years (Table 2.6).

Flounder fishing is done from shore, from private or rental boat, and from party boats, so no one mode can be selected. However, flounder fishing is a relatively inexpensive activity not done primarily on charter boats or the larger private boats, and not requiring expensive equipment; so expenses in the lower range of those shown in Table 2.6, or even lower, are probably appropriate. In 1988 dollars, a range of expense per winter flounder fishing day (fishing trip) of $15 to $35 seems applicable.

Multiplying the minimum and the maximum estimates of expenses per fishing trip by the trip estimates previously developed (Table 2.2) results in a range of total 1988 trip related expenses for winter flounder recreational fishing of $24 million to $117 million (Table 2.7).

The next question to be addressed is resident versus non-resident expenditures, or the degree of economic activity brought into the region as "new money" because of flounder fishing. The MRFSS data base gives some basis for separating resident fishermen from non-residents for the two regions as it identifies the county of residence of the fishermen (Tables 2.8–2.9). On the average, 31.4% of New England anglers and 22.2% of Mid-Atlantic anglers were non-residents of the coastal county for the period 1979–89. In the focus year 1988 the non-resident percentages are 33.8% in New England and 18.6% in the Mid- Atlantic region. It is assumed in the following analysis that the overall percentages can be applied to the flounder fishery.

The remaining important category of information needed has to do with multipliers: the total dollar sales and value added and the total number of jobs generated by each initial dollar of expenditure by recreationists. Based on the other studies (Table 2.10), the ranges of multipliers used here are 2–3 for sales, 1–1.7 for household income, and 40–70 for employment. Although no range was used for the non-resident percentage, designation of non-coastal county residents as non-residents must also be considered arbitrary, and the results would be sensitive to variations in this number as well. When these multipliers (Table 2.10) are applied to dollar values for the regional fisheries (Table 2.7) the range of economic impact becomes 12–43 million dollars in sales, 6 to 24 million dollars in income (Table 2.11).

E. Economic Impact of Commercial Fishing for Winter Flounder

There are several important differences in economic impact procedure for commercial fishing compared to the one used for recreational fishing. First, the impact analysis is based on a known, or at least accuratelyestimated, quantity: the value of landings. Thus, the analysis for 1988 starts with the landings value of $17.9 million. Second, in the case of a commercial fishery it is usually assumed that all of the landings are exported and generated "new money" for the region where the harvest activity took place. This is a contrast to the recreational fishery case, where only non-resident expenditures were assumed to generate "new money" and resident expenditures were assumed to transfer elsewhere if there were a change in the fishery under analysis.

Table 2.6. Summary of estimated trip-related expenses per recreational fishing day from various research studies.

Author	Year	Fishing Mode	Region	1981 or (1985) Expense per day	1988 Adjusted Expenses per day
Hiett *et al.* 1983	1981	Man-made structure	N.Atlantic	$ 20.49	$ 26.64
	1981	Beach-bank	N.Atlantic	27.99	36.39
	1981	Party-charter boat	N. Atlantic	59.06	76.78
	1981	Private rental boat	N. Atlantic	38.41	49.93
	1981	Average, all modes	N. Atlantic	36.85	47.91
USDI	1985	All modes	U.S.	(24.36)	26.80
Storey *et al.* 1990		Shore	Massachusetts		28.23
	1988	Private/rental boat	Massachusetts		64.93
	1988	Party/charter boat	Massachusetts		117.47
	1988	All modes	Massachusetts		56.93

Table 2.7 Estimated 1988 trip-related expenses for winter flounder recreational fishing trips for a range of trip estimates and expenses per trip estimates

Region and Trip Estimating Procedure	Winter Flounder Trips (in thousands)	(Expenses/ Trip in thousands of dollars) Minimum Estimate ($15)	Maximum Estimate($35)
New England	770	11,550	26,950
Mid-Atlantic	839	12,585	29,365
Both Regions	1,609	24,135	56,315

Table 2.8. Estimated recreational fishing by residence category in New England.

Year	Coastal County Residents	Non–Coastal County Residents	Out of State Residents	Total
1979	5002	224	2030	7255
1980	5671	309	1787	7768
1981	4220	510	1826	6556
1982	5097	550	2025	7672
1983	6427	673	2286	9385
1984	4745	294	1600	6639
1985	5839	376	2486	8701
1986	5425	408	2500	8333
1987	4578	232	1483	6293
1988	5098	619	1979	7696
1989	3985	323	1125	5433
MEAN	5099	411	1921	7431

Data Source: National Marine Fisheries Service, U.S. Department of Commerce, Marine Recreational Fishery Statistics Survey, Atlantic and Gulf Coasts 1979–86 issues. The unpublished 1987–89 data was provided by John Witzig of NMFS.

Table 2.9 Estimated recreational fishing by residence category in Mid-Atlantic: New York, New Jersey and Delaware.

Year	Coastal County Residents	Non-Coastal County Residents	Out of State Residents	Total
1979	10686	169	2129	12984
1980	11827	177	3340	15344
1981	6966	134	2100	9200
1982	8041	169	2102	10312
1983	11083	149	2616	13848
1984	11034	143	2604	13781
1985	9264	91	3756	13111
1986	9564	192	3311	13067
1987	8493	177	2070	10740
1988	9756	240	1989	11985
1989	6550	86	1590	8226
MEAN	9388	157	2510	12055

Data Source: National Marine Fisheries Service, U.S. Department of Commerce, Marine Recreational Fishery Statistics Survey, Atlantic and Gulf Coasts 1979–86 issues. The unpublished 1987–89 data was provided by John Witzig of NMFS.

The impacts generated by a dollar of fish landings include consideration of processing, wholesaling and retailing activities. Again we do not have studies for the specific region of winter flounder fisheries, but can get rough approximations from other studies (Table 2.12). Multipliers tend to be somewhat higher for commercial fisheries compared to recreational fisheries. It appears that a range of 3.3–4.7 is appropriate for sales multipliers, 1.5–2.5 for household income multipliers and 125–200 for employment multipliers. When these multipliers are applied to landings, the range of economic impact becomes $59 – $84 million in sales, $27– 45 million in income (Table 2.13).

Table 2.10. Summary of multipliers estimated for recreational fishing expenditures (various research studies).

Reference Author	Year	Species	Region	Multiplier: Household Sales[a]	Multiplier: Income[b]	Multiplier: Employment[c]
Bell *et al.* 1982	1982	All species, tourists only nondurable goods	Florida	5.18	1.60[d]	136
Sport Fishing Institute 1988	1985	Winter Flounder, alll fishermen, trip and durable expenses	New England	2.22	1.60[e]	36
Talhelm 1988	1985	All species, all fishermen, trip and durable expenses	Great Lakes	2.00	----	38
Washington, State of 1988	1988	Salmon non–residents trip expenses	Washington	3.18	1.66[d]	83

[a] Regional sales dollars generated by one dollar of expenditure on recreational fishing.
[b] Regional household income dollars generated by one dollar of expenditure on recreational fishing.
[c] Regional person–years of employment generated by one million dollars of expenditure on recreational fishing.
[d] Wages and salaries.
[e] Value added.

Table 2.11. Estimated 1988 Economic Impact for winter flounder recreational fishery.

Item	New England		Mid Atlantic		Both Regions	
	Minimum Expense Estimate	Maximum Expense Estimate	Minimum Expense Estimate	Maximum Expense Estimate	Minimum	Maximum
	(3,904)	(9,109)	(2,341)	(5,462)		
SALES (thousands of dollars)						
Minimum						
Multiplier(2)	7,808	18,218	4,682	10,924	12,480	29,142
Maximum						
Multiplier(3)	11,712	27,327	6,947	16,386	18,659	43,713
HOUSEHOLD INCOME (thousands of dollars)						
Minimum						
Multiplier(1)	3,904	9,109	2,341	5,462	6,245	14,571
Maximum						
Multiplier(1.7)	6,630	15,485	3,977	9,285	10,607	24,770
Employment (person years)						
Minimum						
Multiplier(2)	156	364	93	218	249	582
Maximum						
Multiplier(3)	273	638	164	382	437	1,020

All economic measures are in thousands of dollars except employment which is in person years.
Economic impacts are calculated for non-residents only. Thus,for example,the minimum expense estimate for New England of $3,904,000 was $11,550,000 (from Table 3.16) times .338 (the fraction of non-resident trips in 1988). The mid Atlantic estimates were based on 18.6 percent non-resident trips in 1988.

Table 2.12 Summary of multipliers estimated for commercial fisheries landings values (from various research studies).

Author	Year	Species	Region	Multiplier: Sales[a]	Multiplier: Household Income[b]	Multiplier: Employment[c]
Briggs et al 1982	1982	All	Maine	---	2.64[d]	---
Mass. Offshore Groundfish Task Force 1990	1986–89	Groundfish	New England	4.30	---	176
			Massachusetts	3.31	---	135
Morris *et al.* 1978	1978	All	Florida	4.69	0.99	---
Smith 1978	1978	Salmon	Oregon	4.94	---	---
Talhelm 1988	1985	All	Great Lakes	3.24	---	220
Washington, State of 1988	1988	Salmon	Washington	3.88	2.39	120

a Regional sales dollars generated by one dollar of landings value.
b Regional household income dollars generated by one dollar of landings value.
c Regional person–years of employment generated by one million dollars of landings value.
d Value added.

Table 2.13 Estimated 1988 economic impact,winter flounder commercial fishery excluding Georges Bank.

Item	New England	Mid Atlantic	Both Regions
SALES (thousands of dollars)			
Minimum Multiplier (3.3)	53,754	5,316	59,070
Maximum Multiplier (4.7)	76,558	7,572	84,130
HOUSEHOLD INCOME (thousands of dollars)			
Minimum Multiplier (1.5)	24,434	2,417	26,851
Maximum Multiplier (2.5)	40,723	4,028	44,751
EMPLOYMENT			
Minimum Multiplier (130)	2,118	209	2,327
Maximum Multiplier (200)	3,258	322	3,580

The multipliers indicated above were applied to landings values of $16,289,000 for New England and $1,611,000 for the Mid Atlantic Region.

Table 2.14. Summary of Estimated 1988 winter flounder economic values and impacts.

Item	Commercial	Recreational
Cost or Expenditures		
Total	16,250 to 17,350	24,140 to 56,315
Non-Resident	---	6,240 to 14,570
Landings Value	17,900	---
Net Economic Value	3,050 to 6,150	16,090 to 42,710
Total Sales Impact	59,070 to 84,130	12,490 to 43,710
Total Household Income Impact	26,850 to 44,750	6,240 to 24,770
Total Employment Impact	2,330 to 3,580	250 to 1,020

All economic measures are in thousands of dollars except employment which is in person years.

F. Summary and Conclusions About 1988 Economic Values and Impacts

All key economic measures estimated for 1988 (Table 2.14) show wide ranges due to the imprecise estimating procedures used. More information specific to these fisheries is required to increase precision on any of the estimates. However certain important generalizations can be made nonetheless.

The recreational fishery clearly produces net economic values greater than those produced in the commercial fishery. The lowest recreational fishery net value estimate of $16.1 million is more than twice the highest commercial fishery net value estimate of $6.2 million. The highest recreational fishery net value estmate of $48 million is more than an order of magnitude larger than the commercial fishery mean net value estimate of $4.6 million.

On the other hand, the commercial fishery produces greater economic impacts than the recreational fishery. The mean sales impact estimate is $71.7 million for the commercial fishery compared to $28.1 million for the recreational fishery, and the median household income impact estimates were $35.8 million for the commercial fishery compared to $15.5 million for the recreational fishery. The mean employment estimates were 2,960 people for the commercial fishery and 635 people for the recreational fishery

The reversal of relative importance of commercial versus recreational between the two types of economic measures is not surprising. Commercial fisheries tend to have relatively large economic impacts per dollar of initial expenditure or income as they are basic industries which export much of their output, bringing "new money" into the regional economy, and which provide the basis for income and employment throughout the entire marketing system from producer to consumer. For residents it is generally felt that a change in the level of one recreational activity will simply result in a transfer of expenditures to another recreational activity within the region. Thus, unless a recreational fishery is heavily tourist-oriented (not the case with winter flounder), then its economic impact per dollar of expenditure tends to be relatively low.

However, the recreational value of a fish is often higher than its food value. Also, commercial fisheries often operate at low or even negative profit levels, leaving consumer surplus as the main component of net economic value. For a small change in the short-run, the marginal value is probably less than the average value. Long run effects are beyond the scope of this paper, but could conceivably be quite different, as short term economic losses might be traded off against long-term economic gain.

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APPENDIX: METHODS EMPLOYED in the WINTER FLOUNDER MANAGEMENT PLAN

A. Methods of Mortality Estimation

1. *Total mortality*

Estimation of total mortality is a key element of stock analysis. Although several methods exist, each is constrained by available data and assumptions which must be met in order to ensure accuracy. Ideally, the chosen method(s) should allow for testing whether the observed data fit underlying statistical assumptions. Methods for estimating mortality rates may be broadly divided into those which rely on age determinations of fish in samples (e.g. catch curves, virtual population analyses) and those which are independent of age data (e.g. tagging, length-based analyses). Imprecise aging may introduce error into mortality estimates. Variability among populations in length-at-age, maturation, and pattern of exploitation make virtual population analysis problematic if landings are not acurately separated by stock origin. Although tagging methods do not require knowledge of absolute age, bias is introduced by tag loss, tag-induced mortality, and non-random distribution of tags and returns. To minimize some of these shortcomings and obtain corroborating estimates of total instantaneous mortality (Z), estimates were derived from both age-based catch curves and tagging studies for Gulf of Maine, Southern New England, and mid-Atlantic stocks. A third method, which examined historic trends in relative exploitation, was applied to commercial landings data for the Southern New England stock, where this fishery constitutes a large proportion of fishing mortality.

a. *Tagging Studies*

Tag return data suitable for mortality estimation were extracted from published literature or ongoing studies in the case of the RIDFW. The minimum data considered usable were instances where flounder had been tagged in one year with tags recovered in at least three years, including year of release. Although mortality estimates may be computed from two years of recovery, such a small data set is insufficient to test model assumptions. Preferred studies included several years of consecutive tagging with several recovery years associated with each release event. Tags were applied over a relatively short time period at the beginning of the recovery year. In all studies, Petersen disc tags were used which have a relatively low loss rate. A total of 33 tagging experiments, starting in 1931, met the above criteria.

Perlmutter (1947) reported the results of 14 such experiments conducted from Long Island to Maine prior to World War II (1931–1942). Several tagging studies were performed in Narragansett Bay and Rhode Island coastal ponds from 1956–1958. (Saila 1961a, 1961b; Berry et al. 1965). Winter flounder were also tagged off Nova Scotia from 1949–1953 (Dickie and McCracken 1955). Extensive tagging experiments were done from 1961–1965 in Massachusetts waters (Howe and Coates 1975) and in Long Island Sound (Poole 1969). During the 1970's tag-return studies of winter flounder were confined to one study in Barnegat Bay, New Jersey (Danila and Kennish 1982). Winter flounder tagging resumed in 1981–1983 in western Long Island Sound (Weber 1984), and at several sites in New Jersey from 1982 through 1987 (Scarlett pers. comm.). Additional tagging was done in the vicinity of Sandy Hook, New Jersey from 1986–1989 (Phelan, B. in press). As part of a power plant impact assessment, tagging studies (1983–1989) were performed in eastern Long Island Sound (NUSCo 1989). Finally, the RIDFW has conducted an annual tagging program in Narragansett Bay since 1986 (Powell 1989).

Two estimation methods were used depending on the number of years in which tags were released. With only one release year, total mortality was estimated following the method outlined by Robson and Chapman (1961), which was originally designed for catch curves. They derived a maximum likelihood estimator of the survival rate (S) for declining abundance spaced equally in time (annual tag recoveries). Variance estimators are given, with a chi-square procedure to test whether the observed distribution of tag recoveries are consistent with the expected distribution of the statistical model. The validity of this method depends on the following assumptions: 1) a constant survival and reporting rate; 2) random distribution of tags within the population; 3) constant catchability; and 4) no tag loss. This model is essentially the same as Model 3 of Brownie *et al.* (1985) described below. The recommended chi-square test does not test specific assumptions, but rather indicates when one or more have been violated. The method allows for truncation of the tag return series until the chi-square value is below the critical level ($P<0.05$). This was not done here. Rather the entire series was analyzed, and those with high chi-square values were omitted. It should be noted that this Robson/Chapman estimator is not the regression estimator commonly used with catch curves which does not give realistic variance estimates (Gulland 1985) or tests of model fit.

When more than one release year was available, the methods of Brownie *et al.* (1985) were used. These maximum likelihood survival estimators were originally designed for bird banding studies but are readily adapted to estimate total mortality for fish stocks. They advocate use of a hierarchical class of models along with a diagnostic testing procedure. The models are stochastic in that they assume that recaptures are a binomial random variable of sample size, recovery rate, and survival rate. A statistical model is assumed for the expected values and parameters most likely to have produced the observed data are estimated using maximum likelihood theory. Four model formulations (0–3) are possible depending on assumptions about recovery and survival rates. A microcomputer program called ESTIMATE (Brownie *et al.* 1985) sequentially fits all four models to the recoveries, and the most parsimonious model which adequately represents the data is identified. Each model progressing from No.0 to No.3, is a special case nested within the previous formulation:

Model 0: Recovery rate and survival rate are year specific. The recovery rate in the first year may be different than recovery rate for other releases in that year. This generalization is useful when tag recoveries are high near the tagging site before they can fully mix with the stock at large.

Model 1: A restriction of model 0 where first year recovery rates do not vary. Recovery rate and survival rate may vary annually.

Model 2: A further restriction where annual survival rate is assumed to be constant but the recovery rates may vary by year.

Model 3: The most restrictive formulation where both survival and recovery rate are assumed constant across years. This model is essentially equivalent to that of Robson and Chapman (1961).

Both of the above methods estimate survival rate (S) which can be log transformed into total mortality rate (Z). Variance estimates for Z were made by using the same coefficient of variation in the survival estimates. No attempt was made to partition Z into F and M since this requires knowledge of the reporting rate, which is unknown. Estimates of F derived from other studies are given in the following section.

Resulting estimates of total mortality (Gibson 1990, Table 2.1 in Management Plan) are summarized by Gulf of Maine stock, Southern New England stock, and mid Atlantic stock and include an estimate from St. Mary's Bay, Nova Scotia. A total of 33 estimates were made, with Robson and Chapman's (1961) method applied to 19 data sets and Brownie *et al.* (1985) applied to 14. Chi-square goodness of fit tests resulted in omission of seven Z estimates due to significant values (P<0.05) suggesting that they could be biased. The overall mean of estimates having acceptable chi-square values was 1.15 (se= 0.03).

b. *Age-based Studies*

Total instantaneous mortality rates (Z) for winter flounder populations in Gulf of Maine, Southern New England, and mid-Atlantic calculated by weighted catch curve regression (Ricker 1975) where age frequencies were available (MA, RI, CT, NY, Table 2.2 in Management Plan). Curves were weighted by age-specific abundance. Length frequencies from the MDMF spring survey (Witherell *et al.* 1990) were converted to age frequencies using stock-specific pooled age-length keys (1983-1989, N=1897), developed from aging studies of flounder north and south of Cape Cod (Fields 1988, Burnett pers. comm.). A pooled key (1986-1988, N=579) developed from an aging study of Narragansett Bay flounder (Fields 1988, Burnett and Haas pers. comm.) was used to age flounder from the RIDWF survey, a winter survey of lower Narragansett Bay by U.R.I. Graduate School of Oceanography, and a winter survey of upper Narragansett Bay (Mt. Hope Bay) by Marine Research Inc. (Gibson 1989b). Pooled keys (1985-1987, N>=600 per area) developed from aging studies of flounder in eastern, central, and western Long Island Sound (CT DEP 1990) were used to age flounder from the monthly Connecticut survey for April-May catches. Annual keys (N>=600) were used in 1988-1990 when sample sizes were larger. Comparative studies (Haas, pers. comm.) demonstrated that the aging methodology used in the Connecticut survey (CTDEP 1990), and the methodology used in the Massachusetts and Rhode Island surveys (Fields 1988, Burnett and Hass, pers. comm.) gave comparable results. Annual age-length keys for western Long Island Sound were used to transform length frequencies to ages from a survey (1988-1989, N=1478) carried out by NYDEC in western Long Island Sound (Castaneda pers. comm.). Finally a catch curve was generated (Castaneda pers. comm.) using historic age frequencies (1961-1963, N=162) available from an aging study of flounder from Great South Bay, Long Island, NY (Poole 1966).

All catch curve regressions included ages from the youngest age fully recruited to the fisheries in the region to the oldest age consistently present in the data set. Because fishing practices and minimum legal size limits differed by location and time period, the ages used to estimate total mortality in each stock also varied (see Table 2.2 in Management Plan).

c. *Relative exploitation*

A third method (Gibson 1990) of estimating Z was applied to the Southern New England stock where total mortality is driven principally by the commercial fishery. A long time series of commercial catch data (statistical area 539, NMFS 1963-1989) allowed mortality to be traced through time using a measure of relative exploitation. Exploitation was calculated as the ratio of total catch to relative stock abundance. Research vessel biomass per tow (NMFS spring trawl survey, strata 1-12, 25, 61-76, smoothed; Almeida pers. comm.) was used as an independent measure of abundance. This time series was dominated by catches southeast of Long Island, with few fish contributed from mid-Atlantic populations. Data sources for annual sport catches were NMFS/MRFSS estimates for Rhode Island 1979-1989; catch estimate from the Rhode Island State creel survey completed in 1978; the slope of the recreational:commercial catch ratio from the U.S. Fish and Wildlife Creel Survey from 1955-85, in five-year intervals, applied to the 1978 catch estimate to generate estimates of sport catch backward in time from 1977 to 1964 from each year's commercial catch. Although this method is imprecise, recreational catch contributed only a small percentage to the total catch for the entire time series.

Calculation of relative exploitation used the formula:

$$E_t = C_t / N_t$$

where: E_t = relative exploitation rate in year t
C_t = area 539 catch + sport catch in year t
N_t = NMFS spring survey catch/tow in year t.

Changes in relative exploitation are assumed to be proportional to fishing mortality (Pope and Shepard 1985, Hoenig *et al.* 1987). The trend in exploitation can be used directly to track mortality through time on a relative basis, or recent mortality estimates available from tagging and aging studies discussed above can be used to scale the time series to match the known values. Resulting scaled fishing mortality estimates are not independent of the assumptions and level of uncertainty in the recent estimates used as scalars. However, relative change in mortality over the time series is independent of any biases inherent in estimates from tagging and aging studies.

Finally, this long time series of fishing mortality was coupled with a second independent measure of abundance for the Narragansett Bay flounder population (Jeffries *et al.* 1988) to relate changes in fishing rate to the past trajectory of stock abundance. Since high fishing rates would reduce future stock size via reductions in spawner abundance, a lag period of seven years was used in the regression to express the generation time for a year class to appear in the abundance survey. Seven years is the average between first reproduction at age three and terminal reproduction at age twelve. Specifically, abundance in year t+7 was regressed against the scaled fishing rate in year t (see Table 2.3 in the Management Section).

2. *Fishing Mortality*

Estimates of instantaneous fishing mortality can be derived directly from estimates of total instantaneous mortality by subtraction of the fraction of mortality (M) attributed to natural causes. Natural mortality rates are difficult to calculate for populations which concurrently experience substantial mortality from fishing. The even more difficult task of estimating increases in M due to non-fishing anthropogenic sources is not addressed here (see Part One of the Management Section, and Almeida and Fogarty 1989).

Under the assumption that natural mortality is constant over time and fish age, a method which employs recapture rates of marked fish (Ricker 1975) was applied to the data sets generated during a ten year tagging program in Massachusetts waters (Howe and Coates 1975), a three year tagging program in Narragansett Bay (Black *et al.* 1988), and a three year tagging study in Great South Bay, NY (Poole 1969). All of these programs used Peterson disc tags and offered substantial reward; the assumption was made that tag loss was low and the reporting rate was high. Resulting estimates of instantaneous natural mortality ranged from M = 0.35 for Massachusetts, 0.36 for Narragansett Bay, RI, and M = 0.90 for Great South Bay, NY.

Although Poole discusses reasons for a very high natural mortality on the Great South Bay stock, a more moderate value for all southern stocks is more reasonable. A value of M=0.35 was chosen.

B. **Methods of Partitioning Landings by Stock Unit**

Recreational catch of winter flounder was derived from the Marine Recreational Fisheries Statistics Survey (MRFSS) catch and effort data base for the North Atlantic and mid-Atlantic regions. The goal of the analysis was to obtain the best measure of trends in total catch, and not trends in abundance or total angler effort. For this reason, only successful trips, or those reporting catch of one or more winter flounder, were included in the analysis (Table 1A).

Because the reported catch for states south of Delaware is very small (0–30 th. lbs., MRFSS 1979–89), and the frequency of successful interviews is very low (0.5%, MRFSS 1988–89), this analysis was applied only to data collected from Maine to Delaware. Although winter flounder are represented in power plant surveys (Heck 1982) and the sport fishery in Chesapeake Bay (Perry 1991), MRFSS data indicate that winter flounder catches are too small to be accurately tracked year to year despite the large recreational effort in Maryland and Virginia. Catches of less than 30 thousand pounds fall within the margin of error associated with these calculations.

The proportion of successful intercepts was slightly higher for the North Atlantic region from ME to CT (9–21%, average=12%) than for the mid-Atlantic region from NY-DE (5–17%, average=9%) (Table 1A). Also, the eleven year mean catch-per-successful-trip was nearly identical in both regions (5.58 versus 5.73 fish), as was the frequency of fish-per-angler. Additionally, the proportion of successful intercepts was similar to the proportion of people who said they were fishing for winter flounder (i.e., Percent Sought, MRFSS 1979–1987) in each region and year. Collectively, these data indicate that anglers in both regions were equally successful in catching winter flounder on average if it was the targeted catch. A larger percentage of anglers in the mid-Atlantic region, however, did not target winter flounder and did not catch them.

In light of the similarity of catch frequency for both the North (ME-CT) and mid-Atlantic regions (NY-DE), annual catch-per-successful-intercept (CSI) was calculated on a regional basis. This approach allows for the pooling of intercept data from adjoining states within each region, and avoids calculations with small and/or variable sample sizes of successful intercepts. Calculations based on single state intercept data were imprecise (CV range 15–100% ME-MD, MRFSS 1987–1989) and probably inaccurate. Using the total number of positive intercepts for the region not only gave larger sample sizes with smaller variance but also better reflected the original random design of the survey which is regional.

Each regional CSI was applied to the contribution in effort (angler trips) made by the states in the region. Total annual catch for each state was calculated using the formula:

$$Catch_s = CSI_r * (PSI_r * T_s)$$

where: $Catch_s$ = total catch in state S;
CSI_r = mean catch (number) per successful intercept in region R;
PSI_r = proportion of successful intercepts in region R;
T_s = total trips in state S

Catch by state was then grouped by Gulf of Maine, Southern New England, and mid-Atlantic stocks for trend analysis.

Table 1A: Estimated recreational trips (in thousands) catching one or more winter flounder by stock unit. Data Source: MRFSS, 1979–1988.

Year	Gulf of Maine	Southern New England	Mid–Atlantic
1979	461	385	935
1980	915	487	1197
1981	492	212	580
1982	636	361	846
1983	706	328	1523
1984	402	254	2288
1985	572	325	1796
1986	408	268	1673
1987	292	187	806
1988	455	209	902
1989	564	272	1567
Mean	537	299	1283
SE	52	27	158

*mid–Atlantic region includes western CT, NY, NJ, and DE

Regional mean catch for intercepts catching one or more winter flounder as a percentage of total intercepts.

	Mean catch per angler		% Total intercepts	
Region: Year	North (ME–CT)	Mid (NY–DE)	North (ME–CT)	Mid (NY–DE)
1979	6.75	7.32	14.9	7.2
1980	6.20	5.51	21.1	7.8
1981	7.39	6.41	11.9	6.3
1982	6.80	6.49	15.0	8.2
1983	4.85	5.79	12.2	11.0
1984	4.84	6.71	11.6	16.6
1985	5.31	5.84	11.7	13.7
1986	5.75	4.43	9.3	12.8
1987	5.82	5.20	9.0	7.5
1988	3.67	5.46	10.0	5.2
1989	4.01	3.88	8.8	4.7
Mean	5.58	5.73	12.3	9.2
SE	0.36	0.30	1.1	1.7

Catches reported for the state of Connecticut were allocated such that 67% were included in the mid-Atlantic stock (Montauk-south) with New York through Delaware, and 33% were included in the Southern New England stock (east Cape Cod to Long Island Sound). This division was based on creel census of the state's shoreline showing equal distribution of angler effort east to west (CT DEP 1985-1987). The percentages therefore reflect the portion of coastline west and east of the Connecticut River, respectively, which marks the division between the Southern New England and mid-Atlantic stocks. Similarly, catches reported for Massachusetts were divided such that 85% were included in the Gulf of Maine stock, and 15% were included in the Southern New England stock. This division was based on analysis of angler effort on Cape Cod (Almeida 1989). The large percentage of effort in the northern counties reflects the historic popularity of winter flounder fishing in the Massachusetts Bay region.

NMFS commercial landings between 1979 and 1989 were also partitioned by stock unit for state and federal waters, with landings from Georges Bank tabulated separately for comparison. Grouping by stock unit required division of the Massachusetts landings such that 25% were included in the Gulf of Maine stock, and 75% were included in the Southern New England stock, based on fishing patterns described by Witherell *et al.* (1990). The Southern New England stock also included all of Rhode Island and Connecticut landings. The mid-Atlantic stock comprised all landings from New York to Virginia.

In order to combine landings by stock unit for both fisheries, total recreational catch for each unit was converted from numbers to weight (lbs.) and added to total commercial landings (NOAA NMFS 1979-1990) from the same areas. Conversions were done using average weight of the catch by region for each year from the MFRSS data base. Average weight for catches from New York to Delaware were 0.93 lbs/fish (range 0.84-1.00), as compared to 1.10 lbs/fish (range 0.92-1.39) for Connecticut to Maine (MFRSS 1979-1989).

3. Thompson-Bell Yield-Per-Recruit and Shepherd Production Models

To examine the relationship between long-term yield and fishing mortality, yield-per-recruit was calculated using a Thompson-Bell model (Ricker 1975, Witherell 1990) under a range of fishing mortalities and recruitment regimes. The model assumed constant recruitment at Age 1, and yield was computed using growth, maturity, and fishery recruitment patterns observed for six flounder populations from north of Cape Cod to New Jersey (Table 2A). By convention (Anthony 1982), the fishable life span used in each model was 3/M, where M is the natural mortality rate. The maximum age modeled was the fishable life span plus all ages recruited less than 50% at the highest length limit modeled. For pre-recruit fish, a 15% discard mortality was assumed for recreationally caught fish (Durso and Iwanowicz 1983), and a 50% discard mortality for commercially caught fish. The 50% estimate was a compromise between observations from 9% (Witherell and Howe, unpublished data) and 95% (Jean 1963). Recruitment to the commercial fishery was determined by mesh selectivity curves (Simpson 1989) applied to length-at-age data. Mesh sizes chosen for analysis are effective, not nominal mesh sizes, which are smaller than the regulated mesh size (NMFS/NEFC 1987). Thus a 5 inch effective mesh approximates a 5.5 inch regulated mesh. Both total yield to the fisheries and surviving biomass of spawning females, in units of weight per 1000 Age 1 recruits, were calculated for each scenario modeled. Surviving biomass was expressed as a percentage of the biomass of spawningfemales in the absence of fishing, or maximum spawning potential (%MSP). The fishing rate at which surviving biomass of female spawners falls below 25% of the maximum is given as a reference point (F_{25}) where stock maintenance is questionable and the stock is overfished.

Because uncertainty in calculating maximum spawning potential tends to underestimate the true maximum, this reference point should be considered as a critical threshold below which the spawning stock is seriously eroded over time. Experience with haddock and yellowtail flounder stocks has shown that fishing rates which preserve less than 25% MSP do not achieve replacement stock levels (Gabriel 1986, Gabriel *et al.* 1989), making stock decline probable.

A more desirable reference fishing rate preserves 40% of the maximum spawning potential (F_{40}). Stocks maintained at this level provide a maximized range of yield to the fishery, reguardless of the relationship between spawning stock size and resulting number of recruits produced. Fishing mortalities that preserve approximately 36% MSP were found to maximize the minimum yield among several possible spawner-recruit relationships examined for six species of New England groundfish, including Georges Bank winter flounder (Clark 1991). In this plan, this reference point is considered a target fishing rate which will allow presently depleted stocks to rebuild.

Table 2A: Assumptions for the Thompson–Bell Yield–per–Recruit model of six winter flounder populations.

Stock Unit:	Gulf of Maine		Southern New England			Mid–Atlantic
Geographic location of data base used:	N. Cape Cod	S. Cape Cod	Narragan–sett Bay	East LIS	West LIS	NJ
Data source:	MA(1)	MA(1)	RI(2)	CT(3)	CT(4)	NJ(5)
Terminal age of model	12	12	12	12	10	10
Commercial/recreational exploitation ratio	52:48	95:5	60:40	60:40	40:60	10:90

For all populations:
Natural Mortality (M) 0.35
Discard Mortality–Recreational 15% of F, Commercial 50% of F

All runs by Witherell of BIOREF model with input data provided by:
(1) Witherell *et al.* (1990)
(2) Gibson (1989a,1989b, and 1989c)
(3) CT DEP (1990) maturity schedule NUSCo. (1987), length weight relationship, NUSCo (1988)
(4) CT DEP (1990) maturity schedule Weber and Zawack (1983)
(5) Danila (1978) and P. Scarlett, NJ DEP, pers. comm.

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