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STATUS OF MIXED SPECIES DEMERSAL FINFISH RESOURCES IN NEW ENGLAND AND SCIENTIFIC BASIS FOR MANAGEMENT

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SUMMARY

The status of demersal finfish resources in the New England region since the implementation of the Magnuson Fisheries Management and Conservation Act in 1977 is reviewed, with emphasis on species that are currently managed under the Fishery Management Plan for the Northeast Multi-Species Fishery prepared by the New England Fishery Management Council.

Currently, virtually all the major species/stocks specifically regulated under the FMP are in poor condition. Total commercial landings of all stocks doubled from 122,000 mt in 1976 to 229,000 in 1982. Since then, landings have declined markedly to 150,000 mt in 1986, the lowest level since enactment of the MFCMA. Trends in abundance based on NEFC bottom trawl survey data and virtual population analysis reflect low or declining stock biomass in the early 1970's, an increase in the late 1970's-early 1980's and subsequent sharp decline between 1983-1986, to near historic low levels at present. Trends in fishing mortality (F) based on NEFC bottom trawl survey data and virtual population analysis indicate increasing mortality rates between 1976-1986, and record high mortality rates after 1983. These trends toward historically low catch and abundance levels, and historically high fishing mortality rates, occur individually for nearly all the species regulated under the FMP: Atlantic cod, haddock, yellowtail flounder, redfish, American plaice, witch flounder, and winter flounder. Pollock abundance, although not historically low, is declining under record high fishing mortality. Only windowpane flounder and white hake presently appear to be stable above median abundance levels.

Between 1976-1986, effort by otter trawlers (as nominal days fished) increased 69%, 49% and 65% in the Gulf of Maine, Georges Bank and Southern New England regions, respectively, and reached record high levels in 1985-1986. The percentage increase in standardized effort (adjusted from fishing power analysis) is even larger (57-97%), because most of the recent increase has been by larger more effective boats with relatively higher fishing power. Although aggregate catch per nominal day fished by small vessels (5-50 GRT) has remained stable from 1976-1986, catch per unit effort by medium and large vessels has declined substantially since the early 1980's, and, in most areas, were at an historical low in 1986.

When stock status is evaluated in terms of spawning stock biomass per recruit (SSB/R), all stocks fall below the target percentages of maximum spawning potential (%MSP) identified in the Northeast Multispecies FMP as biological reference points for stock replacement or rebuilding. Review of the species-specific %MSP target levels contained within the FMP indicates they are probably too low for Georges Bank haddock, adequate for Georges Bank cod, and perhaps too low for Georges Bank yellowtail flounder.

Effective mesh size (observed age/length selection pattern) in the multispecies fishery appears to be approximately 1" smaller than the regulatory mesh size, based on preliminary comparisons of partial recruitment vectors from virtual population analysis of Georges Bank cod and haddock with partial recruitment vectors determined from mesh size experiments.

To achieve %MSP targets consistent with stock maintenance levels for cod, haddock, and yellowtail flounder under current (1986) levels of fishing mortality, the regulatory (not effective) mesh size would need to be increased to at least 8". Even at this mesh size, %MSP levels associated with stock rebuilding would not be met for either cod or yellowtail flounder. If a 6.5" regulatory (5.5" effective) mesh size were used in the fishery, reductions in fishing mortality of between 30-60% (from 1986 levels) would be required just to achieve %MSP levels for stock maintenance.

To compare the effects of possible alternative management measures on future spawning stock biomass and catch levels, an age-structured model was developed, which incorporated stochastic recruitment effects. Projections of median spawning stock sizes and corresponding catches were developed as functions of alternative mesh size regimes and levels of F. These projections were compared to projections incorporating the provisions of the Interim FMP

When larger mesh sizes are used but current F is maintained, projected spawning stock biomasses increase relative to the no-action alternative. Catches initially decline but, within 5-10 years, increase above those projected from the no-action alternative. When larger mesh sizes are used and concurrently accompanied by gradual reductions in F (so that target %MSP levels are achieved in five years), increases in projected catches are somewhat delayed but spawning stock biomass increases more rapidly. Additional projections indicated that it is possible to rebuild the Georges Bank cod stock to 1980 levels in five years if F is reduced by 15% per year, or to 1980 levels in 10 years if F is reduced by 6% per year.

Several alternate management approaches were evaluated, including short term small area closures and limits on the total catches of haddock and redfish in any fishing trip. It is difficult to evaluate the effect of the area closures on meeting the FMP goals, but analyses suggest that the trip limits could be valuable for reducing fishing mortality rates for selected stocks.

The results presented in this paper should be useful for evaluating the effectiveness of current and past management regimes, and for determining the likely effectiveness of several alternate management approaches. The management approaches evaluated are consistent with the principal management approaches identified in the current FMP, and it appears that without increasing otter trawl mesh size greatly or instituting other restrictive measures the goals of the FMP can not be met.

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1. INTRODUCTION

The demersal finfish resources off the northeastern coast of the United States support economically important commercial and recreational fisheries. The mixed species commercial fishery is one of the oldest and most valuable in the United States. It is a highly complex fishery due to the multispecies nature of the catch caused by joint harvesting of species co-occurring in time and space. Fishing effort is often directed at a mixture of species and, as a result, fishing mortality can be generated on a variable number of individual species. The principal fishing gear used in the fishery is relatively non-selective of the demersal fishes in a particular location, so the degree to which the gear can be directed is limited. These two aspects of the fishery have made effective control of fishing mortality difficult.

Prior to 1977, most of the major finfish resources comprising the multispecies complex were managed by the International Commission for the Northwest Atlantic Fisheries (ICNAF). In 1977, when the Magnuson Fishery Conservation and Management Act (MFCMA) was implemented, management of these resources became the responsibility of the New England Fishery Management Council (NEFMC).

Since March 1977, three different Fishery Management Plans (FMPs) have regulated USA fisheries for species within the multispecies complex: the FMP for Atlantic Groundfish (Atlantic cod, haddock, and yellowtail flounder) from 15 March 1977 to 30 March 1982, the Interim FMP for Atlantic Groundfish from 31 March 1982 to 18 September 1986, and the FMP for the Northeast Multi-Species Fishery from 19 September 1986 to the present. Management measures implemented under each of these FMPs have varied but have included: annual and quarterly catch quotas, weekly and/or trip catch limits by vessel size class and gear type, minimum mesh sizes, closed seasons and areas, incidental catch limitations, fishery closures, minimum fish landings sizes, small mesh/large mesh fishing areas and seasons, and record keeping/reporting requirements (Serchuk and Wigley 1986).

The current FMP for the Northeast Multi-Species Fishery, referred to here as the FMP, established goals and objectives for management (NEFMC 1985). A goal of particular relevance to assessment of the status of the stocks is (page iii):

> to adopt initial [management] measures to prevent stocks from reaching minimum abundance levels, defined as those levels below which there is an unacceptably high risk of recruitment failure.

The objective of the FMP is also relevant to assessment of the status of the stocks (page 6.1):

> to control fishing mortality on juveniles (primarily) and on adults (secondarily) of selected finfish stocks within the management unit for the purpose of maintaining sufficient spawning potential so that year classes replace themselves in the stock on a long-term average

basis; and to similarly reduce fishing mortality for the purpose of rebuilding those stocks where it has been demonstrated that the spawning potential of the stock is insufficient to maintain a viable fishery resource; and further to promote the collection of data and information on the nature, behavior and activity of the multi-species fishery, and on the management program.

Specific levels of spawning potential for major species/stocks within the management unit were identified in the FMP as those required for long-term biological productivity. Apart from Georges Bank haddock and Gulf of Maine redfish, stocks which were noted in the FMP as being in severe circumstances and requiring direct action to reduce fishing mortality, the FMP concluded "that spawning potential at the level of approximately 20% of the maximum (20% MSP) is appropriate." For Georges Bank haddock, the FMP concluded that a target level of 30% MSP was necessary to promote an increase in stock abundance while, for Gulf of Maine redfish, the FMP considered it necessary to achieve the largest feasible value of %MSP within the constraints of the multi-species fishery.

The FMP recognized that revisions to the management program, including modifications in the initial management measures, might be needed if "stock or fishery conditions change" (page 7.94). More specifically, the FMP noted several events that may require change in the management measures (page 6.4):

(1) The species explicitly identified in the objective may no longer warrant active management, whereas other species within the management unit may require management action at some level;

(2) Refinements in the basis for determining target levels of %MSP may change, necessitating a respecification of the actual target values; or the target values themselves are determined to be inadequate in consideration of other factors in the fishery.

In this report we first describe the trends in the status of the regulated fishery resources, including changes in landings, in indices of abundance, in mortality rates, and in spawning stock biomass. Second, we describe trends in fishing effort and catch per unit of effort, taking a multispecies perspective. Third, we evaluate the likely future status of the regulated stocks under several alternative managment measures that are consistent with the types of management that are favored in the FMP. From these analyses we draw several conclusions about the status of the stocks and about the likelihood of the current FMP meeting its goals using the presently favored management measures.

2. STATUS OF REGULATED FISHERY RESOURCES

The status of all major fishery resources off the northeast coast of the United States from Canada to Cape Hatteras is reviewed and updated annually by the Conservation and Utilization Division of the Northeast Fisheries Center (NEFC). Synopses of current trends in stock size, landings, recruitment, fishery performance (catch per unit of effort), and fishing mortality are presented by species/stock in a published report entitled **"Status of the Fishery Resources off the Northeastern United States"** (e.g., U.S. Dept of Commerce 1986). These synopses are based on assessment information presented at semi-annual NEFC Stock Assessment Workshops. At these Workshops assessment data and analyses are critically reviewed by the scientific community for technical merit. Results are summarized in the **Reports of the Workshops** (NMFS 1986a, 1986b, 1987) and in individual stock assessment reports distributed as Woods Hole Laboratory Reference Documents.

2.1. Review of Species and Stock Units

The FMP identified 10 species subject to regulation:

Atlantic cod	American plaice
Haddock	Witch flounder
Redfish	Winter Flounder
Pollock	Windowpane Flounder
Yellowtail Flounder	White Hake

Assessments for all of these species except windowpane flounder have been presented at NEFC Stock Assessment Workshops. The following review of stock conditions for these species is derived from the evaluations conducted at the Workshops. All data have been updated through 1986 to reflect current stock and fishery status. The reader is referred to the reports of those workshops, and to the individual assessment documents cited therein, for details.

The ten regulated groundfish species comprise a total of 19 stocks. The assessment information used to characterize the population dynamics and status of each stock varied among stock units, and depended upon the types of data available (Table 2.1). For all 19 stocks, landings data (quantity of landings) and commercial CPUE data (catch per unit of effort) data were examined. Abundance indices derived from research vessel survey results and life history parameters (growth and maturity data) were also available for most of the stocks.

For four of the major stocks (Georges Bank cod, Georges Bank haddock, redfish, and pollock), analytical assessments using virtual population analysis (VPA) exist. These assessments require a long time series of catch data and detailed information on the age composition of the catch in each year. VPAs yield annual estimates of stock size and fishing mortality (total and by age group) that are generally considered to be the most accurate.

Table 2.1. Summary of key data used to evaluate the status of the major species/stocks regulated under the Fishery Management Plan for the Northeast Multispecies Fishery.

Species/Stock	Life History Parameters	Landings Data		Abundance Estimates			Mortality Estimates	
		Comm	Rec[1]	Survey	VPA	CPUE	Survey	VPA
ATLANTIC COD								
Georges Bank & South	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gulf of Maine	Yes	Yes	Yes	Yes	No	Yes	Yes	No
HADDOCK								
Georges Bank	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gulf of Maine	Yes	Yes	Yes	Yes	No	Yes	Yes	No
REDFISH								
Georges Bank/Gulf of Maine	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes
POLLOCK								
Georges Bank/Gulf of Maine/ Scotian Shelf	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
YELLOWTAIL FLOUNDER								
Georges Bank	Yes	Yes	N/A	Yes	No	Yes	Yes	No
Southern New England	Yes	Yes	N/A	Yes	No	Yes	Yes	No
Cape Cod	Some	Yes	N/A	No	No	Yes	No	No
Gulf of Maine	Some	Yes	N/A	No	No	Yes	No	No
Mid-Atlantic	Some	Yes	N/A	No	No	Yes	No	No
AMERICAN PLAICE								
Gulf of Maine/Georges Bank	Yes	Yes	N/A	Yes	No	Yes	Yes	No
WITCH FLOUNDER								
Gulf of Maine/Georges Bank	Yes	Yes	N/A	Yes	No	Yes	No	No
WINTER FLOUNDER								
Georges Bank	Yes	Yes	Yes	Yes	No	Yes	No	No
Southern New England	Yes	Yes	Yes	Yes	No	Yes	No	No
Gulf of Maine	Yes	Yes	Yes	Yes	No	Yes	No	No
Mid-Atlantic	Yes	Yes	Yes	Yes	No	Yes	No	No
WINDOWPANE FLOUNDER								
Georges Bank/So. New England	No	Yes	N/A	Yes	No	Yes	No	No
WHITE HAKE								
Gulf of Maine/Georges Bank	Some	Yes	N/A	Yes	No	Yes	No	No

[1]Recreational landings reported by species, not species/stocks.

However, the lack of a VPA for a given stock does not imply that the determination of stock status by alternative methods (i.e., survey data or CPUE) is less reliable. Where trends in abundance from VPA and from survey data have been compared (Clark 1979; Fogarty et al. 1986) the correspondence has been good.

2.2. Summary of Commercial Landings, 1976-1986

The ten species regulated under the FMP have traditionally accounted for than 75% of the total commercial landings of all groundfish and flounders off the northeast coast of the United States. Both total commercial landings (USA and foreign) and domestic commercial landings (USA only) from these ten species nearly doubled between 1976 and 1982, increasing from 121,000 mt to 225,000 mt (Table 2.2) and from 86,000 mt to 159,000 mt (Table 2.3) respectively. Subsequently the catches markedly declined. By 1986, landings from the species complex had decreased to 1976-1977 levels.

A more detailed examination of landings from individual stocks shows that yields from virtually all of the stocks increased during the late-1970's, peaked in the early 1980's, and rapidly declined afterwards (Figure 2.1, Figure 2.2). The sole exception is pollock where landings have increased since 1983 and attained record-high levels in 1985 and 1986.

Of the ten regulated species, four species (cod, haddock, yellowtail flounder, and pollock) have accounted for more than two-thirds (66%) of the USA commercial groundfish catch during 1976-1986. Cod has been the dominant species, accounting for between 29-35% of the annual USA catch from the regulated multispecies complex.

Most of the foreign catches in Table 2.2 have ben taken by Canadian vessels, especially in the most recent years. Significant Canadian fisheries exist on the Georges Bank cod and haddock stocks, and the Georges Bank/Gulf of Maine/Scotian Shelf pollock stock. During 1976-1986 Canadian landings accounted for about 22% of the total Georges Bank cod catch, for about 33% of the Georges Bank haddock catch, and for nearly 67% of the pollock catch. Since 1984, when the International Court of Justice delimited a maritime boundary between the USA and Canada in the Gulf of Maine/Georges Bank area, Canadian landings of Georges Bank cod and haddock have comprised a much larger percentage of the total catch from these stocks than at any time in the past. In 1986, Canadian landings constituted 33% and 52%, respectively, of the total Georges Bank cod and haddock harvests. The reported Canadian catches from the Gulf of Maine cod stock in recent years (Table 2.2 and 2.3) are unreliable, and are not thought to reflect a significant fishery (Serchuk and Wigley, 1986). At present the Georges Bank cod and haddock stocks and the pollock stock are separately fished and independently managed by each country.

Table 2.2. Total commercial (USA and foreign) landings (thousands of metric tons, live weight) of groundfish from the major stocks subject to regulation under the Fishery Management Plan for the Northeast Multispecies Fishery, 1976 - 1986.

Species/Stock	Year										
	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986[1]
ATLANTIC COD	30.1	39.9	48.3	50.8	61.8	55.5	72.2	65.6	50.9	49.4	36.0
Georges Bank & South	19.9	27.4	35.5	38.7	48.1	42.4	57.2	48.9	38.7	37.3	25.6
Gulf of Maine	10.2	12.5	12.8	12.1	13.7	13.1	15.0	16.7	12.2	12.1	10.4
HADDOCK	6.4	14.1	27.5	24.4	35.1	31.1	24.9	19.5	14.2	10.8	8.5
Georges Bank	4.4	10.8	22.4	19.5	27.6	24.9	18.2	11.9	10.2	7.8	6.7
Gulf of Maine	2.0	3.3	5.1	4.9	7.5	6.2	6.7	7.6	4.0	3.0	1.8
REDFISH											
Georges Bank/Gulf of Maine	10.7	13.2	14.1	14.7	10.2	7.8	6.8	5.3	4.8	4.3	4.0
POLLOCK											
Georges Bank/Gulf of Maine/ Scotian Shelf	37.7	38.5	45.3	46.6	55.5	59.0	52.8	47.2	51.1	63.0	65.0
YELLOWTAIL FLOUNDER	17.2	16.5	11.3	15.9	18.3	15.6	24.9	33.1	18.1	7.4	7.7
Georges Bank	11.4	9.5	4.5	5.5	6.4	6.4	10.6	11.4	5.7	2.5	3.0
Southern New England	1.6	2.8	2.3	5.4	6.0	4.9	10.3	17.5	8.8	3.2	3.3
Cape Cod	3.6	3.5	3.7	4.2	5.1	3.2	3.1	1.9	1.0	1.0	1.0
Gulf of Maine	0.3	0.2	0.4	0.3	0.5	0.4	0.5	0.3	0.2	0.2	0.2
Mid-Atlantic	0.3	0.5	0.4	0.5	0.3	0.7	0.4	2.0	2.4	0.5	0.2
AMERICAN PLAICE											
Gulf of Maine/Georges Bank	3.5	7.3	9.6	11.5	13.6	12.9	15.2	13.2	10.1	7.0	4.5
WITCH FLOUNDER											
Gulf of Maine/Georges Bank	1.8	2.5	3.5	3.0	3.4	3.4	4.8	5.8	6.5	6.1	5.1
WINTER FLOUNDER	6.7	10.2	11.9	12.2	17.3	18.0	15.2	14.7	14.4	10.4	9.3
Georges Bank	2.0	3.6	3.3	3.1	4.0	4.1	3.0	3.9	3.9	2.2	2.0
Southern New England	3.2	4.4	6.3	6.5	10.6	11.1	9.4	8.6	8.8	6.5	6.0
Gulf of Maine	1.5	2.2	2.2	2.0	2.4	2.4	2.8	2.1	1.7	1.6	1.2
Mid-Atlantic	<0.1	<0.1	0.1	0.6	0.3	0.4	<0.1	0.1	<0.1	0.1	0.1
WINDOWPANE FLOUNDER											
Georges Bank/Southern New England	2.2	1.9	2.0	1.6	1.0	1.3	1.1	1.2	1.8	4.1	3.2
WHITE HAKE											
Gulf of Maine/Georges Bank	4.3	5.8	5.3	4.4	5.1	6.2	6.8	7.0	7.5	7.3	5.4
GRAND TOTAL	120.6	149.9	178.8	185.1	221.3	210.8	224.7	212.6	179.4	169.8	148.7

[1]Landings values for 1986 are provisional.

Table 2.3. Total commercial USA landings of groundfish (thousands of metric tons, live weight) from the major stocks subject to regulation under the Fishery Management Plan for the Northeast Multispecies Fishery, 1976 - 1986.

Species/Stock	YEAR										
	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986[1]
ATLANTIC COD	**25.1**	**33.5**	**39.0**	**44.4**	**53.5**	**46.4**	**52.9**	**50.8**	**43.7**	**37.5**	**26.9**
Georges Bank & South	14.9	21.1	26.6	32.7	40.0	33.9	39.3	36.8	32.9	26.8	17.3
Gulf of Maine	10.2	12.4	12.4	11.7	13.5	12.5	13.6	14.0	10.8	10.7	9.6
HADDOCK	**4.8**	**11.2**	**16.7**	**18.9**	**24.8**	**24.9**	**18.2**	**14.3**	**11.6**	**6.5**	**4.9**
Georges Bank	2.9	7.9	12.2	14.3	17.5	19.2	12.6	8.7	8.8	4.3	3.3
Gulf of Maine	1.9	3.3	4.5	4.6	7.3	5.7	5.6	5.6	2.8	2.2	1.6
REDFISH											
Georges Bank/Gulf of Maine	**10.1**	**13.0**	**14.0**	**14.7**	**10.1**	**7.8**	**6.7**	**5.2**	**4.7**	**4.2**	**3.0**
POLLOCK											
Georges Bank/Gulf of Maine/ Scotian Shelf	**10.9**	**13.1**	**17.7**	**15.5**	**18.3**	**18.2**	**14.4**	**14.0**	**17.8**	**19.3**	**24.3**
YELLOWTAIL FLOUNDER	**17.2**	**16.5**	**11.3**	**15.9**	**18.3**	**15.6**	**24.9**	**33.1**	**18.1**	**7.4**	**7.7**
Georges Bank	11.4	9.5	4.5	5.5	6.4	6.4	10.6	11.4	5.7	2.5	3.0
Southern New England	1.6	2.8	2.3	5.4	6.0	4.9	10.3	17.5	8.8	3.2	3.3
Cape Cod	3.6	3.5	3.7	4.2	5.1	3.2	3.1	1.9	1.0	1.0	1.0
Gulf of Maine	0.3	0.2	0.4	0.3	0.5	0.4	0.5	0.3	0.2	0.2	0.2
Mid-Atlantic	0.3	0.5	0.4	0.5	0.3	0.7	0.4	2.0	2.4	0.5	0.2
AMERICAN PLAICE											
Gulf of Maine/Georges Bank	**3.5**	**7.1**	**9.5**	**11.4**	**13.5**	**12.9**	**15.1**	**13.2**	**10.1**	**7.0**	**4.5**
WITCH FLOUNDER											
Gulf of Maine/Georges Bank	**1.8**	**2.5**	**3.5**	**3.0**	**3.4**	**3.4**	**4.8**	**5.8**	**6.5**	**6.0**	**5.1**
WINTER FLOUNDER	**6.7**	**10.2**	**11.8**	**12.2**	**17.3**	**18.0**	**15.2**	**14.7**	**14.4**	**10.4**	**9.3**
Georges Bank	2.0	3.6	3.2	3.1	4.0	4.1	3.0	3.9	3.9	2.2	2.0
Southern New England	3.2	4.4	6.3	6.5	10.6	11.1	9.4	8.6	8.8	6.5	6.0
Gulf of Maine	1.5	2.2	2.2	2.0	2.4	2.4	2.8	2.1	1.7	1.6	1.2
Mid-Atlantic	<0.1	<0.1	0.1	0.6	0.3	0.4	<0.1	0.1	<0.1	0.1	0.1
WINDOWPANE FLOUNDER											
Georges Bank/Southern New England	**2.2**	**1.9**	**2.0**	**1.6**	**1.0**	**1.3**	**1.1**	**1.2**	**1.8**	**4.1**	**3.2**
WHITE HAKE											
Gulf of Maine/Georges Bank	**4.1**	**5.3**	**5.1**	**4.1**	**4.8**	**5.7**	**6.0**	**6.2**	**7.5**	**6.4**	**5.4**
GRAND TOTAL	**86.4**	**114.3**	**130.6**	**141.7**	**165.0**	**154.2**	**159.3**	**158.5**	**136.2**	**108.8**	**94.3**

[1]Landings values for 1986 are provisional.

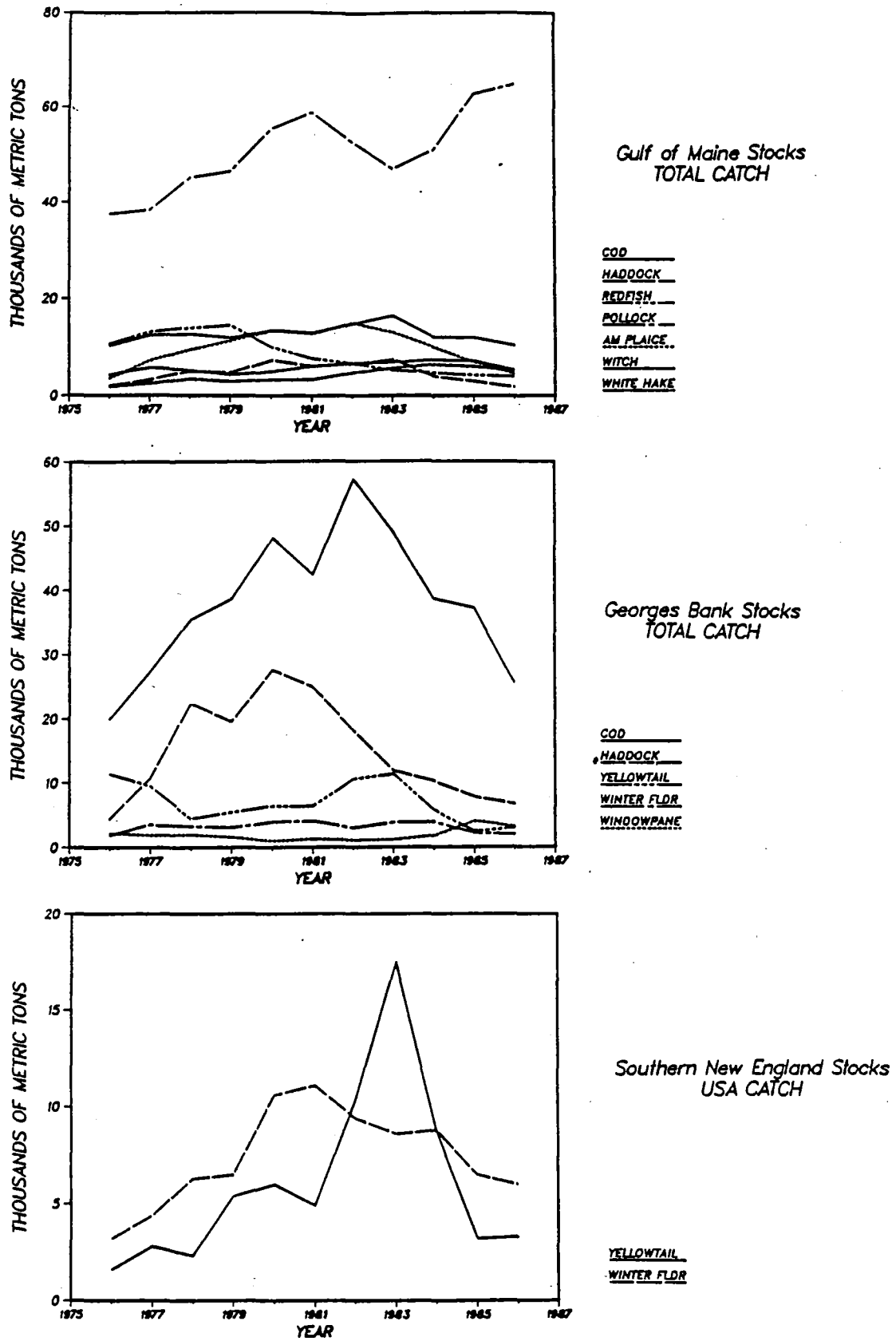


Figure 2.1 Trends in total commercial landings (USA and foreign), 1976 -1986, of the major species/stocks subject to regulation under the Fishery Management Plan for the Northeast Multi-Species Fishery prepared by the New England Fishery Management Council.

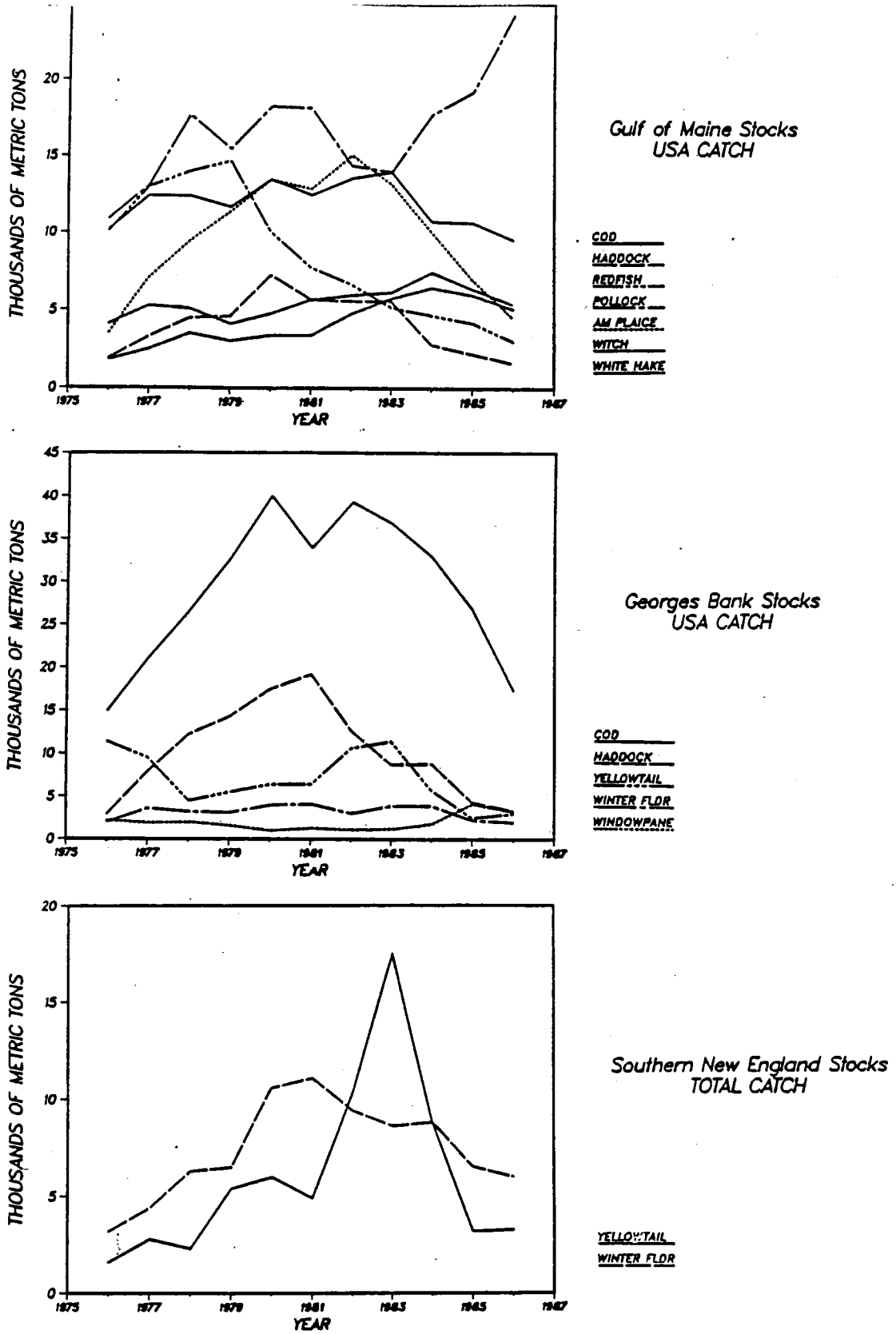


Figure 2.2 Trends in USA commercial landings, 1976 - 1986, of the major species/stocks subject to regulation under the Fishery Management Plan for the Northeast Multi-Species Fishery prepared by the New England Fishery Management Council.

2.3. Trends in Abundance

Trends in abundance for the major species in the multispecies complex were evaluated from NEFC autumn (1963-1986) and spring (1968-1986) bottom trawl survey data and from VPA analyses. Trends in abundance derived from research vessel surveys were modelled using time series analysis (Almeida et al. 1986; Fogarty et al. 1986). Autumn survey data were used for all species except for pollock and winter flounder. For these latter two species more consistent measures of abundance were obtained from the spring surveys. For all stocks survey weight per tow indices were used as measures of relative total stock size (i.e., relative stock biomass).

Survey abundance trends for the major stocks comprising the multispecies fishery complex are illustrated in Figure 2.3, Figure 2.4, and Figure 2.5. In general, stock size trends parallel the trends in catch. For most of the stocks, survey biomass indices were either low or declining in the early 1970's, increased in the late 1970's - early 1980's, and subsequently sharply declined.

Declines in survey biomass indices are evident for nine stocks, including those of cod, haddock, yellowtail flounder, American plaice, witch flounder, and winter flounder during the 1983-1986 period. For almost all of these stocks, average survey biomass indices during 1983-1986 were substantially below historical levels. Only for the four stocks of pollock, windowpane flounder, redfish and white hake have biomass indices have increased in recent years.

For Georges Bank cod, Georges Bank haddock, and redfish, trends in spawning stock sizes derived from VPAs (Figure 2.6) are consistent with those from the surveys. Current (1986) stock biomass levels for each of these stocks are at or near historic lows. For pollock, VPA trends in spawning stock size are inconsistent with those from the spring surveys. The VPA results suggest that the spawning stock size of pollock has markedly declined since 1980. Since pollock tend to school, survey catches are highly variable and the overall survey index reflects the influence of large catches taken in only a small proportion of the survey tows. Trends in USA commercial CPUE for pollock suggest that CPUE has declined in recent years, implying that stock size trends from the VPA may be more indicative of resource conditions than the trends shown in the surveys.

2.4. Trends in Mortality Rates

Estimates of mortality for cod, haddock, yellowtail flounder, redfish, pollock, and American plaice were obtained from survey catch per tow at age data and from VPA analyses. The survey analyses were limited to cod, haddock, yellowtail flounder, and American plaice; there was insufficient ageing data for most of the other species to accurately estimate total mortality rates. Fishing mortality rates were estimated from VPAs for Georges Bank cod and haddock, redfish, and pollock. Mortality rates are difficult to estimate

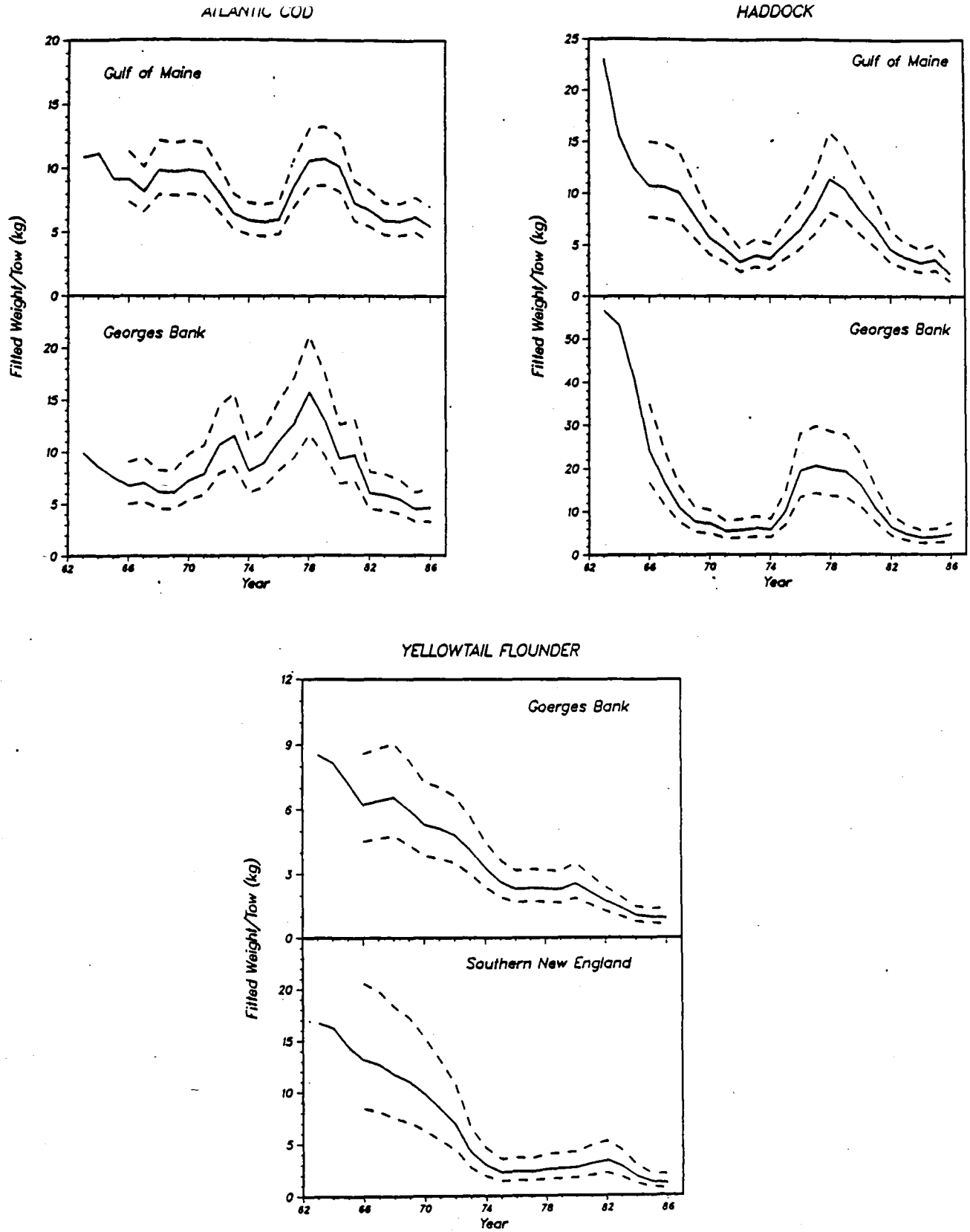


Figure 2.3 Trends in abundance [relative stock biomass], 1963 - 1986, of Atlantic cod, haddock, and yellowtail flounder derived from time-series analyses of Northeast Fisheries Center research vessel bottom trawl survey catch per tow indices [stratified mean weight per tow]. The 80% confidence limits on the abundance estimates are also illustrated.

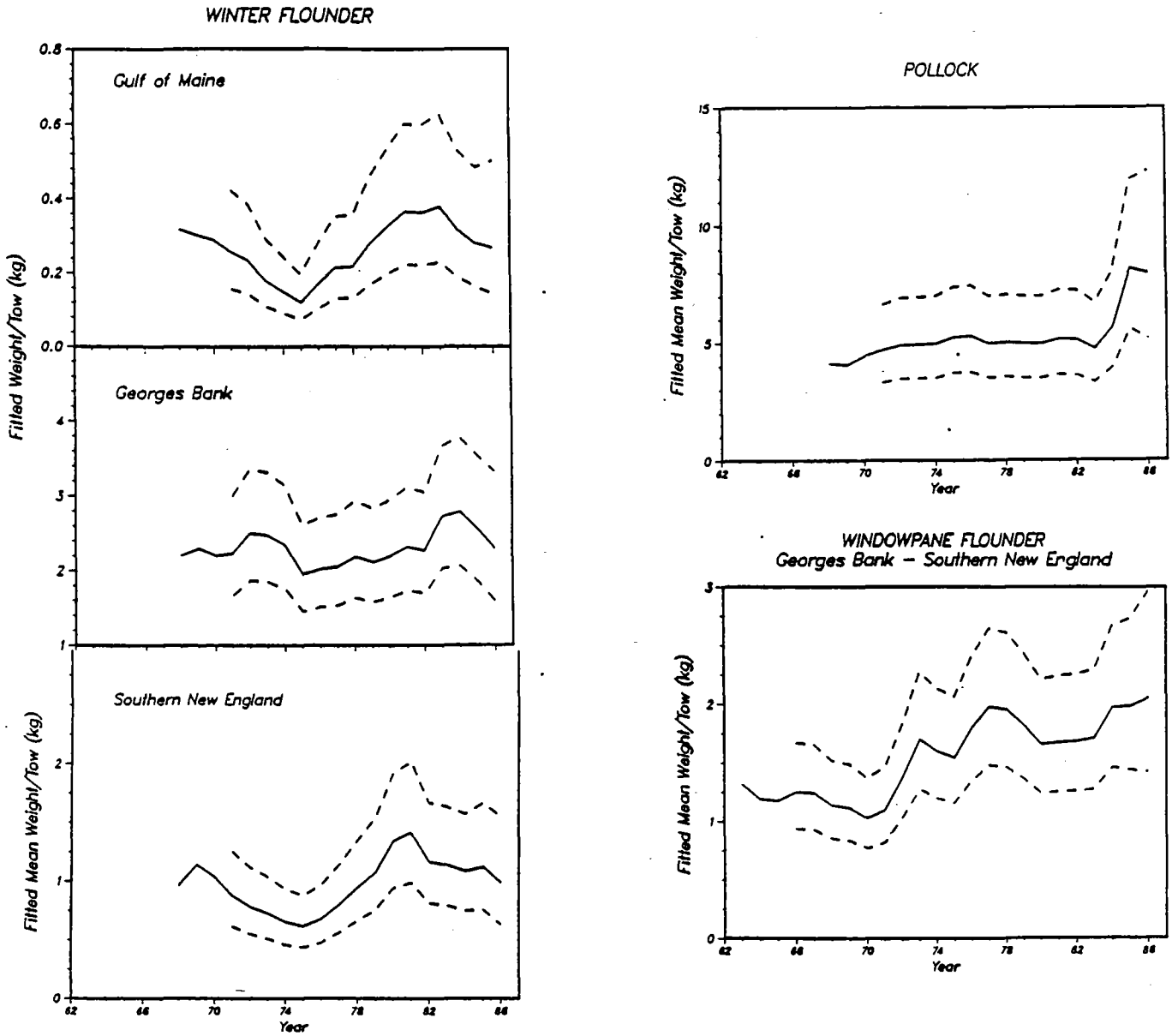


Figure 2.4 Trends in abundance [relative stock biomass], 1963 - 1986, of winter flounder, pollock, and windowpane flounder derived from time-series analyses of Northeast Fisheries Center research vessel bottom trawl survey catch per tow indices [stratified mean weight per tow]. The 80% confidence limits on the abundance estimates are also illustrated.

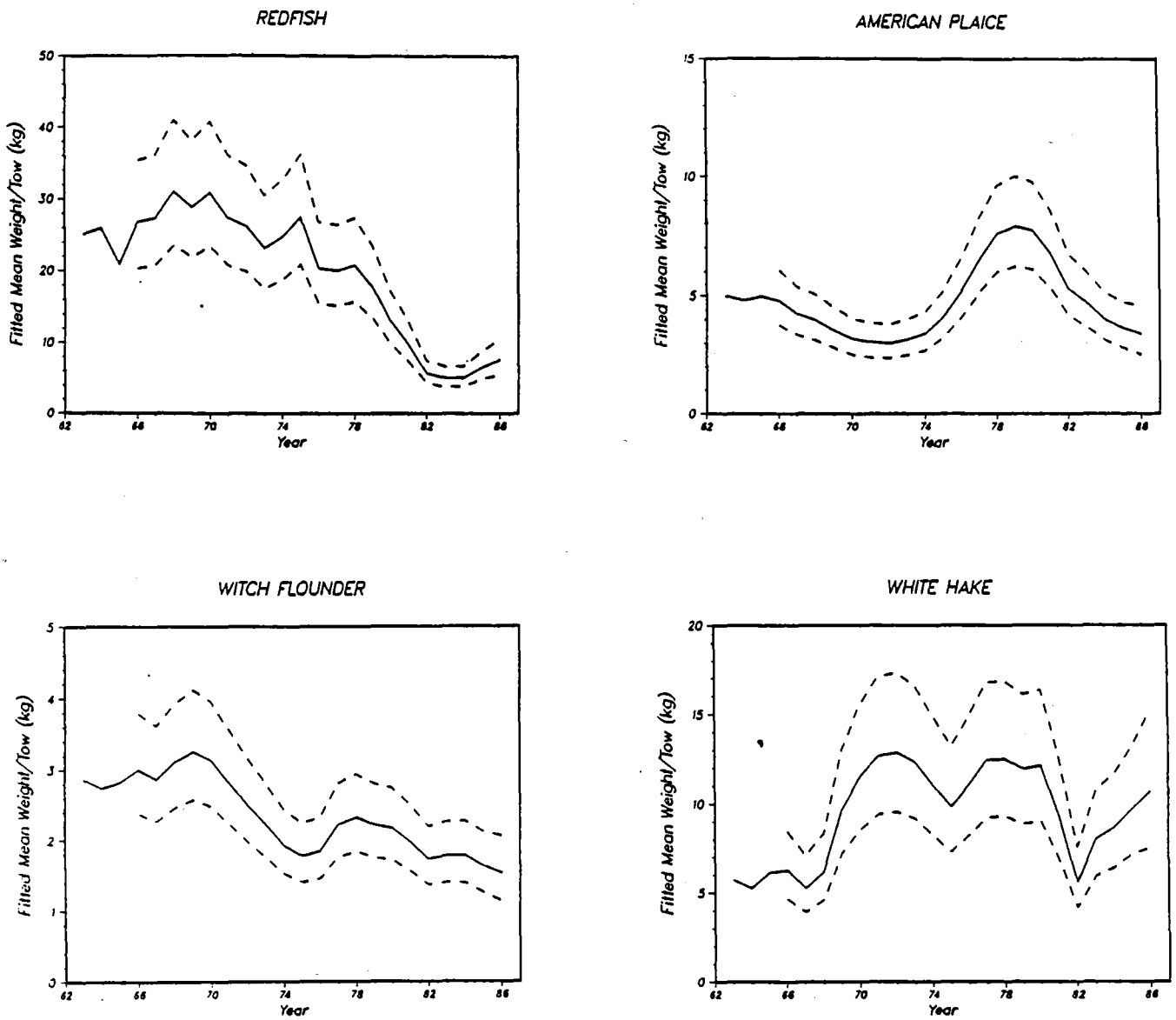


Figure 2.5 Trends in abundance [relative stock biomass], 1963 - 1986, of redfish, American plaice, witch flounder, and white hake derived from time-series analyses of Northeast Fisheries Center research vessel bottom trawl survey catch per tow indices [stratified mean weight per tow]. The 80% confidence limits on the abundance estimates are also illustrated.

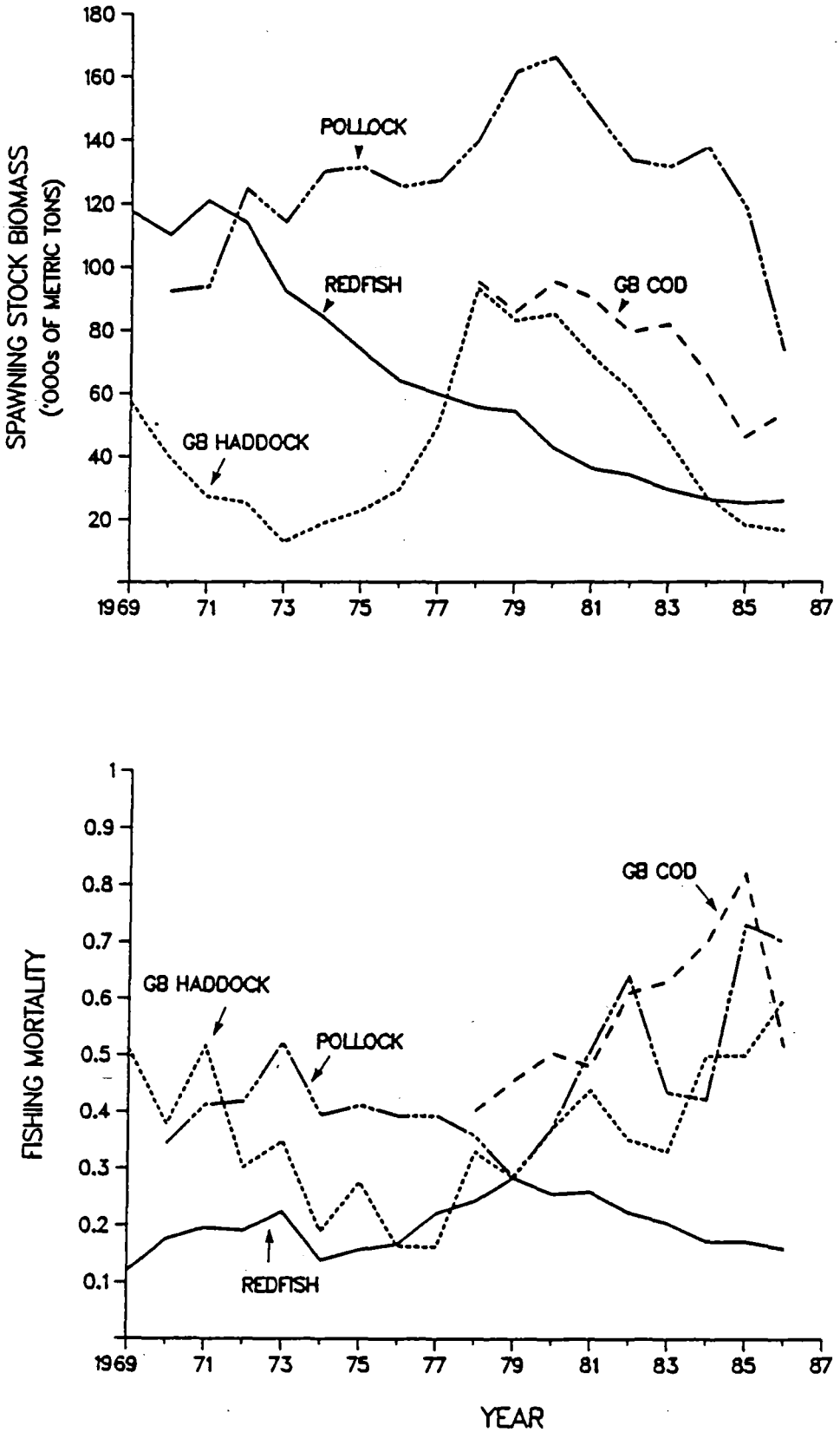


Figure 2.6 Trends in spawning stock biomass (above) and fishing mortality rates (below) of Georges Bank cod, Georges Bank haddock, redfish, and pollock derived from virtual population analyses (VPA).

precisely, and values for individual years should be interpreted with caution. Mean values over several years are more reliable.

The survey trends indicate that total mortaliiy rates generally increased during 1976-1986 on the major stocks in the Gulf of Maine, Georges Bank, and Southern New England regions (Figure 2.7). In virtually all of the stocks analyzed mortality rates were are record high levels during the period 1983-1986. The estimates decreased for both cod stocks and for Gulf of Maine American plaice in the most recent years; however the estimates for these most recent years are the least reliable, so the statistical significance of these declines is unclear.

Trends in fishing mortality derived from VPA (Figure 2.6) show similar patterns to those from the surveys. Prior to 1976 fishing mortality rates were either relatively low or declining. Since the late-1970's fishing mortality rate estimates have progressively increased for Georges Bank cod and haddock, and for pollock. For each of these stocks the mean fishing mortality rate estimates for the period 1983 to 1986 were at record highs. Fishing mortality rates for redfish have been declining steadily since 1979, apparently because directed fishing effort has decreased as abundance has declined.

2.5. Spawning Stock Biomass Per Recruit (SSB/R) Analysis

2.5.1. Conceptual Basis for Management Strategy Based on Spawning Stock Biomass Per Recruit Analysis

The concepts of average long term replacement of year classes and target levels of SSB/R are described by Gabriel et al. (MS in press):

> The SSB/R analysis evaluates the effects of fishing mortality and age at first capture on the spawning potential of a stock. It has traditionally been applied as an extension of yield per recruit analysis. Under natural conditions, the number of individuals in a year class (cohort) decreases with time due to natural mortality. Concurrently, the weight of individuals in the cohort increases as does the proportion of the survivors that are sexually mature. At each age, the number alive times the fraction mature times the weight of an individual represents the spawning stock biomass of the cohort for that age. The total contribution of a cohort to the spawning stock biomass (SSB) over its lifetime is found by summing the cohort's contributions at each age. This total value can then be scaled by the original number of recruits (R), as SSB/R, to provide a general case regardless of the absolute number of recruits.
>
> Maximum spawning stock biomass per recruit is obtained in the absence of fishing. Combinations of instantaneous fishing mortality (F) and the average age at which a cohort becomes subjected to fishery exploitation (t_c) give rise to lower levels of spawning stock biomass per recruit; all

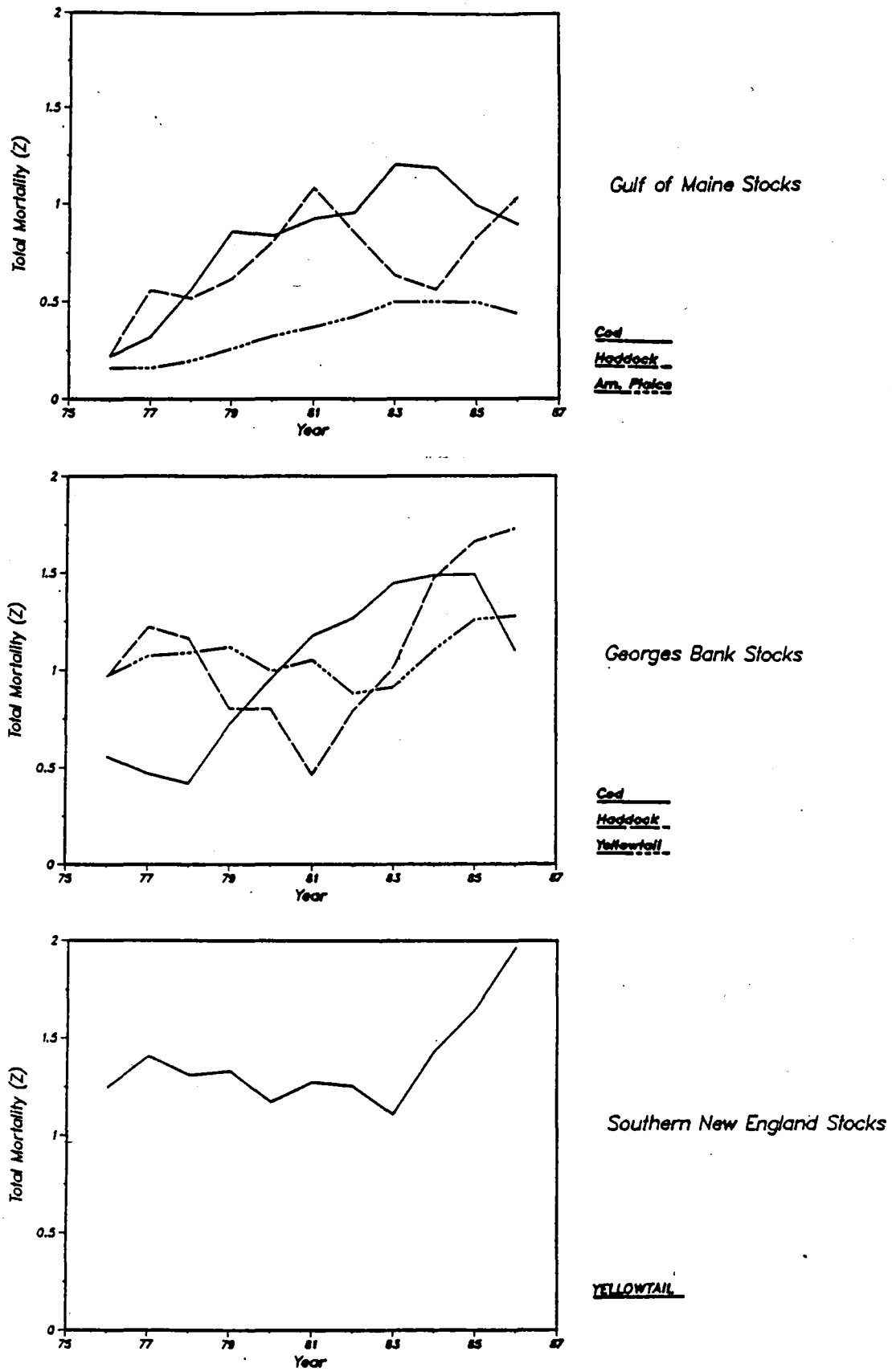


Figure 2.7 Trends in total annual mortality estimates, 1976 - 1986, for major species/stocks in the Gulf of Maine, on Georges Bank, and in Southern New England, derived from analyses of Northeast Fisheries Center research vessel bottom trawl survey catch per tow at age data.

of these can be expressed as percentages of the maximum spawning potential (%MSP), viz.

$$\%MSP = (SSB/R \text{ due to fishing})/(SSB/R \text{ with no fishing}) \times 100$$

Exploitation regimes with high fishing mortality or a young age at first capture will lead to %MSP levels that are low relative to the maximum. Low levels of fishing mortality beginning at early ages can have the same effect on spawning stock biomass as higher F levels applied at later ages. Contours of equal levels of %MSP based on different combinations of fishing mortality and age at first capture can be plotted as isopleths (Figure 2.8).

What level of spawning stock biomass per recruit is necessary to maintain a fish population? To maintain a population in balance, the number of reproducing adults dying must equal the number of maturing; over their lifetimes, two parents must produce two offspring that live to reproduce. With no fishing, maximum SSB/R is attained [%MSP = 100%]. The "average" pair of recruits has many opportunities to spawn. Large numbers of their offspring could die before reaching reproductive age, but if only two out of the many lived to reproduce, the stock would still persist at the same abundance level. When SSB/R [and hence %MSP] is reduced through fishing, the "average" pair of recruits has fewer opportunities to produce offspring. For the population to maintain itself, a higher proportion of the pre-recruit offspring produced by the pair must survive than in the unfished case. For the population to increase, survival of offspring must be even higher.

The likelihood of obtaining adequate survival to offset reduced %MSP from fishing can be evaluated using appropriate historical stock-recruitment data (Figure 2.9). A management regime giving rise to few spawning opportunities (low SSB/R) [or low %MSP as discussed in the previous paragraph] requires good survival (high observed R*/SSB*) to support it (Directly observed values of R and SSB will be designated with a star, in contrast to the theoretical SSB/R values calculated from various combinations of F and t_c). For several stocks, data are available to calculate ratios of observed spawning stock biomass and subsequent number of surviving recruits. When survival is high, many recruits are produced per unit of spawning stock biomass. When survival is low, few recruits are produced per unit of spawning stock biomass and management target levels of SSB/R [and so %MSP] must be higher for maintenance of stock levels: a large amount of spawning effort is required to produce a surviving recruit. If the long-term average observed value of R*/SSB* equals the inverse of the predicted SSB/R based on fishing conditions, the population should fluctuate about the same mean level. Of course, this assumes that normal historic patterns of fluctuations in R*/SSB* will continue in the future.

A comparison of observed levels of R*/SSB* and potential levels of SSB/R can be made using a standard stock-recruitment plot. A potential level

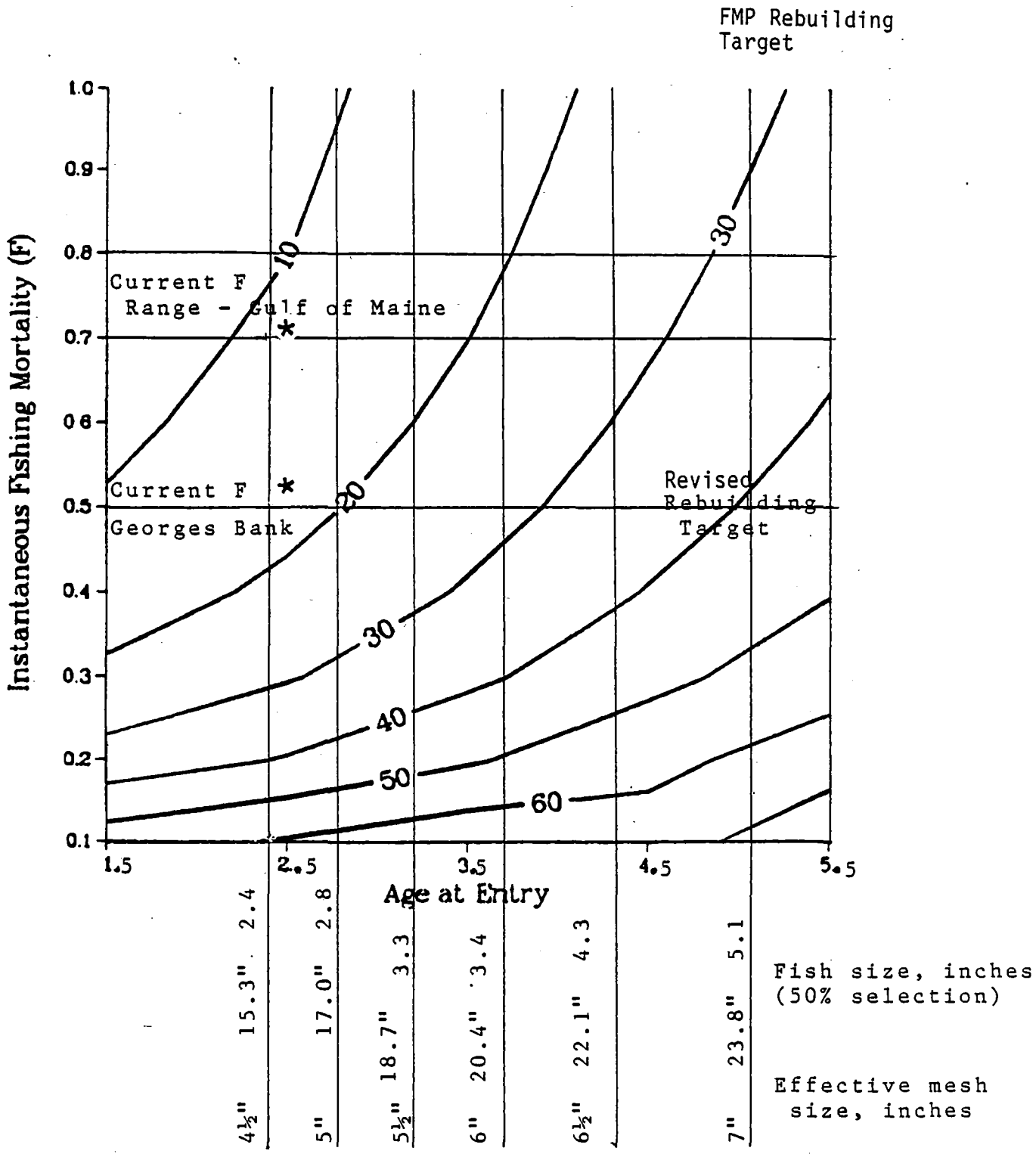


Figure 2.8 Isopleths of percentage of maximum spawning stock biomass per recruit for Georges Bank haddock. Estimated current (1986) level of fishing mortality and age at entry are superimposed, as well as lengths at entry for alternative mesh sizes. Asterisks denote current levels of % MSP for Gulf of Maine and Georges Bank stocks.

ANALYTICAL

CHOOSE F, TC ANTICIPATED UNDER MANAGEMENT REGIME

CALCULATE SSB/R THAT WOULD RESULT (OR ESTIMATE FROM ISOPLETH)

ANTICIPATED SPAWNING POTENTIAL

SSB/R

HIGH=MANY SPAWNING OPPORTUNITIES POSSIBLE
LOW=FEW SPAWNING OPPORTUNITIES POSSIBLE

EQUIVALENTLY

R/SSB (AS A SLOPE ON THE SSB*–R* PLOT)

LOW=MANY SPAWNING OPPORTUNITIES POSSIBLE
HIGH=FEW SPAWNING OPPORTUNITIES POSSIBLE

OBSERVATIONAL

COMPILE ACTUAL SSB*, R* DATA (E.G. FROM VPA)

DISPLAY OBSERVED SSB*–R* DATA PAIRS IN TYPICAL STOCK–RECRUITMENT PLOT

OBSERVED SPAWNING SUCCESS

R*/SSB*

HIGH=MANY RECRUITS PRODUCED PER SPAWNER
THUS, FEWER SPAWNING OPPORTUNITIES
REQUIRED FOR SPAWNERS TO REPLACE SELVES

LOW=FEW RECRUITS PRODUCED PER SPAWNER
THUS, MANY SPAWNING OPPORTUNITIES
REQUIRED FOR SPAWNERS TO REPLACE SELVES

RULE FOR MAINTENANCE:
IF MANY SPAWNING OPPORTUNITIES ARE REQUIRED FOR REPLACEMENT BECAUSE RECRUITMENT SUCCESS IS POOR (R*/SSB* LOW), MORE SPAWNING OPPORTUNITES SHOULD BE PROVIDED UNDER THE MANAGEMENT REGIME (R/SSB LOW OR SSB/R HIGH)

MANY POINTS BELOW SLOPE	POINTS EQUALLY ABOVE AND BELOW SLOPE	MANY POINTS ABOVE SLOPE
R/SSB > R*/SSB*	R/SSB = R*/SSB*	R/SSB < R*/SSB*
DECLINE LIKELY	MAINTENANCE LIKELY	INCREASE LIKELY

Figure 2.9 Use of SSB/R analysis and historical stock and recruitment data (designated with star) to evaluate potential effects of fishing strategies on stock levels.

of SSB/R can be superimposed on the plot as its reciprocal, R/SSB; this reciprocal is expressed as a slope. The level may be displayed as a percentage of the maximum SSB/R [% maximum spawning potential, %MSP]: 100% would correspond to SSB/R (and its reciprocal, R/SSB) with no F. High F would lead to lower SSB/R, lower percentages of the maximum SSB/R [lower %MSP], higher R/SSB, and steeper slope (Figure 2.10).

In cases where calculated values of deterministic stock-recruitment relationships are defined from observed data, the intersection of the slope with the stock-recruitment curve indicates the level at which stock biomass and recruitment level would theoretically stabilize. This equilibrium is the multiple-age analog to the equilibrium defined by Ricker (1954) for single-aged stocks. In reality, the equilibrium is likely to be obscured by effects of environmental fluctuations (Shepherd 1982). When deterministic stock-recruitment relationships are obscured by environmental fluctuations, location of stock-recruitment points can be examined with respect to the slope. Points above the line defined by the slope represent years in which recruitment was more than adequate to maintain spawning stock biomass under the defined pattern of fishing mortality. In those years, observed R*/SSB* was high (so observed SSB*/R* was low) and survival was more than adequate to offset reduced SSB/R [%MSP] under the associated regime of fishing mortality. Points below the line represent years in which observed recruitment was inadequate to maintain spawning stock biomass under the fishery conditions, leading to short-term stock decline. If points are equally distributed above and below that line, the stock is likely to persist over the long-term average. This slope can thus be evaluated as a "replacement line". [In the example for Georges Bank haddock (Figure 2.10), the dashed line represents current SSB/R under existing fishery conditions. More points are below the line than above, indicating that replacement would not occur under current conditions.]

The conceptual bases outlined above underlies the current FMP, and provides a basis for comparing the effects of different management strategies in terms of the long-term replacement of year classes and in the maintenance of spawning stock biomass per recruit target levels.

2.5.2. Theory and Practice of Mesh Regulation to Achieve Target Levels of Spawning Stock Biomass Per Recruit

In the context of SSB/R analysis, the age at first capture and selection pattern can be manipulated to achieve target levels of spawning potential. This is the primary management approach of the FMP. Effective manipulation enables the shifting of fishing mortality to particular sizes or age groups within a stock. Several possible mechanisms are available to achieve such shifts; adjusting the size selection pattern of gear by changing mesh size or hook size is the most common. The pattern can be further altered by adjusting the mixture of gear types, as selection patterns differ among gears. Equally, when stocks show clear patterns of size-specific distribution in time and space, time-area closures may also be used to shift fishing mortality to or away from particular size or age groups. Thus, in theory, a wide variety of

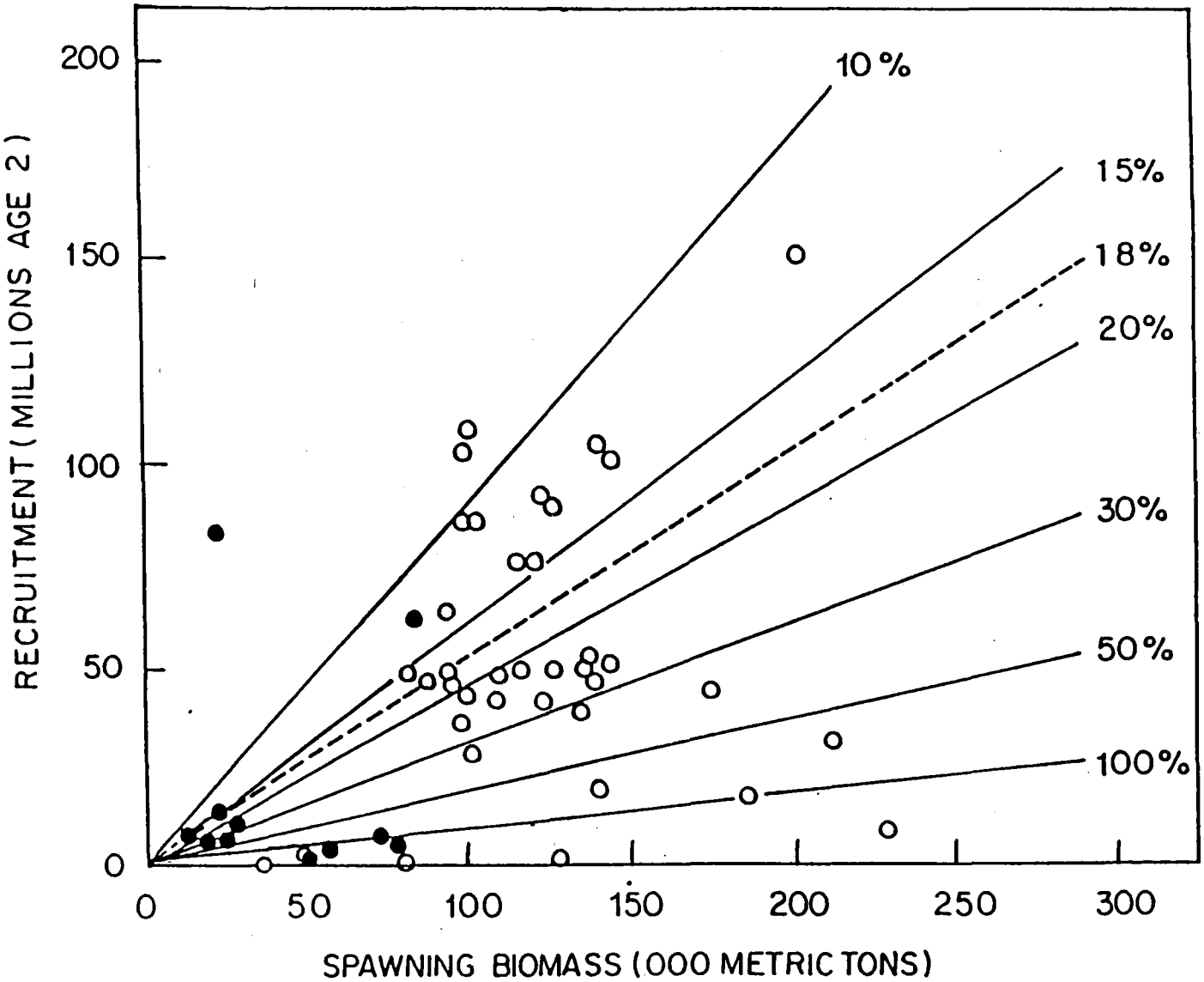


Figure 2.10 Spawning stock biomass (000's metric tons) and subsequent recruitment (millions, age 2) for Georges Bank haddock, 1931-1981. The 1963 point (178,534 mt, 368.8 million recruits) has been omitted. Straight lines represent slopes (inverse) of SSB/R as a percentage of maximum. Dashed line (18%) is close to current fishing regime of SSB/R. Filled points = 1971-1981.

exploitation patterns could be applied or the same exploitation pattern could be obtained from various combinations of gear types, mesh/hook sizes and time-area closures.

Alternatively or in combination with changes in age specific selectivity of fishing gear, the rate of fishing mortality can be manipulated to achieve target %MSP levels in the SSB/R context. Several mechanisms for doing this are available, including regulating total catches, total fishing effort and areas fished. Such measures are not the primary approaches of the FMP.

To evaluate the impacts of manipulating exploitation patterns in the northeast multispecies fishery to achieve target %MSP levels, otter trawl mesh size selectivity patterns from field experiments (Smolowitz 1983) were examined. The exploitation patterns derived from these experiments relate to effective mesh size: the size selection pattern actually imposed on the stock, regardless of the regulatory or nominal mesh size in the fishery. In practice, several operational factors make the effective mesh of an otter trawl smaller than the regulatory or nominal mesh size:

1. Size of catch in the codend: Diamond meshes in trawls constrict in the throat when the catch in the codend is large. These constricted meshes retain more smaller-sized fish which hinders escapement through the packed cod end.

2. Length of tow: As tow length increases, the probability of incurring rubble (or large catches) in the codend increases, restricting escapement of small fish through the codend meshes.

3. Clogging or gilling: Fish with prominent teeth, bony projections or spines (e.g., redfish) do not escape as easily as smooth-bodied species.

4. Extrusion: Small fish, even though extruded through meshes, are still likely to suffer some possibly delayed mortality caused by scale loss, internal injuries or other stresses inflicted during codend escapement.

Other operational factors leading to different but unquantifiable deviations in otter trawl mesh selection from experimental selection patterns are:

5. Performance of net material: Although synthetic materials are widespread, mesh characteristics, in terms of shrinkage, stretch and knotting, will still vary somewhat from material to material.

6. Tow speed, trawl rigging: Depending on water currents, bottom conditions, and/or species sought, skippers often modify trawl shape and design, in turn affecting mesh efficiency.

In addition to these factors, effective mesh size will be smaller than the regulated or nominal mesh when the total fishing mortality on a stock is generated from a mixture of small mesh and large mesh fisheries. The effective mesh then becomes an average of all operating mesh selection patterns.

For Georges Bank cod, the difference between regulated and effective mesh size was examined by comparing the field experiment results to the partial recruitment vector obtained from virtual population analysis (Serchuk and Wigley 1986). During the period 1982-1985 a 5 1/2" mesh regulation was in place. The partial recruitment of fish at each age from the VPA (column A, Table 2.4) corresponds most closely to the mesh selectivity given by Smolowitz (1983) for a 4 1/2" effective mesh, based on age-length relationships from Penttila and Gifford (1976). The proportion that would be landed by age is estimated as the proportion retained by 4.5" mesh (column B, Table 2.4) multiplied by the fraction of fish greater than the minimum size limits (column C, Table 2.4). The resulting exploitation pattern for cod (column D, Table 2.4) corresponds closely to that observed in the fishery (column A, Table 2.4). That is, the observed age specific selectivity from the VPA during a time-period when the regulatory mesh size in the otter trawl fishery was primarily 5 1/2" is consistent with that predicted from experimental results using a 4 1/2" mesh.

Similar results have been obtained for Georges Bank haddock, although they are less pronounced because fishing effort has been redirected to dominant haddock year classes. As a consequence, the VPA partial recruitment vector varies from year to year. However, during the early 1980s when regulated mesh size was 5 1/8", the VPA partial recruitment vector (Overholtz et al. 1983) was comparable to that for a 4 1/4" effective mesh size if discard effects due to minimum fish size are assumed to be negligible (VPA partial recruitment vector = age 1: 0.0; age 2: 0.6; age 3: 1.0; 4 1/4" proportion retained = age 1: 0.1; age 2: 0.6; age 3: 0.9; calculated as for cod, Table 2.4).

These two differences between regulated and effective mesh sizes [1" for cod (5 1/2" minus 4 1/2") and 7/8" for haddock (5 1/8" minus 4 1/4")] presumably result from a combination of:

(1) any unregulated small mesh fishery;

(2) a regulated large mesh fishery with actual age specific selectivity less than that experimentally observed;

(3) other gear types in the fishery (such as gillnets, longlines, etc.) with less well defined selectivity; and

(4) lack of compliance.

Table 2.4 Comparison of observed exploitation patterns for Georges Bank cod with age specific selection patterns corresponding to a 4 1/2" effective mesh [including adjustment for 17" minimum fish landing size].

Age	Observed[1] Exploitation Pattern (A)	Predicted Exploitation Patterns, 4 1/2" Mesh		
		Proportion Retained[2] (B)	Proportion Landable[3] (C)	Proportion Landed (D)
1	0.02	0.17	0.00	0.00
2	0.52	0.69	0.82	0.57
3	1.00	0.97	1.00	0.97
4	1.00	1.00	1.00	1.00

[1]Geometric mean of partial recruitment values during 1982-1985 (from Serchuk and Wigley 1986).

[2]From probit analysis of data in Smolowitz 1983, assuming selection factor of 3.6 (Smolowitz 1983).

[3]Percentage of fish at age equal to or greater than 17" in length (Penttila and Gifford 1976).

These differences must be interpreted with the understanding that:

(1) partial recruitment patterns from VPA are likely to be highly variable from year to year and patterns estimated for the most recent years are most sensitive to tuning procedures;

(2) the extent of the calculated difference is not as large as that obtained from an informal review of Coast Guard boarding data (Smolowitz, R. Northeast Regional Offfice, pers. comm.)

(3) the effects of exempted or small mesh fisheries are likely to be larger in other areas, as estimates have been based only on data from Georges Bank stocks.

Based on these observations and recognizing the uncertainties in the analyses, regulatory (or nominal) mesh size is defined for purposes of this report as effective mesh size plus 1".

2.5.3. Evaluation of Current %MSP Levels Relative to Targets

Current exploitation patterns and levels of fishing mortality result in estimates of %MSP levels as shown in Table 2.5. Estimates of fishing mortality used in Table 2.5 are taken from the documents listed, adjusted where necessary for more recent information, and from the smoothed survey indices (Figure 2.7). These latter estimates were based on average 1985-1986 values, adjusted downward for Southern New England yellowtail flounder (as 1985-1986 values appeared to reflect large amounts of variability) and upward for American plaice (to approximate effects of increased survey catchability in 1985. Estimates were generally chosen near the bottom or middle of ranges.

Target %MSP levels set in the current FMP are listed in Table 2.6 for three Georges Bank stocks in the columns labeled FMP. Targets were defined for maintenance of present spawning stock sizes for all three stocks, and for rebuilding of spawning stock size for Georges Bank haddock. Recent data suggest that some of these target levels are unlikely to lead to stock maintenance or rebuilding. In the case of Georges Bank haddock, the FMP target for rebuilding was based on stock-recruitment patterns for the past 50 years (Gabriel et al. 1984). At recent low stock sizes, however, recruitment has been disproportionately poor. Regardless of the method used to define the replacement level using the most recent recruitment patterns (linear regression: Gabriel 1985; or median of lognormal distribution: Gabriel et al. in press), new estimates establish the replacement level at 28-30% MSP. Although the revised methodology (Gabriel 1985) also yields a higher level of %MSP than originally calculated (18%, Table 2.5), the difference between current %MSP and the replacement level is still substantial. The original target for haddock rebuilding on Georges Bank was set in the FMP at replacement level + 10% (or 20% + 10% = 30%). By analogy, a revised target to encourage rebuilding of the Georges Bank haddock stock could be defined as (28-30%) + 10% = 38-40% (Table 2.6).

Table 2.5 Current % MSP estimated from (1986) exploitation patterns and levels of fishing mortality for major groundfish stocks subject to regulation under the Fishery Management Plan for the Northeast Multispecies Fishery.

Species/Stock	% MSP 1986	Exploitation Pattern	Fishing Mortality Source	Fishing Mortality	Source
ATLANTIC COD					
Georges Bank & South	9	4.5" Effective mesh	Comparison of partial recruitment vectors, VPA, and mesh selection ogives.	0.50	Serchuk & Wigley (1986) (revised using 1986 catch data.)
Gulf of Maine	7	4.5" Effective mesh	By analogy from above comparison.	0.62	Serchuk & Wigley (1986)
HADDOCK					
Georges Bank	18	4.5" Effective mesh	Comparison of partial recruitment vectors, VPA, and mesh selection ogives.	0.50	NEFC (Report of the 4th SAW) NMFS (1987: in prep)
Gulf of Maine	11	4.5" Effective mesh	By analogy from above comparison.	0.70-0.80	Modified estimate from smoothed survey data.
REDFISH					
Georges Bank/ Gulf of Maine	14	Partial recruitment vector	VPA (NEFC Lab. Ref. 86-09). Poor relation to existing patterns.	0.17	NEFC (1986a)
POLLOCK					
Georges Bank/ Gulf of Maine/ Scotian Shelf	14	Partial recruitment vector	VPA (NEFC Lab. Ref. 86-14). Composite of multiple gear types.	0.73	NEFC (1986b)
YELLOWTAIL FLOUNDER					
Georges Bank	6	4.5" Effective mesh	By analogy from cod and haddock analyses.	1.00-1.10	Modified estimate from smoothed survey data.
Southern New England	6	4.5" Effective mesh	By analogy from cod and haddock analyses.	1.00-1.20	Modified estimate from smoothed survey data.
AMERICAN PLAICE					
Gulf of Maine/ Georges Bank	19	4.5" Effective mesh	By analogy from cod and and haddock analyses.	0.35	Modified estimate from smoothed survey data.

Table 2.6 Target % MSP levels for Georges Bank cod, haddock and yellowtail flounder, for maintenance and rebuilding as given in the FMP and as suggested here (REVISED).

	% MSP	MAINTENANCE		REBUILDING	
	1986	FMP	REVISED	FMP	REVISED
cod	9%	15-20	20	-	25-30
haddock	18%	20	28-30	30	38-40
yellowtail	6%	20	25-30	-	35-40

In the case of Georges Bank Atlantic cod, the development of a VPA (Serchuk and Wigley 1986) enabled calculation of observed SSB*/R* ratios and preliminary definition of target levels of SSB/R for replacement. When spawning stock biomasses are adjusted for within-year fishing and natural mortalities, annual variations in weight at age, and fraction mature at age (as detailed in Gabriel 1985), the median observed level (1978-1985) of SSB*/R* was approximately 15% of maximum. Given the inherent uncertainty in such estimates, a 15-20% level is consistent with the 20% MSP target in the FMP. By analogy with haddock, a rebuilding target would be 15-20% plus 10% = 25-30% (Table 2.6).

A modified DeLury estimate of population abundance at age of Georges Bank yellowtail flounder allows a preliminary review of historically observed SSB*/R* levels. Median SSB*/R* from 1974-1983 was estimated at between 25-30% of maximum possible SSB/R (recruitment at age 2). Both the current SSB/R level (6% MSP, Table 2.5) and the existing FMP target (20% MSP, Table 2.6) are far below this historic 25-30% replacement range. The development of a VPA will enable more accurate estimation of replacement levels in the future, and the 25-30% estimate is likely to be revised further when that analysis becomes available. A higher target would be justified if stock rebuilding is desired, when again by analogy with haddock such a revised target might be 35-40% (Table 2.6).

Estimates of current %MSP levels (Table 2.5) are substantially less than the FMP maintenance targets (Table 2.6) for Georges Bank cod and yellowtail flounder, and the FMP rebuilding targets for Georges Bank haddock. These differences are sufficiently large that even given the uncertainties in the analyses, it does not appear likely that the goals of the FMP are being met under current fishing practices.

2.5.4. Mesh Size and Fishing Mortality Combinations Yielding Target SSB/R Levels

Combinations of effective mesh size and fishing mortality yielding various %MSP levels for 9 stocks can be displayed in SSB/R isopleth diagrams (Figure 2.8, Figures 2.11 - 2.15) (Gabriel 1985). Current %MSP levels, for current F and exploitation patterns are denoted by asterisks, and target contours of percentage of maximum spawning stock biomass per recruit are labelled. targets for stocks where direct estimates do not exist were established by analogy in the FMP except for redfish.

Management regulations to achieve the target %MSP levels shown in these figures would have to change mesh size, and hence age-specific selectivity of the fishing gear, or fishing mortality rates, or both. Alternate approaches to achieving these targets are:

(1) maintaining current F levels and increasing effective mesh (moving right along the line of current F until the target contour is reached, and then estimating the required effective mesh size from the x axis below), or

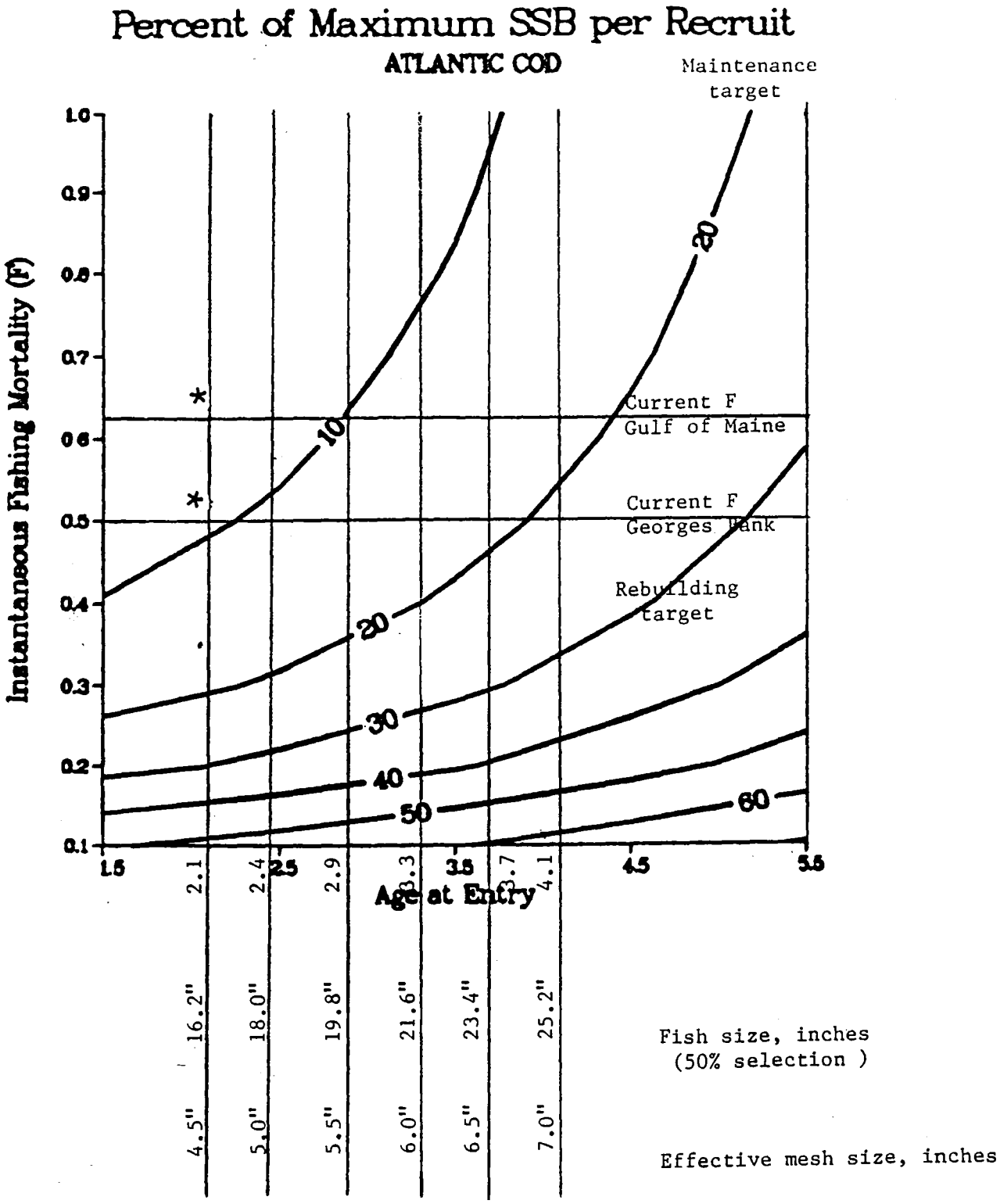


Figure 2.11 Isopleths of percentage of maximum spawning stock biomass per recruit for Atlantic cod. Asterisks denote current (1986) levels of % MSP for Georges Bank and Gulf of Maine stocks.

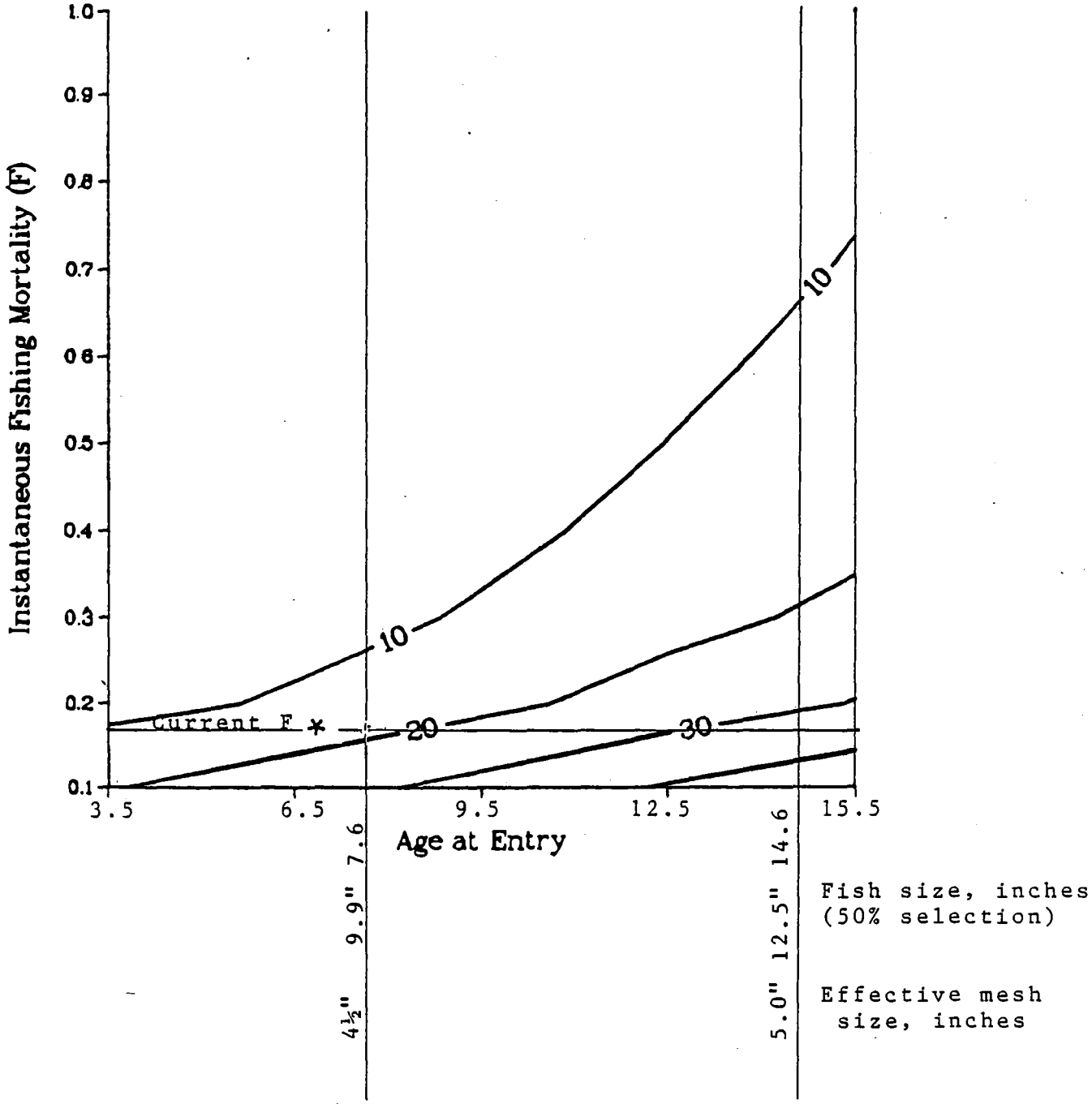


Figure 2.12 Isopleths of percentage of maximum spawning stock biomass per recruit for redfish. Asterisk denotes current (1986) level of % MSP.

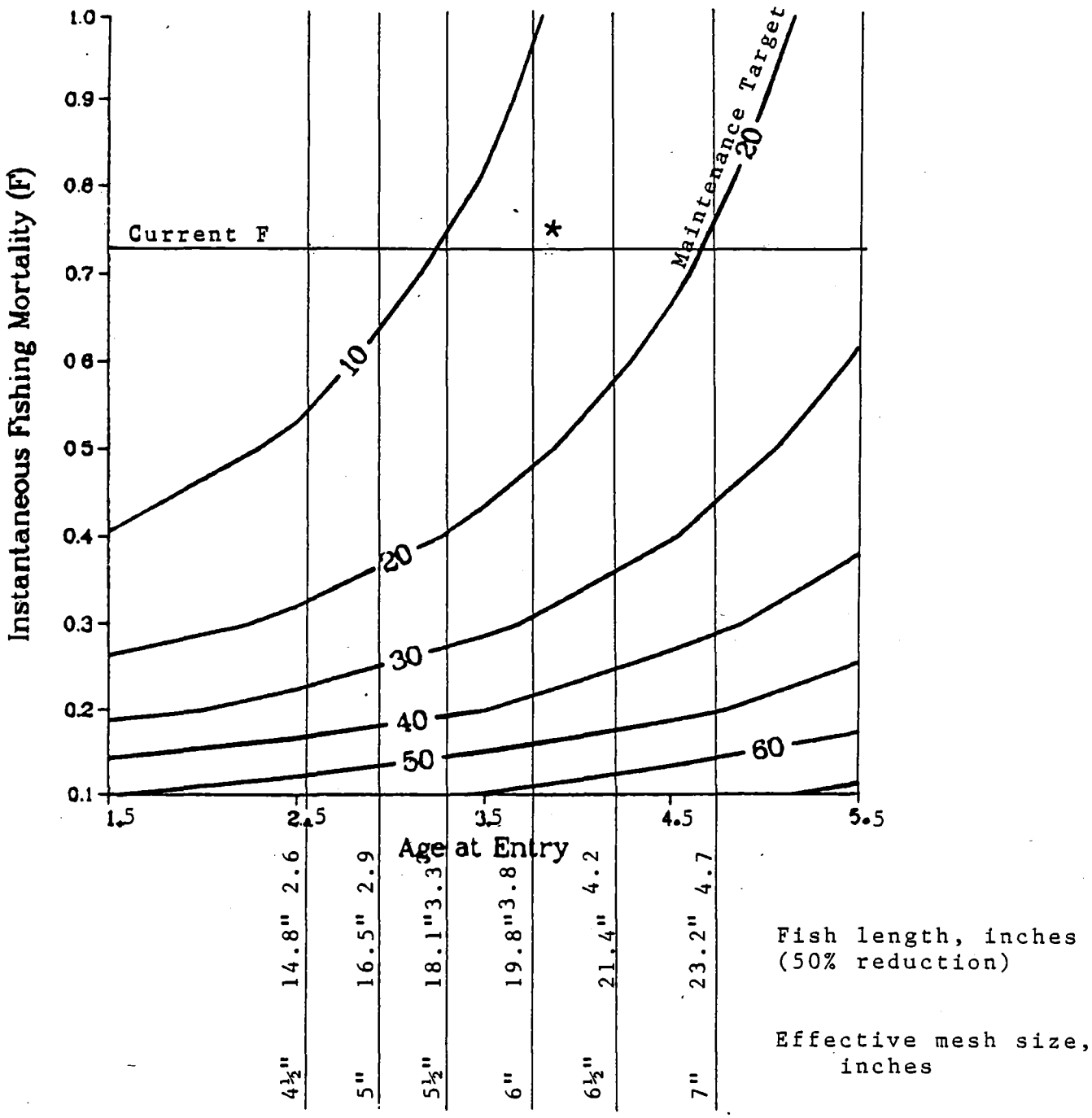


Figure 2.13 Isopleths of percentage of maximum spawning stock biomass per recruit for pollock. Asterisk denotes current (1986) level of % MSP.

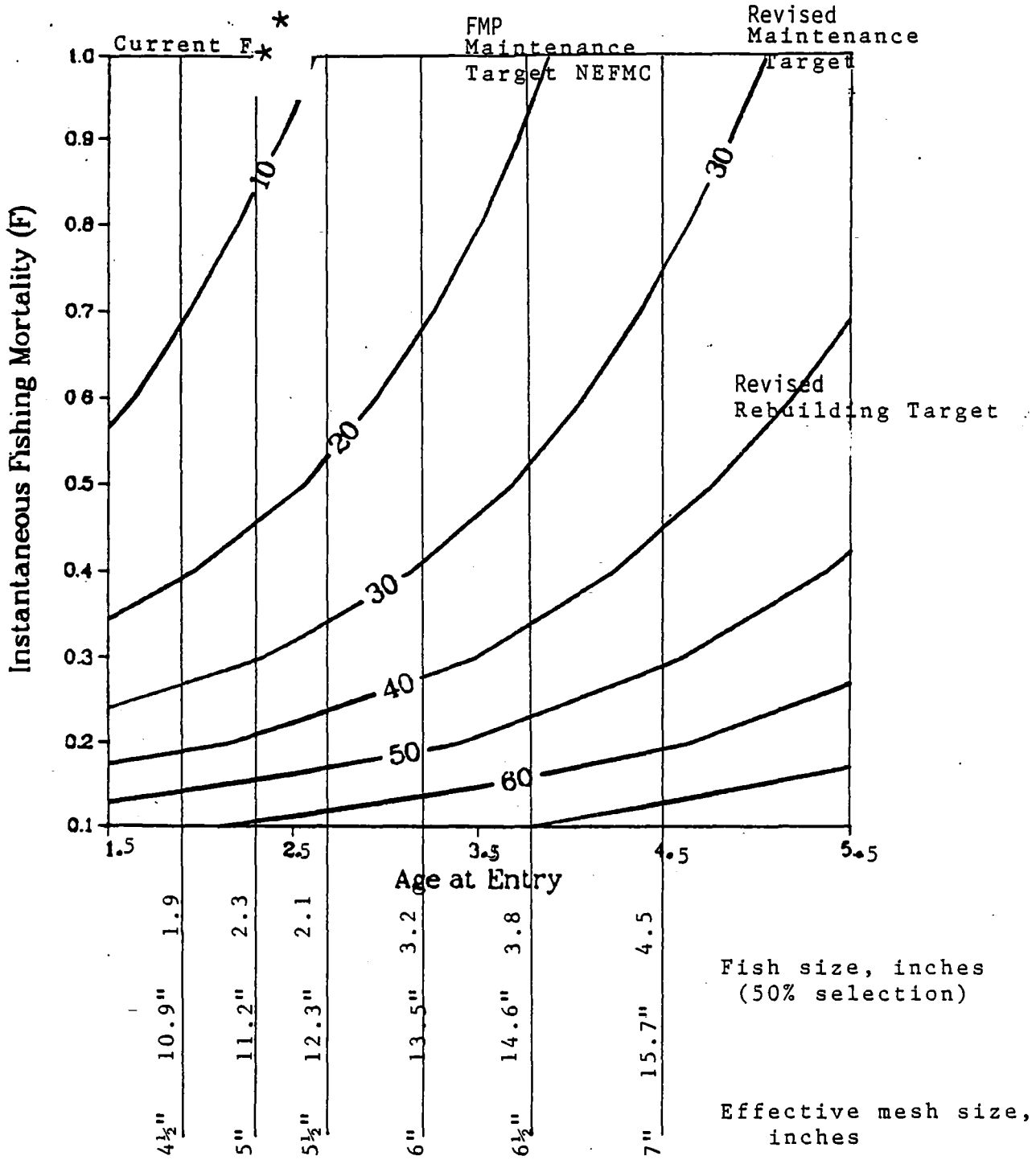


Figure 2.14 Isopleths of percentage of maximum spawning stock biomass per recruit for yellowtail flounder. "Current F" based on lowest value in range of estimates of fishing mortalities. Asterisks denote current (1986) levels of % MSP for Georges Bank and Southern New England stocks.

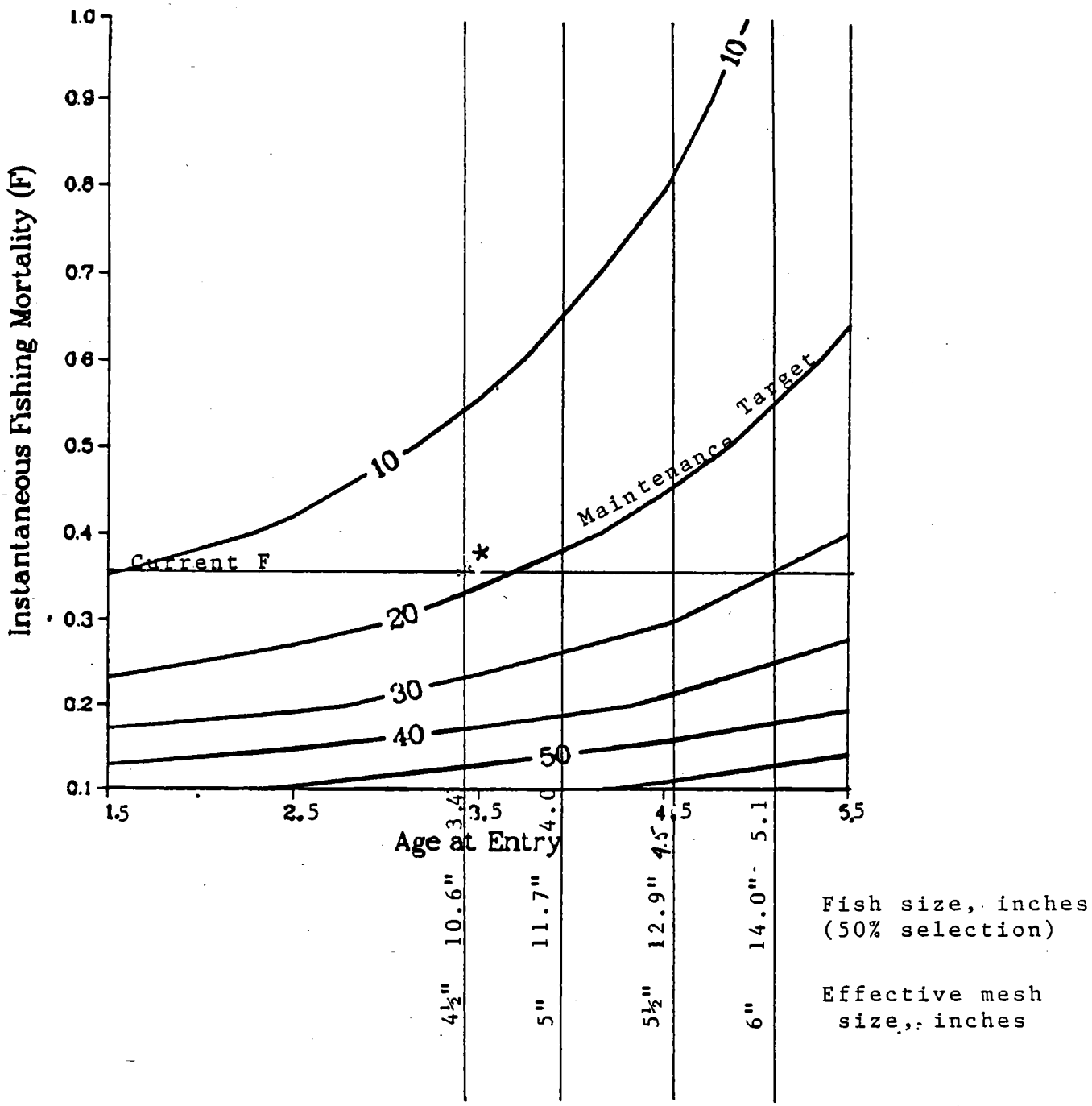


Figure 2.15 Isopleths of percentage of maximum spawning stock biomass per recruit for American plaice. Asterisk denotes current (1986) level of % MSP.

(2) maintaining the current exploitation pattern and reducing F (moving down along the line of current effective mesh size until the target contour is reached, and then estimating the required level of F, from the y axis to the left), or

(3) by a combination of reducing F and increasing effective mesh (moving generally toward the lower right corner until the target contour is reached).

The percentage changes in fishing mortality rates that would be required to meet alternate %MSP targets for the principle Georges Bank stocks for several mesh sizes are shown in Table 2.7. At the current regulated mesh size of 5.5" the fishing mortality rate would have to be reduced by 42% to meet the FMP maintenance target %MSP for Georges Bank cod (20%). Increasing the regulated mesh size, the principle management approach of the FMP, from its current 5.5" to 6.5", for example, would allow this same target to be met with a reduction in fishing mortality of only 30%. However, to meet the target for cod by changing only mesh size would require a regulated mesh size in excess of 7.5".

If the Georges Bank stock targets are extended to the species in other areas (as in the current FMP), percentage reductions in F necessary to achieve targets are displayed in Table 2.8. For these stocks as well, as for the Georges Bank stocks in Table 2.7, the percentage reductions in fishing mortality rates required are large under present mesh regulations. Unless mesh sizes substantially larger than presently in use are to be required it appears that some other management measures that regulate fishing mortality will be necessary if the FMP goals are to be met.

2.6. Summary of the Status of the Fishery Resources

Currently, virtually all of the major species/stocks comprising the northeast multispecies complex are in poor condition (Table 2.9). Abundance levels in 1986 were at or near the lowest levels ever observed. Landings and commercial CPUE have sharply declined to record or near-record lows, while fishing mortality rates have increased to historic highs. All of the stocks exhibit signs of growth overfishing (i.e., fishing mortality rates in excess of the level producing maximum yield per recruit); depressed recruitment levels in many of the stocks suggests that recruitment overfishing (i.e., the inability of the stock to replace itself due to reduced spawning success resulting from excessive fishing mortality) has also occurred.

In addition to the downward trends in stock size and recruitment, nearly all of the stocks exhibit other symptoms characteristic of stressed populations. These include a decline in the average age of fish in the stock, the presence of fewer age groups in the spawning population, and a shift to fewer and younger age groups in the commercial catch. In haddock, increases in growth rate and fecundity have been accompanied by a decline in the average

Table 2.7 Percent changes in fishing mortality (F) required to achieve individual species target % MSP levels for Georges Bank stocks of cod, haddock, and yellowtail flounder, as a function of mesh size. Asterisks indicate that no reduction in current F (1986) would be necessary to achieve target % MSP at specified effective mesh size. (Footnotes defined after Table 2.8.)

Mesh Size		Atlantic Cod		Haddock		Yellowtail Flounder		
Effective	Regulated	20% MSP	30% MSP	30% MSP	40% MSP	20% MSP	30% MSP	40% MSP
4.5"	5.5"	-42%	-60%	-42%	-60%	-60%	-72%	-79%
5.0"	6.0"	-36%	-56%	-36%	-54%	-54%	-70%	-79%
5.5"	6.5"	-30%	-52%	-24%	-48%	-46%	-65%	-76%
6.0"	7.0"	-22%	-46%	- 6%	-40%	-31%	-59%	-72%
6.5"	7.5"	- 8%	-42%	*	-22%	- 3%	-46%	-65%
7.0"	8.0"	*	-32%	*	*	*	-22%	-53%

Table 2.8 Percent changes in fishing mortality (F) required to achieve individual species target % MSP levels for Gulf of Maine cod and haddock stocks, and Southern New England yellowtail flounder, as a function of mesh size. Asterisks indicate that no reduction in current F (1986) would be necessary to achieve target % MSP at specified effective mesh size.

		Gulf of Maine				Southern New England		
Mesh Size		Atlantic Cod		Haddock		Yellowtail Flounder		
Effective	Regulated	20% MSP	30% MSP	30% MSP	40% MSP	20% MSP	30% MSP	40% MSP
4.5"	5.5"	-53%	-68%	-58%	-71%	-60%	-73%	-80%
5.0"	6.0"	-48%	-64%	-54%	-67%	-55%	-70%	-79%
5.5"	6.5"	-44%	-61%	-46%	-63%	-46%	-65%	-76%
6.0"	7.0"	-37%	-56%	-33%	-57%	-31%	-59%	-72%
6.5"	7.5"	-26%	-53%	-11%	-44%	- 3%	-46%	-65%
7.0"	8.0"	-13%	-45%	*	-24%	*	-22%	-53%

Table 2.9. Summary information of the condition of the major species/stocks within the Northeast Multispecies Fishery.

Species/Stock	1986 Total Stock Size	Fishing Mortality 1983-1986	Recent Commercial CPUE	1986 USA Commercial Landings	Spawning Stock Biomass Per Recruit (% MSP)	
					1986	FMP Target[1]
ATLANTIC COD						
Georges Bank & South	At historic low	Record high	Record low in 1984-1986	Lowest since 1976	9% MSP	20% MSP
Gulf of Maine	At historic low	Record high	Record low in 1984-1986	Lowest since 1975	7% MSP	20% MSP
HADDOCK						
Georges Bank	At historic low	Record high	Record low in 1985-1986	Lowest since 1976	18% MSP	30% MSP
Gulf of Maine	At historic low	Near median	Record low in 1985-1986	Lowest since 1975	11% MSP	>20% MSP
REDFISH						
Georges Bank/Gulf of Maine	Near historic low	Near median	Record low in 1986;	Lowest since 1934	14% MSP	Largest %MSP
POLLOCK						
Georges Bank/Gulf of Maine/ Scotian Shelf	At median	Record high	At median; declining	Highest on record	14% MSP	20% MSP
YELLOWTAIL FLOUNDER						
Georges Bank	At historic low	Record high	Record low in 1984-1985	Second lowest	6% MSP	20% MSP
Southern New England	At historic low	Record high	Record low in 1984-1985	Near lowest	6% MSP	20% MSP
AMERICAN PLAICE						
Gulf of Maine/Georges Bank	Near historic low	Record high	Record low in 1986	Lowest since 1976	19% MSP	20% MSP
WITCH FLOUNDER						
Gulf of Maine/Georges Bank	At historic low	Unknown	Record low in 1985-1986	Near record-high	Unknown	20% MSP
WINTER FLOUNDER						
Georges Bank	At median	Unknown	Record low in 1985-1986	Lowest since 1976	Unknown	20% MSP
Southern New England	At median	Unknown	Record low in 1985-1986	Lowest since 1977	Unknown	20% MSP
WINDOWPANE FLOUNDER						
Georges Bank/S. New England	At historic high	Unknown	Above median; stable	Second highest	Unknown	20% MSP
WHITE HAKE						
Gulf of Maine/Georges Bank	Near median	Unknown	Above median; stable	Lowest since 1980	Unknown	20% MSP

[1]As specified in NEFMC FMP for the Northeast Multispecies Fishery.

age at sexual maturity, signs normally observed in the most heavily fished stocks. For all of the stocks spawning stock biomass per recruit levels in 1986 were below the target levels specified in the FMP as necessary to insure that year classes replace themselves on a long-term average basis (Table 2.9).

The principle management approach of the current FMP, regulating otter trawl age-specific selectivity by mesh and minimum fish sizes, does not appear sufficient to allow the FMP goals to be met without using regulated mesh sizes in excess of 7.5".

In the aggregate, the productivity of the multispecies complex has been severely diminished during the past five years. The spectrum of biological and fishery indicators used to evaluate the present status of this complex are consistent in depicting extremely poor resource conditions, with little prospect for improvement under current management approaches given current record-high levels of fishing effort and fishing mortality.

3. CHANGES IN FISHING EFFORT AND MULTISPECIES CPUE

3.1. Descriptions of Methods and Data

Analyses of trends in fishing effort and catch per unit of effort (CPUE) were undertaken to describe recent (1976-1986) changes in patterns of fishing effort in the New England region by area, gear and vessel class, and to summarize changes in CPUE of the major groundfish stocks in the area using CPUE as an index of relative abundance.

3.1.1. Catch and Effort Data Base

Commercial catch and effort data have been collected by National Marine Fisheries Service (NMFS) port agents in the Northeast region since 1964 (Burns et al. 1983). Since that year, an extensive time series of individual trip records has been developed, including date, catch in weight by species, statistical reporting area, days fished, days absent from port, as well as other attributes not analyzed here. Vessel trip records are available for most trips landing at New England ports, particularly for the larger vessels making multi-day fishing trips ('trip boats', as opposed to 'day boats'). When vessel trip data cannot be directly collected by port agent interviews, catch information is derived from 'weighout' slips, and an area fished during the trip is assigned based on typical fishing patterns of the vessel, species composition, and operating patterns of similar vessels in the port of landing. Effort data (days fished, days absent from port, number of trips) are similarly derived for non-interviewed trips, and prorated to statistical reporting areas.

For the purpose of these analyses, individual vessel catch, effort, and ex-vessel revenue data were aggregated by year, statistical area, gear type, species and vessel size class. Patterns of catch and CPUE were analyzed by three vessel tonnage classes (TC) based on their gross registered tonnage (GRT):

TC 2 = 5-50 GRT

TC 3 = 51-150 GRT

TC 4 = 151-500 GRT

Landings by vessels under 5 GRT ('under-tonnage vessels') were not included in these analyses; they are only a minor fraction of the total. Between 1976-1986, several vessels greater than 500 GRT (e.g. large freezer trawlers) operated in the Southern New England area. Since these vessels accounted for very little of the catch of the ten demersal species analyzed here, catch and effort data for vessels larger than 500 GRT were combined with those for TC 4.

3.1.2. Definition of Sub-Areas

Analyses of multispecies effort, CPUE, and revenue were further aggregated into three relatively large sub-regions of the extended New

England area, generally reflecting logical breaks separating species/stocks, species composition of landings, and the development of regional fisheries. The Gulf of Maine, Georges Bank and Southern New England regions comprise the following statistical reporting areas (Figure 3.1):

Gulf of Maine	=	511-515	=	AREA 51
Georges Bank	=	521-526	=	AREA 52
Southern New England	=	537-539, 611-616	=	AREA 53

The Southern New England area was extended to the statistical reporting areas off New Jersey since some quantities of regulated species under the Northeast Multispecies Fishery Management Plan are caught in these areas (e.g. yellowtail flounder, winter flounder, cod), and because fishing vessels with New England home ports (e.g. New Bedford) have at times accounted for a substantial proportion of the effort and landings from these areas.

These area groupings are generally consistent with the underlying stock structure within species (e.g. cod, haddock), but sub-divide some stocks (e.g. portions of the Cape Cod and Southern New England yellowtail flounder stocks are caught in areas 521-526 = Georges Bank region; portions of the coastal winter flounder stocks are caught in areas 521 and 526).

3.1.3. Species and Fishing Gears Analyzed

Landings data for each area, vessel tonnage class and gear type were aggregated over all species in the landed catch, including invertebrates such as squid and northern shrimp caught by otter trawl. Additionally, landings of 10 species were totaled by year, area, vessel tonnage class and gear type:

American Plaice	= AMP
Atlantic Cod	= COD
Haddock	= HAD
Pollock	= POL
Redfish	= RED
Silver Hake	= SHK
Winter Flounder	= WFL
White Hake	= WHK
Witch Flounder	= WIT
Yellowtail Flounder	= YT

These species include nine of the ten regulated species under the FMP. Silver hake was included as a regionally important component in demersal fisheries and as a species co-occurring with many of the regulated species. Windowpane flounder, a regulated species, was not included, as the species contributes less than 3% of the total landings of all regulated species.

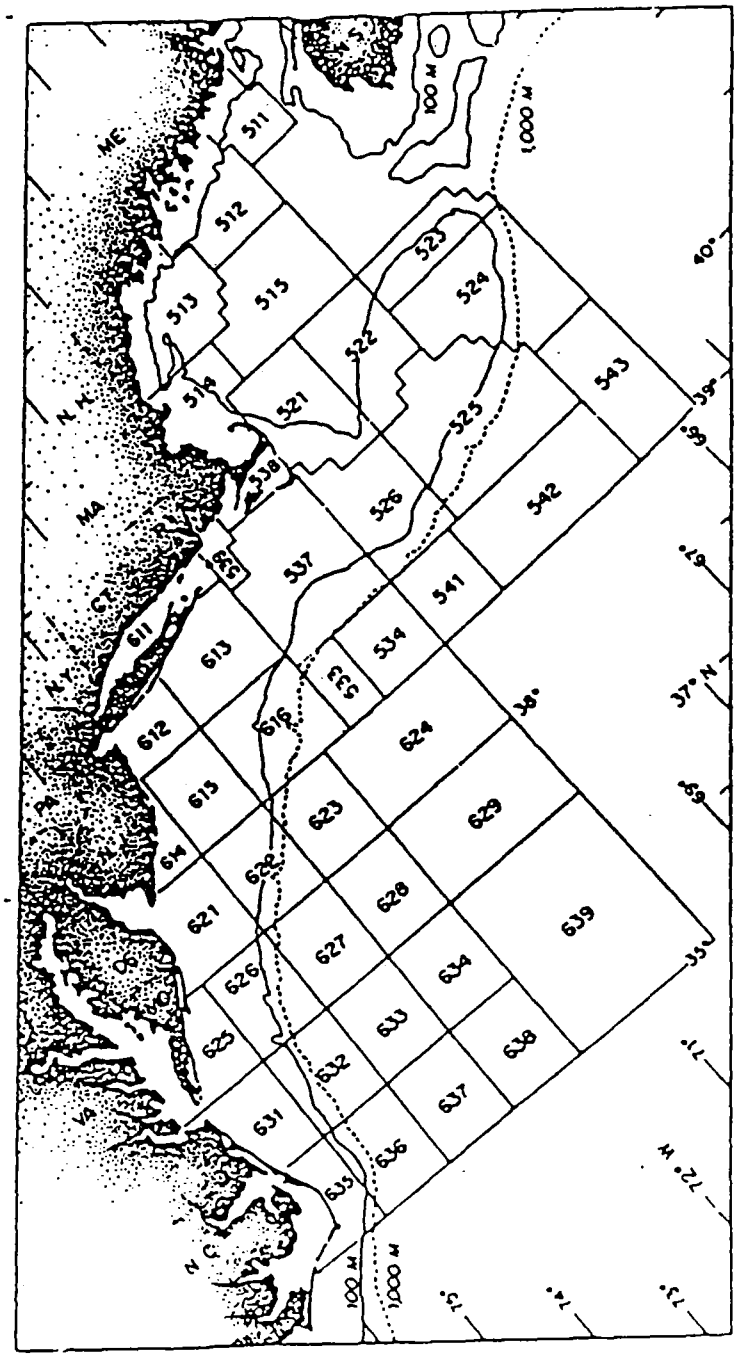


Figure 3.1 National Marine Fisheries Service statistical reporting areas (3-digit areas) in the Northwest Atlantic. For the purposes of this document, Gulf of Maine is defined as areas 511-515; Georges Bank is defined as areas 521-526; and Southern New England is defined as areas 537-539 + areas 611-616.

Three gear type designations were also included in these analyses:

Otter Trawl = Code 5
Gill Net = Code 10
Other Gears = Code 99

The category 'other gears' includes scallop dredges, Danish and Scottish seines, purse seines, clam dredges, harpoons, long-lines, etc. Between 1976-1986, otter trawls produced a substantial proportion of the landings of the ten species analyzed (Table 3.1), accounting for virtually all of the haddock, silver hake, witch flounder, winter flounder, redfish, yellowtail flounder and American plaice landings. During the mid-late 1970's gill nets accounted for a significant proportion of white hake and pollock landings (Table 3.1). However, gill net effort has remained relatively stable over time (Table 3.2), while otter trawl effort increased greatly during the period (Section 3.2), resulting in an increasing proportion of cod, white hake and pollock being landed by otter trawlers (Table 3.1). In 1986, otter trawl catches accounted for between 73% (pollock) and 99% (silver hake, redfish) of the landings of each of the ten species analyzed.

The ten species listed above generally account for most of the otter trawl catch in the Gulf of Maine and Georges Bank regions and for a significant proportion of the otter trawl landings in Southern New England. Otter trawl landings of those 10 species accounted for the following proportions of the total otter trawl landings during the period 1976-1986, and for 1986 alone:

	Gulf of Maine			Georges Bank			Southern New England		
Class	2	3	4	2	3	4	2	3	4
Mean 76-86	0.79	0.82	0.95	0.84	0.92	0.95	0.52	0.41	0.30
SD	0.08	0.07	0.03	0.06	0.03	0.03	0.10	0.11	0.17
1986	0.63	0.82	0.92	0.70	0.86	0.89	0.45	0.36	0.23

In 1986, these proportions were less than or equal to the average from 1976-1986 for all vessel size/area combinations. Species accounting for the remainder of the landings vary greatly by area and vessel size class. In the Gulf of Maine, northern shrimp, cusk, and wolffish contribute most of the "other landings". On Georges Bank, windowpane flounder, ocean pout and summer flounder account for the majority of "other landings". In Southern New England, other species obtained in otter trawl landings include summer

Table 3.1 Proportions of New England landings of 10 demersal fish stocks, by gear type, 1976-1986. Data are given for all stock areas combined, and may sum to more than 1.0 due to rounding.

Species	Gear[1]	Year 1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
C	05	0.80	0.86	0.81	0.81	0.80	0.88	0.89	0.92	0.89	0.88	0.88
O	10	0.11	0.09	0.10	0.09	0.16	0.11	0.09	0.08	0.10	0.10	0.10
D	99	0.10	0.05	0.09	0.10	0.03	0.01	0.02	0.01	0.01	0.02	0.02
H	05	0.93	0.94	0.94	0.95	0.93	0.96	0.98	0.95	0.96	0.95	0.96
A	10	0.05	0.05	0.05	0.04	0.06	0.04	0.02	0.04	0.03	0.03	0.03
D	99	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.02	0.01
S	05	1.00	1.00	0.99	1.00	0.99	1.00	1.00	1.00	0.99	0.99	0.99
H	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K	99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
W	05	0.39	0.47	0.46	0.53	0.59	0.65	0.64	0.78	0.79	0.77	0.80
H	10	0.47	0.45	0.48	0.41	0.39	0.33	0.34	0.20	0.19	0.17	0.15
K	99	0.14	0.08	0.07	0.06	0.02	0.02	0.02	0.02	0.02	0.06	0.05
W	05	1.00	0.99	0.98	0.98	0.97	0.99	0.98	0.97	0.97	0.96	0.97
I	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T	99	0.00	0.01	0.02	0.02	0.03	0.01	0.02	0.03	0.03	0.04	0.03
W	05	0.97	0.98	0.97	0.98	0.98	0.99	0.98	0.99	0.99	0.99	0.97
F	10	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
L	99	0.01	0.00	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02
R	05	1.00	1.00	1.00	1.00	0.99	1.00	0.99	1.00	0.99	1.00	0.99
E	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
D	99	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Y	05	0.99	0.99	0.97	0.95	0.95	0.97	0.99	0.99	0.99	0.98	0.97
T	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L	99	0.00	0.01	0.03	0.05	0.05	0.03	0.01	0.01	0.01	0.02	0.03
P	05	0.65	0.60	0.54	0.52	0.61	0.61	0.72	0.80	0.77	0.76	0.74
O	10	0.33	0.38	0.43	0.43	0.37	0.38	0.27	0.20	0.23	0.24	0.26
L	99	0.02	0.02	0.02	0.05	0.03	0.01	0.00	0.00	0.00	0.00	0.00
A	05	0.99	0.99	0.99	0.99	0.97	0.99	0.98	0.98	0.99	0.98	0.98
M	10	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00
P	99	0.00	0.00	0.01	0.01	0.02	0.00	0.01	0.01	0.01	0.01	0.01

[1]05 = Otter trawls; 10 = Gill nets; 99 = Other Gear.

Table 3.2 Annual gill net effort (days fished) for the Gulf of Maine, Georges Bank and Southern New England areas, 1976-1986. Data are grouped for all vessel tonnage classes.

	Area			
Year	Gulf of Maine	Georges Bank	S. New England	Total
1976	4840.7	5.3	5.4	4851.4
1977	6286.9	52.4	-	6339.3
1978	6854.2	71.5	313.9	7239.6
1979	6107.7	257.8	215.3	6580.8
1980	6531.0	657.5	96.8	7285.3
1981	5310.3	174.8	117.9	5603.0
1982	4505.9	219.5	75.2	4800.6
1983	5340.9	124.5	128.7	5594.1
1984	5433.6	185.3	181.9	5800.8
1985	5441.0	210.0	222.2	5873.2
1986	5980.4	241.5	182.3	6404.2

flounder, butterfish, scup, Loligo squid, windowpane flounder, ocean pout and black sea bass, among others (Murawski et al. 1983).

As a result of these landings patterns, analyses of changes in multispecies fishing effort and CPUE are focused on otter trawl gear due to the importance of otter trawl catches of the demersal species considered in the FMP and, in particular, the ten regulated species.

3.1.4. Methods for Aggregate Analyses of Catch, Effort and CPUE

Traditional single-species analyses attempt to associate directed effort (i.e., that effort targeted at a particular species) with the ensuing catch of a particular species. Otter trawl fisheries, however, may or may not be targeted at a single species; and catches from those fisheries may be highly mixed, with several species co-dominant. If a particular trip is described as directed to a single species, based on, e.g., a percentage contribution to the total trip catch, the single-species abundance measure will be biased, underestimating declining trends. The importance of this problem varies with the species diversity in the catch and the degree to which it can be controlled by fishery operations. The problem may be mitigated by analysis of trends in aggregate nominal and standardized fishing effort for otter trawl vessels.

The multispecies aggregate approach to effort and CPUE analyses was used to describe aggregate effort behavior in each of the three areas, particularly with respect to changes in stock abundance (i.e. to allow investigation of the possibility of 'switching' among alternative resources as preferred stocks decline), and to investigate changing effort patterns among areas. Total multispecies CPUE (thousands of pounds per nominal day fished) includes all species (including species in addition to the ten listed above) landed by otter trawlers in various area/vessel size categories, and all effort by otter trawlers in various area/vessel size categories. CPUE analyses for single species include all effort by otter trawlers in various area/vessel size categories.

3.2. Analyses of Changes in Fishing Effort by Area, Gear, and Vessel Class

Gillnet fishing effort (Table 3.2) was primarily concentrated in the Gulf of Maine region; during 1986, 93% of total gillnet days were fished there, with 4% on Georges Bank and 3% in Southern New England. Gillnet effort increased somewhat between 1976-1978, declined somewhat during the early 1980's, and has increased slightly again to 6.4 thousand days fished in 1986. In general, however, total gillnet effort has remained relatively stable both in total days fished and relative areal distribution. For example, the coefficient of variation (ratio of standard deviation to the mean) of total days fished is approximately 14% over the 10 year series, and the coefficient of variation of the annual proportion of days fished within the Gulf of Maine relative to total days fished over all regions is approximately 3% over the time series.

Nominal otter trawl fishing effort has, however, increased dramatically since 1976 in all areas primarily as a result of increased participation by TC 3 and 4 vessels (Table 3.3, Figure 3.2). In the Gulf of Maine area, effort by TC 2 vessels has remained relatively stable at about 6,0000 nominal days fished, but TC 3 effort increased 183% during 1976-1986, and TC 4 effort likewise increased 408%. In terms of nominal days fished TC 3 has since 1985 accounted for most effort, followed by TC 2 and TC 4.

Georges Bank effort has been dominated by TC 3 effort with a very small contribution by TC 2 and moderate TC 4 effort (Table 3.3). Since 1976 nominal effort first increased for all vessel classes, peaking in 1980 for TC 2 and 1984 for TC 3 and TC 4, then decreased. Nominal days fished by TC 2 vessels decreased in 1986 to the lowest on record (282 days fished), while TC 3 and 4 effort decreased 13% and 14% respectively between 1985-86.

Southern New England otter trawl effort is also dominated by TC 3 vessels, which have shown a 105% increase in nominal days fished since 1976 (Table 3.3). Effort by TC 2 has remained relatively stable at about 2,000 days fished over the period; TC 4 effort increased from 55 days fished in 1976 to 907 in 1986 (+1,549%).

3.3. Changes in Multispecies CPUE for Otter Trawl Fisheries, 1976-1986

Total multispecies CPUE (thousands of pounds per nominal day fished, Figure 3.3) is inclusive of **all** species (including species in addition to the ten listed in Section 3.1) landed by otter trawlers in the various area/tonnage class categories. In the Gulf of Maine region, TC 4 CPUE declined sharply since 1979 to a series low in 1986. Likewise TC 2 and 3 CPUE values in the Gulf of Maine are at series lows, but declined at slower rates. TC 2 CPUE remained the most stable over time.

Relative changes in multispecies CPUE among Gulf of Maine vessel classes are generally explained by the differing species compositions of the landings (Figure 3.4). TC 2 otter trawlers (Figure 3.4a) have in recent years appear to have relied increasingly on silver hake to offset declining CPUE of cod, American plaice, witch and winter flounder. Other species such as northern shrimp have also been substituted for declining landings of traditional groundfish stocks. Nevertheless, multispecies CPUE has declined steadily for TC 2 otter trawlers in the Gulf of Maine since 1983. TC 3 CPUE (Figure 3.4b) has been dominated to an increasing extent in recent years by pollock and silver hake, as cod, haddock, American plaice, and redfish have declined in abundance. In the most recent years, the species diversity of landings exhibited by TC 3 vessels in the Gulf of Maine has been greatly reduced. TC 4 CPUE was dominated by redfish during the mid-late 1970's (Figure 3.4c), but with the decline of the redfish stock, shifted to cod, haddock and pollock. Currently, with the depressed condition of cod and haddock stocks, TC 4 CPUE is dominated by pollock, with lesser amounts of cod and white hake. Other species contribute small amounts to the TC 4 CPUE.

Table 3.3 Total nominal otter trawl fishing effort (days fished), by area and vessel tonnage class[1], 1976-1986.

AREA	YEAR	VESSEL TONNAGE CLASS CLASS 2	CLASS 3	CLASS 4
Gulf of Maine				
	1976	5926.8	2234.9	614.6
	1977	5491.3	2570.2	707.6
	1978	6251.9	2828.9	923.5
	1979	6809.5	2597.6	908.0
	1980	7824.2	3395.5	989.3
	1981	5624.0	3455.2	1020.2
	1982	6736.3	4561.1	1485.4
	1983	6012.8	4937.8	1814.6
	1984	6057.0	5293.1	1692.8
	1985	5699.5	6150.7	2759.0
	1986	5392.3	6315.7	3122.1
Georges Bank				
	1976	607.0	11487.8	1891.8
	1977	757.6	11330.2	1796.5
	1978	863.9	11578.9	1819.1
	1979	940.4	12137.1	2846.2
	1980	1092.8	12552.5	3637.6
	1981	1013.5	12409.3	4270.9
	1982	830.7	13943.0	5112.5
	1983	520.6	14216.9	6026.9
	1984	483.4	17418.9	6581.6
	1985	510.4	17394.1	6366.3
	1986	281.8	15133.7	5471.8
Southern New England				
	1976	2386.9	3070.3	55.0
	1977	1596.1	1635.0	46.9
	1978	2143.6	2716.0	50.3
	1979	2233.5	2906.1	192.0
	1980	2124.8	2208.3	147.7
	1981	2078.3	2732.9	137.2
	1982	1948.3	3375.4	270.3
	1983	1982.5	4895.8	509.7
	1984	1789.8	4807.4	614.1
	1985	1974.9	5447.4	777.4
	1986	1912.9	6289.1	906.9

[1]Class 2 = 5-50 GRT; Class 3 = 51-150 GRT; Class 4 = 151-500 GRT.

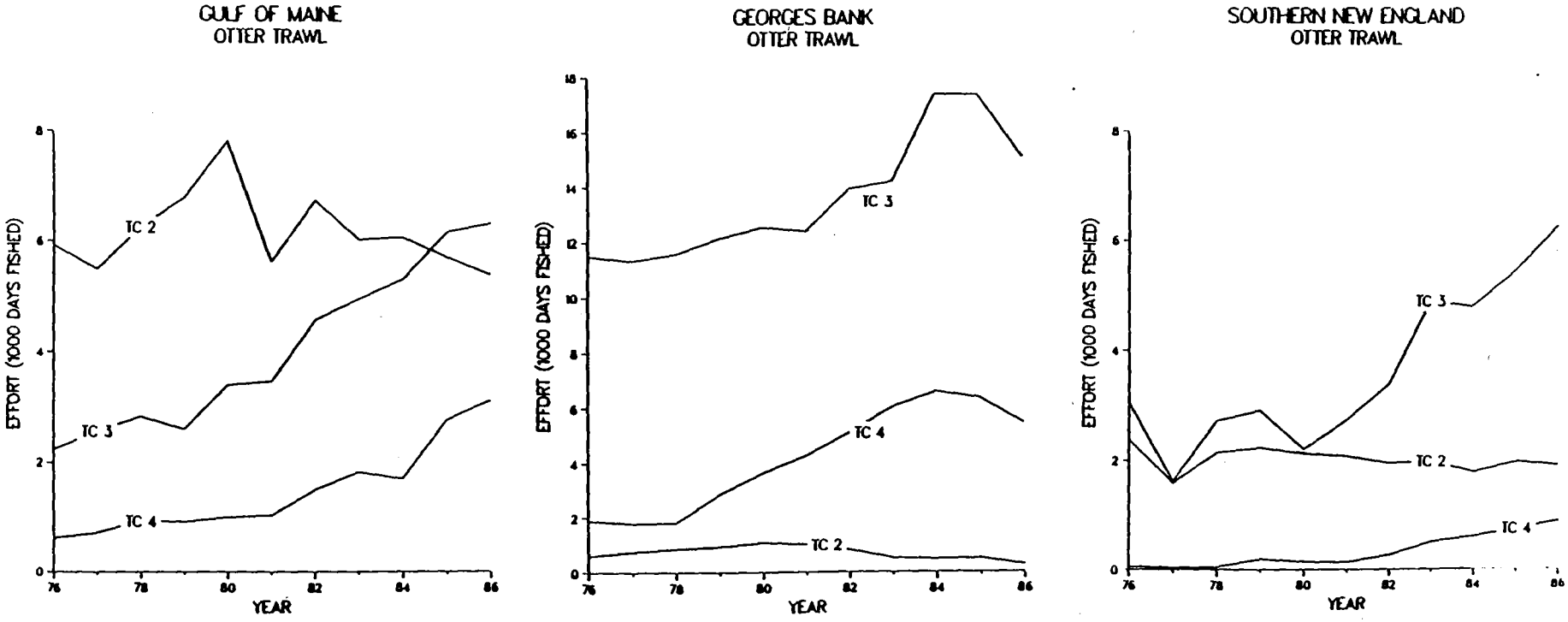


Figure 3.2 Total nominal fishing effort (days fished) by otter trawl vessels in three tonnage size classes fishing in the Gulf of Maine, Georges Bank, and Southern New England, 1976-1986.

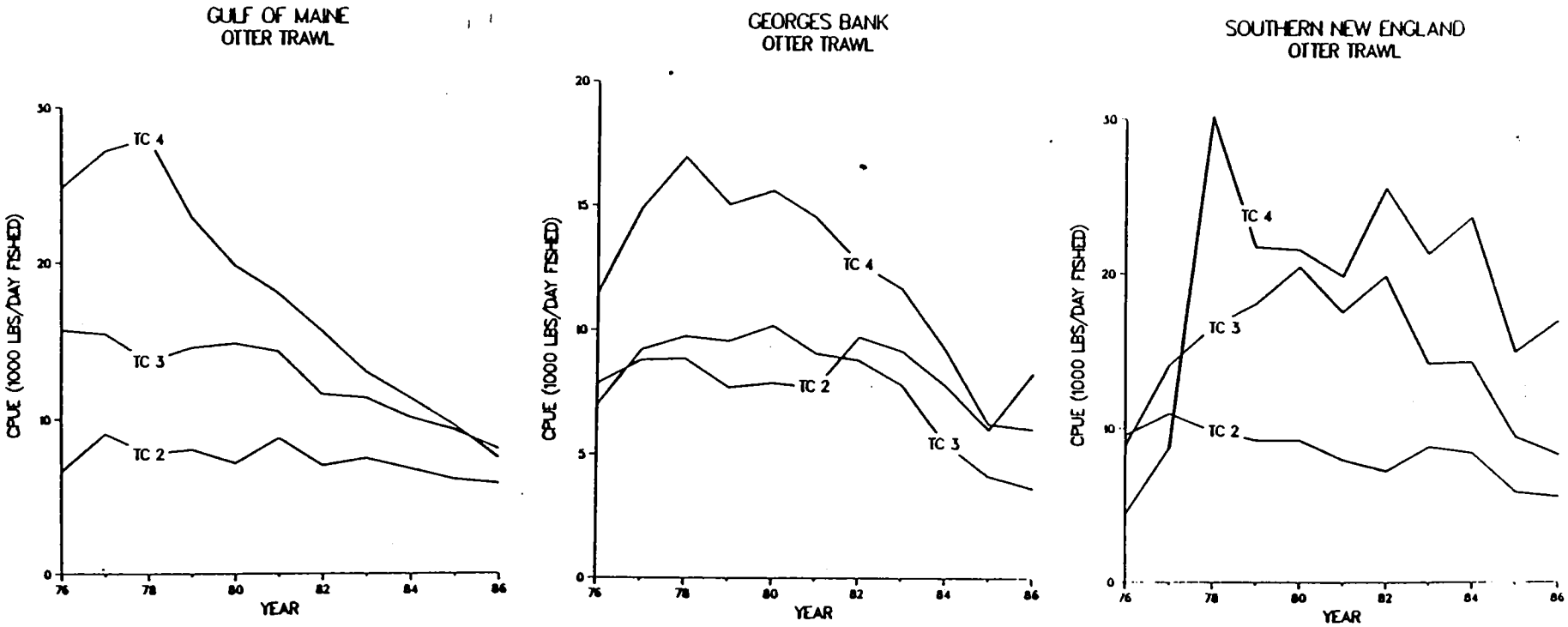


Figure 3.3 CPUE (pounds per day fished) by otter trawl vessels in three tonnage size classes fishing in the Gulf of Maine, Georges Bank, and Southern New England, 1976-1986.

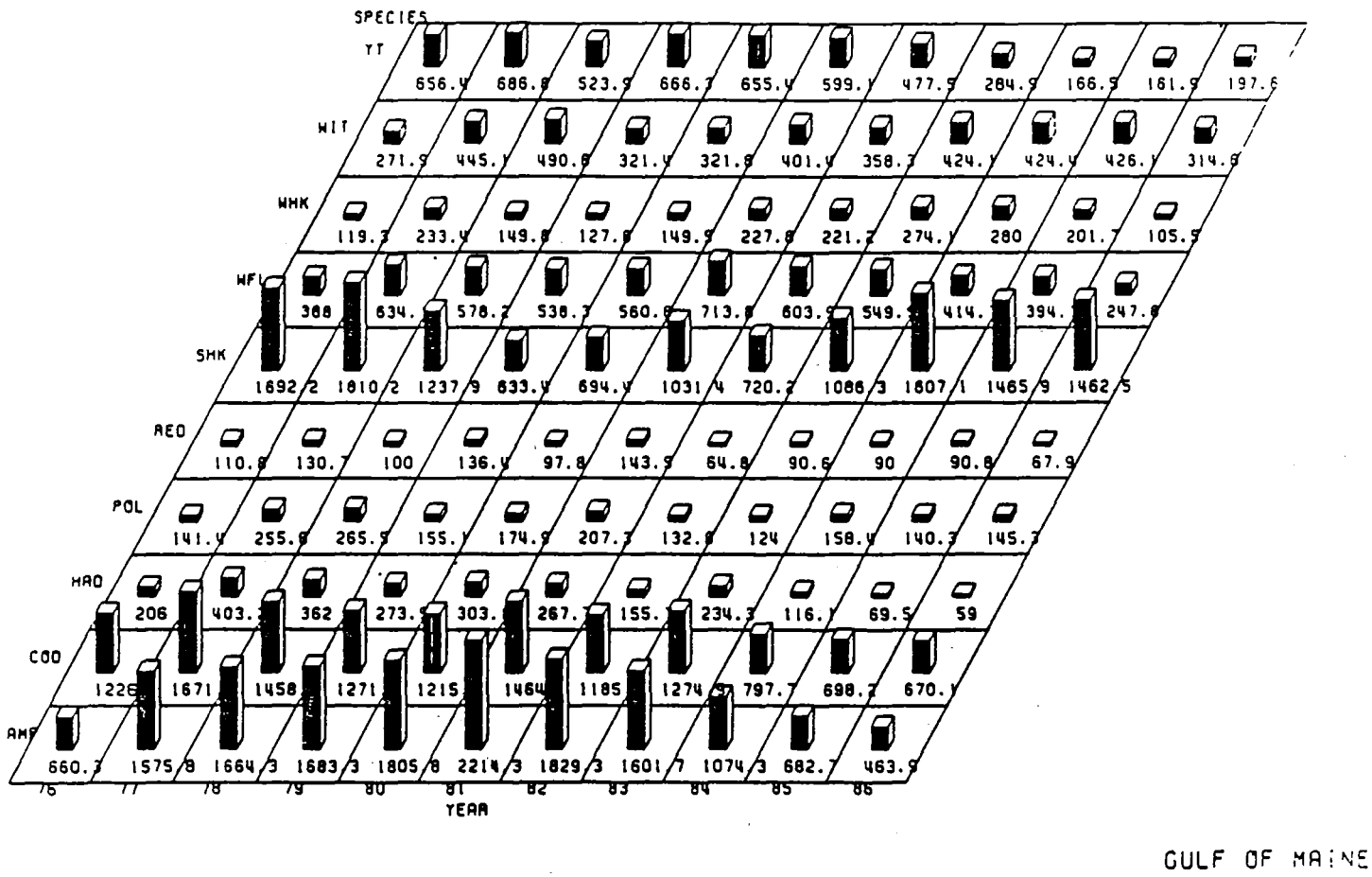
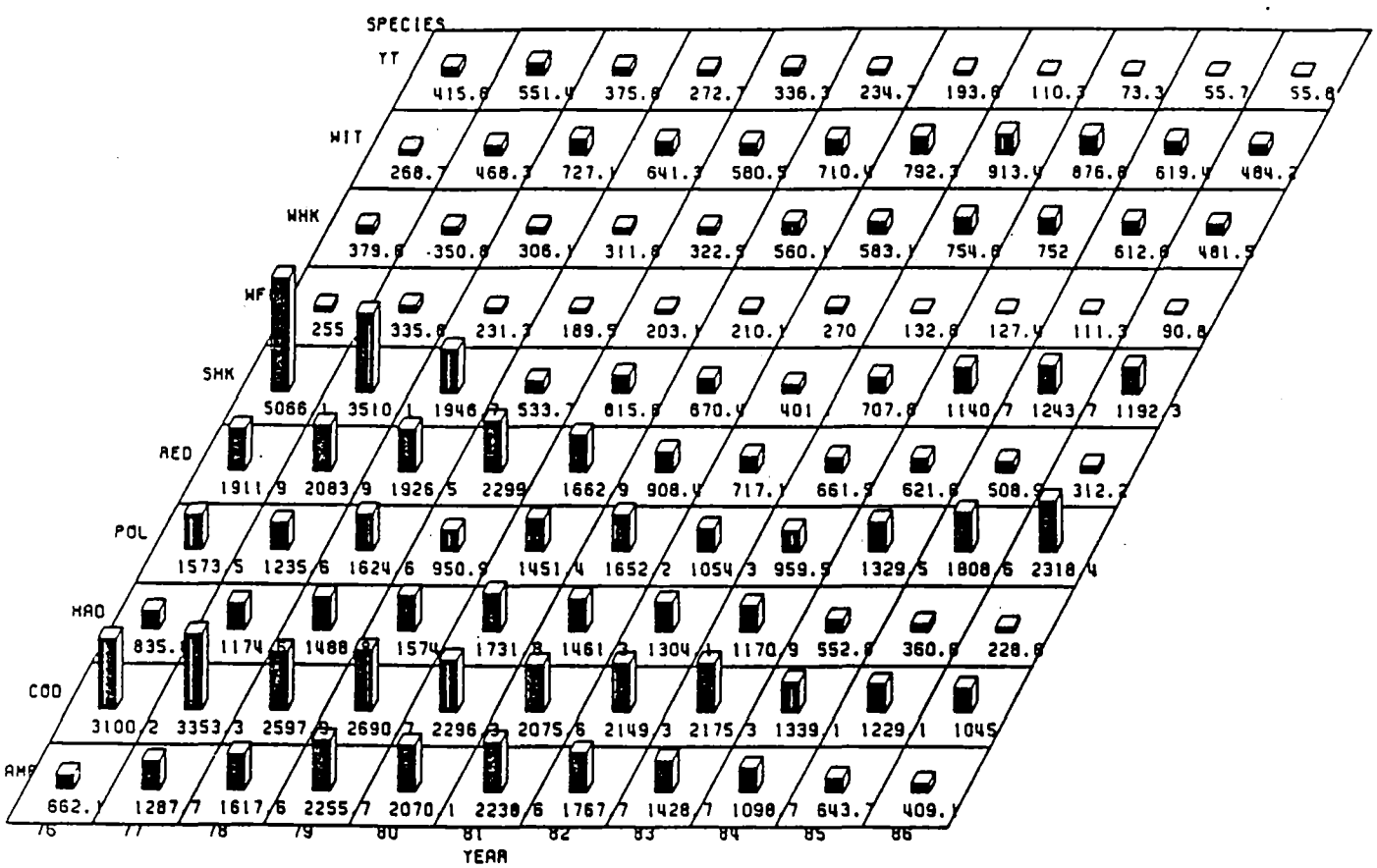
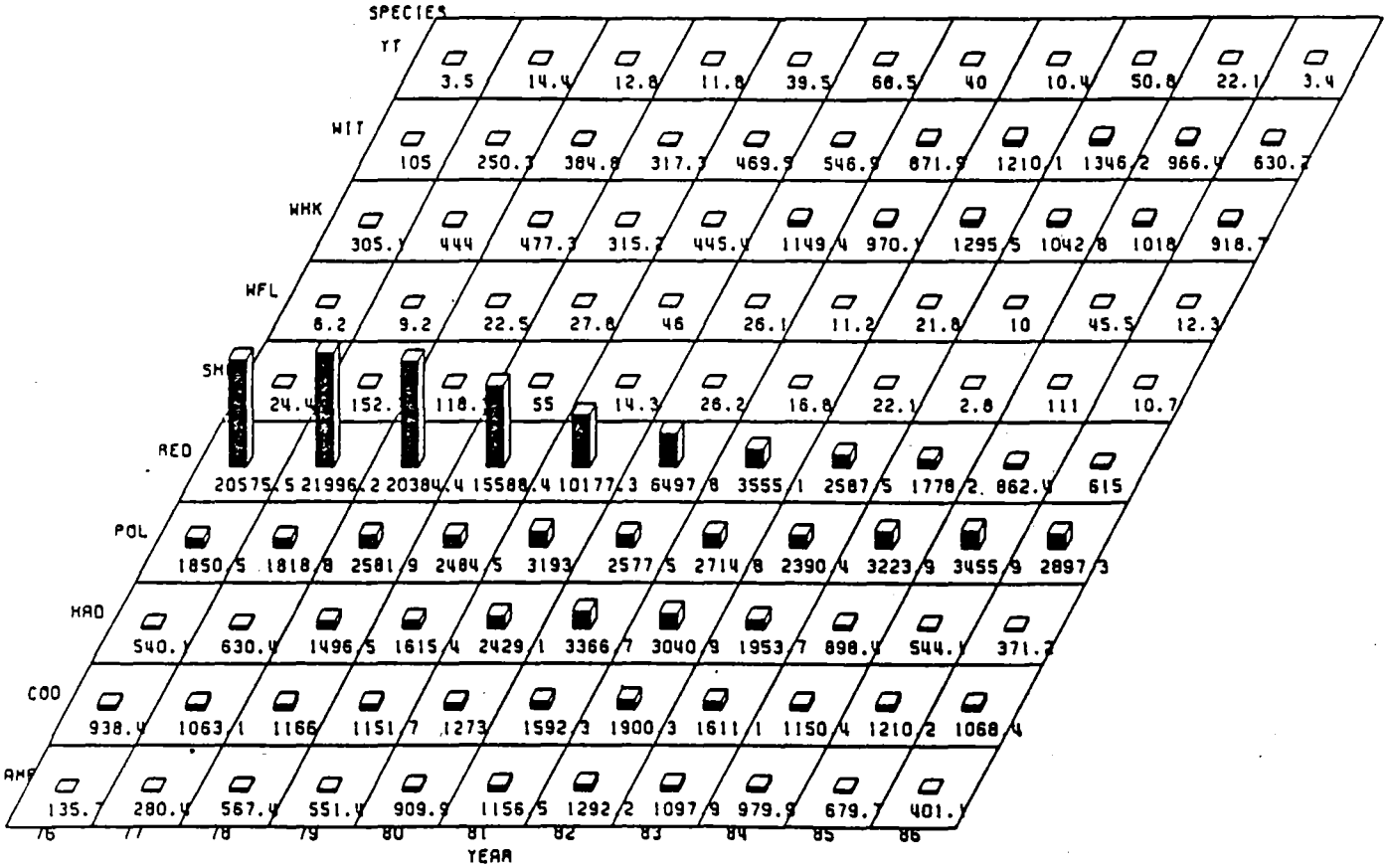


Figure 3.4a Species composition (expressed in pounds per day fished) of landings by tonnage class 2 otter trawl vessels fishing in the Gulf of Maine, 1976-1986. Data are additive within years.



GULF OF MAINE

Figure 3.4b Species composition (expressed in pounds per day fished) of landings by tonnage class 3 otter trawl vessels fishing in the Gulf of Maine, 1976-1986. Data are additive within years.



GULF OF MAINE

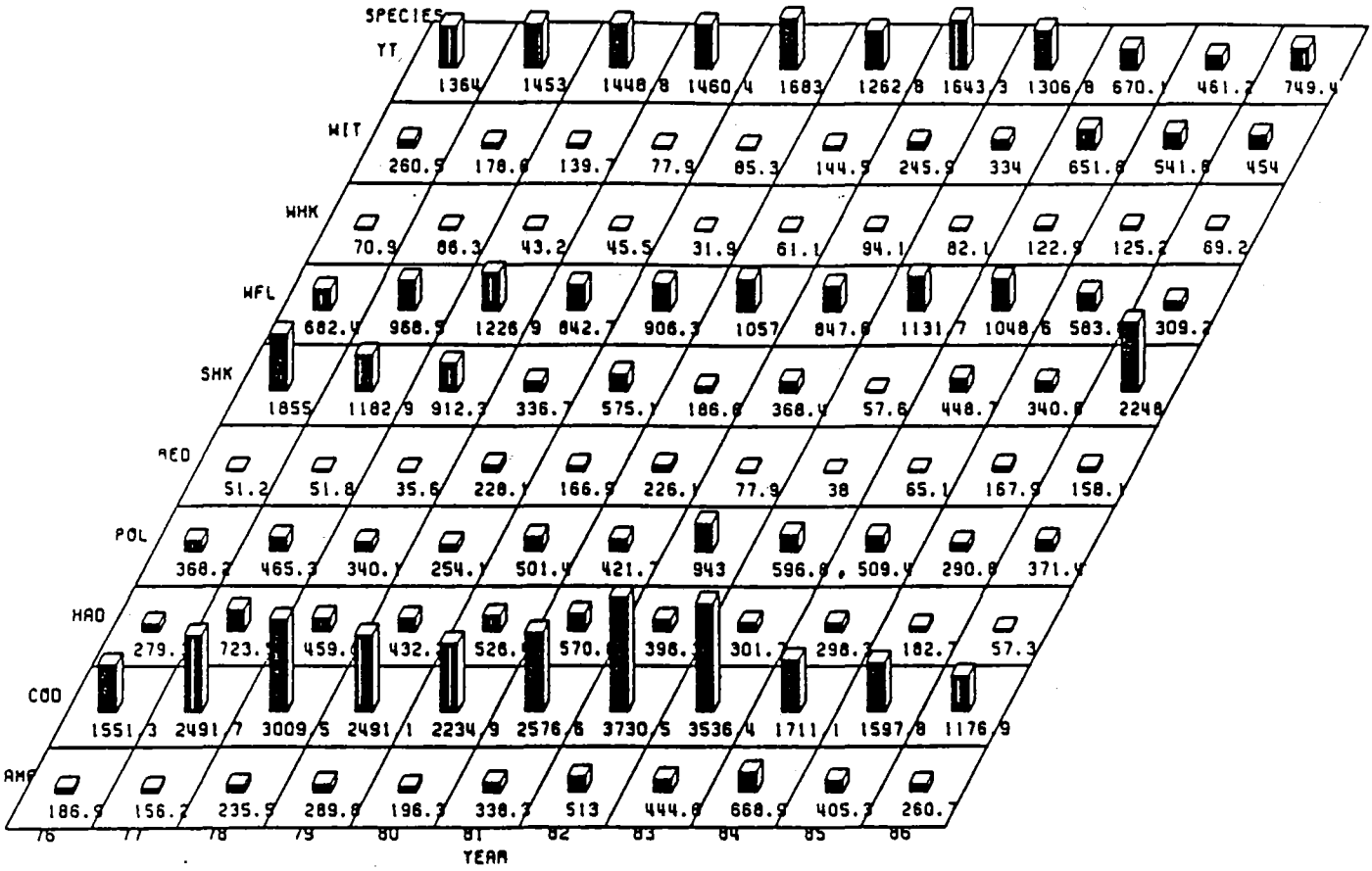
Figure 3.4c Species composition (expressed in pounds per day fished) of landings by tonnage class 4 otter trawl vessels fishing in the Gulf of Maine, 1976-1986. Data are additive within years.

In the Georges Bank region, TC 2 CPUE has remained relatively stable, whereas TC 3 and 4 multispecies CPUE has declined steadily and significantly since 1978 for TC 4 and 1980 for TC 3 (Figure 3.5). TC 2 catches on Georges Bank account for a very small proportion of the regional total, and have been composed primarily of cod, winter flounder and yellowtail flounder (Figure 3.5a). However with the recent declines in these resources, silver hake has increased in importance, especially in 1986. TC 3 CPUE has in past years been dominated by four species: cod, haddock, yellowtail flounder, and winter flounder (Figure 3.5b). Given the lack of abundant alternative species on Georges Bank and declines in aggregate CPUE, it appears unlikely that TC 3 vessels have been successfully compensating for declining CPUE in these particular stocks by substituting large quantities of other species in their catches. TC 4 vessels on Georges Bank have relied on cod, haddock and to an extent pollock, which has become increasingly important in recent years (Figure 3.5c).

In the Southern New England region multispecies CPUE is determined primarily by species not included in the ten analyzed herein. CPUE by TC 2 vessels off Southern New England declined steadily since 1977 (Figure 3.6). Three of the ten demersal species contribute significant proportions of TC 2 SNE CPUE, including silver hake, winter flounder, and yellowtail flounder (Figure 3.6a). All three species have exhibited declining CPUE by TC 2 during recent years. TC 3 multispecies CPUE has declined markedly since 1982, coincident with declines in CPUE of yellowtail flounder, winter flounder, and silver hake (Figure 3.6b). TC 4 CPUE has fluctuated erratically over the period, primarily as a result in changes in availability and abundance of pelagic populations sought by this class (e.g. squid, butterfish). Nevertheless, CPUE by TC 4 vessels of yellowtail, winter flounder and silver hake have declined since 1983 (Figure 3.6c).

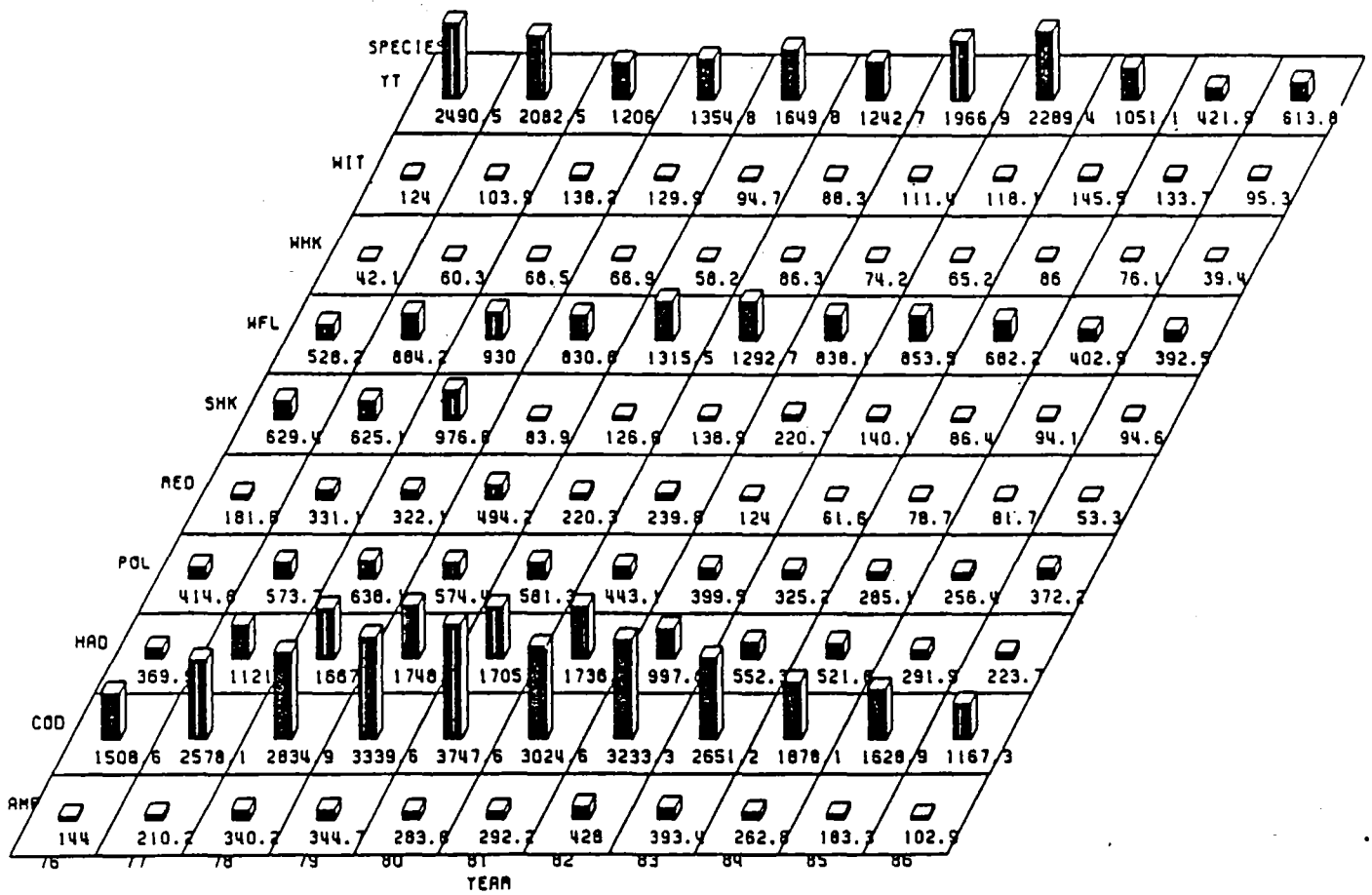
3.4. Summary of Trends in Fishing Effort and CPUE

Analyses of time-series data on interannual trends in nominal otter trawl fishing effort and catch per unit effort, by area and vessel size class, document the rapidly declining resource abundance of the multispecies groundfish complex as a whole, coincident with increasing fishing mortality rates and effort, particularly since 1980. Total nominal effort increased from 28.3 thousand days fished in 1976 to 34.0 thousand days in 1980 (+20%), and to 44.8 thousand days in 1986 (+58% over 1976). A disproportionate increase in effort was attributable to larger, more efficient stern-rigged trawlers, and thus if standardized to a common vessel size class, the increase in effort during the period would be even more dramatic. For example, effort of class 2 vessels in the Gulf of Maine remained relatively stable during the 11 year period, but for classes 3 and 4 increased 183% and 408%, respectively (Table 3.3). Similar patterns are apparent for the Georges Bank and Southern New England areas. Since a large, and increasing, percentage of the landings of the ten regulated species are derived by otter trawl gear, the dramatic increases in fishing mortality rates observed for stocks such as Georges Bank cod and Gulf of Maine cod and haddock are certainly attributable to increased otter trawl effort during this period.



GEORGES BANK

Figure 3.5a Species composition (expressed in pounds per day fished) of landings by tonnage class 2 otter trawl vessels fishing on Georges Bank, 1976-1986. Data are additive within years.



GEORGES BANK

Figure 3.5b Species composition (expressed in pounds per day fished) of landings by tonnage class 3 otter trawl vessels fishing on Georges Bank, 1976-1986. Data are additive within years.

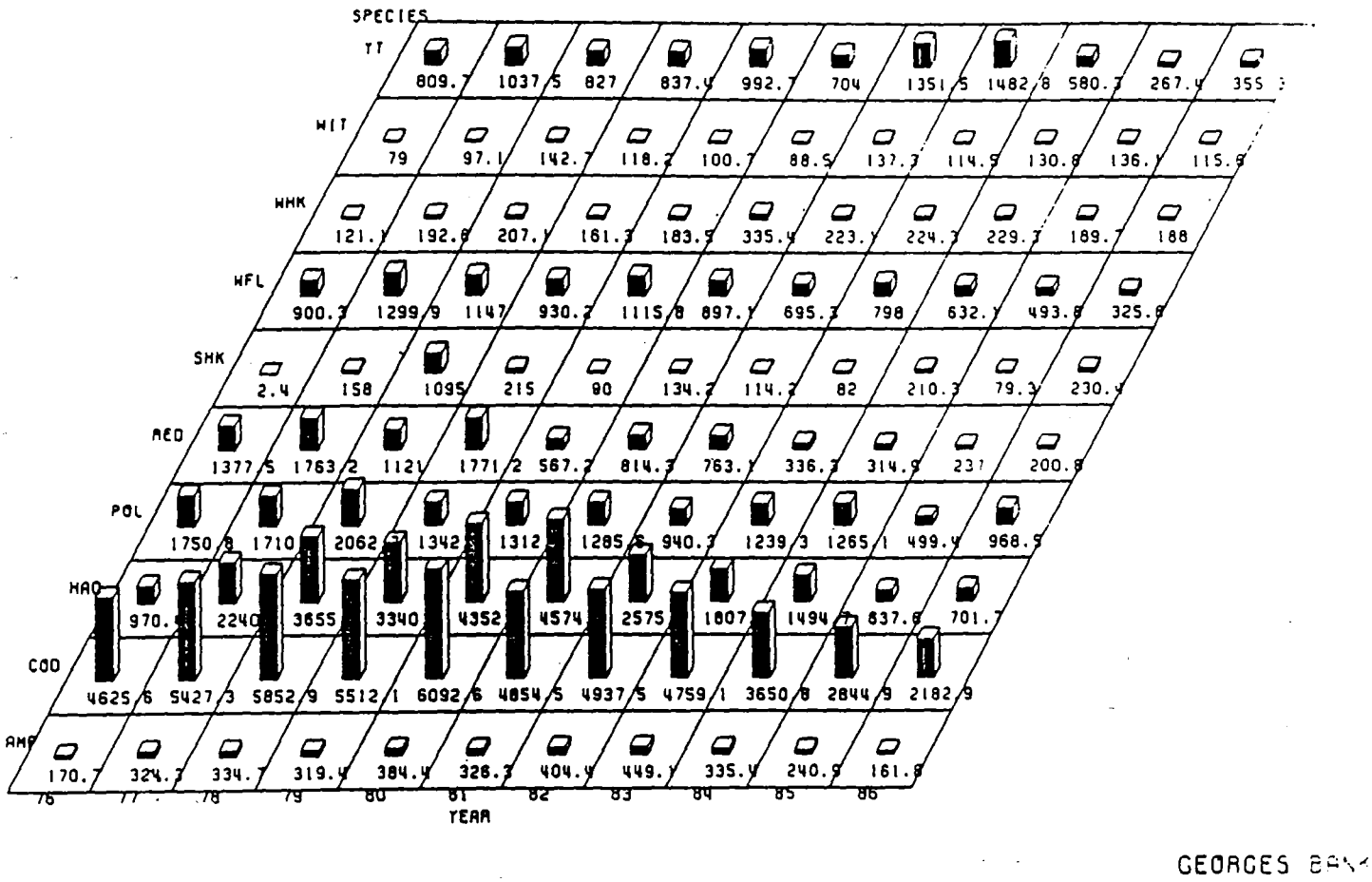
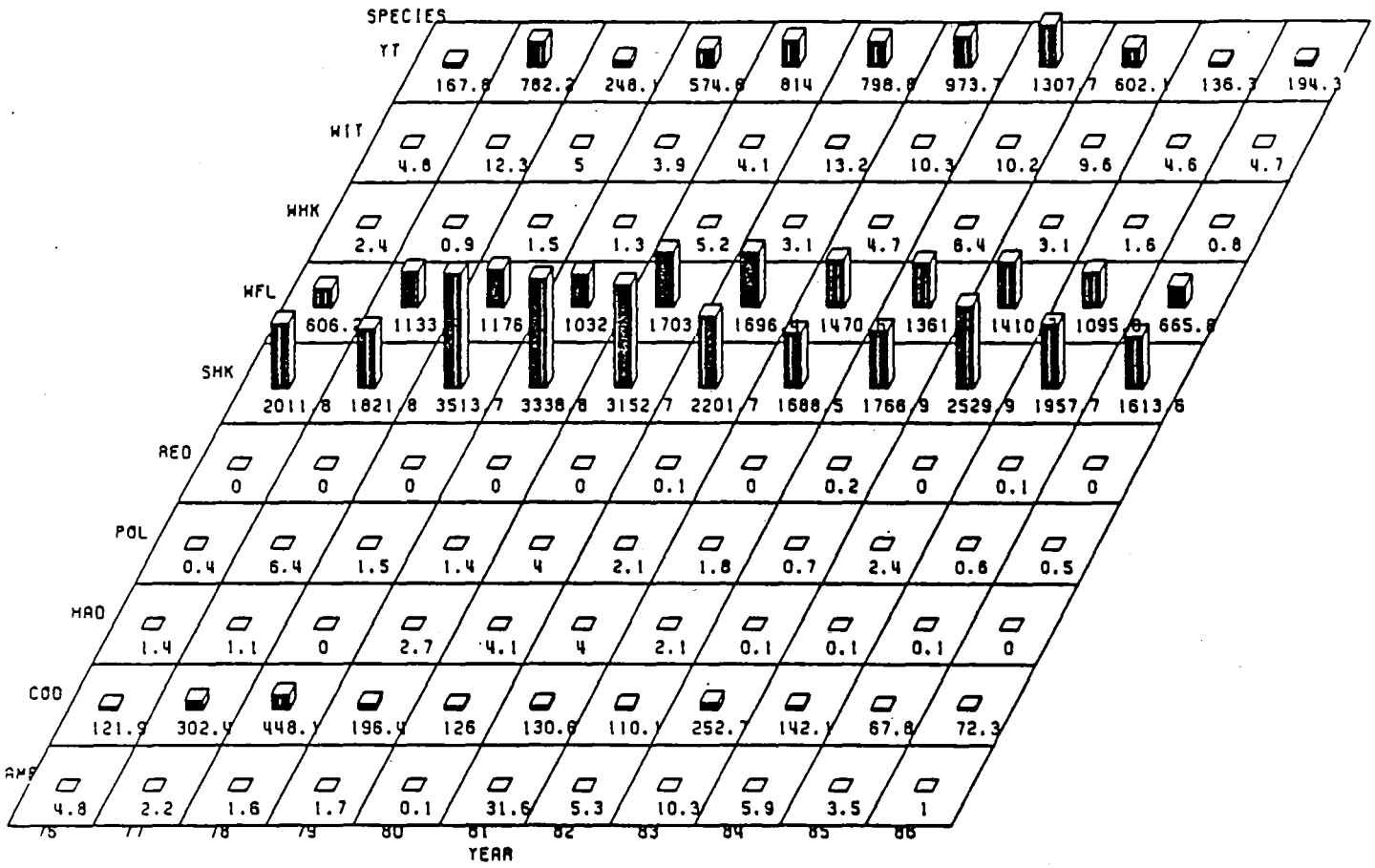
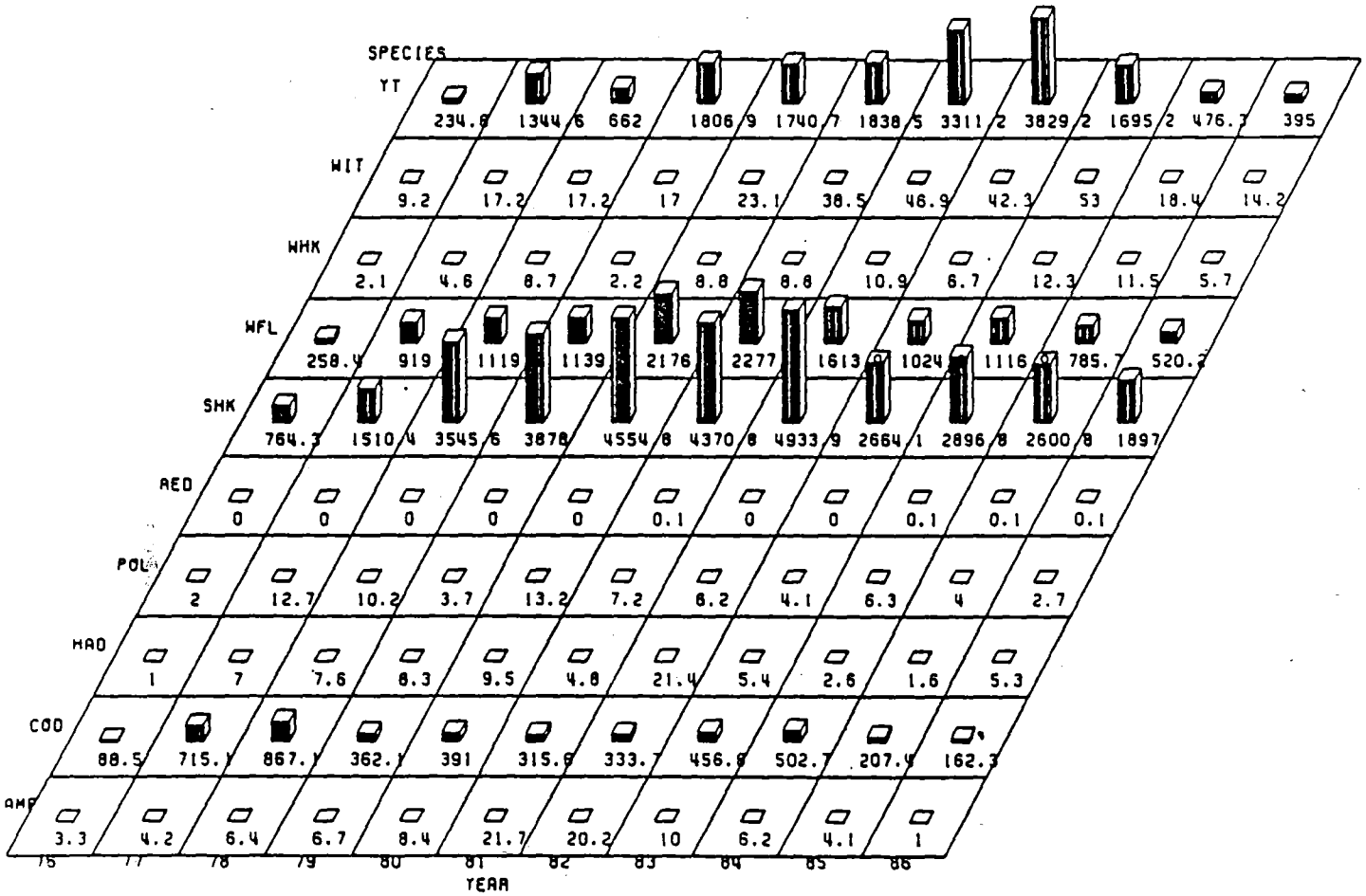


Figure 3.5c Species composition (expressed in pounds per day fished) of landings by tonnage class 4 otter trawl vessels fishing on Georges Bank, 1976-1986. Data are additive within years.



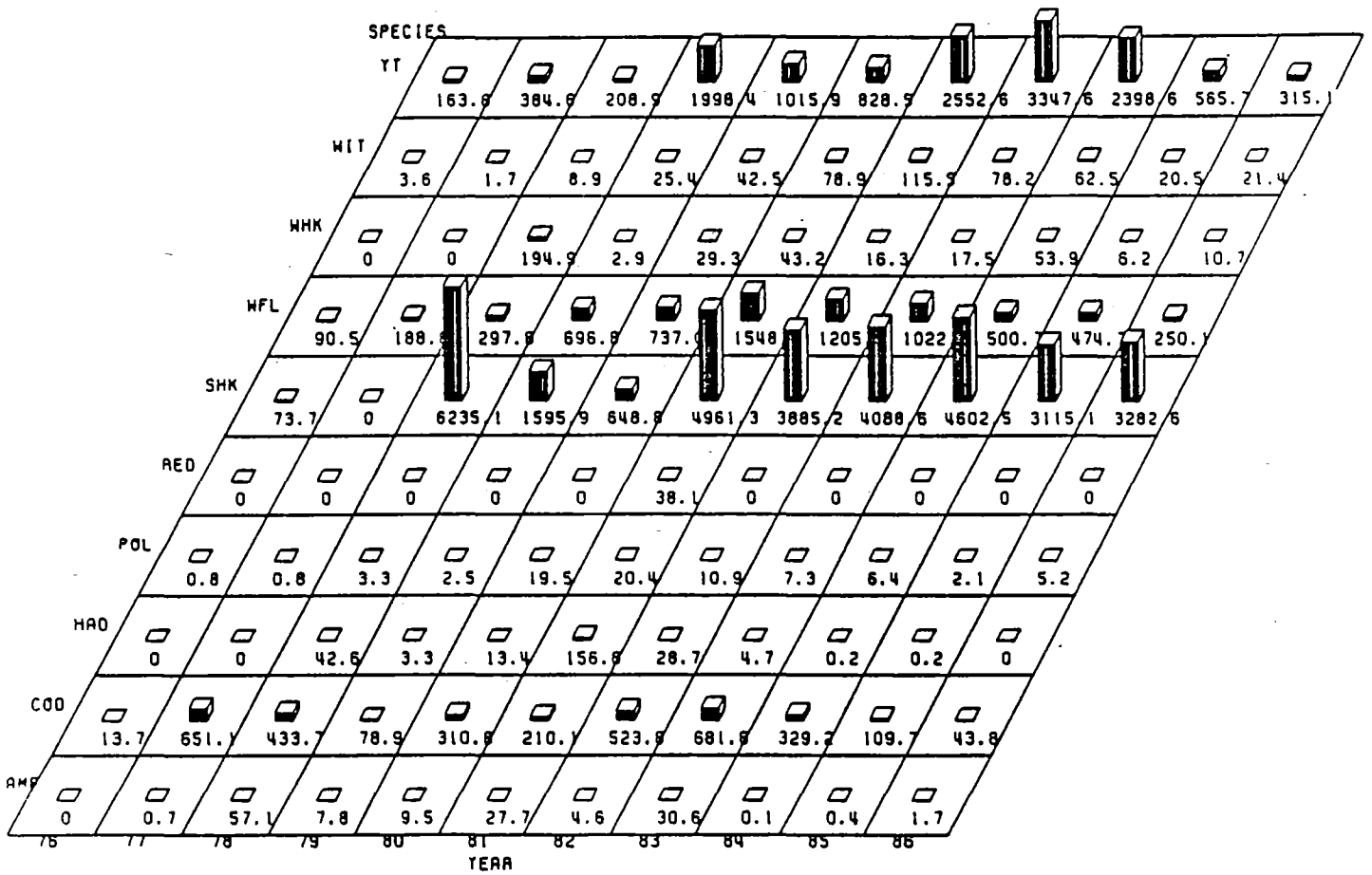
SNE

Figure 3.6a Species composition (expressed in pounds per day fished) of landings by tonnage class 2 otter trawl vessels fishing in Southern New England, 1976-1986. Data are additive within years.



SNE

Figure 3.6b Species composition (expressed in pounds per day fished) of landings by tonnage class 3 otter trawl vessels fishing in Southern New England, 1976-1986. Data are additive within years.



SNE

Figure 3.6c Species composition (expressed in pounds per day fished) of landings by tonnage class 4 otter trawl vessels fishing in Southern New England, 1976-1986. Data are additive within years.

Changes in fishery productivity as measured by landings per nominal day fished are likewise indicative of rapidly increasing effort and declining multispecies stock abundance. Even without accounting for increases in relative fishing power of vessels within size classes during the period, multispecies CPUE has declined drastically for most vessel size classes. All-species CPUE declined from 14.9 thousand pounds per day for class 3 vessels in the Gulf of Maine during 1980 to 8.1 thousand pounds in 1986 (-46%). Similarly, landings per day for class 3 on Georges Bank declined 64%, from 10.2 to 3.7 thousand pounds. Smaller (class 2) vessels have generally exhibited smaller decreases in productivity because of their declining reliance on the regulated species. Nevertheless, these small vessels have accounted for a decreasing share of total otter trawl landings during the period.

Decreases in fishery productivity for particular species are even more dramatic than the aggregate statistics. In most cases the dramatic declines in productivity of relatively high-valued species (e.g. haddock, cod, flounders) have been partially substituted for low-value species such as silver hake, pollock, and white hake. Barring a dramatic increase in abundance of some of the currently depressed species, however, it is unlikely that landings per day fished can be stabilized at the current high effort levels, and further declines in CPUE and multispecies stock abundance will occur during the next few years.

4. STOCK AND CATCH PROJECTIONS UNDER DIFFERENT MANAGEMENT OPTIONS

4.1. Description of Methods

Several types of management actions could be taken to meet the target %MSP goals of the FMP, as discussed above. Because the difference between the current %MSP and the FMP targets is large, management measures that would meet the targets would necessarily have large effects on future catches in the short term. To provide a basis for evaluating the economic consequences of such management actions, a model of the dynamics of the several populations was developed. This model projects future stock size and catches under a variety of management options over several years. The projected catches over time can be compared to determine the relative consequences of alternate management actions.

4.1.1. Age Structured Population Projections

Future catches and population sizes were estimated using an age structured model. The basic form of the model is:

$$N_{t+1,i+1} = N_{t,i} e^{-(r_{t,i} F_t + M)} \quad . \tag{4.1}$$

where $N_{t,i}$ = number of individuals i in year t of age i

M = instantaneous natural mortality rate

F_t = instantaneous fishing mortality ratein year t

$r_{t,i}$ = the fraction of the individuals age i at time t that are recruited into the fishery

Using equation 4.1 to project the population, the projected landings can be calculated as:

$$C_t = \sum_{i=1}^{k} W_i L_i \left(\frac{r_{t,i} F_t}{r_{t,i} F_t + M}\right) N_{t,i} \left(1 - e^{-(r_{t,i} F_t + M)}\right) \tag{4.2}$$

where C_t = the total landings in year t

$L_{t,i}$ = the proportion of an age class in year t that was landed given that it was caught

W_i = the average weight of an individual i years of age

k = the oldest age of individuals in the catch

and the other parameters are as defined as above.

Also the size of the spawning stock biomass at the time of spawning can be estimated as:

$$S_t = \sum_{i=1}^{k} W'_i P_i N_{t,i} e^{-(r_{t,i} F_t B_1 + M B_2)} \qquad (4.3)$$

where S_t = the spawning stock biomass in year t

P_i = the proportion of individuals of age i which are mature

B_1 = the fraction of annual fishing mortality that occurs before spawning

B_2 = the fraction of annual natural mortality that occurs before spawning

W'_i = the average weight of individual age i at the time of spawning

and other parameters as defined above.

Equations 4.1 to 4.3 represent commonly used fishery equations for modelling the dynamics of fish stocks under exploitation, and are similar to those used in the FMP. The present model is an improvement over that used in the FMP however, in incorporating both density dependent and stochastic effects on recruitment. These improvements partly meet the research requirements identified by Marchesseault (1986).

Instantaneous fishing mortality over all ages can be modelled as the product of a constant fishing mortality rate parameter (F_t) times an age (size) selective recruitment parameter ($r_{t,i}$). The latter parameter is part of a partial recruitment vector, an age-specific exploitation pattern obtained from a size-selection pattern of gear or a mixture of gears. In evaluating any proposed management option with this model, it is necessary to translate or estimate the effect of a management option in terms of these two sets of parameters.

4.1.2. Stochastic Recruitment

In order to project future catches and stock sizes, it is necessary to model the recruitment process, that is how new individuals entering the population. Standard recruitment models generally assume density dependence, that is, that the recruitment rate increases as the population declines. However, the recruitment process is probably the most difficult to study and the least understood of the several dynamic processes affecting the fish stocks under the FMP. With the exception of Georges Bank haddock and possibly the pollock and redfish stocks considered, there is little empirical evidence for density-dependence in recruitment and consequently only a limited basis for developing density-dependent models.

Available data on recruitment suggest that there is a large amount of year to year variability in the recruitment process, and it was considered important to incorporate this variability into the population projections. The following model was used to produce estimates of future recruitment:

$$R_t = R\, e^{x_t} \tag{4.4}$$

where R_t = recruitment in year t

R = the geometric average of the observed recruitment

x_t = a random normal variable with mean 0 and variance S^2_R (S^2_R calculated from the logarithm of the observed recruitment) .

Equation 4.4 assumes that the recruitment process is random with a constant mean and log normal variance. Available data suggest that the recruitment distributions tend to be skewed (i.e. the majority of the observations are less than the mean with a few very large values above the mean), for which the log normal provides a reasonable approximation. Although this uncorrected form gives somewhat biased results, the resulting conservative values of R are suitable for relative comparisons.

Application of the stochastic model above varied for different stocks, depending on available data. For Georges Bank haddock, and for redfish and pollock, there is evidence that R changes at different stock sizes. For these three stocks a step function was used for R and S^2_R. R and S^2_R were assumed to be constant within a given range of population size. When the population moved into a different range, a different mean R, and a different variance S^2_R were assumed to apply. The actual values used were calculated from estimates of recruitment and stock sizes from VPA analysis and are given in Table 4.1. By making R a step function of population size, recruitment for these stocks has a density dependent component.

Table 4.1 Spawning stock size ranges (metric tons) and corresponding parameter values for stocks in which a density dependent stochastic recruitment model was used. R is mean recruitment (000s of fish) and S_R is the standard deviation of R expressed on a logarithmic scale.

Stock	Stock Size Range	R	S_R
Georges Bank Haddock			
	0 - 50,000	7,168	1.669
	50,000 - 100,000	15,934	1.623
	100,000 - 150,000	44,449	1.549
	150,000 - 200,000	66,636	1.549
	>200,000	19,160	1.661
Pollock			
	<105,000	39,034	0.435
	>105,000	26,030	0.739
Redfish			
	<75,000	2,216	2.063
	>75,000	4,741	2.092

For all the other stocks, the mean recruitment was assumed to be constant since the available data were insufficient to parameterize a change in R with changes in stock size. For some stocks (i.e. American plaice, Georges Bank winter flounder, Southern New England winter flounder and witch flounder) data did not exist to estimate even the variance in the recruitment process. For these stocks, S^2_R was set to zero, or in other words, a constant fixed model was used for the recruitment process. The values of the parameters used for those stocks with constant recruitment are given in Table 4.2.

Constant stochastic or fixed models for recruitment were used because of data limitations. The expected gains and losses under different management options are dependent on the recruitment model. For example, the potential gains under management measures for rebuilding will be much lower with a constant recruitment model than with a model incorporating strong density-dependent responses. Similarly, the effect of a management policy that resulted in "overfishing" would be underestimated or might not even be apparent under a constant recruitment model. Catch projections become more sensitive to the recruitment model as the length of the projection increases and as the equilibrium stock size and age structure implied by a management option differ from the initial conditions. Future research, in terms of analysis of existing data, development of alternative recruitment models, and future data collections could both improve and change the estimated projections provided below.

4.1.3. Partial Recruitment

In order to estimate projected catch using the age structured model described above, it is necessary to specify the age-specific selection pattern or a partial recruitment vector that will operate under a specified management option. In the projections below, all of the partial recruitment vectors were generated from previous mesh selectivity studies. Vectors were applied under the assumption that all vessels would operate with a given effective mesh size and size selective pattern observed by Smolowitz (1983). Note, as was emphasized in Section 2.6, that a regulatory mesh size cannot be expected to equal effective mesh size, i.e., regulatory mesh will generally yield a partial recruitment vector that corresponds to a smaller effective mesh size.

Partial recruitment vectors were developed by first assuming that a mesh selection ogive (curve showing proportion of fish retained by a given mesh size as a function of fish length) could be described by a cumulative normal function. The variance was estimated from probit analysis of data from reported mesh selection studies (Smolowitz 1983). The mean was estimated as the mesh selection factor (Smolowitz 1983) times the effective mesh size. Table 4.3 provides the species-specific values for mesh selection parameters and the variances used for the cumulative normal functions.

In order to use the above theoretical size selective function in the context of the age structured model, it was necessary to translate the size selectivities into age selectivities or an age-specific partial recruitment vector. This was done by estimation from species-specific age-length growth

Table 4.2 Values for recruitment parameters for stocks modeled assuming constant recruitment. R is mean recruitment (000s of fish) and S_R is the standard deviation of R expressed on a logarithmic scale.

Stock		R	S_R	Source for Parameters
American Plaice		44,795	0.000	Equilibrium[1]
Cod:	Georges Bank	21,036	0.517	VPA (1979-1986)
	Gulf of Maine	8,047	0.256	Backcalculation[2] (1981-1984)
Haddock:	Gulf of Maine	659	1.730	Backcalculation[2] (1980-1984)
Winter flounder:				
	Georges Bank	4,162	0.000	Equilibrium[1]
	Southern New England	36,049	0.000	Equilibrium1
Witch flounder		58,180	0.000	Equilibrium[1]
Yellowtail flounder:				
	Georges Bank	25,271	0.637	Modified DeLury (1974-1983)
	Southern New England	18,215	1.470	Backcalculation[2] (1980-1984)

[1]Recruitment was estimated such that the population would be stationary, given the initial population age structure and the current (1986) level of fishing mortality.

[2]Recruitment was estimated by back calculation from initial population size, assuming constant F, M, and partial recruitment at the current (1986) level over the life of all cohorts. For the most recent year classes, recruitment was adjusted based on NEFC survey information on relative year class strength.

Table 4.3 Parameter values used for estimating the partial recruitment vector corresponding to a specific effective mesh size.

Species	Mesh Selection Parameters	Variances
American Plaice	2.35	6.849
Cod	3.60	7.918
Haddock	3.40	7.580
Pollock	3.30	7.696
Redfish	2.50	6.234
Winter Flounder	2.20	5.121
Witch Flounder[1]	2.20	5.121
Yellowtail Flounder	2.25	4.647

[1]No mesh selectivity data were available for witch flounder. Values were assumed to be equal to those for winter flounder.

curves from previous studies. For any given age i, the estimated partial recruitment value was calculated by taking the length interval of an age i to i + 1 fish from the growth curve, dividing it into 10 equal sizes and then taking the average partial recruitment over all of these 10 sizes as the partial recruitment value for age i. This method of estimating the partial recruitment value for a specified age given a growth curve and size-specific retention function is an approximation that essentially assumes growth is deterministic and linear throughout an age interval and ignores the within-year reduction in the size of an age class due to mortality.

4.1.4. Initial Age Structure

For stocks for which VPA (Georges Bank cod, Georges Bank haddock, pollock, redfish) or modified DeLury estimates (Georges Bank yellowtail flounder; Collie and Sissenwine, 1983) were available, initial numbers at age from those analyses were used. New regulations were assumed to take effect January 1988, and so projections were begun from the last year of the number-at-age analysis to develop an initial number at age in 1988.

For species-stocks for which recent age composition of the catch was available (Gulf of Maine cod, Gulf of Maine haddock, Southern New England yellowtail flounder), initial numbers at age were estimated using the Baranov catch equation, assuming current F levels, species-specific exploitation patterns, and that fish below the minimum length would be discarded.

For species for which no recent age data were available, (witch flounder, winter flounder, American plaice), numbers at age were generated from catch and individual weights at age assuming constant F, recruitment, exploitation and discard patterns for all cohorts in the standing stock. These "equilibrium" assumptions, though unrealistic, allowed catch projections to be undertaken to satisfy data requirements of economic analyses. In most cases, current F was unknown and was estimated based on F's observed from other species in the same region. Reliability of these estimates is then the lowest of the three groups described. Until age-specific estimates of catch can be obtained, the effects of alternative assumptions on stock size estimates should be evaluated, as these assumptions are essentially responsible for the results. No estimates were attempted for windowpane flounder and white hake.

4.1.5. Input Parameter Estimates

In order to apply the age structured model described, a large number of input parameters are required, most of the sources of which have been discussed above. In all cases, the most recent and "best" available data were used to estimate each parameter. For some stocks, relevant data were not available, and parameter values were extrapolated from analogous values for similar stocks. In the case of interacting parameters such as growth and maturity rates, both rates were extrapolated. Table 4.4 summarizes the values or sources used for the main input parameters that have not been displayed above.

Table 4.4 Summary of input parameters used for catch and stock size projections for major species/stocks regulated under the Fishery Management Plan for the Northeast Multispecies Fishery.

Input Parameters	Cod GB	Cod GM	Haddock GB	Haddock GM	Yellowtail Flounder GB	Yellowtail Flounder SNE	Pollock	Redfish	American Plaice	Winter Flounder GB	Winter Flounder SNE	Witch Flounder
Current F (1986)	0.50	0.62	0.50	0.70	1.00	1.00	0.73	0.17	0.35	0.50	0.50	0.30
Initial Stock Age Structure (Source)	VPA	Comm Catch	VPA	Comm Catch	DeLury Analysis	DeLury Analysis	VPA	VPA	Equil	Equil	Equil	Equil
Recruitment Model[1]	Const Stochast	Const Stochast	Density Depend Stochast	Const Stochast	Const Stochast	Const Stochast	Density Depend Stochast	Density Depend Stochast	Const Fixed	Const Fixed	Const Fixed	Const Fixed
USA Proportion of Total Catch	0.75	1.00	0.50	1.00	1.00	1.00	0.33	1.00	1.00	1.00	1.00	1.00
Proportion of Annual Mortality Occurring Before Spawning	0.17	0.17	0.17	0.17	0.33	0.33	0.00	0.50	0.21	0.25	0.07	0.50
Age/Length Equation (Source)	Penttila & Gifford (1976)		Overholtz et al. (1983)		Lux & Nichy (1969)		Mayo & Clark (1980)	Mayo (1980)	Sullivan (1982)	Lux (1969b)	Berry et al. (1965) Howe & Coates (1975)	Burnett (1987)
Length/Weight Equation (Source)	Serchuk & Wigley (1986)		Overholtz et al. (1983)		Lux (1969a)		Mayo & Clark (1980)	Brown (1963)	Lux (1969a)	Lux (1969a)	Lux (1969a)	Lux (1969a)
Maturity Schedule (Source)	Morse (1979)		Overholtz (Pers Comm)		Morse (1979)		Beacham (1983)	Perlmutter & Clark (1949)	Morse (1979)	Morse (1979)	Morse (1979)	Burnett (1987)

[1]See Section 4.1.2 for fuller explanation of recruitment models.

The parameter L_i (the proportion of catch that was landed for age class i) reflects the effect of fish size limits on landings. For each effective mesh size, the legal minimum fish size was set equal to the 25% retention length (i.e., 25% of the fish at that length would be retained by the associated mesh). The proportion of fish in an age class at or above that length was estimated from the mesh selection ogive and age-length curves (Section 4.1.3). All fish greater than the size limit that were caught were assumed to be landed and all fish smaller then the size limit were assumed discarded. The survival rate for the discards was assumed to be zero.

Starting values of initial stock size and age structure in 1988 were obtained by projecting the most recent available stock size and age structure estimates forward until the beginning of 1988, assuming current F_t, partial recruitment vector for 4 1/2" effective mesh, and recruitment based on models described above.

The age structured model provides estimates of the total catch for a stock. Four of the stocks (Georges Bank haddock, pollock, Georges Bank cod, and Gulf of Maine cod) are jointly fished by U.S. and Canadian fisherman. In order to project the U.S. catch, it was assumed that the Canadian fishery would follow any changes in U.S. mesh regulations and that the fraction of the total catch landed by U.S. fishermen would be a constant based on the average observed fractions in the 1980's. The effects of alternate assumptions about the Canadian fishery are also explored.

4.1.6. Assumptions in the Catch Projections

A. Recruitment

As described above, recruitment data sets exhibiting density dependence are scarce (Georges Bank haddock, redfish, and, very weakly, pollock). Observations are required over a range of stock sizes. Models with constant mean and variance (cod, Gulf of Maine haddock, yellowtail flounder) show no density dependence and hence, will overestimate recruitment at higher stock sizes, rather than reflecting likely compensatory declines (e.g. as observed in the case of Georges Bank haddock). Likewise, at low stock sizes, the same mean recruitment is assumed to be obtained; in effect allowing identical mean recruitment at stock sizes of approximately zero, as at intermediate and maximum sizes. Thus, the most serious effects in these projections would be to overestimate recruitment at higher stock levels, and, for stocks that have most recently declined (e.g. Atlantic cod) overestimate recruitment at depressed stock levels. Models with constant mean and no variance (winter flounder, witch flounder, American plaice) suffer from identical shortcomings, compounded by virtually no information on stock and recruiting year-class sizes.

The definition of spawning stock biomass includes no density dependent mechanisms. Length (and age) at maturity is assumed constant over the entire range of stock sizes, even though length at maturity at low stock size is likely to be lower than at high stock size. Fecundity (and fertility) per

unit of mature spawning stock biomass is assumed to be equivalent regardless of age or stock size, an assumption also incorporated in defining SSB/R levels for replacement (Gabriel 1985).

All spawning is assumed to occur at a single point in time, which is constant from year to year. The effects of fishing mortality on pre-spawning biomass will vary if timing of spawning varies from year to year, if spawning is protracted, or if there is a seasonal component to the fishery. If spawning occurs after the designated point, spawning stock biomass would be overestimated. If a strongly seasonal component to the fishery to the fishery develops before spawning, spawning stock biomass would also be overestimated.

B. GROWTH

Weights (and lengths) at age in both the catch and stock are assumed to remain constant regardless of stock sizes, i.e. there are no mechanisms to incorporate effects of density dependent growth. In reality, mean weight at age is likely to decrease as stock size increases or, within a cohort, as a very large cohort moves through the stock. The net effect is to overestimate the spawning stock biomass and catch at higher stock sizes. The length - weight relationship is assumed to be constant over time. This relationship may change with stock or cohort density. At high densities, fish often weigh less at a given length than they do at lower spawning stock biomass and cohort densities.

For purposes of evaluating vulnerability to the gear at age, growth is assumed to be linear (non-seasonal) within any year, and lengths of all fish within the year are assumed identical at any instant. In reality, some fish will be smaller and some larger. Thus, fishing mortality on partially, theoretically unrecruited ages may be underestimated, as the fishery would likely remove the fastest growing animals within any age group.

Weights at age are assumed identical between Gulf of Maine and Georges Bank stocks of Atlantic cod and haddock, and between Georges Bank and Southern New England yellowtail flounder.

C. MORTALITY

Natural mortality rates are assumed to be constant over age, time and stock size. In fact, this results in an overestimate of spawning stock biomass and catch at high stocks sizes, since natural mortality may be expected to increase as stock size increases.

Fishing mortality is assumed to be generated primarily by large mesh otter trawls in simulations of mesh-related management options. The effects of small mesh/exempted fisheries are not explicitly incorporated in any alternative. It is not possible at this point to distinguish how much of the observed difference in effective and regulated mesh is due to operational characteristics of large otter trawls or the contribution of a small mesh component. There is also no provision for the selection patterns of alternate

gear types (gill nets, scallop dredges, long lines, pots, etc.) or seasonality in a fishery.

The selection ogives for large mesh sizes (>5.5") have been extrapolated from data collected for smaller meshes (Smolowitz 1983). This assumes that a cumulative normal distribution is the best fit to those data, and that the variance parameter within that distribution (leading to the steepness of the ogive) is constant for all mesh sizes. In fact, there may be skew if disproportionately higher fractions of small fish are retained so a cumulative normal distribution may not be the best fit. As well, the ogive shape and overall trawl performance may shift in an unpredictable way at sizes outside the range of observations.

The recreational component to any fishery has not been treated. In the case of species for which VPA's are available (Georges Bank cod and Georges Bank haddock, redfish, pollock), estimates of fishing mortality have been obtained from commercial sources alone. This will underestimate the total fishing mortality on those stocks, and hence overestimate spawning stock biomasses. Where F has been estimated from survey data (Gulf of Maine haddock, Gulf of Maine cod, yellowtail flounder, American plaice), all sources of fishing mortality are incorporated into the estimate. Thus, although spawning stock biomass may be more accurately estimated, the catch projections attributed to the commercial fishery will also include recreational catches.

D. OTHER COMPONENTS

Environmental conditions that may affect survival of recruits and growth are assumed to remain constant over the projection. Effects of changing levels of prey, predators or competitors are assumed to be negligible.

4.1.7. Model Output

The fully parameterized model has been used to project possible future stock sizes and catches. These projections depend on the specific parameter estimates used, and their behavior has not been compared to previous experience with the stocks. That evaluation or validation phase of this modeling work needs to be done before the absolute values of projected stock sizes and catches can be relied on. In the absence of that validation step, however, the projected stock sizes and catches can be compared for different management options to evaluate their relative effects. Such comparisons are likely conservative and are most reliable for evaluating small changes from the present management regime.

Model output consists of a series of 30 year vectors of mean and median catches, spawning stock biomasses and recruitment for each management option (a particular schedule of effective mesh sizes and fishing mortality rates). For species with stochastic recruitment models, the 30 year series is generated 1000 times, giving rise to a distribution of annual values, which in turn are characterized by annual means and medians (and percentile values)

within the distribution. Where recruitment models reflect strong density dependence, there may be wide divergence between each of the 1000 30-year scenarios, e.g., Georges Bank haddock. By chance, good recruitment early in a time series may rapidly lead to higher stock sizes and increased mean recruitment (with a subsequent chance of even higher recruitment). More often, recruitment and stock size remain low in early years. Under these conditions, the distribution for any year may consist of many low and only a few very high values. Because the mean (average) directly incorporates potentially very large values for relatively rare events, the mean will lead to an overly optimistic estimate of the most likely event. The observations will be divided 50/50 above and below the median, which may be significantly lower but within the range of more frequent observations than the mean.

4.2. Management Measures Considered

Several management measures were evaluated with the above described model. These include provisions of the current FMP and other provisions that have been suggested as feasible under the management approach of the FMP to better achieve its goals. These measures are evaluated using the provisions of the Interim FMP as a baseline. Insufficient information was available to quantify the likely effect of some of the management measures that have been suggested, as noted below.

4.2.1. Definition of a Base Line - No Action Alternative

The base line projection serves as a basis for comparing effects of various management options with effects of previous or existing management. The base line, or no-action alternative, approximates the Interim Plan: current fishing mortality rates (Table 4.4) and partial recruitment vectors (4 1/2" effective or 5 1/2" nominal mesh) were assumed to remain constant throughout the projections. However, minimum fish sizes were set at the 25% retention lengths(for 4 1/2" effective mesh, consistent with the projections based on alternative mesh sizes. Thus, effects of changes in mesh sizes could be evaluated without being confounded with changes in how size limits would be determined (e.g., to minimize discards). Also, except for haddock, cod and yellowtail flounder, no size limits were in effect under the Interim Plan.

4.2.2. Large Mesh Options

Catch and stock size projections were calculated for a range of possible nominal mesh sizes from 6.0" to 8.0" (5.0 to 7.0" effective), beginning in 1988. Relative to the base line, only mesh size and corresponding minimum fish size were assumed to change in the fishery. A partial recruitment vector was calculated for a theoretical effective mesh size 1.0" less that the specified nominal mesh size (Section 2.6) and the proportion of catch landed for each age class (L_i) was based on the 25% retention length associated with the effective mesh size. All other parameters in the model were held constant.

In Figure 4.1, the absolute differences between the projected catch under various large mesh options and the base line catch are displayed for the major stocks. In all cases, projected catches under larger mesh options initially decline relative to projected catches under the no action alternative. In all cases, except for redfish, the catches under larger mesh options exceed those of the no action alternative in less than 10 years and generally in less than 5 years. The projected differences between large mesh options and the base line catch generally stabilize within about 10 years. After this time, the variation in the projected differences is due to the stochastic recruitment portion of the model. For cod and yellowtail flounder, the greatest difference between a large mesh option and the base line occurs for the 8.0" nominal mesh option (although for yellowtail flounder the difference between 7.5" and 8.0" is slight.). For haddock and pollock the greatest difference occurs with a 7.5" nominal mesh although the difference between 7.5" nominal mesh and a number of the other options is small. An 8.0" nominal mesh provides the smallest difference between a large mesh option and the base line for these two stocks.

In Figure 4.2, the absolute differences between the projected spawning stock biomass under various large mesh options and the base line projections are presented. For all stocks, there is an immediate and sustained increase in the projected spawning stock biomass under any of the alternative mesh size options. At successively larger nominal mesh sizes, the amount of increases in spawning stock biomass become larger.

4.2.3. Haddock Spawning Area Closures

Spawning area closures have been in effect on Georges Bank since 1970 when ICNAF implemented the regulations that were agreed upon during 1969. The original intent of the time-area closures was to prevent disturbance to spawning fish during the peak of spawning activity on Georges Bank. Prior to 1970, the stock had declined dramatically so scientists and industry advisors alike agreed that measures to protect or enhance the stock were necessary. Area and seasonal closures were proposed and the industry readily accepted the concept. The original closure areas were based on the distribution of fish by maturity stage and commercial landings of haddock in the Georges Bank area. There was apparently no biological justification for these closures at the time and there is still no theoretical or analytical basis for the concept of protecting fish during spawning. The effect of the closures on the stock over the years has not been measured or quantified, and so could not be included in the simulations.

4.2.4. Southern New England Closure for Yellowtail Flounder

Analyses of Southern New England and Mid-Atlantic yellowtail flounder landings patterns during the recent past suggest that, had the seasonal area closure provided for in the FMP been in effect during 1982-1986, annual yellowtail landings would have been reduced by no more than 3 to 13 percent (Table 4.5). Over the five-year period, closed area catches during the FMP

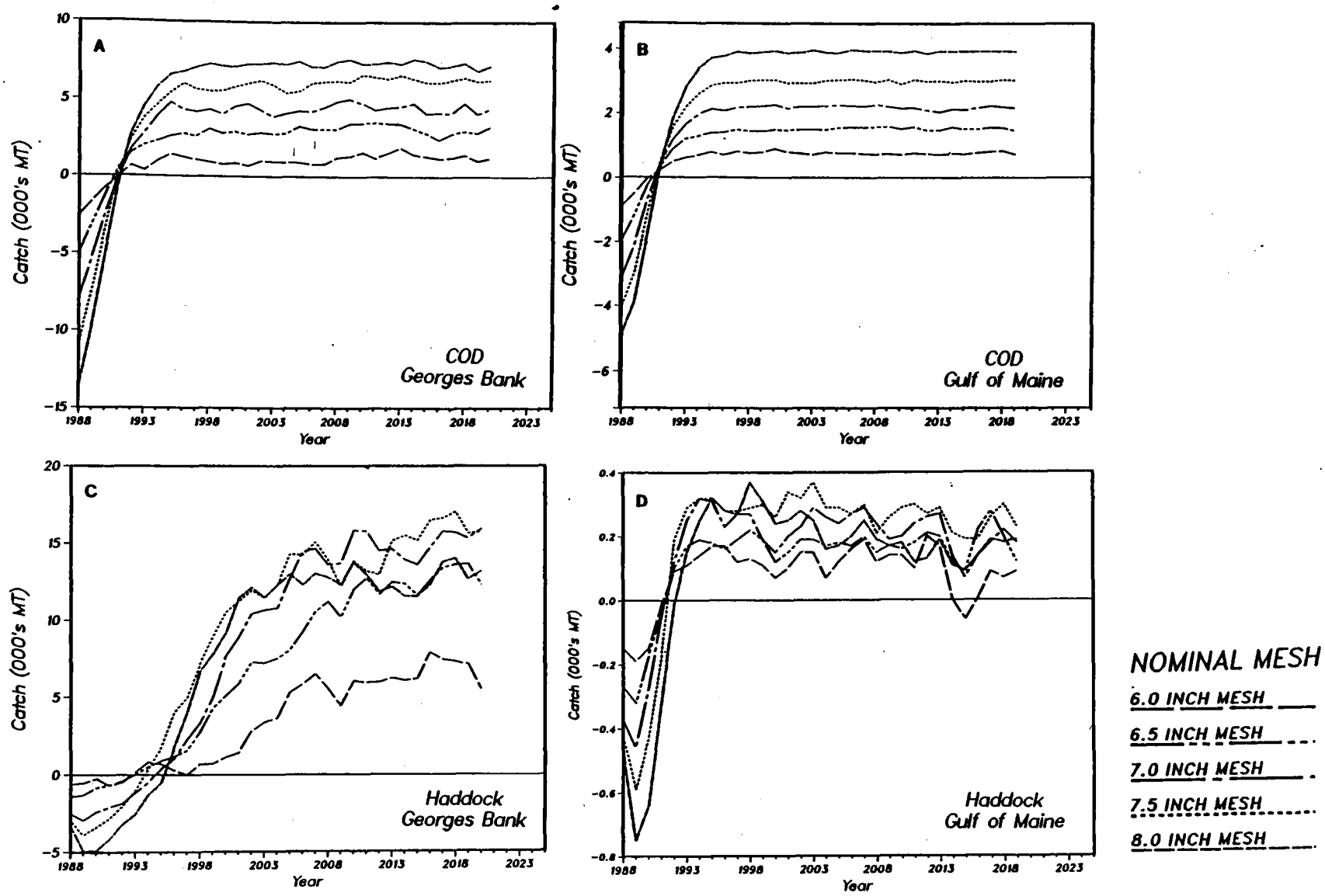


Figure 4.1 The absolute difference in projected U.S. catches relative to the base line or no action alternative projections for a range of nominal mesh sizes. Note nominal mesh size is assumed to equal effective mesh size plus 1.0 inch.

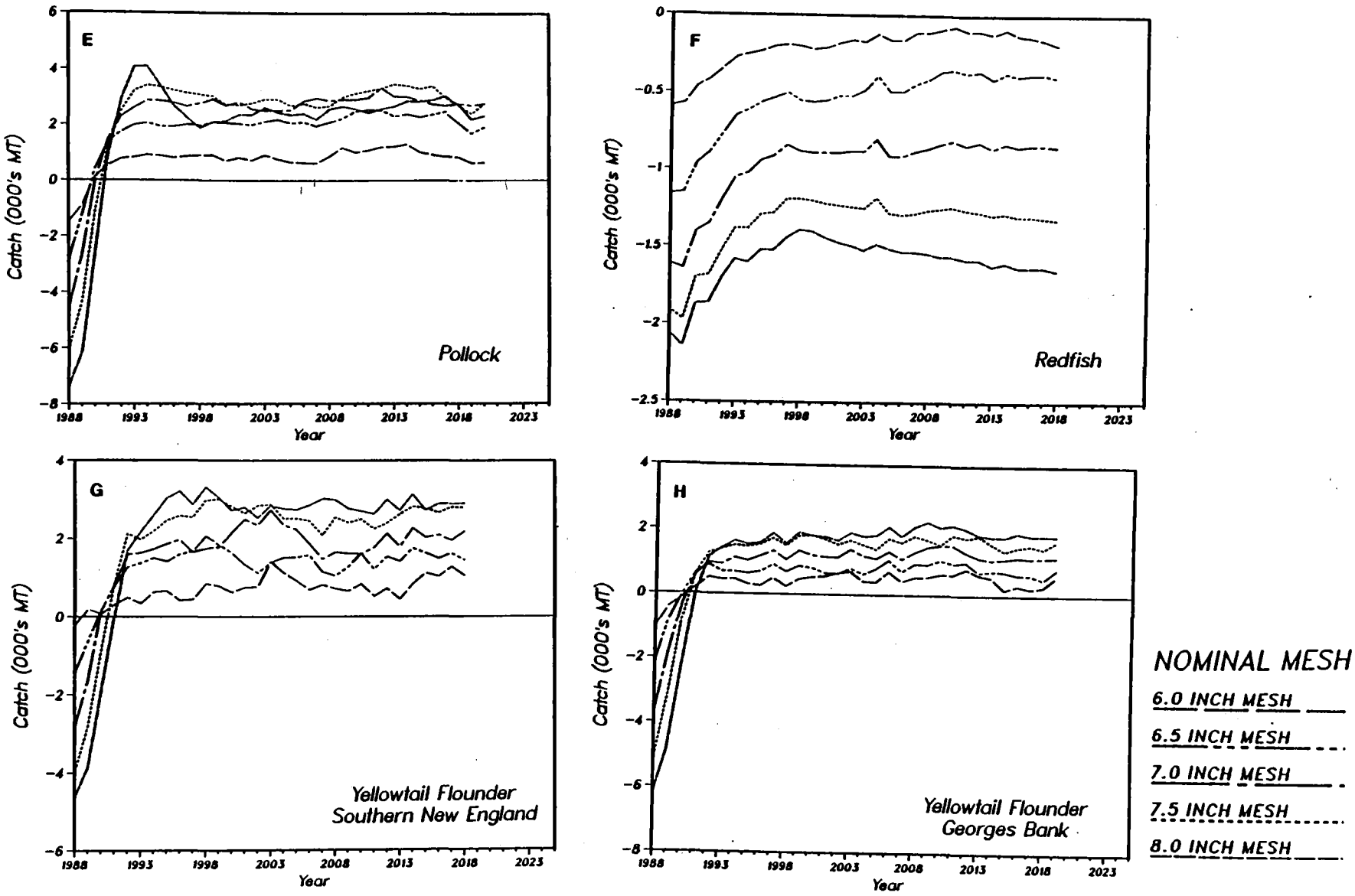


Figure 4.1 (Continued) The absolute difference in projected U.S. catches relative to the base line or no action alternative projections for a range of nominal mesh sizes. Note nominal mesh size is assumed to equal effective mesh size plus 1.0 inch.

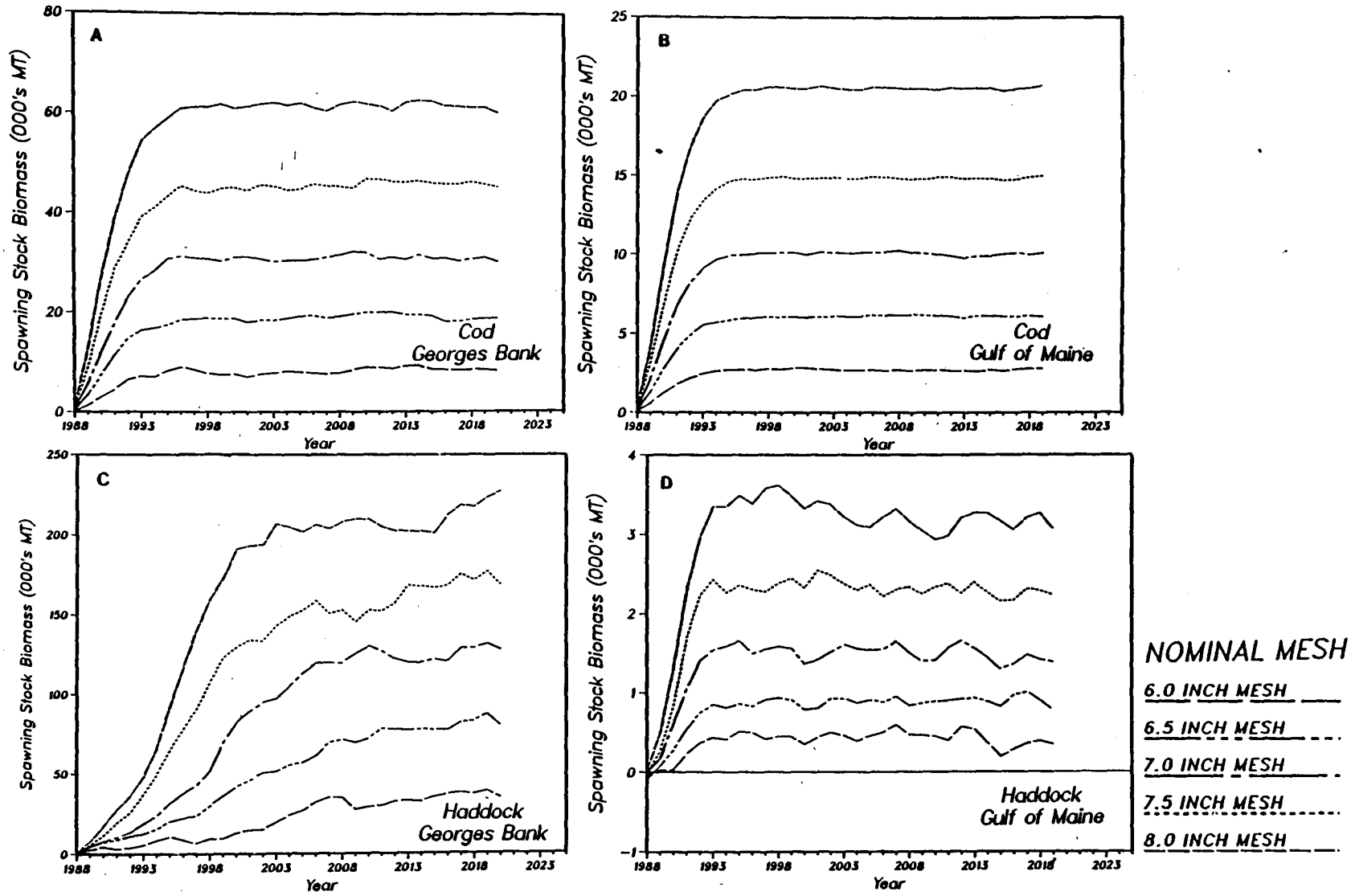


Figure 4.2 The absolute difference in projected spawning stock biomass estimates relative to the base line or no action alternative projections for a range of nominal mesh sizes. Note nominal mesh size is assumed to equal effective mesh size plus 1.0 inch.

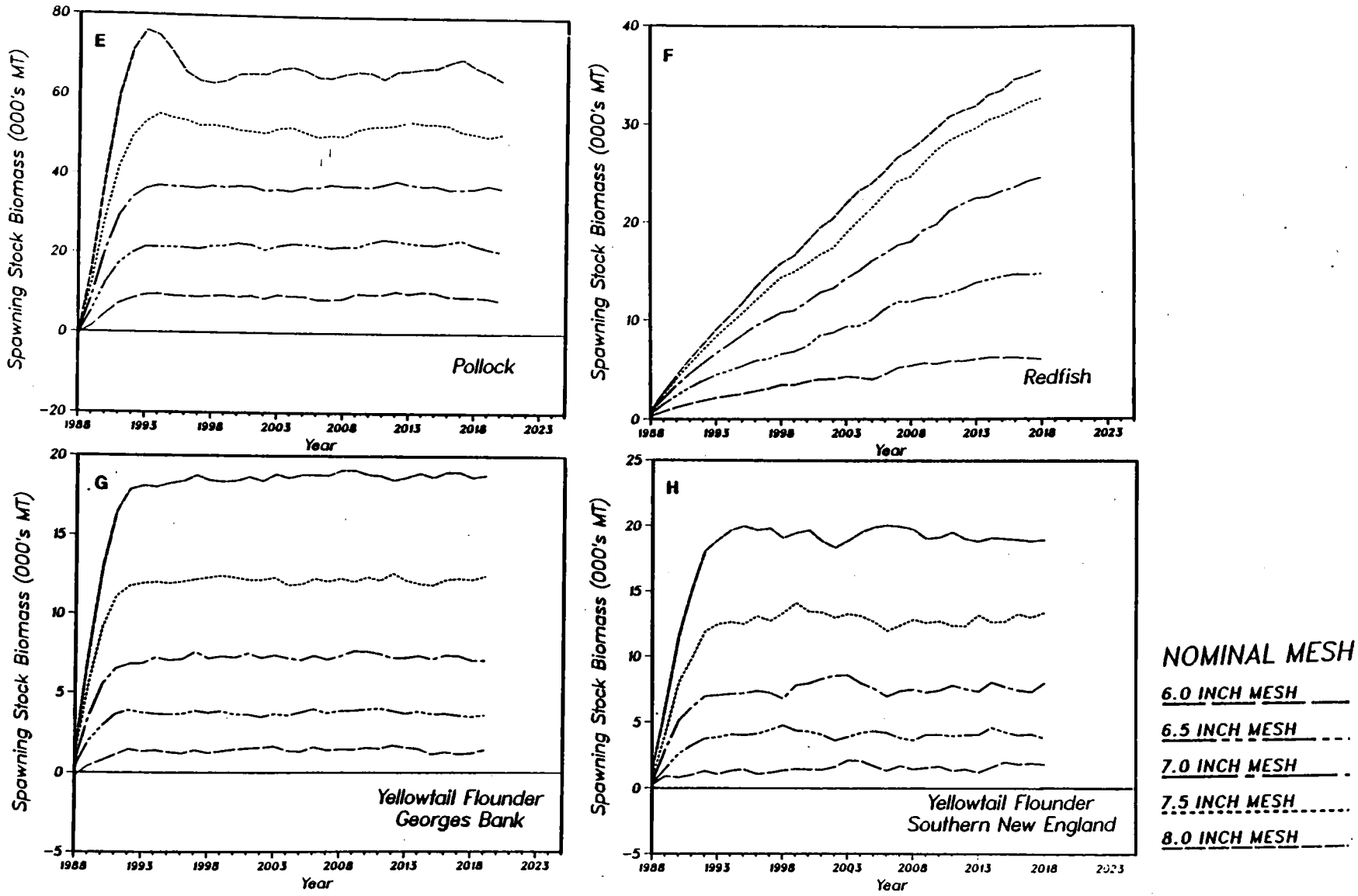


Figure 4.2 (Continued) The absolute difference in projected spawning stock biomass estimates relative to the base line or no action alternative projections for a range of nominal mesh sizes. Note nominal mesh size is assumed to equal effective mesh size plus 1.0 inch.

Table 4.5 Evaluation of reduction in landings (metric tons, live) of yellowtail flounder from Southern New England (Stat Areas 526 & 537-539) and from Statistical Area 613 in the Mid-Atlantic region had the Southern New England/Mid-Atlantic seasonal area closure included in the Northeast Multispecies Management Plan (and variations on this closure scheme) been in effect during 1982 - 1986.

Year	Statistical Area	(A) Annual Landings	(B) Annual Closure Landings	(C) Closure Period Landings Mar/Apr-May	(D) Closure Period Landings Mar-May	(E) Closure Period Landings Feb-May	% (B)/(A)	% (C)/(A)	% (D)/(A)	% (E)/(A)
1982										
	526	4708	1931	169	169	232	41.0%	3.6%	3.6%	4.9%
	537	4867	3345	310	310	475	68.7%	6.4%	6.4%	9.8%
	539	1875	1530	336	376	566	81.6%	17.9%	20.1%	30.2%
	SNE TOTAL	11450	6806	815	855	1273	59.4%	7.1%	7.5%	11.1%
	613 TOTAL	1091	270	0	47	47	24.7%	0.0%	4.3%	4.3%
	OVERALL TOTAL	12541	7076	815	902	1320	56.4%	6.5%	7.2%	10.5%
1983										
	526	7137	2193	215	215	435	30.7%	3.0%	3.0%	6.1%
	537	8400	6073	1469	1680	2070	72.3%	17.5%	20.0%	24.6%
	539	2315	1931	665	887	1224	83.4%	28.7%	38.3%	52.9%
	SNE TOTAL	17852	10197	2349	2782	3729	57.1%	13.2%	15.6%	20.9%
	613 TOTAL	1213	515	173	356	404	42.5%	14.3%	29.3%	33.3%
	OVERALL TOTAL	19065	10712	2522	3138	4133	56.2%	13.2%	16.5%	21.7%
1984										
	526	3969	850	151	151	250	21.4%	3.8%	3.8%	6.3%
	537	3253	1903	274	290	539	58.5%	8.4%	8.9%	16.6%
	539	1229	1052	200	318	569	85.6%	16.3%	25.9%	46.3%
	SNE TOTAL	8451	3805	625	759	1358	45.0%	7.4%	9.0%	16.1%
	613 TOTAL	1961	1044	217	500	894	53.2%	11.1%	25.5%	45.6%
	OVERALL TOTAL	10412	4849	842	1259	2252	46.6%	8.1%	12.1%	21.6%

Table 4.5 (Continued).

Year	Statistical Area	(A) Annual Landings	(B) Annual Closure Landings	(C) Closure Period Landings Mar/Apr-May	(D) Closure Period Landings Mar-May	(E) Closure Period Landings Feb-May	% (B)/(A)	% (C)/(A)	% (D)/(A)	% (E)/(A)
1985										
	526	1350	325	72	72	133	24.1%	5.3%	5.3%	9.9%
	537	1261	532	65	65	177	42.2%	5.2%	5.2%	14.0%
	539	564	373	46	58	118	66.1%	8.2%	10.3%	20.9%
	SNE TOTAL	3175	1230	183	195	428	38.7%	5.8%	6.1%	13.5%
	613 TOTAL	436	164	75	89	93	37.6%	17.2%	20.4%	21.3%
	OVERALL TOTAL	3611	1394	258	284	521	38.6%	7.1%	7.9%	14.4%
1986										
	526	1931	443	39	39	77	22.9%	2.0%	2.0%	4.0%
	537	1142	791	60	60	179	69.3%	5.3%	5.3%	15.7%
	539	172	73	7	10	33	42.4%	4.1%	5.8%	19.2%
	SNE TOTAL	3245	1307	106	109	289	40.3%	3.3%	3.4%	8.9%
	613 TOTAL	213	102	12	20	33	47.9%	5.6%	9.4%	15.5%
	OVERALL TOTAL	3458	1409	118	129	322	40.7%	3.4%	3.7%	9.3%
1982 - 1986[1]										
	526						28.0%	3.6%	3.6%	6.2%
	537						62.2%	8.5%	9.1%	16.1%
	539						71.8%	15.0%	20.1%	33.9%
	SNE TOTAL						48.1%	7.3%	8.3%	14.1%
	613 TOTAL						41.2%	9.6%	17.8%	24.0%
	OVERALL TOTAL						47.7%	7.7%	9.5%	15.5%

[1]Mean of annual percentages.

closure period amounted to less than 8% of the Southern New England/Area 613 landings. Since these percentage reductions would be lower due to shifts in effort to other areas of yellowtail availability (not evaluated in the analyses), the impact of the area closure in reducing catches appears to be minimal. If the fishery patterns observed in the past are maintained in the future, there is likely to be little benefit from implementing the current area closure scheme. For a more detailed analysis of this problem, see Serchuk and Wigley (1987). Since the effect of this closure area appears to be negligible, it could not be included in the simulations.

4.2.5. Trip Limits on Haddock and Redfish

Data from 1986 commercial trips that caught haddock or redfish were analyzed to determine the statistical patterns and composition of the catches. Trips and associated catches that could be assigned to a specific fishing trip were grouped within 1,000 lb intervals of catch per trip. For each interval, total trips, percentage of overall total trips, mean catch per trip, total catch, percentage of overall total catch and cumulative percentage of overall total catch were calculated (Tables 4.6-4.7). For both species most trips landed catches in the 0-1,000 lb range. Although over 70% of the trips of both haddock and redfish were in this category, less than 15% of the total catch resulted (Tables 4.6-4.7). Only about 5% of the haddock trips fell into the 5,000 lb or greater group, but this category accounted for about 48% of the total catch. Similarly with redfish, only about 7% of the trips were greater than 5,000 lb, but 53% of the total catch occurred in this group.

An analysis of the effect of a possible trip limit on both species was conducted. In the analysis, it was assumed that the 1986 data represent the situation for the foreseeable future. It was also assumed that no discarding would occur, no misreporting would occur, trips with catch below a possible limit in 1986 would not catch the limit in future years, and all trips that caught more than the proposed limit in 1986 would catch the full trip limit.

The situation for haddock is more complicated than for redfish because part of the catch is taken on Georges Bank and part in the Gulf of Maine.The analysis is further complicated since about half of the haddock catch on Georges Bank is taken by Canada. In the analysis below, it is assumed that the distribution of catch per trip is similar for the Georges Bank and Gulf of Maine stocks and for U.S. and Canadian vessels.

The effect of a 5,000 lb trip limit was estimated by first calculating 1986 landings as if a trip limit had been in place: a trip landing more than 5,000 lb in 1986 instead would be assumed to land only 5,000 lb, but a trip landing less than 5,000 lb in 1986 would land the same amount as observed. These revised U.S. landings were to be compared to original U.S. landings without trip limits. Under a 5,000 lb trip limit, U.S. landings would be reduced 26% (Table 4.6). For the Georges Bank stock this would correspond to a reduction in F from 0.50 to 0.38 if Canada adopted a similar management regime and a reduction in F from 0.50 to 0.44 if no corresponding management was instituted in Canada. Similar analyses for a 4,000 lb and 2,000 lb trip limit

Table 4.6 Summary of USA commercial fishing trips in 1986 in which haddock was landed. Data are provided on the distribution of commercial trip catches of haddock [by 1000s pound groups], the total and mean catch of haddock within each group, and the percent and cumulative percent of the 1986 total USA haddock catch accounted for by each group.

Catch Range (lbs)	Number of Trips	% of Total Trips	Mean Catch Per Trip (lbs)	Total Catch (000s lbs)	% of Total Catch	Cumulative % of Total Catch
<1000	6003	74.5	231	1386	14.4	14.4
1000-2000	895	11.1	1444	1292	13.4	27.8
2001-3000	432	5.4	2466	1065	11.1	38.9
3001-4000	229	2.8	3489	799	8.3	47.2
4001-5000	108	1.3	4460	482	5.0	52.2
>5000	396	4.9	11606	4596	47.8	100.0
Total	8063	100.0	1193	9620	100.0	

Table 4.7 Summary of USA commercial fishing trips in 1986 in which redfish was landed. Data are provided on the distribution of commercial trip catches of redfish [by 1000s pound groups], the total and mean catch of redfish within each group, and the percent and cumulative percent of the 1986 total USA redfish catch accounted for each group.

Catch Range (lbs)	Number of Trips	% of Total Trips	Mean Catch Per Trip (lbs)	Total Catch (000s lbs)	% of Total Catch	Cumulative % of Total Catch
<1000	3658	73.1	231	844	12.8	12.8
1000-2000	541	10.8	1436	777	11.9	24.7
2001-3000	250	5.0	2479	620	9.4	34.1
3001-4000	129	2.6	3512	453	6.9	41.0
4001-5000	91	1.8	4521	411	6.2	47.2
>5000	337	6.7	10298	3470	52.8	100.0
Total	5006	100.0	1314	6576	100.0	

give a 31% and 51% reduction in U.S. catch and corresponding declines in F to 0.34 and 0.25 respectively assuming Canada adopts a similar management policy.

For Gulf of Maine haddock the same proportional reductions in F would result in an F of 0.52, 0.48, and 0.35 for trip limits of 5,000, 4,000, and 2,000 lbs, respectively, based on an estimate of the current F for the Gulf of Maine haddock equal to 0.70.

The analysis for redfish proceeded in a similar fashion. Since redfish are caught only in the Gulf of Maine and only by the US fleet, the estimation was similar. A 5,000 lb trip limit on redfish would result in a 27% reduction in catch and F would decline from 0.16 to 0.116 (Table 4.7). If a 4,000 lb or a 2,000 lb trip limit were imposed, catches would decline by 33% and 50% and F would be reduced to 0.107 and 0.079 respectively.

Note that the estimated reduction in F is dependent upon the assumption that the partial recruitment vector and the size distribution of the population stay constant. If the partial recruitment vector changes (e.g. mesh size) the number of trips landing under the trip limit would be different. The actual size distribution of the catch within trips would have to be examined to estimate the effect on F of a specific trip limit in conjunction with management measures that result in a change in the partial recruitment vector.

In order to evaluate the effects of a trip limit on projected catches and spawning biomass estimates for the redfish and haddock stocks, a series of projections were performed in which it was assumed that the imposition of a 2,000 pound trip limit would result in a permanent and constant reduction in F equal to the estimated short term reductions in F if Canada also adopted a similar management regime (Table 4.8, Table 4.9). Projections are only presented for a 5.5" nominal (4.5" effective) mesh since the estimated reduction in F is dependent upon the assumption that the partial recruitment vector and size distribution of the population would be similar to that in 1986. With an increase in mesh size, both the partial recruitment vector would change and shift in the size distribution would be expected. As such, the above analyses are insufficient to estimate what the reduction in F would be as the result of a trip limit.

In Figure 4.3, the spawning stock biomass resulting from a reduction in F due to such trip limits for a 5.5" nominal mesh size is compared with spawning stock biomass projected under the large mesh size option alone, the base line in this case. Projected catches are presented in Figure 4.4 for the same comparisons. The reduction in F leads to marginal loss of catch in the short run. In the long run, marginal gains in catch depend on whether marginal gains in stock size (Figure 4.3) offset reduction in F.

These projections become increasingly unrealistic in terms of the effect of a trip limit as stock sizes change from current levels. As stock sizes increase and trip limits are held constant, the number of trips that would be required to harvest the projected catches becomes unrealistically large.

Table 4.8 Projected reductions in U.S. haddock catch and total haddock fishing mortality (F), under three different trip limit options. Analyses were based on 1986 data (Table 4.6) and current (1986) fishing mortality (F = 0.50).

Trip Limit of Haddock (lbs/trip)	Percentage Reduction in Annual U.S. Haddock Catch	Fishing Mortality (F) Trip limits only for U.S. vessels	Similar Mgmt. Regime in Canada
5000	26.2%	0.44	0.38
4000	30.8%	0.42	0.34
2000	50.6%	0.37	0.25

Table 4.9 Projected reductions in total USA redfish catch and redfish fishing mortality (F), under three different trip limit options. Analyses were based on 1986 data (Table 4.7) and current (1986) fishing mortality (F = 0.16).

Trip Limit of Redfish (lbs/trip)	Percentage Reduction in Annual USA Redfish Catch	Fishing Mortality (F)
5000	27.2%	0.12
4000	33.0%	0.11
2000	50.5%	0.08

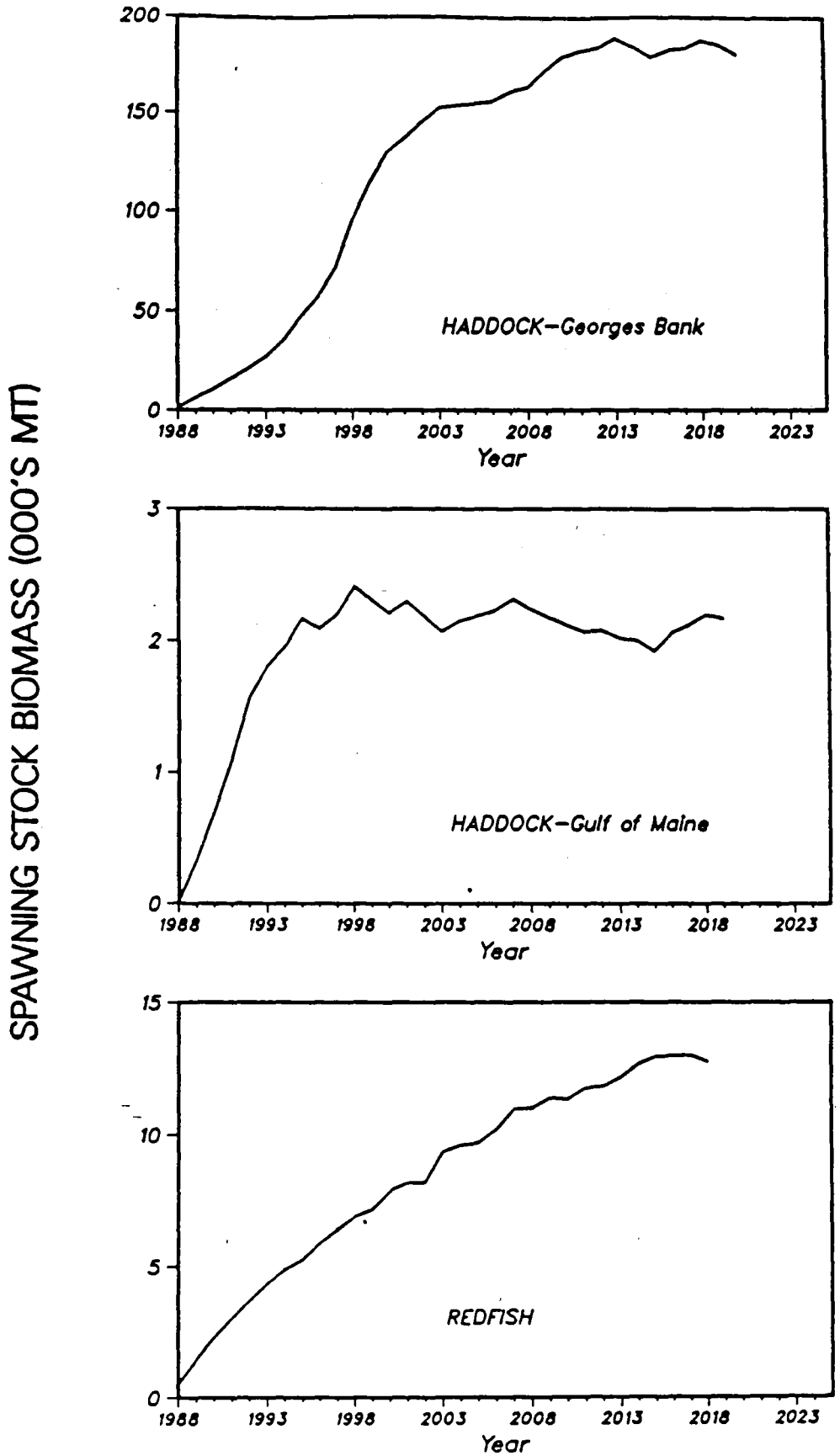


Figure 4.3 The marginal difference in projected spawning stock biomass estimates with a reduction in F due to a trip limit compared to the baseline or no action alternative.

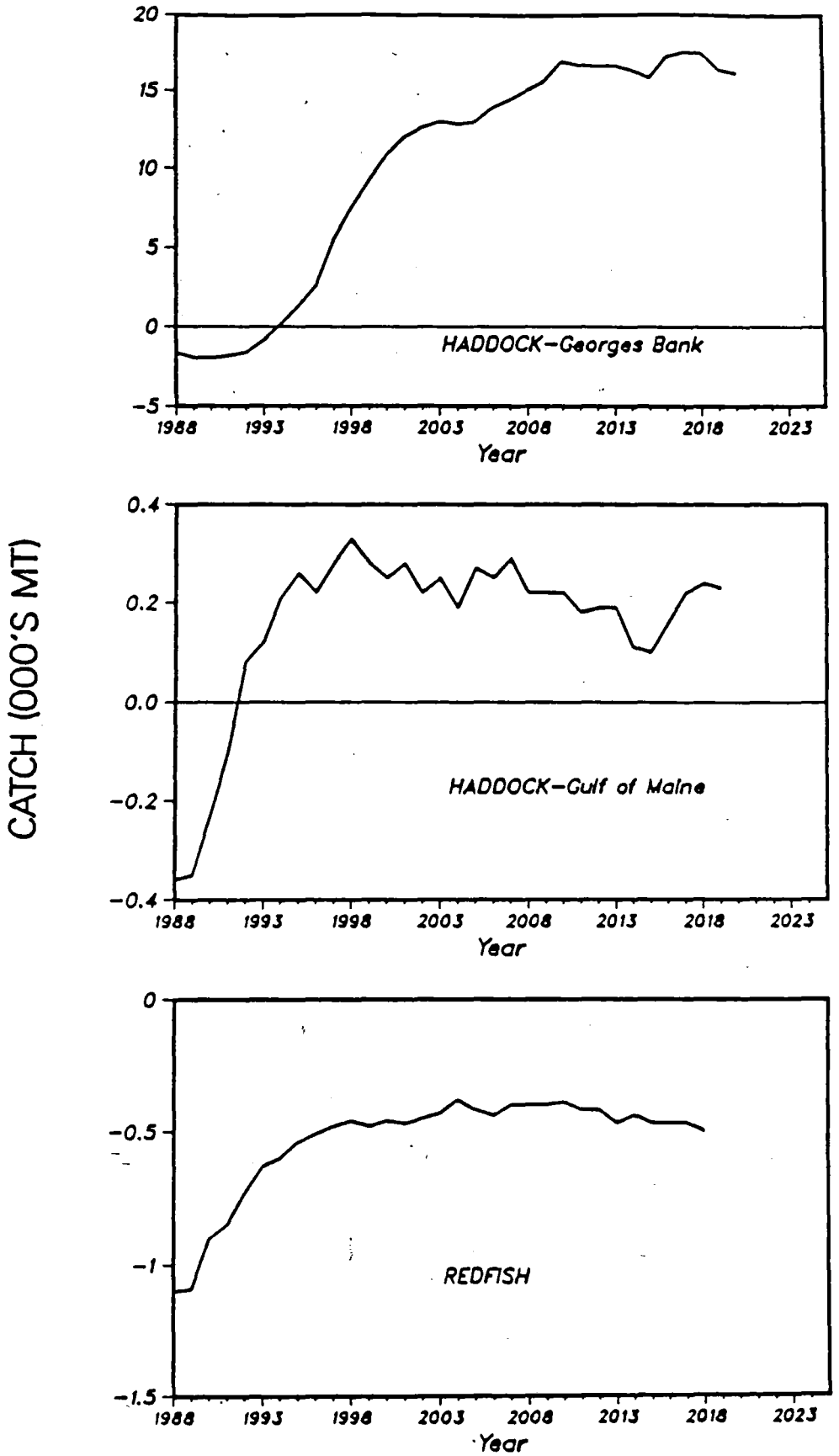


Figure 4.4 The marginal difference in projected catch estimates with a reduction in F due to a trip limit compared to the baseline or no action alternative

An alternative way to interpret the projected stock sizes and catches in Figure 4.3 and 4.4 is to consider that trip limits would be continually adjusted so that the resultant overall effect would be to maintain a constant F. However, it is unclear how trip limits could be adjusted in practice to achieve such a goal. Substantial discarding would be likely at high stock sizes, which would negate the assumed benefit.

4.3. Stock and Catch Projections when %MSP Goals are Met

4.3.1 Description of Methods

Catch and spawning stock size projections were developed for three Georges Bank stocks, cod, haddock, and yellowtail flounder, to evaluate alternative combinations of mesh size and fishing mortality that would achieve various possible target %MSP goals. The %MSP goals evaluated were (Table 4.6)

Atlantic cod:	20% MSP
	30% MSP
Haddock:	30% MSP
	40% MSP
Yellowtail:	30% MSP
	40% MSP

Projections were performed for each %MSP goal using six different effective mesh size options, 4.5", 5.0", 5.5", 6.0", 6.5", and 7.0". The effective mesh size was assumed to be implemented in the fishery beginning in 1988. Fishing mortality was then assumed to decrease linearly each year from the 1988 level (assumed to be equal to the F in 1986) at a rate such that the mesh size and fishing mortality rate combination resulted in attainment of the %MSP target at the end of five years (by 1993). The projections were then continued to cover a 33-year period from 1988 to 2020.

4.3.2. Projection Results

Results of the projections are displayed in Figure 4.5 for spawning stock biomass and Figure 4.6 for catch for each of the three stocks. For each specific %MSP target, the absolute differences between projected catches and spawning stock biomasses and those expected from the no-action alternative are shown.

For any of the %MSP targets, spawning stock biomass stabilizes at about the same level regardless of the fishing mortality and mesh combination used to achieve the target. This is not unexpected since, in all options, the %MSP goals are met at the end of the first five years of the projections. Under the larger mesh size options, spawning stock biomasses increase rapidly due to increase in the age at first capture in the fishery. Using smaller mesh

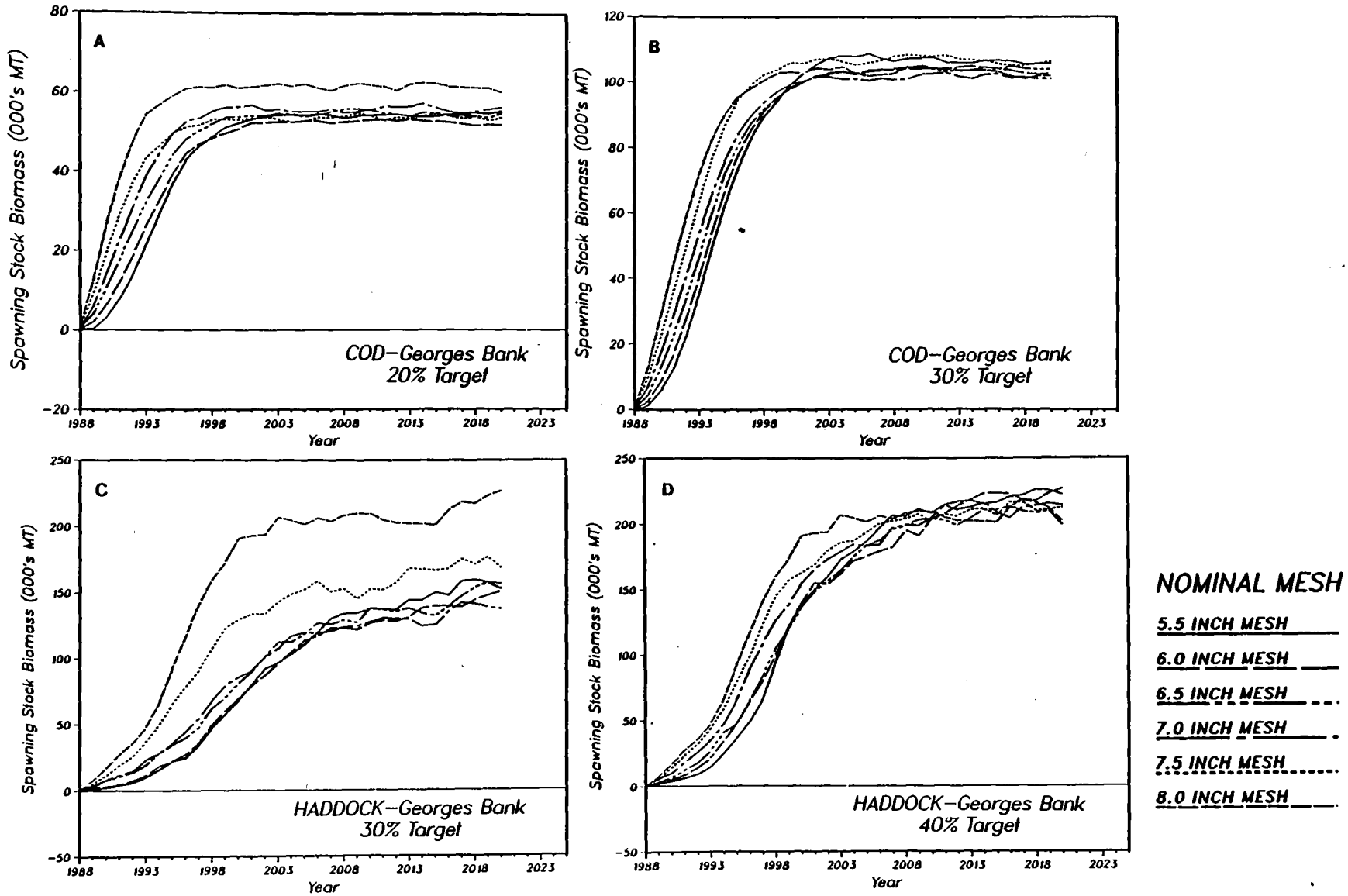


Figure 4.5 Absolute difference in projected spawning stock biomass estimates relative to the base line or no action alternatives; projections for combinations of nominal mesh sizes and five year schedules of reductions in F to achieve target levels of SSB/R. Note nominal mesh is assumed to equal effective mesh size plus 1.0 inch.

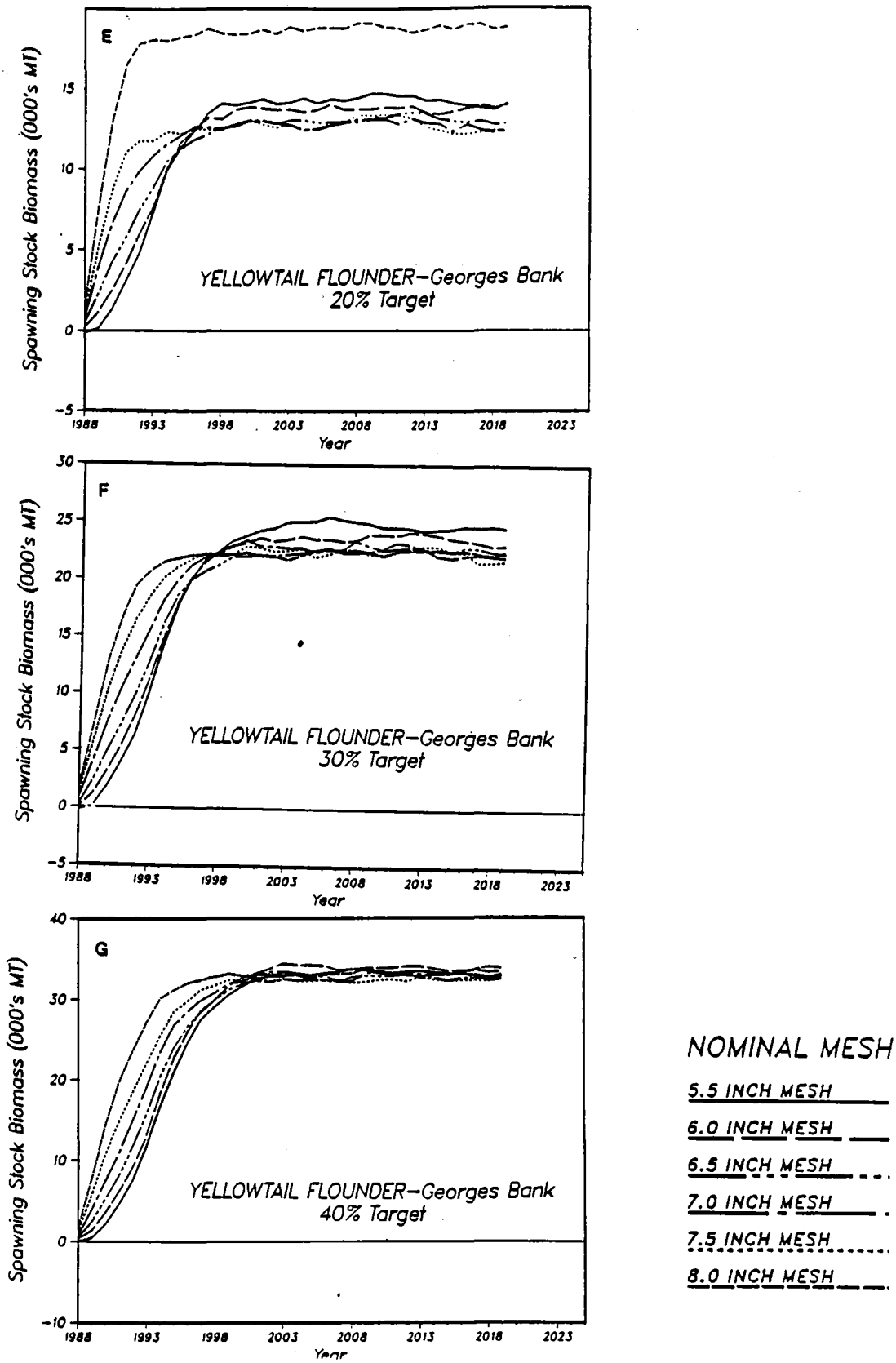


Figure 4.5 (Continued) Absolute difference in projected spawning stock biomass estimates relative to the base line or no action alternatives; projections for combinations of nominal mesh sizes and five year schedules of reductions in F to achieve target levels of SSB/R. Note nominal mesh is assumed to equal effective mesh size plus 1.0 inch.

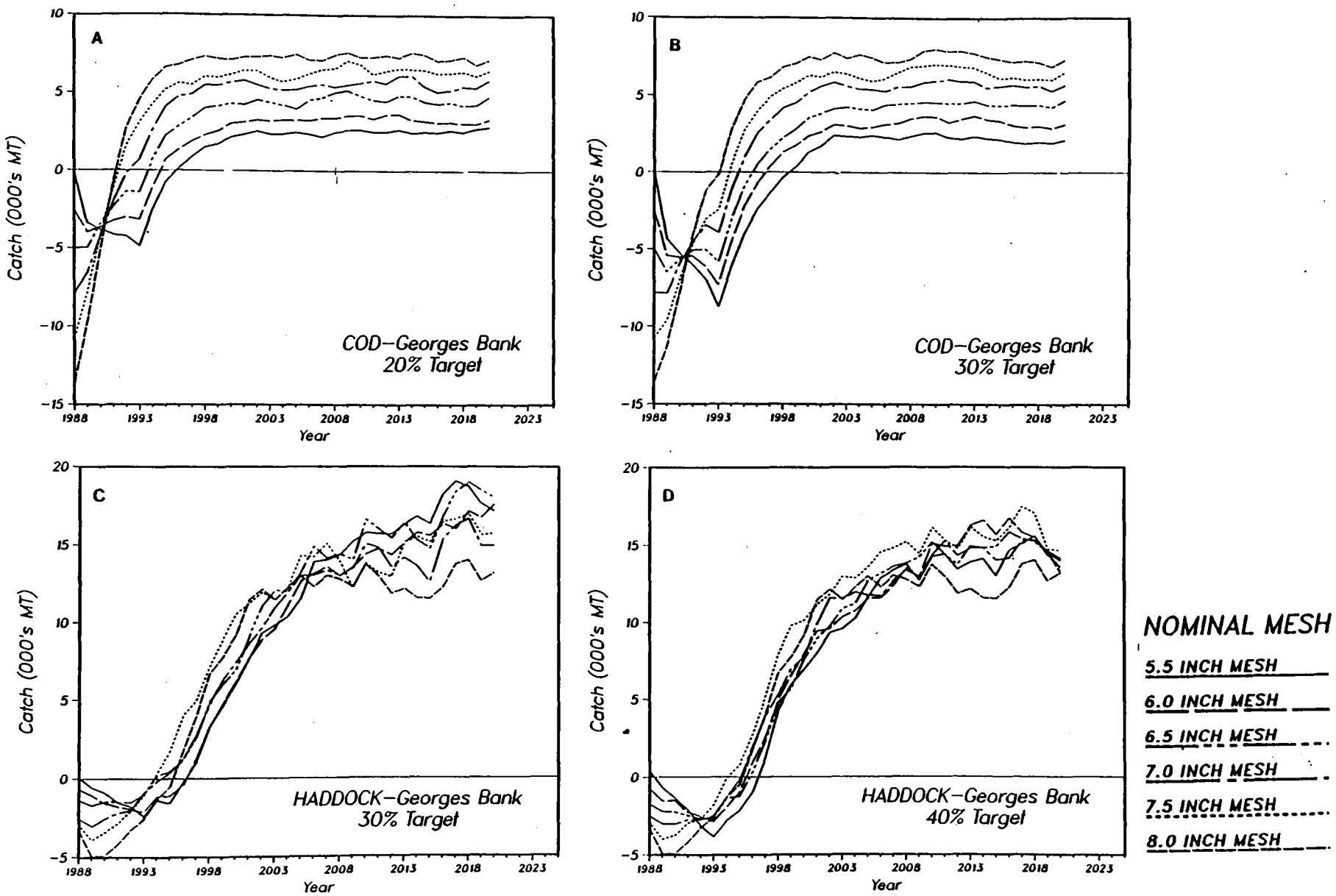


Figure 4.6 Absolute differences in projected catch estimates relative to the base line or no action alternatives; projections for combinations of nominal mesh sizes and five year schedules of reductions in F to achieve target levels of SSB/R. Note nominal mesh is assumed to equal effective mesh size plus 1.0 inch.

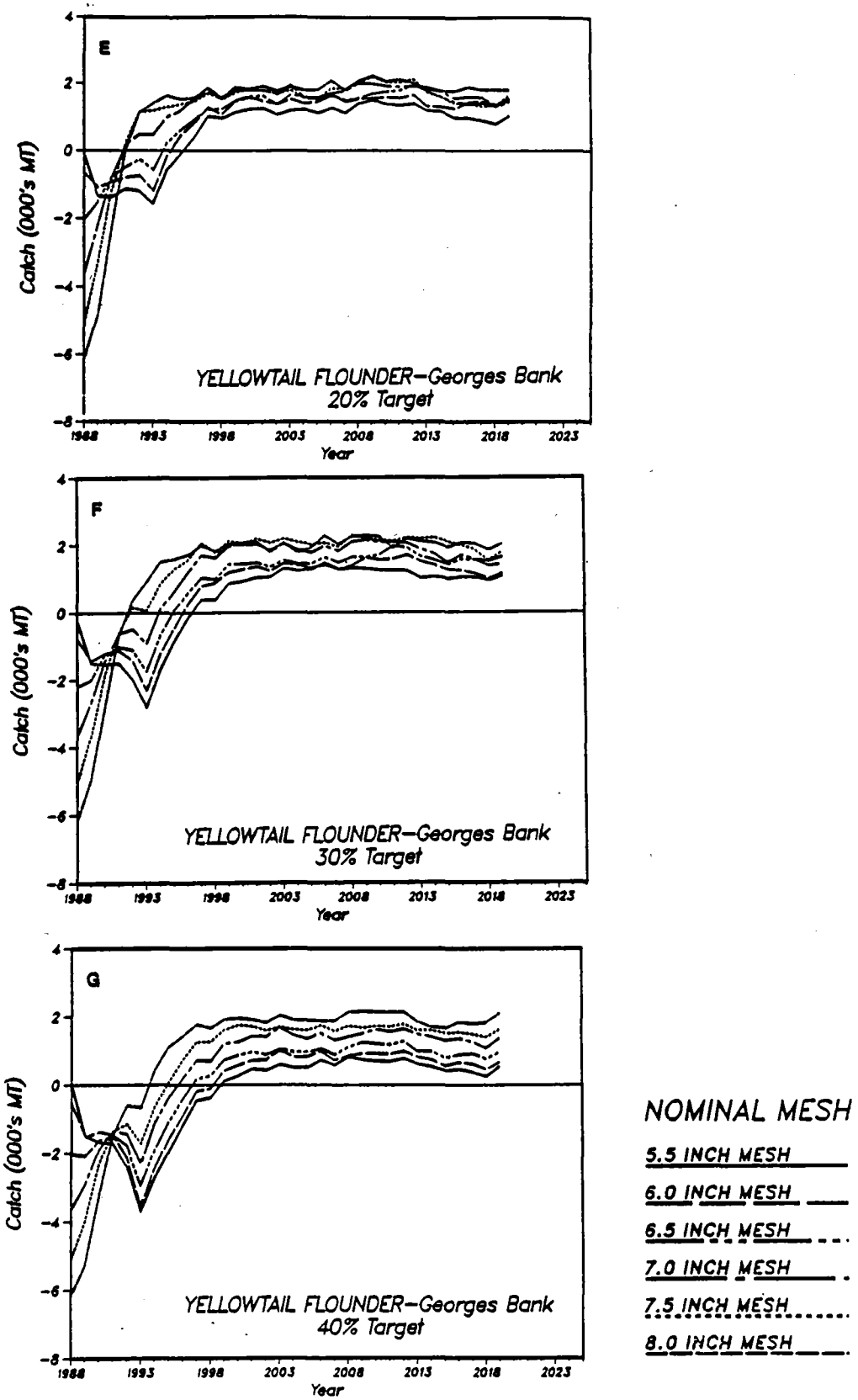


Figure 4.6 (Continued) Absolute differences in projected catch estimates relative to the base line or no action alternatives; projections for combinations of nominal mesh sizes and five year schedules of reductions in F to achieve target levels of SSB/R. Note nominal mesh is assumed to equal effective mesh size plus 1.0 inch.

sizes, increases in spawning stock biomass are delayed until fishing mortality is substantially reduced since more age groups in the stock are subject to exploitation.

Although large immediate declines in catch occur under the large mesh regimes, these declines are quickly reversed. Within a few years, catches rapidly recover and exceed those projected from the smaller mesh options.

4.4. Alternative Model of the Canadian Fishery

Three of the stocks covered under this plan are jointly fished to a significant degree by both U.S. and Canadian fishermen, Georges Bank haddock, Georges Bank cod, Gulf of Maine cod and pollock. Currently, there are no formal arrangements for the joint implementation of management measures for any of species. Where stocks are jointly fished, the Canadian response to any management measure imposed on the U.S. fishery (e.g., mesh size regulation) is of course unknown. In the projections described above, it was assumed that both U.S. and Canadian fisheries would adopt similar effective mesh sizes. Here the alternative assumption that the Canadian fishery will continue to operate with the same effective mesh size as under the no action alternatives explored. Using the same model, alternative projections are made to estimate the effect of different mesh size options if Canadian management practices did not change in response to the adoption of large meshes by the USA.

In these projections, the partial recruitment vector for the Canadian fishery was set equal to that generated by a 5 1/2" nominal mesh (4 1/2 inch effective) for the entire projection, while the partial recruitment vector for the U.S. fishery was changed in 1988 to the specified mesh option. All other parameter values used in these projections were the same as those in Section 4.2.2.

The results from these projections are displayed as the absolute differences between median projected stock size when the Canadian fishery adopts the same large mesh option as the USA, and median projected stock size when the Canadian fishery maintains the current effective mesh size (Figure 4.7). Projected catches under the two alternatives are compared in Figure 4.8.

In all cases, if the large mesh option were adopted only by the USA fishery, overall long-term gain in spawning stock biomass and catch would be lower than if mesh options were adopted jointly by the USA and Canada. The effects are larger for pollock and Georges Bank haddock than for Georges Bank cod because the Canadian proportion of the total catch for the latter is smaller. The effects were also greatest for the largest mesh size option. These projections suggest that, for these three stocks, the effectiveness of adopting a large mesh option will be reduced unless management measures employed by Canada result in similar size selective regimes.

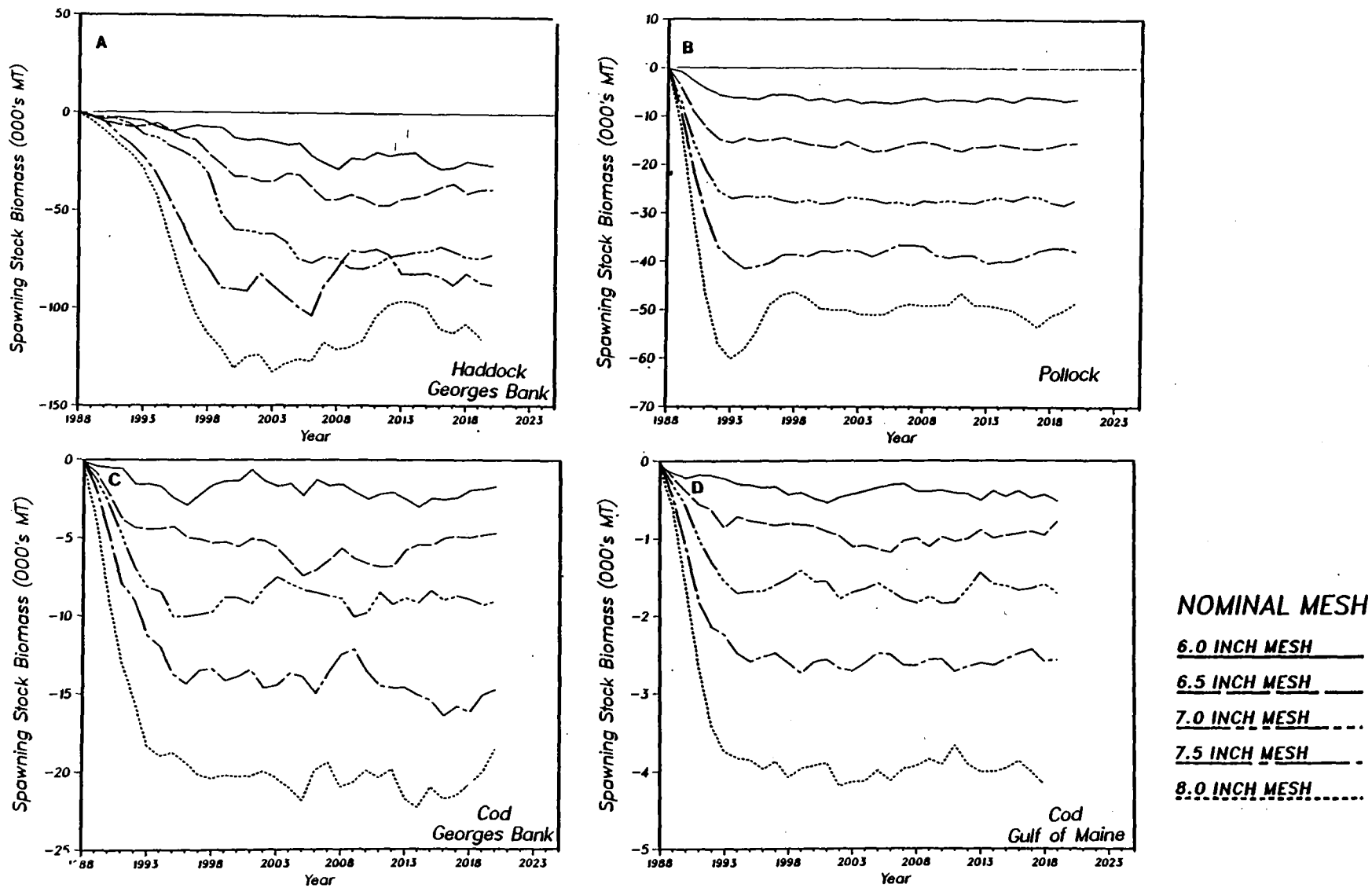


Figure 4.7 The absolute difference in the median projected spawning stock biomass estimates if the Canadian fishery is assumed to continue to operate with the current 5 1/2" nominal mesh compared with if the Canadian fishery adopts the same large mesh option as the U.S. Note nominal mesh is assumed to equal effective mesh plus 1.0 inch.

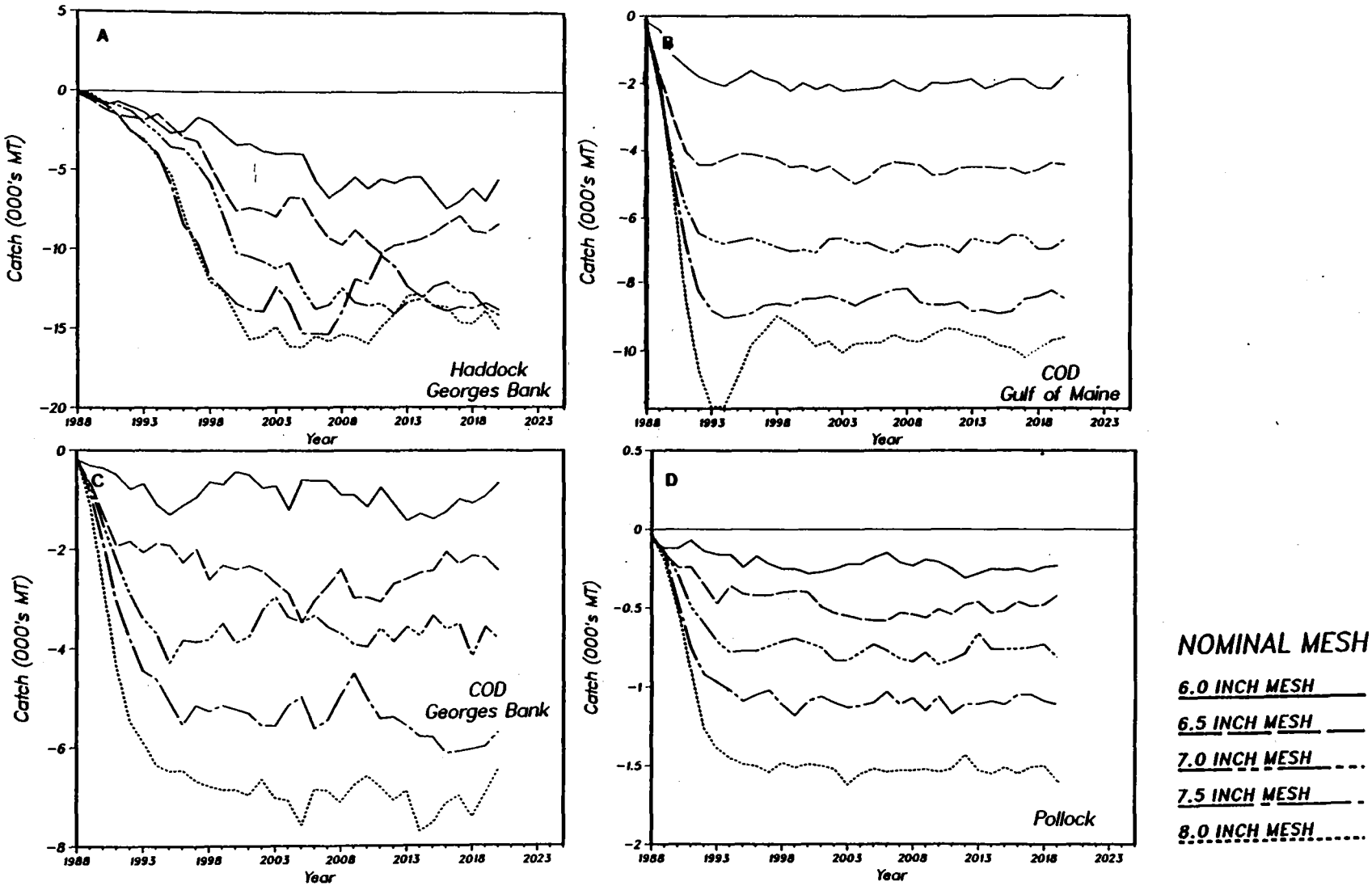


Figure 4.8 The absolute difference in the median projected U.S. catch estimates if the Canadian fishery is assumed to continue to operate with the current 5 1/2" nominal mesh compared with if the Canadian fishery adopts the same large mesh option as the U.S. Note nominal mesh is assumed to equal effective mesh plus 1.0 inch.

4.5. Alternate Projections Accounting for Strong Year Classes

Alternative projections were made to demonstrate the possible impacts of changes in fishing mortality on yield and stock size that might be obtained by husbanding strong year classes (e.g. the 1985 cod year class). These differ from projections described above earlier, as they emphasize the effect of a single year classes rather than specific management options such as mesh size. Consequently, the stochastic recruitment models are not employed here.

4.5.1. Catch Projections for Georges Bank Haddock

The Georges Bank haddock stock has fluctuated dramatically over the last 30 years, but most recently the stock has produced poor recruiting year classes. With the exception of the 1975 year class, a large cohort that was produced from a relatively small spawning stock, all the year classes since 1969 have been poor when SSB was less than about 70,000 mt. The frequency of a good cohort occurring under these conditions was 1 chance in 17. Because of poor recruitment in recent years and relatively high fishing mortality, the stock has remained at very low levels relative to the earlier years in the fishery (1931-1960).

To investigate how haddock would respond to changes in the current fishing mortality pattern, a series of projections were made. All of the projections were based on 10-year forecasts with constant recruitment at the level of the mean of the 1978-1984 year classes (5 million fish). If fishing on haddock ceased, stock size would gradually increase over the 10-year period (Table 4.10). Nonetheless, the stock would not recover to levels that consistently produced good recruitment in the past. Spawning stock biomass in 1997, however, would be nearly six times as large as in 1987.

Another series of forecasts were performed assuming different levels of fishing mortality, and recruitment of a "good" year class in the eighth year of the 10-year period. This enabled a comparison of the effect of an immediate reduction in F before a strong year class appeared versus maintaining F at current levels under the same scenario. Table 4.11 shows the situation if F were reduced to 0 and a strong cohort (60 million fish) occurred in 1995. SSB would increase and, upon recruitment of the year class to the spawning stock, would double to about 130,000 mt.

This can be contrasted to the situation where F is held constant at near current levels and a strong cohort occurs. SSB in 1996 is about half as large (66,000 mt) as in the previous case and begins to immediately and rapidly decline in 1997 (Table 4.12).

Because of the mixed species nature of the trawl fishery, maintaining F at near zero levels would be impossible; therefore, several other alternatives were investigated that simulated a strict bycatch fishery (F=0.1) and an $F_{0.1}$ strategy (F=0.2). If F were lowered to 0.1 and maintained at this level over a 10-year period, SSB would gradually increase and improve markedly when a good year class recruited (Table 4.13). SSB would be about twice as large as that under the current F. Fishing the stock at F0.1 would also

Table 4.10. Ten year (1987-1997) catch and stock size projections for Georges Bank haddock assuming: no fishing mortality (F) from 1987 onward and constant age 2 recruitment of 5 million fish per year. Data for 1986 are provided for reference purposes.

Year	Mean F (2+)	Total Catch (age 2+) Numbers (millions)	Total Catch (age 2+) Weight (000's mt)	Jan 1 Stock Size (age 3+) Numbers (millions)	Jan 1 Stock Size (age 3+) Weight (000's mt)
1986	0.6	3.5	7.5	8.0	16.5
1987	0.0	0.0	0.0	4.0	9.5
1988	0.0	0.0	0.0	14.7	26.6
1989	0.0	0.0	0.0	12.2	27.1
1990	0.0	0.0	0.0	14.1	32.3
1991	0.0	0.0	0.0	15.6	37.1
1992	0.0	0.0	0.0	16.8	41.4
1993	0.0	0.0	0.0	17.8	44.8
1994	0.0	0.0	0.0	18.6	48.2
1995	0.0	0.0	0.0	19.3	51.1
1996	0.0	0.0	0.0	19.9	53.7
1997				20.3	55.9

Table 4.11. Ten year (1987-1997) catch and stock size projections for Georges Bank haddock assuming: no fishing mortality (F) from 1987 onward and constant age 2 recruitment of 5 million fish per year during 1987-1994 and 1996-1997 and a recruitment pulse of 60 million fish (age 2) in 1995. Data for 1986 are provided for reference purposes.

Year	Mean F (2+)	Total Catch (age 2+) Numbers (millions)	Total Catch (age 2+) Weight (000's mt)	Jan 1 Stock Size (age 3+) Numbers (millions)	Jan 1 Stock Size (age 3+) Weight (000's mt)
1986	0.6	3.5	7.5	8.0	16.5
1987	0.0	0.0	0.0	4.0	9.5
1988	0.0	0.0	0.0	14.7	26.6
1989	0.0	0.0	0.0	12.2	27.1
1990	0.0	0.0	0.0	14.1	32.3
1991	0.0	0.0	0.0	15.6	37.1
1992	0.0	0.0	0.0	16.8	41.4
1993	0.0	0.0	0.0	17.8	44.8
1994	0.0	0.0	0.0	18.6	48.2
1995	0.0	0.0	0.0	19.3	51.1
1996	0.0	0.0	0.0	64.9	123.1
1997				57.2	128.6

Table 4.12. Ten year (1987-1997) catch and stock size projections for Georges Bank haddock assuming: an annual fishing rate of F=0.4 from 1987 onward and constant age 2 recruitment of 5 million fish per year during 1987-1994 and 1996-1997 and a recruitment pulse of 60 million fish (age 2) in 1995. Data for 1986 are provided for reference purposes.

Year	Mean F (2+)	Total Catch (age 2+) Numbers (millions)	Total Catch (age 2+) Weight (000's mt)	Jan 1 Stock Size (age 3+) Numbers (millions)	Jan 1 Stock Size (age 3+) Weight (000's mt)
1986	0.6	3.5	7.5	8.0	16.4
1987	0.4	4.3	6.6	4.0	9.5
1988	0.4	3.3	6.3	10.9	19.3
1989	0.4	2.9	5.5	6.1	13.3
1990	0.4	3.0	5.5	6.4	13.4
1991	0.4	3.1	5.6	6.6	13.5
1992	0.4	3.1	5.6	6.7	13.6
1993	0.4	3.1	5.7	6.8	13.7
1994	0.4	3.2	5.7	6.8	13.8
1995	0.4	15.4	19.6	6.8	13.8
1996	0.4	13.4	22.6	40.9	66.3
1997				25.5	50.7

Table 4.13. Ten year (1987-1997) catch and stock size projections for Georges Bank haddock assuming: an annual fishing rate of F=0.1 from 1987 onward and constant age 2 recruitment of 5 million fish per year during 1987-1994 and 1996-1997 and a recruitment pulse of 60 million fish (age 2) in 1995. Data for 1986 are provided for reference purposes.

Year	Mean F (2+)	Total Catch (age 2+) Numbers (millions)	Total Catch (age 2+) Weight (000's mt)	Jan 1 Stock Size (age 3+) Numbers (millions)	Jan 1 Stock Size (age 3+) Weight (000's mt)
1986	0.6	3.5	7.5	8.0	16.5
1987	0.1	1.2	1.8	4.0	9.5
1988	0.1	1.2	2.3	13.6	24.5
1989	0.1	1.2	2.4	10.3	22.7
1990	0.1	1.3	2.7	11.4	25.6
1991	0.1	1.4	2.9	12.3	28.0
1992	0.1	1.4	3.1	12.9	30.1
1993	0.1	1.5	3.2	13.3	31.5
1994	0.1	1.5	3.4	13.7	32.0
1995	0.1	4.9	7.3	13.9	33.9
1996	0.1	5.2	9.5	56.1	99.5
1997				45.5	97.1

result in a much larger stock in 1997 (Table 4.14) than if the current level of F was maintained.

Under the latter two options of fishing mortality (F=0.1 and F=0.2), projected catches are only slightly lower than those obtained by maintaining the current (1986) F, but SSB would be dramatically higher. The small reduction in the amount of catch would result in major increases in stock sizes in the long term.

4.5.2. Catch Projections for Georges Bank Cod

The most recent assessment of the Georges Bank cod stock indicated a marked decline in stock abundance between 1978 and 1985 (Serchuk and Wigley 1986). Total stock biomass (age 1+) declined 20% during this period while spawning stock biomass (3+) dropped by 52%. These declines occurred despite strong recruitment from the 1980 and 1983 year classes. Fishing mortality doubled during the eight-year period, from 0.40 in 1978 to 0.82 in 1985. As a consequence, spawning stock biomasses in 1985 and 1986 were at record-low levels (Table 4.15).

Stock and catch projections were performed to evaluate a management program in which the objective was to rebuild spawning stock biomass to the 1980 level. Three different scenarios were assessed:

1. Projected rebuilding of SSB assuming no fishing mortality after 1987.

2. Projected rebuilding of SSB under a management program to rebuild the stock to 1980 levels in five years.

3. Projected rebuilding of SSB under a management program to rebuild the stock to 1980 levels in ten years.

All of the projections assume that the 1985 year class is strong; year-class strength for this cohort was set at 31 million fish at age 1. Subsequent year classes (1986 and beyond) were assumed to be average in strength (20 million fish at age 1). Fishing mortality in 1987 was assumed to be equal to that estimated in 1986 (0.517). In all of the projections, estimates of total stock size (age 1+), "harvestable" stock size (2+), and spawning stock sizes (3+) were calculated.

The results from the projections indicate that rebuilding to stock sizes seen in 1980 is possible under any of the scenarios. In the absence of fishing, the stock will rebuild to the 1980 level by 1989 (Table 4.16). The question marks used in Table 4.16 and others to follow indicated that the actual mix of catches between the USA and Canada is unknown; it would need to be considered in fully evaluating the effect of each scenario on the USA

Table 4.14. Ten year (1987-1997) catch and stock size projections for Georges Bank haddock assuming: an annual fishing rate of F=0.2 from 1987 onward and constant age 2 recruitment of 5 million fish per year during 1987-1994 and 1996-1997 and a recruitment pulse of 60 million fish (age 2) in 1995. Data for 1986 are provided for reference purposes.

Year	Mean F (2+)	Total Catch (age 2+) Numbers (millions)	Total Catch (age 2+) Weight (000's mt)	Jan 1 Stock Size (age 3+) Numbers (millions)	Jan 1 Stock Size (age 3+) Weight (000's mt)
1986	0.6	3.5	7.5	8.0	16.5
1987	0.2	2.3	5.6	4.0	9.5
1988	0.2	2.1	4.0	12.6	22.6
1989	0.2	2.0	4.0	8.6	19.0
1990	0.2	2.1	4.3	9.3	20.4
1991	0.2	2.2	4.5	9.8	21.6
1992	0.2	2.3	4.6	10.1	22.5
1993	0.2	2.3	4.7	10.3	23.0
1994	0.2	2.3	4.8	10.5	23.6
1995	0.2	8.9	12.3	10.5	24.0
1996	0.2	8.8	15.6	49.8	84.6
1997				36.9	76.4

Table 4.15 Commercial landings (000s mt) of Atlantic cod from the Georges Bank stock (NAFO Division 5Z & Statistical Area 6), 1978-1986, and estimates of fishing mortality (F) and stock biomass (000s mt) derived from virtual population analysis.

Year	Commercial Landings USA	CAN	Total	Mean F (3+)	Jan 1 Stock Biomass (1+)	Jan 1 Stock Biomass (2+)	Jan 1 Spawning Stock Biomass (3+)	(Ogive)
1978	26.6	8.9	35.5	0.403	113.3	98.5	95.6	75.9
1979	32.6	6.0	38.6	0.457	127.3	111.9	86.0	84.9
1980	40.1	8.1	48.2	0.505	127.7	116.6	95.4	88.2
1981	33.8	8.5	42.3	0.481	134.6	106.2	90.1	82.4
1982	39.3	17.9	57.2	0.611	126.7	117.1	79.5	80.1
1983	36.8	12.1	48.9	0.632	103.6	97.0	82.1	72.1
1984	32.9	5.8	38.7	0.701	105.9	75.2	66.2	60.0
1985	26.8	10.4	37.2	0.820	90.2	79.3	46.2	50.1
1986	19.1	8.4	27.5	0.517	92.2	67.3	53.9	45.1

Table 4.16 Projected rebuilding of the Georges Bank cod stock size (000s mt) to 1980 levels assuming no fishing mortality (F) after 1987.

Year	Comm Landings (000s mt) USA	CAN	Total	Mean F (3+)	Jan 1 Stock Biomass (1+)	Jan 1 Stock Biomass (2+)	Jan 1 Spawning Stock Biomass (3+)	(Ogive)
1987	?	?	31.4	0.517	98.9	82.9	51.4	50.9
1988	0.0	0.0	0.0	0.000	101.6	85.6	65.4	57.8
1989	0.0	0.0	0.0	0.000	139.8	123.8	103.4	93.5

fishery. Under a five-year rebuilding program, the 1980 level can be attained by reducing fishing mortality by 15% per year (Table 4.17). This scenario implies that fishing mortality declines from 0.517 in 1987 to 0.230 by 1992 (56% overall reduction in F). As a result, annual catch would drop by 23% between 1987 and 1992 (31,400 mt vs 24,200 mt). Under a 10-year rebuilding program, the 1980 SSB level would be attained by 1997 if fishing mortality was reduced by 6% per year. This implies a decline in F from 0.517 in 1987 to 0.279 in 1997 (46% overall reduction in F). Annual catches would not decline significantly during the period, but would range between 29-33 thousand tons (Table 4.18).

4.6. Summary of Effects of Alternate Management Measures

The several alternate management measures evaluated above would have different effects on the mixed species trawl fishery in terms of both short and long term catches and the degree to which their implementation might help achieve the FMP goals.

When larger mesh sizes are used but current F is maintained, projected spawning stock biomasses increase relative to the no-action alternative. Catches initially decline but, within 5-10 years, increase above those projected from the no-action alternative. When larger mesh sizes are used and concurrently accompanied by gradual reductions in F (so that target %MSP levels are achieved in five years), increases in projected catches are somewhat delayed but spawning stock biomass increases more rapidly. Additional projections indicated that it is possible to rebuild the Georges Bank cod stock to 1980 levels in five years if F is reduced by 15% per year, or to 1980 levels in 10 years if F is reduced by 6% per year.

Because assemblages of species are targeted to some degree in the mixed species fishery, fishing mortality on selected species may be controlled by restricting the amount of those species that can be caught on each fishing trip. This may be particularly important for stocks at extremely low stock sizes. For Georges Bank haddock and for redfish a small fraction of the fishing trips caught a large proportion of the total catches. Thus imposition of trip limits for those two species would appear to affect a relatively small proportion of trips but could substantially reduce fishing mortality. Several other possible catch limits on redfish and Georges Bank haddock were evaluated, and it appears that such measures could help meet the FMP goals.

The effects of adopting a large mesh option on stocks fished jointly will be less than predicted unless Canadian fisheries have similar management.

The use of the alternate management measures evaluated here would not achieve the %MSP targets for all species identified in the FMP without extremely large changes in mesh sizes. The combination of increased mesh sizes and gradual reductions of fishing mortality each year would gradually lead to meeting the targets, with initial short term losses followed by longer term gains first in spawning stock biomass and then by catches. Fishing mortality might be reduced on selected stocks in particularly poor condition that are to some degree targeted, such as redfish and Georges Bank haddock, by use of trip limits.

Table 4.17 Projected commercial landings and stock size (000s mt) of the Georges Bank cod stock under a management program to rebuild the stock to 1980 levels in five year a 15% reduction in fishing mortality per year will achieve this objective assuming average age 1 recruitment of 20 million fish per year.

Year	Commercial Landings USA	CAN	Total	Mean F (3+)	Jan 1 Stock Biomass (1+)	Jan 1 Stock Biomass (2+)	Jan 1 Spawning Stock Biomass (3+)	(Ogive)
1987	?	?	31.4	0.517	98.9	82.9	51.4	50.9
1988	?	?	30.5	0.440	101.6	85.6	65.4	57.8
1989	?	?	28.3	0.374	106.7	90.7	70.5	64.4
1990	?	?	26.7	0.318	113.6	97.6	77.4	72.1
1991	?	?	25.1	0.270	122.0	106.0	85.7	80.0
1992	?	?	24.2	0.230	132.9	116.9	96.6	90.4

Table 4.18 Projected commercial landings and stock sizes (000s mt) of the Georges Bank cod stock under a management program to rebuild the stock to 1980 levels in ten years a 6% reduction in fishing mortality per year will achieve this objective assuming average age 1 recruitment of 20 million fish per year.

Year	Commercial Landings USA	CAN	Total	Mean F (3+)	Jan 1 Stock Biomass (1+)	Jan 1 Stock Biomass (2+)	Jan 1 Spawning Stock Biomass (3+)	(Ogive)
1987	?	?	31.4	0.517	98.9	82.9	51.4	50.9
1988	?	?	33.0	0.486	101.6	85.6	65.4	57.8
1989	?	?	32.3	0.457	103.9	87.9	67.7	62.0
1990	?	?	31.6	0.430	106.2	90.2	70.0	65.4
1991	?	?	30.7	0.404	108.6	92.6	72.4	67.5
1992	?	?	30.4	0.380	112.3	96.3	76.1	71.0
1993	?	?	30.2	0.357	116.7	100.7	80.5	75.2
1994	?	?	29.8	0.336	120.1	104.1	83.9	78.4
1995	?	?	29.6	0.315	125.4	109.4	89.1	83.5
1996	?	?	29.3	0.297	129.6	113.6	93.3	87.5
1997	?	?	29.1	0.279	135.0	119.0	98.8	92.8

5. REFERENCES

Almeida, F. P., M. J. Fogarty, S. H. Clark, and J. S. Idoine. 1986. An evaluation of precision of abundance estimates derived from bottom trawl surveys off the northeastern United States. ICES C.M. 1986/G:91, 19 p.

Beacham, T. D. 1983. Variability in size or age at sexual maturity of white hake, pollock, longfin hake, and silver hake in the Canadian Maritime area of the Northwest Atlantic Ocean. Can. Tech. Rept. of Fish and Aquatic Sciences, No. 1157.

Berry, R. J., S. B. Saila, and D. B. Horton. 1965. Growth studies of winter flounder, Pseudopleuronectes americanus (Walbaum), in Rhode Island. Trans. Am. Fish. Soc. 94:259-264.

Burns, T. S., R. Schultz, and B. E. Brown. 1983. The commercial catch sampling program in the northeastern United States, p. 82-95. In: W.G. Doubleday and D. Rivard [eds.] Sampling commercial catches of marine fish and invertebrates. Can. Spec. Pub. Fish Aquat. Sci. 66.

Burnett, J. M. MS. 1987. The population biology of the witch flounder, Glytocephalus cynoglossus (L.), in the Gulf of Maine - Georges Bank region. M.Sc thesis, Department of Forestry and Wildlife Management, University of Massachusetts, Amherst, Mass.

Clark, S. H. 1979. Application of bottom-trawl survey data to fish stock assessment. Fisheries 4(3):9-15.

Collie, J. S., and M. P. Sissenwine. 1983. Estimating population size from relative abundance data measured with error. Can. J. Fish. Aquat. Sci. 40: 1871-1879.

Colton, J. B., Jr., W. G. Smith, A. W. Kendall, Jr., P. L. Berrien, and M. P. Fahay. 1979. Principal spawning areas and times of marine fishes, Cape Sable to Cape Hatteras. Fish. Bull., U.S. 76:911-915.

Finney, D. J. 1941. On the distribution of a variate whose logarithm is normally distributed. Journal of the Royal Statistical Society 7:155-161.

Fogarty, M. J., J. S. Idoine, F. P. Almeida, and M. Pennington. 1986. Modelling trends in abundance based on research vessel surveys. ICES C.M. 1986/G:92, 13 p.

Gabriel, W. L., M. P. Sissenwine and W. J. Overholtz. MS (in press). Spawning stock biomass per recruit analysis: an example for Georges Bank haddock. North. Am. J. Fish. Management

Gabriel, W. L., W. J. Overholtz, S. A. Murawski, and R. K. Mayo. 1984. Spawning stock biomass per recruit analysis for seven Northwest Atlantic demersal finfish species, Spring 1984. NMFS, NEFC, Woods

Hole Lab. Ref. Doc. No. 84-23.

Gabriel, W. L. 1985. Spawning stock biomass per recruit analysis for seven Northwest Atlantic demersal finfish species. NMFS, NEFC, Woods Hole Lab. Ref. Doc. No. 85-04.

Howe, A. B., and P. G. Coates. 1975. Winter flounder movements, growth, and mortality of Massachusetts. Trans. Am. Fish. Soc. 104:13-29.

Lux, F. E. 1969a. Length-weight relationships of six New England flatfishes. Trans. Am. Fish. Soc. 98:617-621.

Lux, F. E. 1969b. Age and growth of the winter flounder, Pseudopleuronectes americanus, on Georges Bank. Fish. Bull., U.S. 71:505-512.

Lux, F. E., and F. E. Nichy. 1969. Growth of yellowtail flounder, Limanda ferruginea (Storer), on three New England fishing grounds. ICNAF Res. Bull. 6:5-25.

Marchesseault, G.D. 1986. Research requirements for fishery management in the Northwest Atlantic: A New England Fishery Management Council perspective. MS, New England Fishery Management Council, Saugus, Massachusetts.

Mayo, R. K. 1980. Exploitation of redfish, Sebastes marinus (L.) in the Gulf of Maine - Georges Bank region, with particular reference to the 1971 year class. J. Northw. Atl. Fish. Sci. 1:21-37.

Mayo, R. K., and S. H. Clark. 1984. An assessment of the pollock (Pollachius virens L.) stock in the Scotian Shelf, Gulf of Maine and Georges Region in 1984. NMFS, NEFC, Woods Hole Lab. Ref. Doc. No. 84-13.

Mayo, R. K., A. M. Lange, S. A. Murawski, M. P. Sissenwine, and B. E. Brown. 1981. Estimation of discards in mixed trawl fisheries off the Northwest coast of the United States, based on bottom trawl survey catches. NMFS, NEFC, Woods Hole Lab. Ref. Doc. No. 81-18.

Morse, W. W. 1979. An analysis of maturity observation of 12 groundfish species collected from Cape Hatteras, North Carolina to Nova Scotia in 1977. NMFS, NEFC, Sandy Hook Lab. Ref. Doc. No. 79-32.

Murawski, S. A., A. M. Lange, M. P. Sissenwine, and R. K. Mayo. 1983. Definition and analysis of multispecies otter-trawl fisheries off the northeast United States. J. Cons. int. Explor. Mer. 41:13-27.

National Marine Fisheries Service. 1986a. Report of the Second NEFC Stock Assessment Workshop (Second SAW). NMFS, NEFC, Woods Hole Lab. Ref. Doc. No. 86-09, 114 p.

National Marine Fisheries Service. 1986b. Report of the Third NEFC Stock Assessment Workshop (Third SAW). NMFS, NEFC, Woods Hole Lab. Ref. Doc. No. 86-14, 98 p.

National Marine Fisheries Service. 1987. Report of the Fourth NEFC Stock Assessment Workshop (Fourth SAW). NMFS, NEFC, Lab. Ref. Doc. No. 87-07.

New England Fishery Management Council. 1985. Fishery Management Plan for the Northeast Multi-Species Fishery. New England Fishery Management Council, Saugus, Massachusetts, USA.

Overholtz, W. J., S. H. Clark, and D. Y. White. 1983. A review of the status of the Georges Bank and Gulf of Maine haddock stocks for 1983. NMFS, NEFC, Woods Hole Lab. Ref. Doc. No. 83-23.

Overholtz, W.J., M.P. Sissenwine, and S.H. Clark 1986. Recruitment variability and its implications for manageing and rebuilding the Georges Bank haddock (Melanogrammus aeglefinus) stock. Can. J. Fish. Aquat. Sci. 43: 748-753.

Penttila, J. A. and V. M. Gifford. 1976. Growth and mortality rates for cod and the Georges Bank and Gulf of Maine areas. ICNAF Res. Bull. 12:29-36.

Perlmutter, A., and G. M. Clarke. 1949. Age and growth of immature rosefish (Sebastes marinus) in the Gulf of Maine and off Nova Scotia. Fish. Bull. U.S. 51:207-228.

Ricker, W.E. 1954. Stock and recruitment. J. Fish. Res. Board Can. 11:559-623.

Serchuk, F. M. and S. E. Wigley. 1986. Assessment and status of the Georges Bank and Gulf of Maine Atlantic Cod stocks - 1986. NMFS, NEFC, Woods Hole Lab. Ref. Doc. No. 86-12, 84 p.

Serchuk, F. M. and S. E. Wigley. 1987. Evaluation of the Southern New England/Mid-Atlantic seasonal area closure in reducing fishing mortality and enhancing spawning opportunities for yellowtail flounder: An historical assessment. NMFS, NEFC, Woods Hole Lab. Ref. Doc. No. 87-04, 28 p.

Shepherd, J. G. 1982. A versatile new stock-recruitment relationship for fisheries, and the construction of sustainable yield curves. J. Cons. int. Explor. Mer, 40:67-75.

Smolowitz, R. J. 1983. Mesh size and the New England groundfishery - application and implications. NOAA Tech. Rep. NMFS SSRF-771. 60 p.

Sullivan, L. F. 1982. American plaice, Hippoglossoides platessoides, in the Gulf of Maine. M. S. Thesis, Biological Oceanography, University of Rhode Island, 95 pp.

U.S. Department of Commerce. 1986. Status of the Fishery Resources off the Northeastern United States for 1986. NOAA Tech. Mem. NMFS-F/NEC-43, 130 p.

6. ACKNOWLEDGEMENTS

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