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Persistence in Northwestern Demersal Fish Assemblages

by

Wendy L. Gabriel

National Marine Fisheries Service, Northeast Fisheries Center
Woods Hole, Massachusetts 02543, USA

ABSTRACT

Persistent spatial boundaries and species membership of groundfish assemblages in the Northwest Atlantic were defined based on cluster analysis of Northeast Fisheries Center autumn bottom survey data, 1967-1981. A strong boundary appeared between Gulf of Maine and Georges Bank along the northern edge of the shelf. Separate inshore and offshore components of the Gulf of Maine appeared intermittently in some years as did the Northeast Peak. A boundary between Georges Bank and southern New England also appeared, but was variable from year to year in strength and location. Mid-Atlantic boundaries were highly variable. Boundaries were consistent with mesoscale oceanographic circulation features. Composition of clusters of species was constant from year to year. Trends in diversity and relative abundance can be attributed in part to fishery effects, including technological interactions. Environmental influences on distributions appeared to increase further south. Diversity on Georges Bank and in southern New England has been increasing recently, and the proportion of biomass comprising elasmobranchs is increasing in the Gulf of Maine and Georges Bank. These are symptoms of ecosystems under stress. Reversibility of the effects of perturbations due to fishing appears rare.

SPECIAL SESSION ON CHANGES IN FISH POPULATIONS

INTRODUCTION

Concern over irreversible changes to assemblage structure and dynamics due to perturbations by fisheries has been based on both empirical and theoretical evidence. Although not caused by exploitation alone, the simplification of the Great Lakes fishery production system serves as a qualitative example of apparent irreversibility of assemblage structure (e.g., as discussed by Tyler _et al_., 1982). Theoretical studies reviewed by Beddington (1984) indicate that multiple stable states of community structure are possible and that "formal" reversibility is unlikely.

Opportunities for controlled experiments to assess assemblage reactions to fishery perturbations are rare: for marine fish complexes, the cost of observation may be high, and the value of new information may be outweighed by the risk of obtaining irreversible results (Pikitch, 1988). An alternative is to evaluate empirical data from systems that have undergone uncontrolled perturbations. Although this alternative is clearly less desirable, it may be the only opportunity available to observe behavior of some assemblages.

Northwest Atlantic groundfish assemblages have been significantly perturbed by fishing twice in the past thirty years. Historical patterns in fishing effort for Georges Bank cod (Figure 1) are typical for many groundfish harvested in the region by multispecies otter trawl fisheries: First, the distant water fleet arrived in the middle 1960's and exerted record-high levels of effort. As biomass was depleted and regulations became more restrictive, effort declined in the early and mid-1970's. Then, effort by the domestic fleet began to expand after the implementation of the Magnuson Fishery Conservation and Management Act (MFCMA). In the case of Georges Bank cod, current levels of fishing mortality may be exceeding levels previously associated with foreign fishing (Anon., 1985; Anon., 1989).

Earlier examinations of these issues have been limited to Georges Bank, with observations between 1963-1978 (Overholtz and Tyler, 1983). For that region and time period, the authors indicated that biomass showed some signs of recovery in the late 1970's, which they attributed to several good year classes and declining effort under the MFCMA. Significant additional information on persistence and reversibility may be gained by examining patterns which may emerge from other areas of the Northwest Atlantic and from the most recent years of data, however.

The objectives of this paper are: 1.) to identify persistent spatial boundaries and species membership of groundfish assemblages in the Northwest Atlantic; 2.) to describe the behavior of several of these assemblages in the face of fishery perturbations; and 3.) to hypothesize mechanisms for structuring the assemblages consistent with observed patterns of persistence.

METHODS

The Northeast Fisheries Center has conducted trawl surveys of the Northwest Atlantic continental shelf annually since 1963, extending from the Scotian Shelf to the Mid-Atlantic Bight, and south to Cape Hatteras after 1967 (Azarowitz, 1981; Figure 2). Surveys have been based on stratified random design and were conducted with standardized techniques and gear (36' Yankee otter trawl rigged with roller gear and lined with 1/4" mesh). Catches are identified to species, counted and weighed. The autumn time series was used for these analyses because it was longer than the spring series and required no standardization for inclusion of a second gear type used mid-way in the spring series.

Hierarchical agglomerative cluster analysis (Clifford and Stephenson, 1975; Ludwig and Reynolds, 1988) was used to produce a series of site groups with similar species compositions for each year from 1967-1981. Observations at each site consisted of proportionalized $\log_{10}$ transformed biomass per tow of each of 53 species. Bray-Curtis dissimilarity coefficients were calculated for each pair of sites. Clustering was based on group average fusion strategy, and a dendrogram was produced for each analysis showing at what dissimilarity levels sites and groups were fused. Site groups were mapped as boundaries drawn around sites that belonged to clumps found in a dendrogram site cluster. A site group boundary was considered justifiable if sites within the cluster group were contiguous on a map. For summary statistics (described below), assemblage regions were approximated by combinations of survey stratum areas. Cluster analysis was also used to produce a series of species groups with similar spatial distributions for each year (inverse classification) as well as for all years combined.

A series of descriptive statistics was generated for each assemblage region for each year, including frequency of occurrence of species at sites in the region, mean and standard deviation of catch per tow, and indices of diversity (including Simpson's diversity index; Ludwig and Reynolds, 1988).

RESULTS

When site groups were compared on a coastwide basis (dissimilarity level of 0.7-0.9 between regions), major features in the northern segment regularly included a Scotian Shelf region (in the years of higher station density in that region), a Gulf of Maine region and a Georges Bank region (Figure 3). Other areas appeared as regions or subregions from year to year: Jeffries

Ledge/Stellwagen Bank, a "transition zone" strip from northern Georges Bank to the southern Gulf of Maine, and the Northeast Peak of Georges Bank. The amount of area associated with the Northeast Peak varied from year to year. Strong boundaries were always observed along the northern edge of Georges Bank. A weaker boundary subdivided sites within the Gulf of Maine into deep and shallow sites in some years.

Location of site group boundaries was more variable from year to year with more southward-located sites. Sites with similar species composition extended from Georges Bank west to Long Island and occasionally to the New Jersey coast (e.g., 1967-1968). The eastern boundary of Georges Bank appeared to be truncated by the South Channel in some years, but not at a high level of dissimilarity. A highly distinct southern New England patch did not appear every year. A strip extending west from the southeastern edge of Georges Bank varied from year to year in its length and width of extension north onto the Bank and west into southern New England waters. In earlier years (1967-1969), separate site groups appeared off New Jersey and south of Delaware Bay. A strong north-south boundary intersected the New Jersey coast 1967-1972; but after 1972, the region off New Jersey became more closely affiliated and continuous with the Mid-Atlantic region instead of Georges Bank.

A group of deepest sites formed at relatively higher dissimilarity levels than shallower sites, but was present each year. This region extended from Cape Hatteras to the southwestern edge of Georges Bank 1967-1970 and moved further north and east along the south edge of the Bank 1971-1974. In 1975, the area was defined only as far north as the South Channel, but extended to the eastern edge of the Bank in years after.

These features were approximated by a series of survey strata regions (Figure 2): Gulf of Maine Deepwater, strata 24, 28-30, 37, 36; Gulf of Maine Inshore, strata 26-27, 38-40; Transition Zone, strata 23, 25; Georges Bank, strata 13, 16, 19-21; Southern New England, strata 1-2, 5-6, 9-10; Mid-Atlantic, 61-62, 65-66, 69-70, 73-74; and Offshore, 3-4, 7-8, 11-12, 14-15, 17-18, 62-63, 67-68, 71-72, 75-76. As noted above, although the Gulf of Maine was clearly separated from Georges Bank by the cluster analysis, boundaries within and between southern New England and Mid-Atlantic varied from year to year, and this approximation is most arbitrary for those two regions.

Like site groups, species groups with distributions centered more northward were less variable in membership from year to year than those further south. Results of analysis of all years combined (Table 1) were similar to those produced for each year. These groups correspond to regions formed from site group analysis. The second area in a group name is one of secondary concentration or a second stock area for many species. Species groups included: A. Gulf of Maine Deepwater, B. Gulf of Maine/Georges Bank Transition Zone, C. Gulf of Maine-Georges Bank, D. Georges Bank-Southern New England Shallow, E. Southern New England-Georges Bank, F. Southern New England-Mid-Atlantic and G. Southern Slope.

Over time, fluctuations in diversity were lowest for the Gulf of Maine inshore assemblage region (Figure 4). The single largest dip was due to high catches of spiny dogfish in 1982. Peaks in aggregate catch per tow appeared in the late 1960's-early 1970's and again in the late 1970's, which in part were contributed by haddock and American plaice. The relative contribution of redfish, thorny skate and spiny dogfish trended downward from 1963 to 1977, but elasmobranch abundance may have upturned slightly in the late eighties. (The increase in proportion of redfish is not supported by abundance in the offshore assemblage region, discussed below.) The relative importance of cod has remained fairly constant in the earlier two-thirds of the time series, with indications of increasing importance in some recent years. The aggregate composition has shifted, however, from a mix of redfish, haddock and Atlantic cod to Atlantic cod with an increasing contribution by silver hake as aggregate biomass has declined.

Aggregate biomass in the deepwater Gulf of Maine showed an overall decline between 1963 and 1975, but rose between 1973 and 1980 (Figure 5). The decline can be attributed to nearly continuous decrease in abundance of redfish, but also accompanied by declines in relative abundance of thorny skate and haddock. This reduction in the importance of redfish may have contributed to a potential increase in diversity, as a dominant species was removed. The biomass increase that followed in the late 1970's was supported in part by cod and haddock. The low aggregate biomass observed from 1982 onward consists primarily of spiny dogfish, silver hake, white hake and occasionally pollock.

The Georges Bank region also showed a potential increase in diversity as biomass of a previously dominant species, haddock, was removed in the mid-1960's (Figure 6). Diversity trended downward from 1974 to 1984. Although some of the earlier dominant species (haddock, yellowtail flounder) produced large year classes in the late 70's, some relatively minor species did not (e.g., Winter flounder and long-horned sculpin (of species group D.) remained at low levels or trended downward after the early 1970's). Meanwhile, relative abundance of spiny dogfish and winter skate increased continuously.

Although diversity in the southern New England region had fluctuated from year to year before 1981, the drop between 1981-1988 is the largest seen for any area examined. (Figure 7) The result is a an assemblage dominated by spiny dogfish, species group E. (including Loligo, butterfish and four-spot flounder) and the skates of species group D. The relative importance of species group E. has increased as the importance of species group C. has declined somewhat since the mid-1970's: Although spiny dogfish remain a substantial fraction of the survey catch in this region, its relative importance has declined from the early 1960's to present. Relative abundance of goosefish has declined since the early 1970's; red hake also appears to be trending down, depending on the interpretation of a spike in 1983.

Aggregate abundance declined overall between 1963 and 1976. A brief peak in aggregate abundance in 1972 arose from a combination of spiny dogfish and yellowtail flounder. Yellowtail flounder abundance then declined sharply until 1976, where it remained at relatively low levels. Subsequent increases in biomass have been derived from group D., as noted above, although a small peak in yellowtail relative abundance occurred in 1982-1983.

In the Mid-Atlantic, patterns are often characterized by intermittent spikes. The aggregate biomass index (Figure 8) shows decline from 1967-1974, peaks in 1975-1977, decline until 1982 and a second peak centered in 1985. Throughout the time series, diversity has been highly variable, apparently depending on the relative abundance of Loligo, a dominant species in the region. Spot and croaker, and to a lesser extent, scup, (part of species group F.) show similar patterns of high relative abundance 1975-1977 and again between 1983 and 1986. Northern sea robin has declined continuously throughout the time series.

DISCUSSION

The question of persistence and reversibility within the Georges Bank portion of the Northwest Atlantic was raised by Overholtz and Tyler (1985). They identified persistent spatial boundaries to assemblage distributions on Georges Bank, which recurred between seasons and among years; and characteristic species lists for each region. It is now possible to generalize that mesoscale oceanographic features (coupled with depth) are the likely bases of spatial patterns in Northwest Atlantic demersal fish assemblages: in the Gulf of Maine, a relatively slowly circulating closed counterclockwise gyre receives water at depth through the Northeast Channel; water flows outward over Nantucket Shoals toward the Mid-Atlantic Bight. On Georges Bank, the assemblage region boundaries correspond very closely to the Bank's four physical regimes, influenced by semidiurnal tides: the northern flank corresponds to the Gulf of Maine-Georges Bank transition region; the bank crest corresponds to the Central Georges Bank region and its attendant shallow water assemblage (group D); the southern flank which extends southwestward toward the southern New England region corresponding to the mid-shelf Southern New England-Georges Bank site groups; and the deeper segment of the southern flank which does not recirculate around the bank but mixes with slope water corresponding to the Deepwater Break region. General southwest flow along shore continues along the Mid-Atlantic Bight, consistent with the distribution of Mid-Atlantic assemblages (Butman and Beardsley, 1987).

These scales are appropriate for evaluating stability or persistence of a natural community over time, based on theoretical criteria (e.g., Connell and Sousa (1983)): these boundaries represent the smallest areas for replacement of adults, because they include the spawning and recruitment areas for resident species. It thus is not surprising that these areas correspond in many cases to single species stock areas.

For the same reasons, these spatial scales are also appropriate for aggregation to reduce complexity in demersal fisheries management systems (Sugihara et al., 1984). Spatial aggregation has been considered appropriate if productivity parameters (such as growth and fecundity rates) are homogeneous throughout the region, and if the unit responds in a statistically homogeneous way to perturbation of productivity rates (Tyler et al., 1982). Species-specific variability in recruitment is problematic for any case of aggregation in marine fisheries. In this case, consistency with stock areas reflects the aggregation of recruitment patterns (including reproduction) over the quasi-evolutionary time scale which produces stock structure.

Use of broader spatial scales is especially appropriate when assemblage regions may be linked by migrant species. The increase in spiny dogfish biomass on Georges Bank has been the object of several discussions (e.g., Murawski and Idoine, 1989 MS). A portion of that biomass increase may be due to changing distribution patterns of dogfish, however: as relative abundance on Georges Bank was increased, relative abundance in the Gulf of Maine (Figure 4) and southern New England (Figure 7) decreased. This alternative interpretation may not have arisen by considering individual assemblage regions in isolation.

Overholtz and Tyler (1985) suggested that for Georges Bank, fishing, coupled with trophic interactions, determined trends in assemblage distribution, composition and abundance. They proposed that weaker trophic linkages among species found in deeper water might make that assemblage less susceptible to changes in species composition and relative abundance, but that shallow water species were more vulnerable to fishing pressure.

The effect of technological interactions appears to be significant in the inshore Gulf of Maine region. Parallel responses by haddock and American plaice correspond to historical patterns in the northern shrimp fishery. This small mesh fishery operates in the nearshore area where haddock and American plaice are distributed as juveniles (Wigley and Gabriel, 1989 MS). High shrimp abundances and effort in the shrimp fishery occurred from 1968-1973. The shrimp stock collapsed in 1974. Shrimp abundance began trending up again in 1978. Conversely, haddock and American plaice abundances were near record low levels in inshore areas between 1970-1974 and began to rebound around 1975-1976, after shrimp landings had dropped substantially. Although the effects of perturbation by the shrimp fishery appeared reversible, current declines in haddock and American plaice cannot be attributed solely to the shrimp fishery, however, and are likely due to record high effort levels in the Gulf of Maine (Anon., 1987).

Effects of perturbations do not appear as readily reversible for the Georges Bank assemblage. Even though effort (Figure 1) returned to pre-peak levels from about 1970 to approximately 1981, many components of the assemblage continued to decline through that period (winter flounder, yellowtail flounder, haddock). Increases in observed ratios of spawning stock biomass per recruit for haddock may indicate poorer survival from egg to recruit (Gabriel et al., in press) in recent years.

The role of temperature in structuring assemblages appears to increase southward, consistent with results obtained for estuarine and inner shelf assemblages (Tyler, 1971). Periods of peak Loligo relative abundance in southern New England occurred around 1975 and 1985. Those years are centered in periods of positive bottom water temperature anomalies (Holtzwarth and Mountain, in prep.). In the Mid-Atlantic region, similar patterns appear for spot, croaker and to a certain extent Loligo.

Evidence for reversibility of the effects of fishery perturbations is intermittent at best. In none of these assemblage systems was the perturbation ever completely removed. Environmental effects were seen to directly influence distribution of adults; effects on recruitment are also likely, but more difficult to quantify and model. When underlying variability in recruitment patterns is added to the picture, it becomes difficult to distinguish between a "flip" into another stable state and a "slip" within a region of bounded fluctuations.

Ecosystem responses to stress have been well documented (Rapport et al., 1985). While fishery yields depend on "coping mechanisms," (e.g., surplus production when density dependent mechanisms are activated) the possibility of ecosystem "breakdown" exists when stress is prolonged or intense. Assemblage diversity in recent years appears to have decreased in Georges Bank and southern New England assemblage regions. The increase in elasmobranch abundance could be considered a unique form of "retrogression." From an empirical perspective, several symptoms of ecosystem stress in the Northwest Atlantic deserve continued attention.

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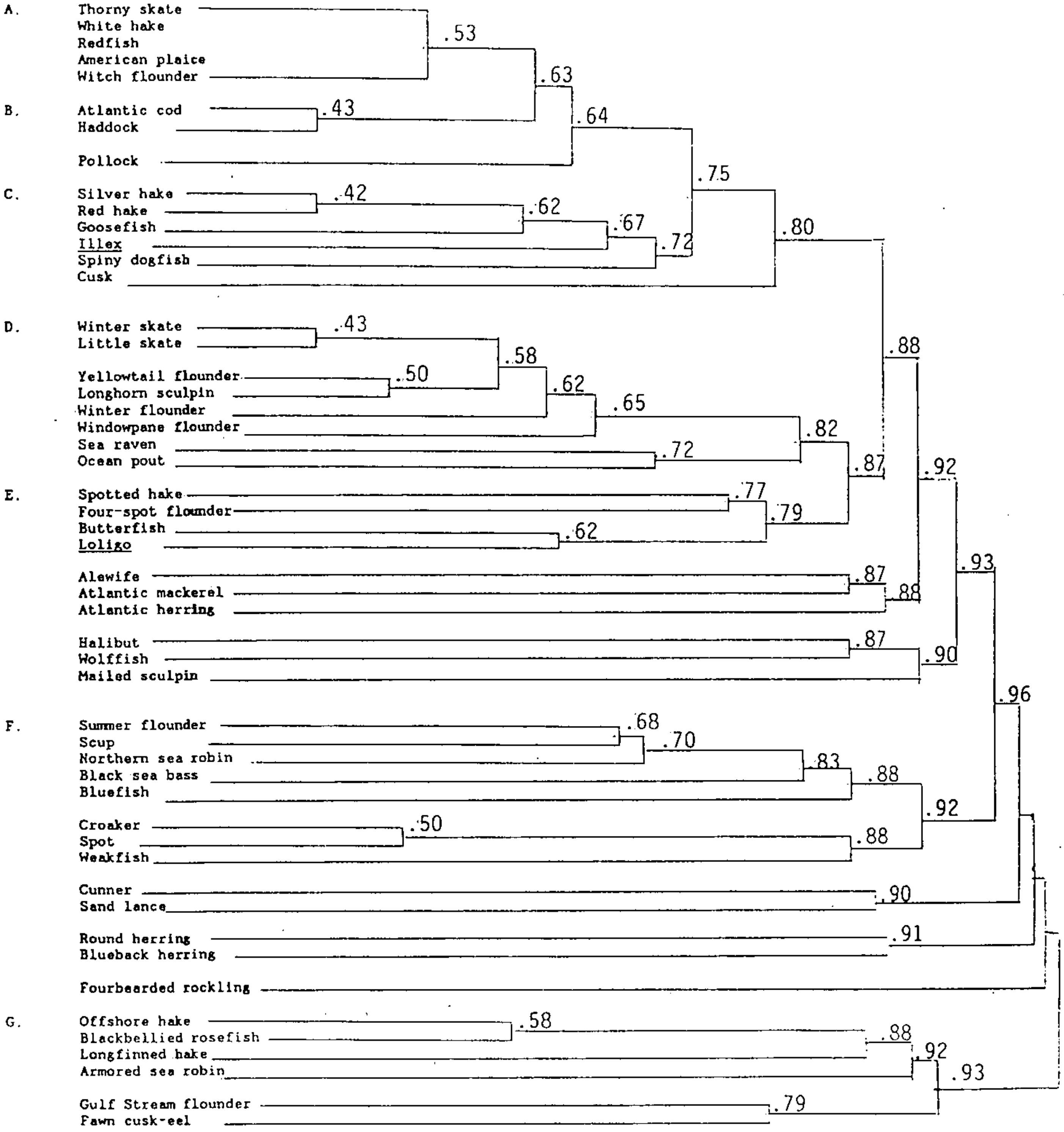
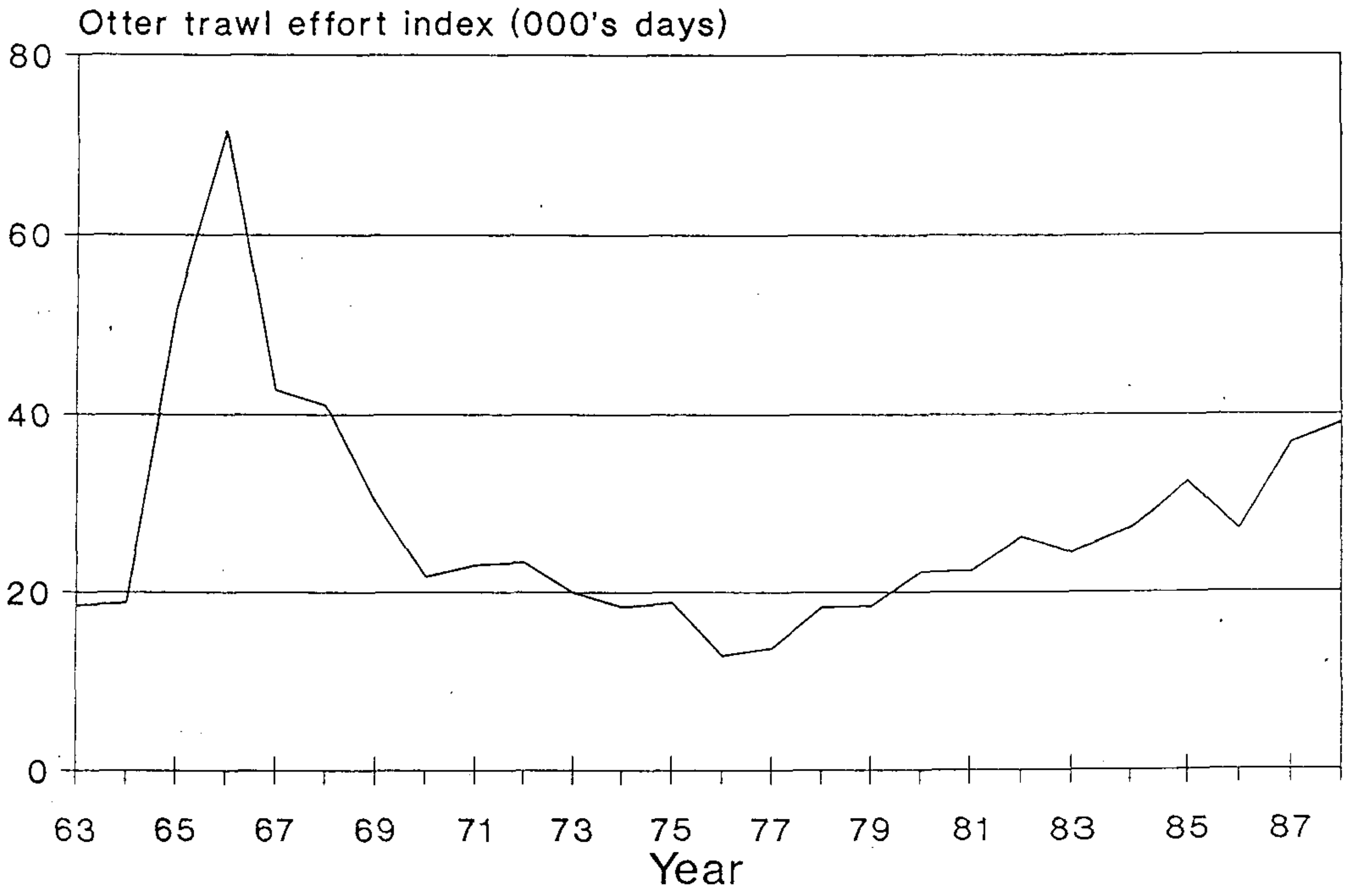
Table 1. Species groups and schematic dendrogram based on cluster analysis of 1967-1981 autumn groundfish survey data. Species groups A = Gulf of Maine Deepwater, B = Gulf of Maine Transition Zone, C = Gulf of Maine - Georges Bank, D = Georges Bank - Southern New England, E = Southern New England - Georges Bank, F = Southern New England and South, G = Deepwater Shelf Break. (Second areas in group names represent secondary areas of concentration and/or second stock area for many species.) Dissimilarity level is included on dendrogram, not to scale.





Adapted from Serchuk, pers. comm.

Figure 1. Estimates of otter trawl effort in the Atlantic cod fishery, Georges Bank and south, standardized to adjust for tonnage class effect (Serchuk, pers. comm.). 1963-1964 points were estimated from regression of commercial catch per unit effort and NEFC autumn survey index.

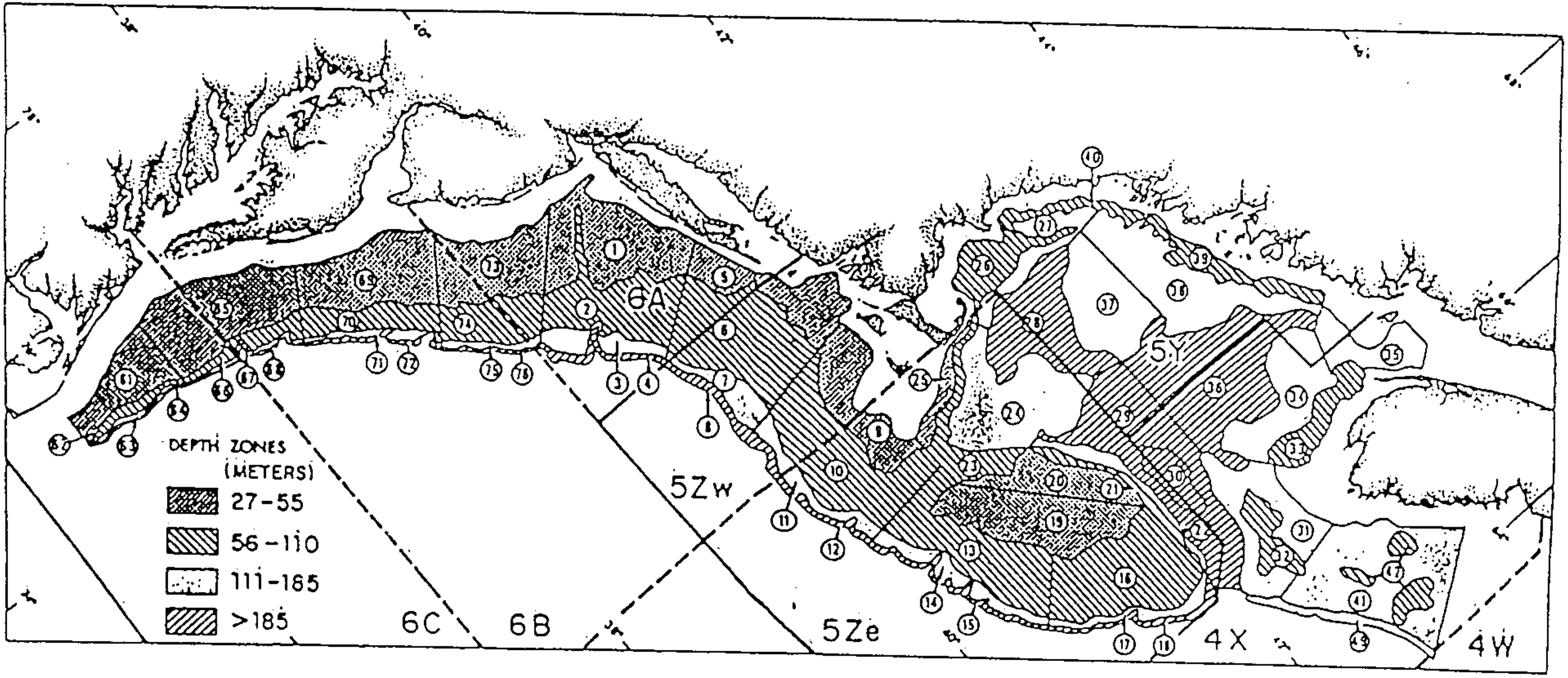


Figure 2. Northeast Fisheries Center offshore (>27 m) bottom trawl sampling strata in the Northwest Atlantic, Cape Hatteras to Nova Scotia.

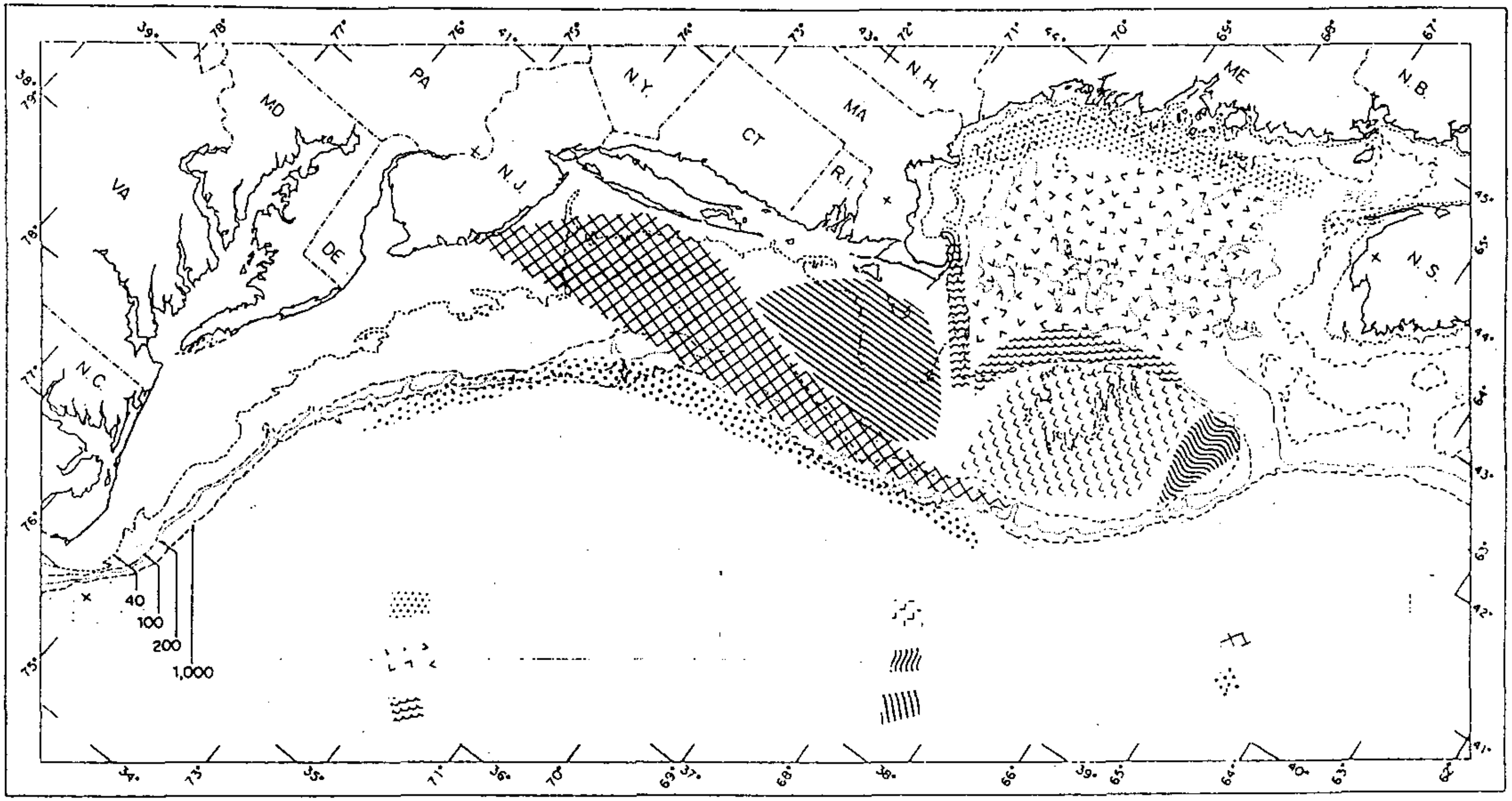


Figure 3. Composite of assemblage maps based on cluster analysis of NEFC autumn trawl survey data, 1967-1981. Boundaries may shift from year to year, and not all features are equally strong each year.

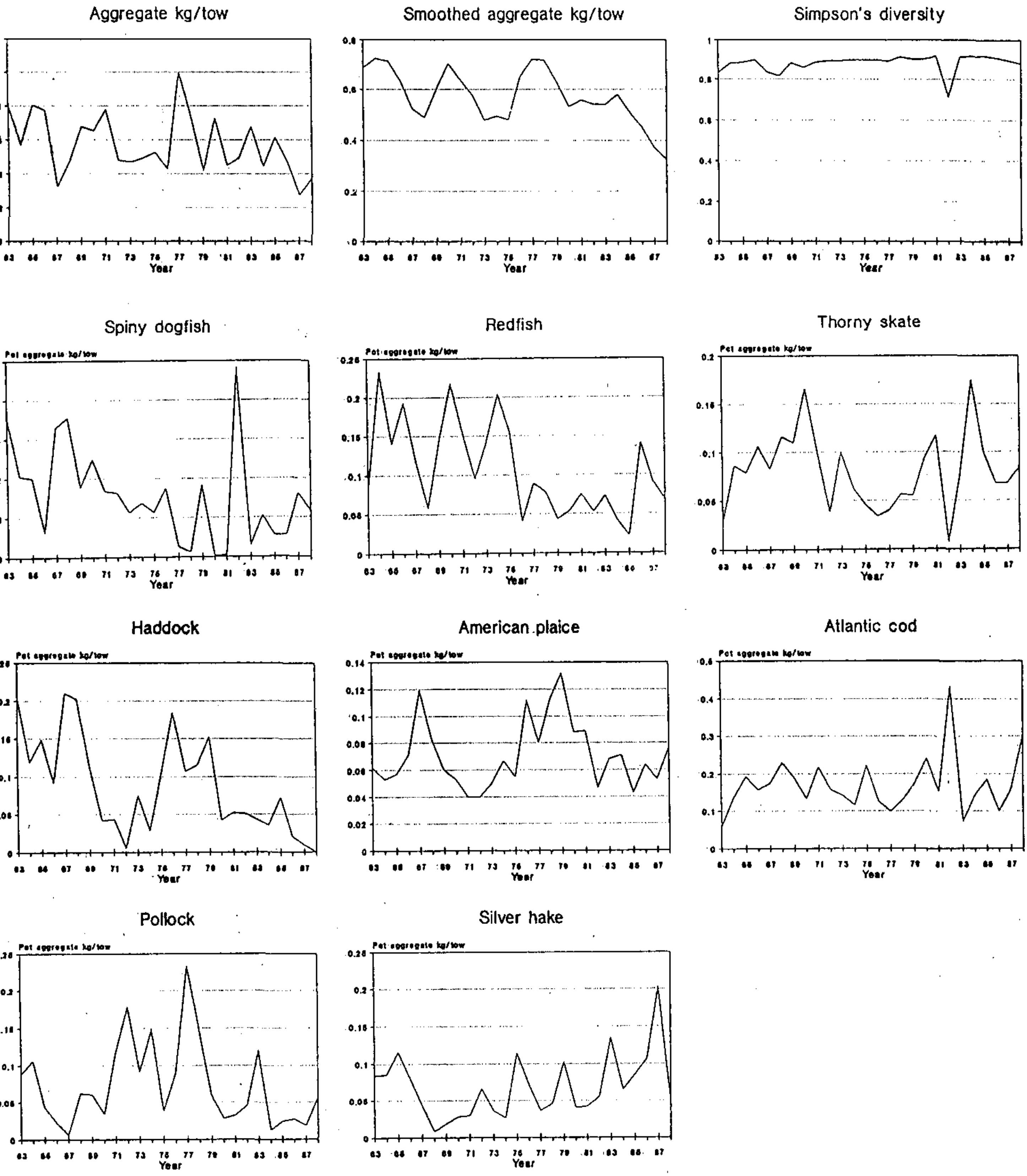


Figure 4. Aggregate kg/tow as a percentage of series maximum value, smoothed aggregate kg/tow as 3-year moving average of aggregate, Simpson's diversity index, and percentage of annual aggregate kg/tow for selected species (after spiny dogfish have been removed from aggregate total) from Gulf of Maine inshore region (NEFC survey strata 26-27,38-40).

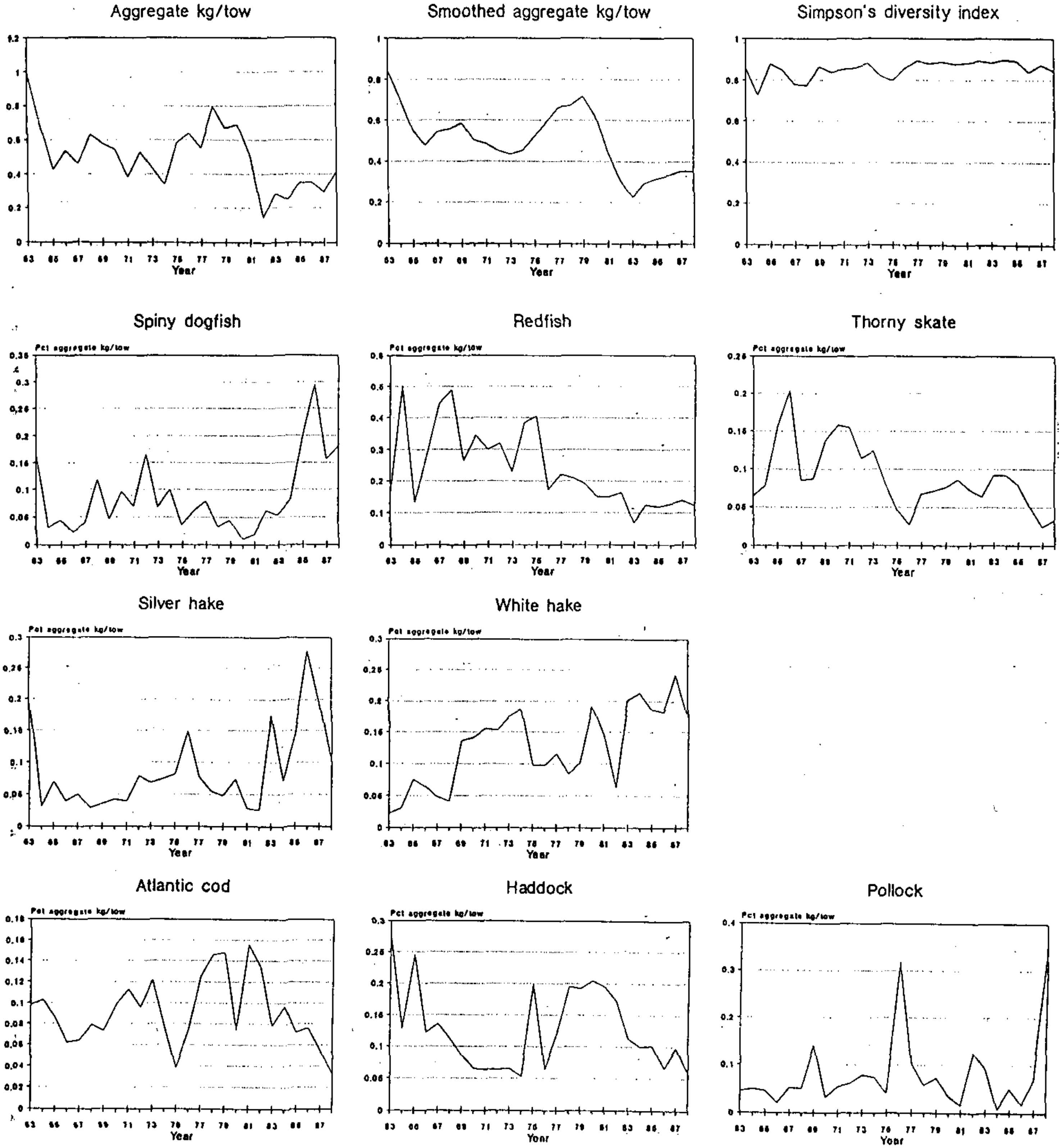
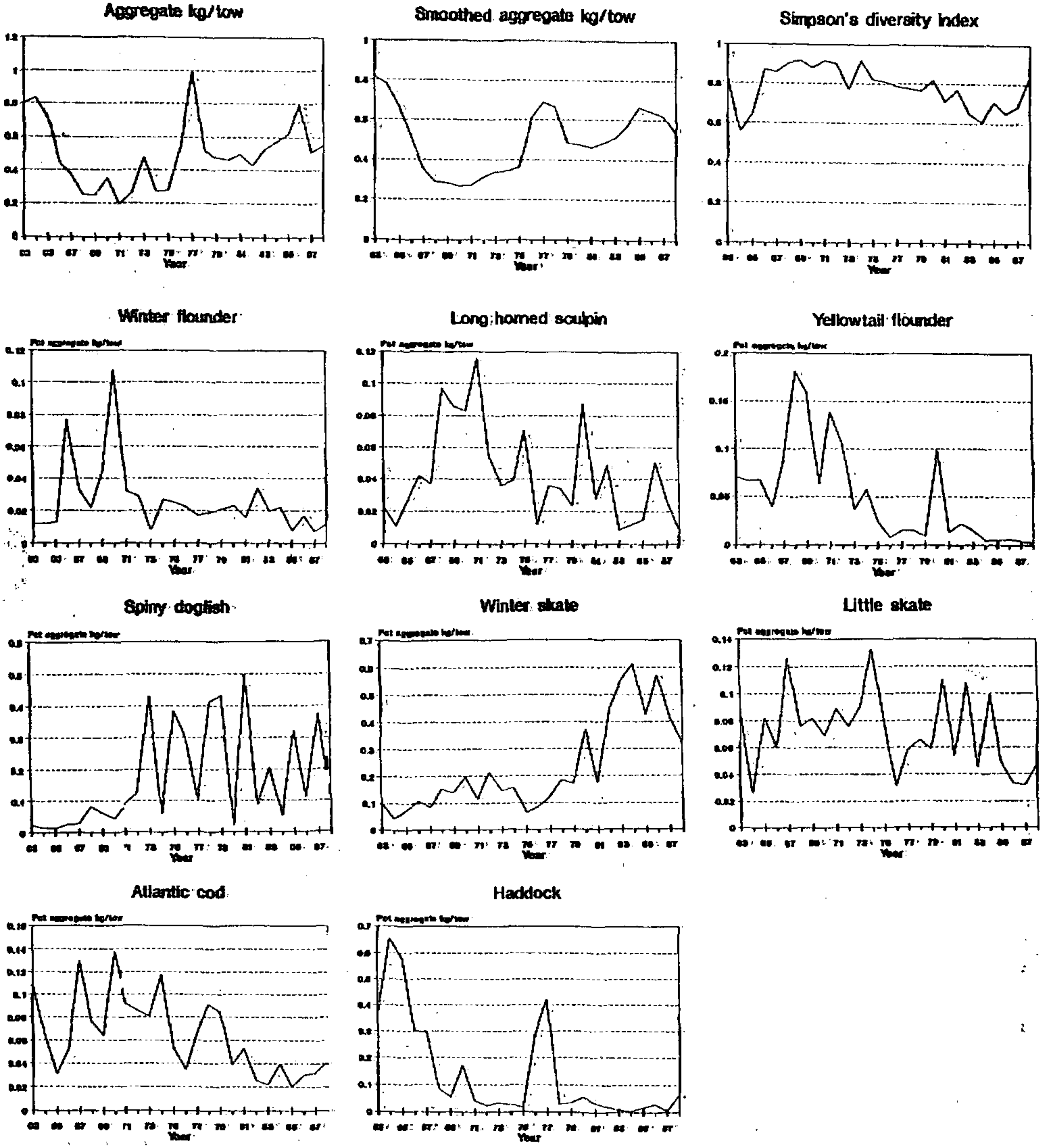


Figure 5. Aggregate kg/tow as a percentage of series maximum value, smoothed aggregate kg/tow as 3-year moving average of aggregate, Simpson's diversity index, and percentage of annual aggregate kg/tow for selected species (after spiny dogfish have been removed from aggregate total) from Gulf of Maine offshore region (NEFC survey strata 24, 28-30, 36, 37).



Aggregate kg/tow

Smoothed aggregate kg/tow

Simpson's diversity index

Winter flounder

Long-horned sculpin

Yellowtail flounder

Spiny dogfish

Winter skate

Little skate

Atlantic cod

Haddock

Figure 6. Aggregate kg/tow as a percentage of series maximum value, smoothed aggregate kg/tow as 3-year moving average of aggregate, Simpson's diversity index, and percentage of annual aggregate kg/tow for selected species (after spiny dogfish have been removed from aggregate total) from Georges Bank region (NEFC survey strata 13, 16, 19-21).

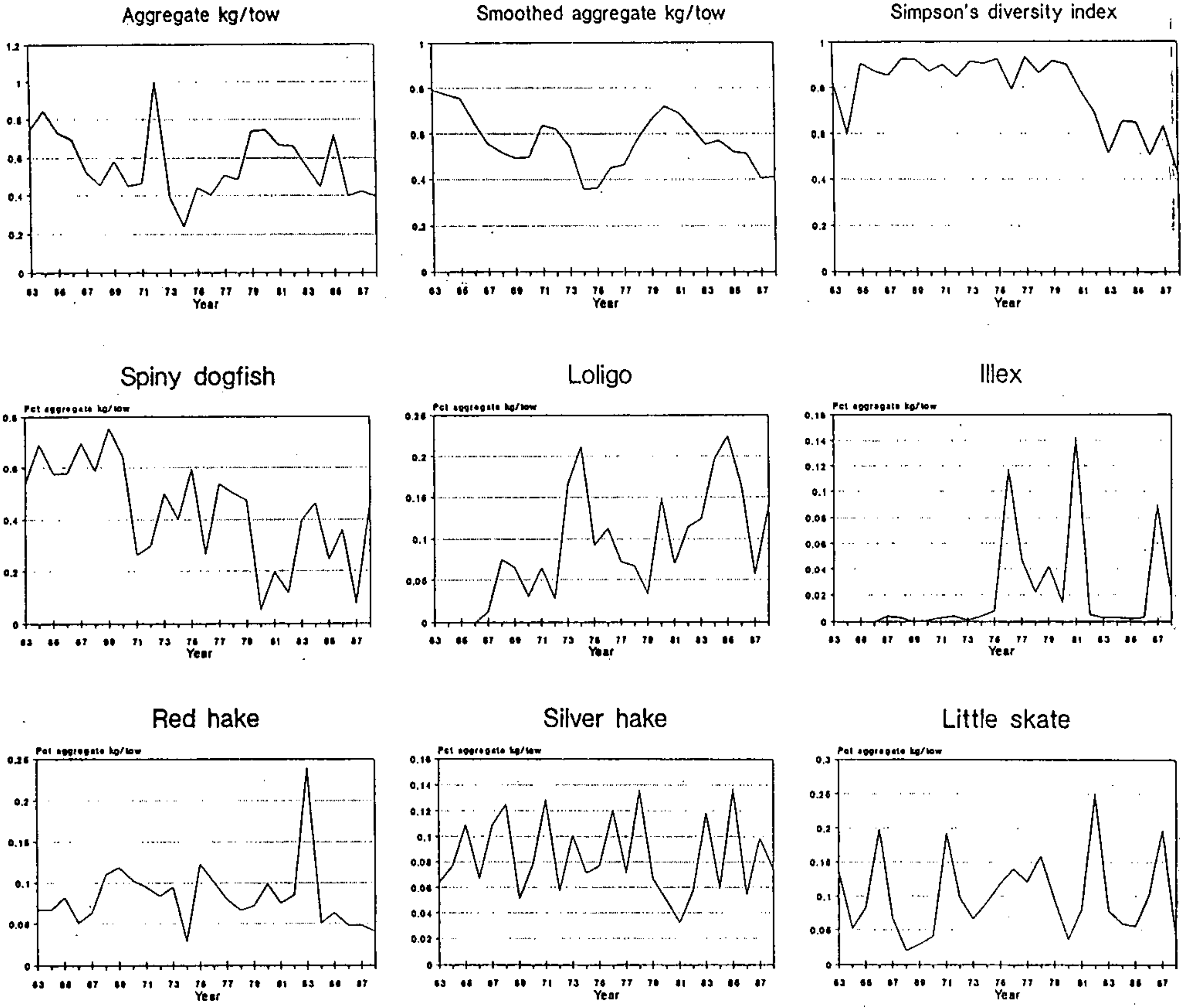
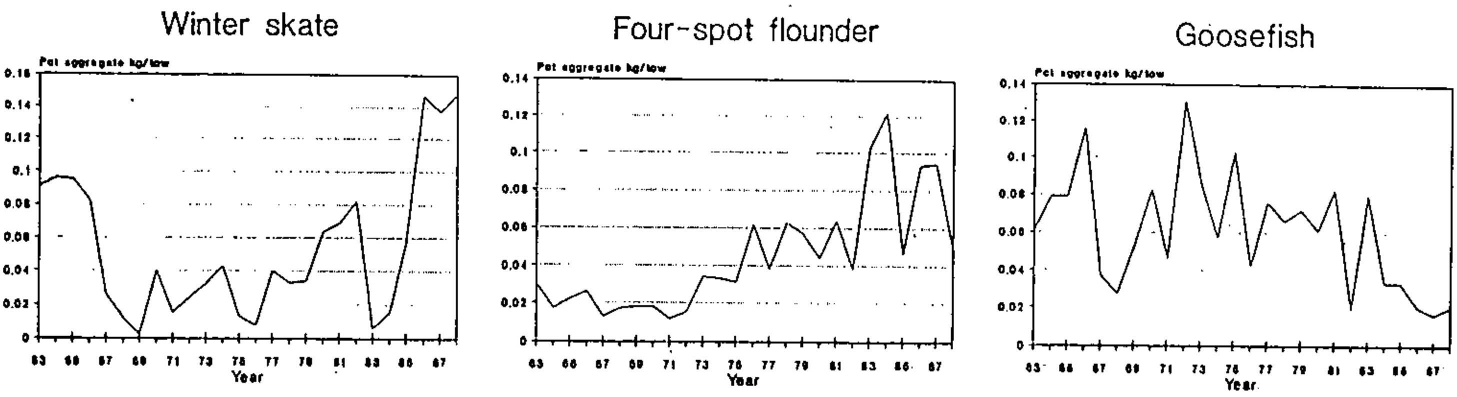
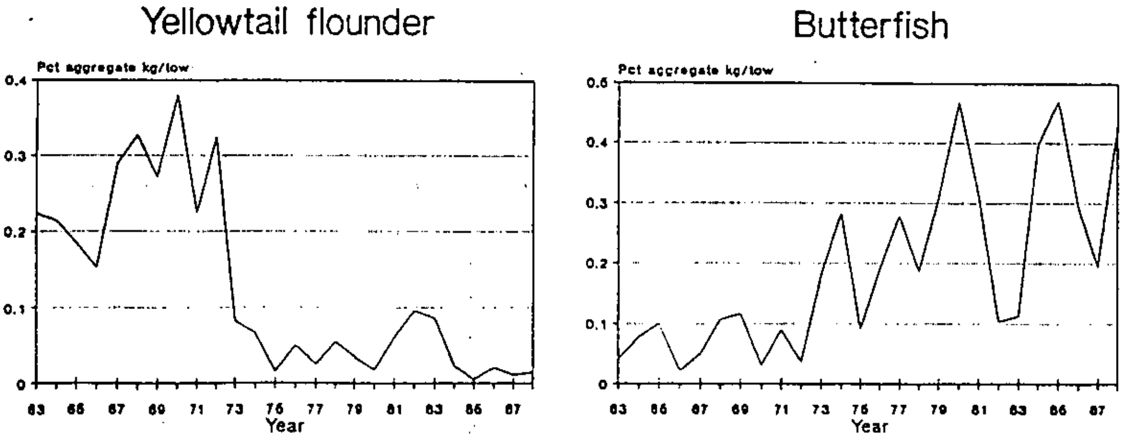


Figure 7. Aggregate kg/tow as a percentage of series maximum value, smoothed aggregate kg/tow as 3-year moving average of aggregate, Simpson's diversity index, and percentage of annual aggregate kg/tow for selected species (after spiny dogfish have been removed from aggregate total) from southern New England region (NEFC survey strata 1-2, 5-6, 9-10).


Winter skate

Four-spot flounder

Goosefish


Yellowtail flounder

Butterfish

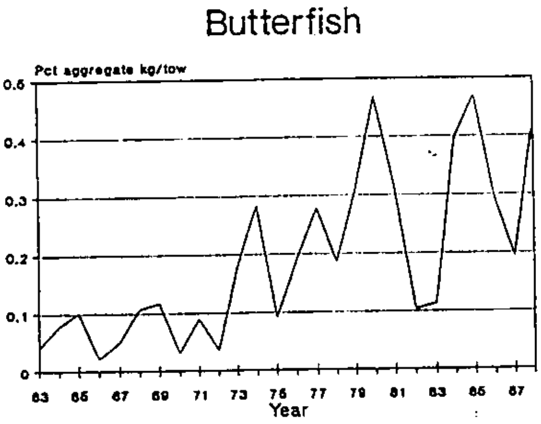

Butterfish

Fig 7. continued

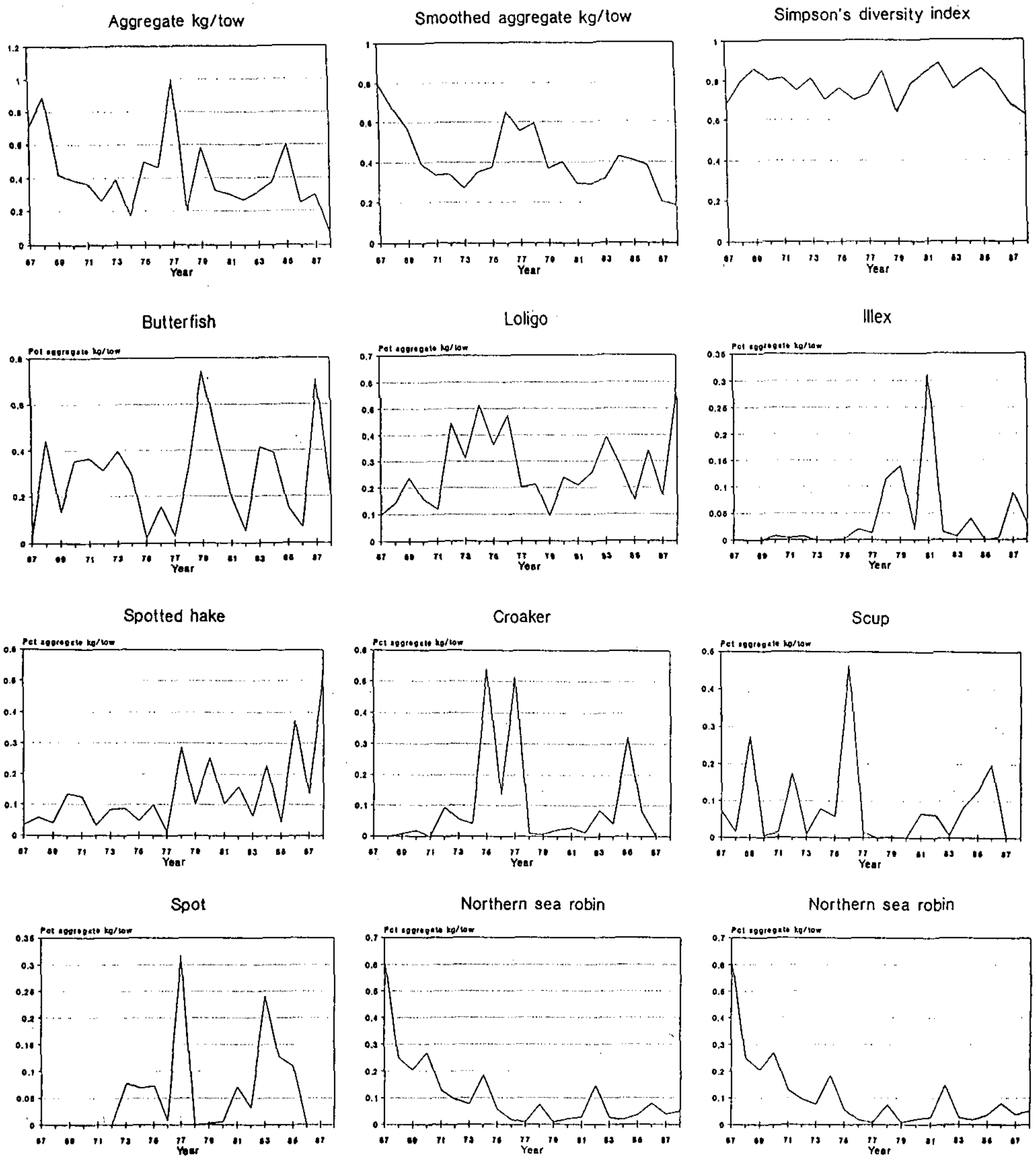


Figure 8. Aggregate kg/tow as a percentage of series maximum value, smoothed aggregate kg/tow as 3-year moving average of aggregate, Simpson's diversity index, and percentage of annual aggregate kg/tow for selected species (after *Loligo* have been removed from aggregate total) from Mid-Atlantic region (NEFC survey strata 61-62, 65-66, 69-70, 73-74).