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Multispecies Size Composition: A Conservative Property of Exploited Fishery Systems?

by

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ABSTRACT

During the past 25 years the species composition and abundance of finfishes on Georges Bank has changed dramatically, as measured by standardized trawl surveys and fishery performance data. Remarkably, however, the aggregate size composition (normalized numbers at length) has remained much more stable. The descending limb of the aggregate species numbers-at-length curve estimates the weighted average rates of survival and growth (cumulative energy transfer) from one length category to the next. Observed changes in the slope of the aggregate size composition on Georges Bank can be correlated with various stanzas in the exploitation regime. Similar studies from other temperate fishery ecosystems indicate much different characteristic slopes to the aggregate catch at length curves. The conservation of aggregate size composition within fishery ecosystems may be indicative of sized-based trophic interrelationships that tend to buffer against perturbations to particular species and/or length components of the ecosystem. If such feedback mechanisms exist, they have important implications for the development of long-term multispecies management policy.

SPECIAL SESSION ON CHANGES IN FISH POPULATIONS

INTRODUCTION

The theme of this Special Session is the documentation and resolution of fishery ecosystem change in the northwest Atlantic over the past three decades. There is ample previous literature and considerable new research presented here at the Session enumerating the 'bumps and grinds' of species composition, abundance and production over this long period. No more so than for Georges Bank (Figure 1). Fishery production and fishable biomass has undergone profound change on Georges Bank, primarily in response to fishing (Brown et al. 1976; Clark and Brown 1977; Grosslein et al. 1980; Anonymous 1988). During the past three decades there have been three more-or-less distinct fishery regimes on Georges Bank: (1) a highly selective fishery targeted for cod, haddock and flounders, primarily by the coastal states, (2) advent of intensive distant water fleet fishing with a considerable expansion of the target species composition, and (3) the post-extended jurisdiction phase, in which an intensive, and again highly species-selective fishery was re-established by the coastal countries (Anonymous 1988).

One would assume that given the profound changes in biomass, production and species composition (Clark and Brown 1977), that fundamental ecological processes such as trophic interrelationships among fishes, and energy transfer rates and routes would also have been extensively modified. A dynamic energy budget for Georges Bank does not exist. A potential alternative indicator of stability of ecological processes may be the aggregate size composition of the fish component of the ecosystem (Pope and Knights 1982). Considerable contemporary research has identified energy transfer among size spectra as a structuring mechanism in marine communities (Sheldon et al. 1972; Platt and Denman 1978; Sprules and Munawar 1986; Dickie et al. 1987). Comparative analyses of aggregate size spectra of the fish components of marine ecosystems have revealed significant differences among systems (Pope and Knights 1982; Pope et al. 1987). Interestingly, there seems to be relatively little variation in normalized size composition **within** fishery ecosystems, even over a relatively long time period. Characteristic fish size compositions for particular areas may be indicative of system-dependent ecological or fishing-induced processes that act to constrain the size spectra of fishes, eventhough individual species undergo wide variations in abundance. This is an interesting possibility and may serve as a mechanism to explain some cases of observed 'species replacement' in the northwest Atlantic and elsewhere.

In this study we review information on changes in the abundance and species composition of fishes on Georges Bank, and relate those changes to variation in the aggregate-species size composition (Pope et al. 1987). We then, (1) speculate on the ways in which size-dependent population processes may act to structure the fish community, (2) explore the ramifications of size-based compensatory population mechanisms for the development of long-term management strategies, and (3) consider how one might investigate potential size-based population regulation mechanisms.

CHANGES ON GEORGES BANK

Variation in the abundance and fishery productivity of the 'trawlable' component of the Georges Bank region has been monitored since the early 1960s through research vessel trawl surveys (Clark and Brown 1977), and by commercial fishery sampling (Brown et al. 1976; Anonymous 1988). The pelagic system components have been monitored primarily through fishery-dependent means (Grosslein et al. 1980; Anonymous 1988).

Bottom trawl surveys of the region have been conducted annually in the autumn since 1963; in the spring since 1968 (Figure 1; Clark and Brown 1977). Aggregate species catch per tow data for autumn bottom trawl surveys are given in Table 1 and Figure 2. Total weight per tow declined steadily and significantly from 142 kg/tow in 1963 to a low of 54 kg/tow in 1969 (-62%; Table 1). During this period the character of the fishery changed from being highly species selective, targeting at haddock, cod and flounders (by fleets from the coastal states), to an intensive multi-national fishery, with a wider diversity of species targets. Concern for the status of resources on Georges Bank and elsewhere in the northwest Atlantic lead to restrictive catch and effort regulations in the early 1970s. The extension of coastal state jurisdiction was coincident with a rapid increase in total system biomass (as measured by aggregate weight/tow). The total fish biomass available to the bottom trawl has stabilized at levels equivalent to those exhibited before the advent of intensive distant water fleet fishing (Table 1; Figure 1).

One important aspect of the fluctuation in biomass of fishes on Georges Bank is the very apparent change in species composition of survey catches. During the 1960s, elasmobranchs comprised an average of 21% in weight and 9% in numbers of trawl survey catches on Georges Bank (Table 1; Figure 2). These proportions remained relatively stable through the mid-1970s, but have since changed greatly. The proportion of elasmobranchs (skates and dogfish) has increased steadily and significantly to about 75% in weight of the autumn survey catches. If elasmobranchs and other species not usually landed from Georges Bank by USA fishermen are not included in the analysis, it is clear that the biomass of 'marketable' fish has decreased to record-low levels (Figure 2).

Commercial fishery catch and effort data confirm the trend of decreasing abundance of 'marketable' species in recent years (Table 2; Figures 3-5). The primary method of fishing on Georges Bank is otter trawling. Otter trawl landings increased between 1976-1982, with the partial recovery of haddock, cod and flounder stocks during that period (Figures 3-5). However, since 1982, landings have declined (-49%) to 45,805 t in 1988. Trawl effort increased 85% between 1976-1984, and has since declined 8%. Landings per unit of effort (LPUE) was highest in 1980 (4.8 t/df), and declined 61% to 1988 (Table 2). LPUE of the mixed-species trawl fleet is highly correlated with the aggregate survey catch per tow of 'marketable' species (Figure 2).

Species compositions of landings have changed greatly with the various fishing regimes in place on Georges Bank. Before the advent of distant water fleet fishing, USA landings from Georges Bank were primarily haddock, cod, and yellowtail flounder. Distant water fleets targeted an expanded species spectrum, and retained much of the by-catch for reduction. Thus, there were significant catches of elasmobranchs and other species now considered 'unmarketable' in the current USA fishery. Since the extension of fishery jurisdictions, trawl catches on Georges Bank are again dominated by a very few species: cod, winter flounder and yellowtail flounder (Figures 3-5).

The size composition of aggregate trawl survey catches from 1963-1985 are plotted in Figures 6 (actual numbers at length) and 7 (log numbers at length). The average fish weight (kg) in autumn surveys is given in Table 1. These data indicate a slight reduction in the number and proportion of relatively large fish (>50 cm) during the period of intensive distant water fleet fishing in the mid-1960s to early 1970s. The average fish weight also declined slightly in this period. Since the mid-1970s, the number and proportion of fish in larger size categories has increased. Likewise, the average weight of fish has increased (except for 1985 when a very large year class of silver hake was encountered in the surveys). A large proportion of the fish >70 cm is comprised of elasmobranchs (>80%). Thus, the increase in abundance of elasmobranchs is mostly responsible for the increasing numbers of larger fish in the autumn surveys.

The Georges Bank trawl survey data were compared and contrasted with similar information for the North Sea by Pope et al. (1987). They noted the increase in the proportion of larger fish on Georges Bank as a decrease in the slope of the catch-at-length curve computed from annual data plotted in Figure 7. Interestingly, although there were changes in the aggregate size composition of Georges Bank trawl catches, these differences were minor when the Georges Bank catch compositions were compared to data from the North Sea. The North Sea data exhibited a very much steeper slope (more rapid reduction in numbers per unit length range). In the case of both systems, the differences in slopes between years were minor, as compared to differences in slopes between fishery ecosystems. Pope and Knights (1982) reached a similar conclusion when comparing trawl catches from the Faroe Bank and the North Sea.

CONSERVATION OF SIZE COMPOSITION?

It is interesting to speculate on the reasons for the vastly different aggregate size distributions in the North Sea and on Georges Bank. There are two potential reasons that seem most plausible. First, North Sea fisheries tend to exploit smaller-sized fish (e.g. flounders and roundfish) than are taken on Georges Bank. This would tend to increase the skew of the curve to smaller-sized individuals (Pope and Knights 1982; Pope et al. 1987). Second, and probably of more importance, in the North Sea a consistently larger fraction of the diets of fish are comprised of fish, as compared with a higher incidence of invertebrate food on Georges Bank (e.g. Ursin et al. 1985). If higher predation mortality rates at length occur in the North Sea than on Georges Bank, the aggregate size composition should be highly skewed to smaller sizes.

If in fact size structure is a characteristic property of a fishery ecosystem, how would conservation of size composition be maintained? Highly selective fishing, as practiced by the USA fleets on Georges Bank, acts to select certain species and size groups from the available array at length. Currently the USA catches are dominated by cod (a partial piscivore) and flounders (primarily consuming benthic macrofauna). Given that these species may be selectively extracted from the ecosystem, it is plausible that dogfish and skates have increased in abundance to exploit available food resources, since the dietary overlaps between cod-dogfish and flounders-skates are generally high (Grosslein et al. 1980).

Another potential mechanism supporting stability in size composition would be the effects of density-dependent growth. If density-dependent growth does occur for some gadoids (e.g. haddock) and flounders (e.g. yellowtail), then as the abundance of these species is reduced through fishing, increased growth may result in the remaining individuals of those species, and others with similar diet compositions. Higher growth rates would result in more rapid accumulation of biomass (numbers) in larger size intervals, thus partially compensating for high fishing mortality rates that tend to 'push-down' the right-hand limb of the aggregate size distribution.

The existence of conservative mechanisms acting to maintain stable size distributions could potentially have important ramifications for the development of long-term management strategies. It may not necessarily be feasible from an energetics perspective to increase the minimum or average landed sizes of several fish species simultaneously, without decreasing the abundance of those or yet other species. If there is a limit on the proportion of biomass (numbers) by length interval, then 'stockpiling' of biomass in larger size intervals may result in reduced growth, delayed maturity, etc., resulting in increased 'transit times' between size increments. Similarly, if there are population mechanisms maintaining proportional size spectra in the fishes, it may not necessarily be feasible to increase the abundance of a particular species, in the presence of an established competitive population at the 'desired' size interval. For example, given the current high abundance of skates and dogfish, it may not be possible to increase gadoid and flounder abundance without 'extracting' some of the current standing stock.

Finally, we have speculated on the existence of population control mechanisms which have not been empirically verified. How might one conduct a field program or otherwise collect data to test these potential mechanisms? An important aspect to the question of stable size structure is the verification of length-based trophic processes in exploited fishery ecosystems. If there is multispecies compensation in predation, growth and maturity rates then it would be prudent to compare energetics relationships, including diet compositions, among potential competitors within the various size intervals. A second method to test for conservation of size composition would be to conduct controlled microcosm experiments, varying the density and initial size compositions of interacting species. Controlled harvesting of particular species or size intervals may allow for inferential assessment of the degree of system-compensation to specific perturbations. Lastly, there are but a precious few systems for which aggregate species size spectra have been analyzed. An important step in this research is to conduct these analyses for a greater number of fishery ecosystems, particularly emphasizing a diversity of habitats (e.g. tropical and boreal, as well as temperate systems).

ACKNOWLEDGMENT

John Pope is the godfather of this idea.

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Table 1. Stratified mean weight (kg) and numbers per tow of all species taken in bottom trawl surveys of Georges Bank, 1963-1987. Mean weights (kg) and proportion of total catch comprised of elasmobranchs are also given. Data are for autumn surveys.

Year	Total Weight	Total Numbers	$\bar{W}$	Proportion Elasmobranchs Weight	Numbers
1963	142	288	0.49	0.24	0.13
1964	136	262	0.52	0.13	0.05
1965	120	206	0.58	0.14	0.12
1966	85	155	0.55	0.23	0.09
1967	69	149	0.46	0.25	0.10
1968	65	144	0.45	0.28	0.11
1969	54	171	0.32	0.20	0.06
1970	69	172	0.40	0.28	0.08
1971	47	180	0.26	0.26	0.07
1972	75	240	0.31	0.33	0.09
1973	136	359	0.38	0.48	0.12
1974	50	362	0.14	0.35	0.06
1975	82	411	0.20	0.40	0.11
1976	189	400	0.47	0.38	0.15
1977	132	299	0.44	0.33	0.12
1978	184	422	0.44	0.50	0.20
1979	185	409	0.45	0.52	0.27
1980	123	511	0.24	0.42	0.06
1981	196	502	0.39	0.54	0.17
1982	90	313	0.29	0.55	0.18
1983	115	307	0.37	0.68	0.21
1984	93	261	0.36	0.64	0.21
1985	151	883	0.17	0.74	0.15
1986	195	383	0.51	0.76	0.25
1987	141	308	0.46	0.75	0.45

Table 2. Total mixed-species landings (tons), standardized trawl fishing effort[1] (thousands of days fished) and landings per unit effort (LPUE, t/df) by USA otter trawlers on Georges Bank, 1976-1988.

Year	Landings	Effort	LPUE
1976	48,617	14.5	3.35
1977	62,540	14.3	4.37
1978	68,889	14.7	4.69
1979	75,510	16.7	4.52
1980	87,710	18.3	4.79
1981	82,993	19.0	4.37
1982	88,934	21.5	4.14
1983	84,671	22.8	3.71
1984	73,061	26.8	2.73
1985	52,381	26.5	1.98
1986	41,587	22.8	1.82
1987	40,227	22.9	1.76
1988	45,805	24.6	1.86

[1] Effort standardized to a class 3 otter trawler (51-150 GRT), based on mixed-species LPUE.

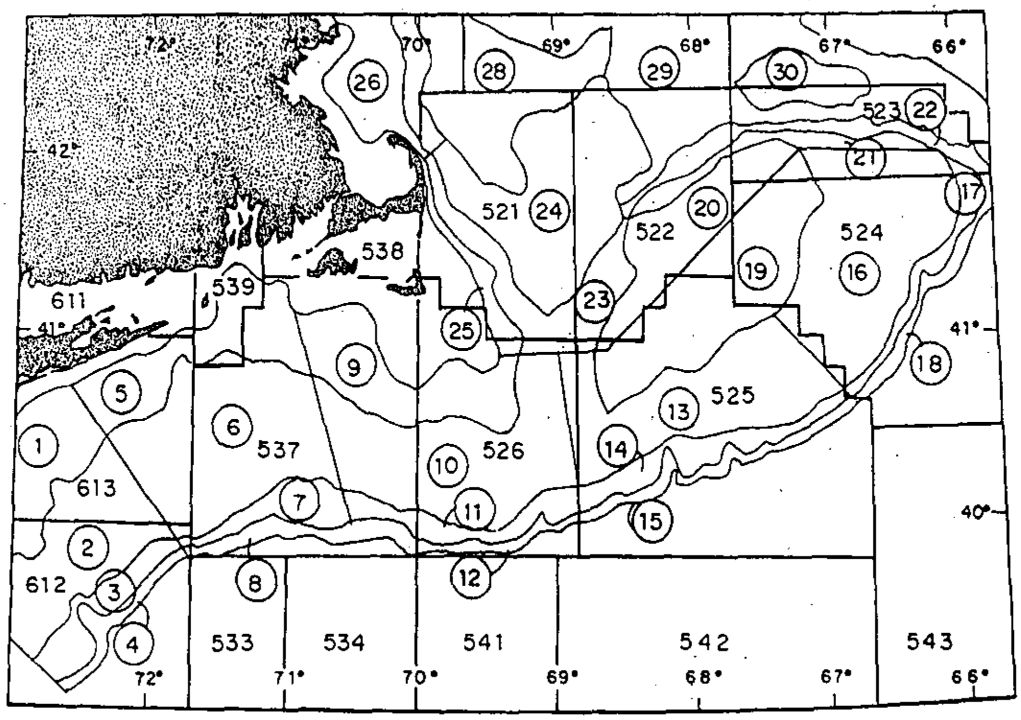

Figure 1. Geographical boundaries of bottom trawl strata (circled numbers) used for National Marine Fisheries Service surveys of the Georges Bank region.

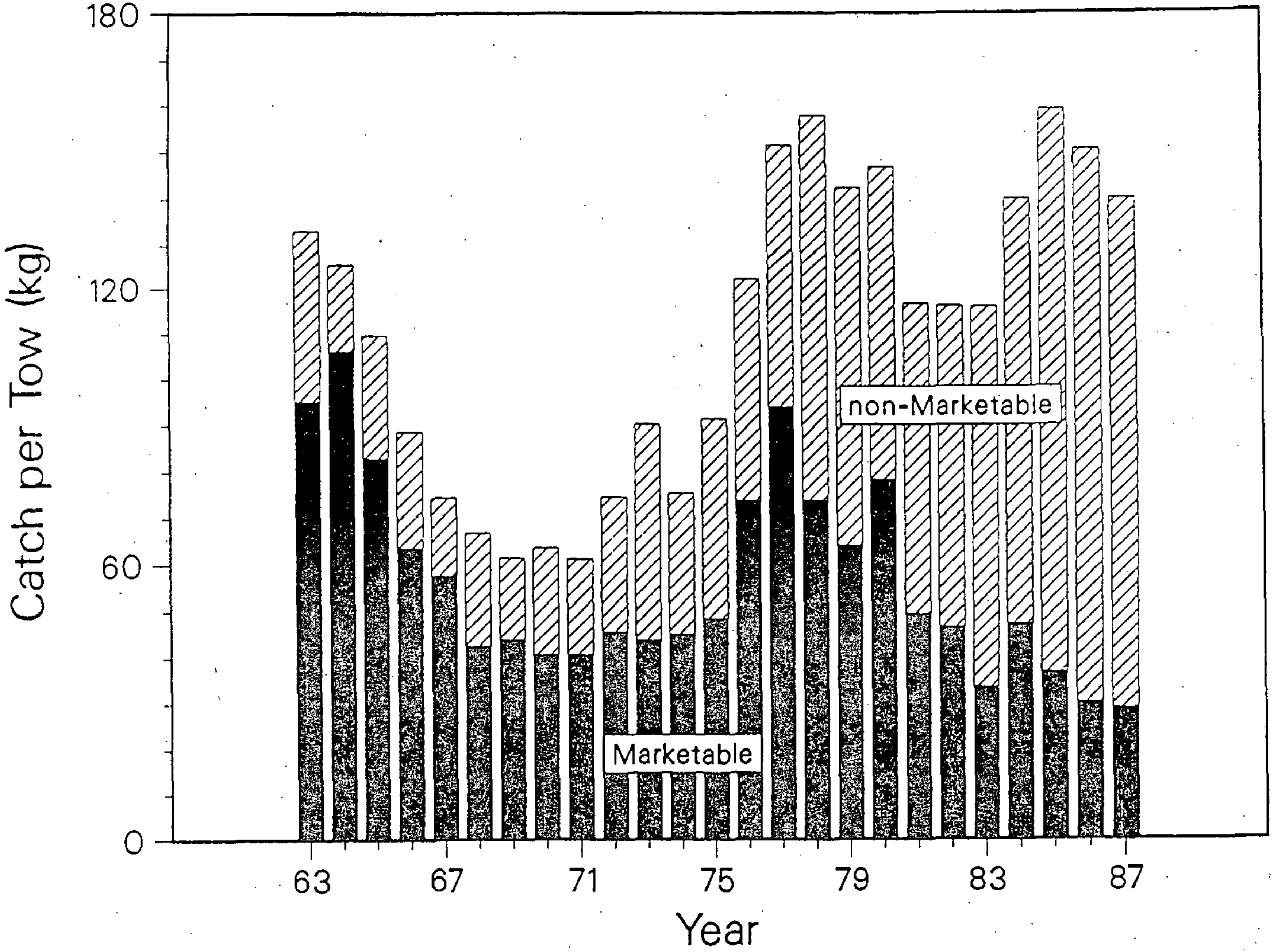

Figure 2. Smoothed bottom trawl survey indices (kg/tow) for total mixed -species catches on Georges Bank, 1963-1987. Species are aggregated in two groupings: marketable species are those which have been regularly landed by USA fishermen during the time period; non-marketable species include skates, dogfish, sculpins, etc.

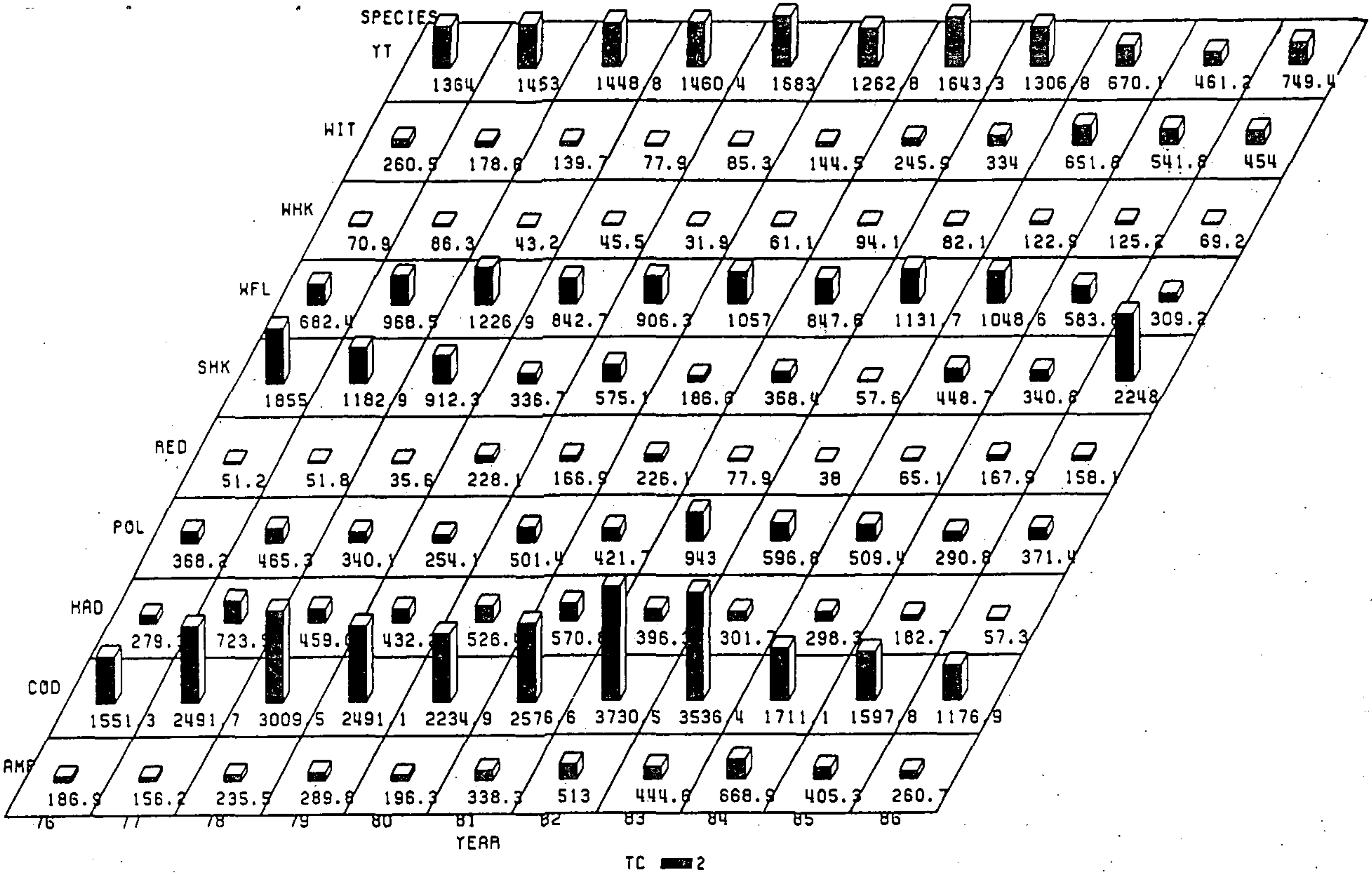

Figure 3. Landings per standardized day fished (pounds) for 10 important demersal fish species by class 2 trawlers (5-50 GRT) on Georges Bank, 1976-1986. Species are: YT=yellowtail flounder, WIT=witch flounder, WHK=white hake, WFL=winter flounder, SHK=silver hake, RED=redfish, POL=pollock, HAD=haddock, COD=cod, AMP=American plaice.

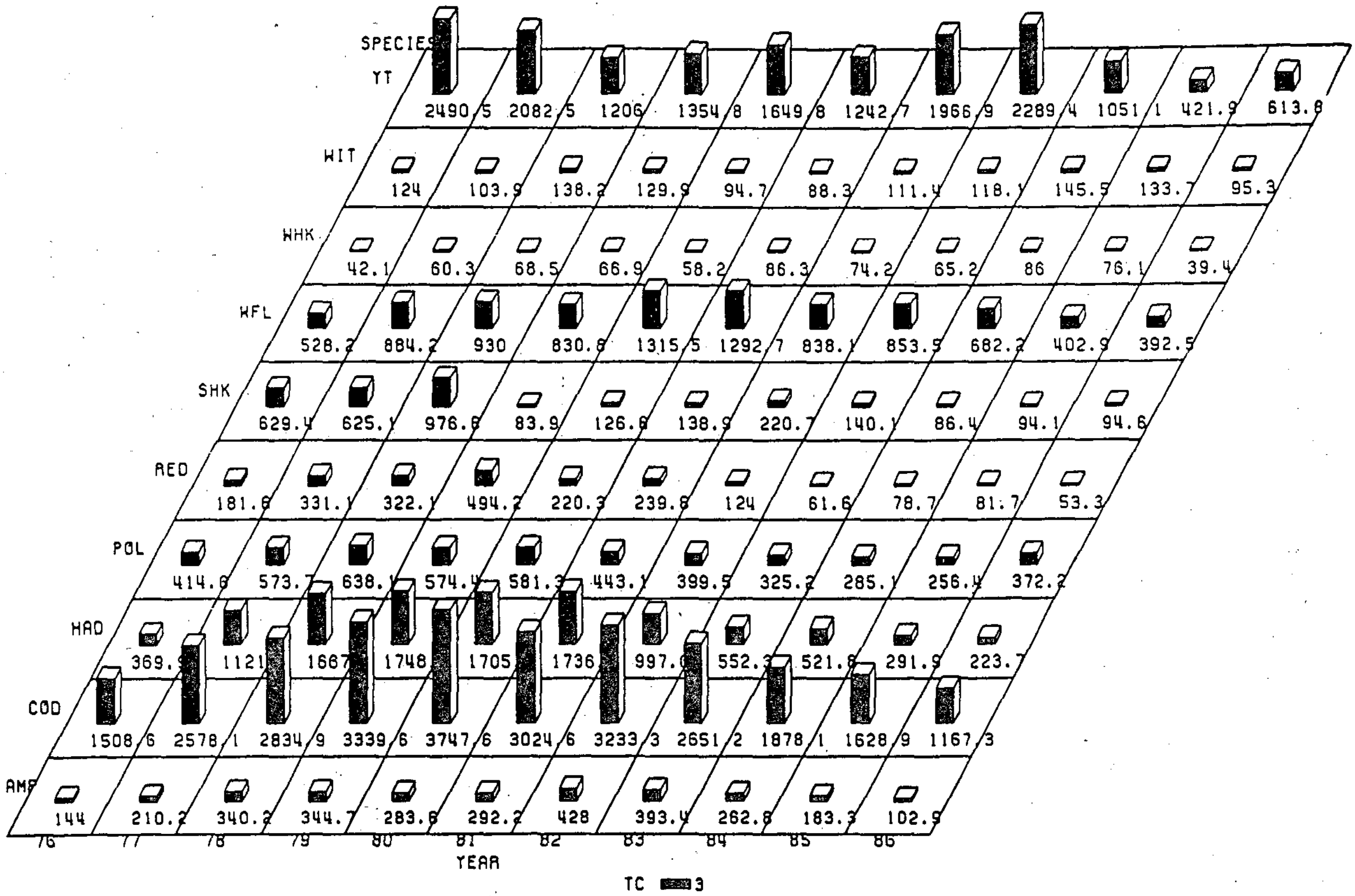

Figure 4. Landings per standardized day fished (pounds) for 10 important demersal fish species by class 3 trawlers (51-150 GRT) on Georges Bank, 1976-1986. Species are: YT=yellowtail flounder, WIT=witch flounder, WHK=white hake, WFL=winter flounder, SHK=silver hake, RED=redfish, POL=pollock, HAD=haddock, COD=cod, AMP=American plaice.

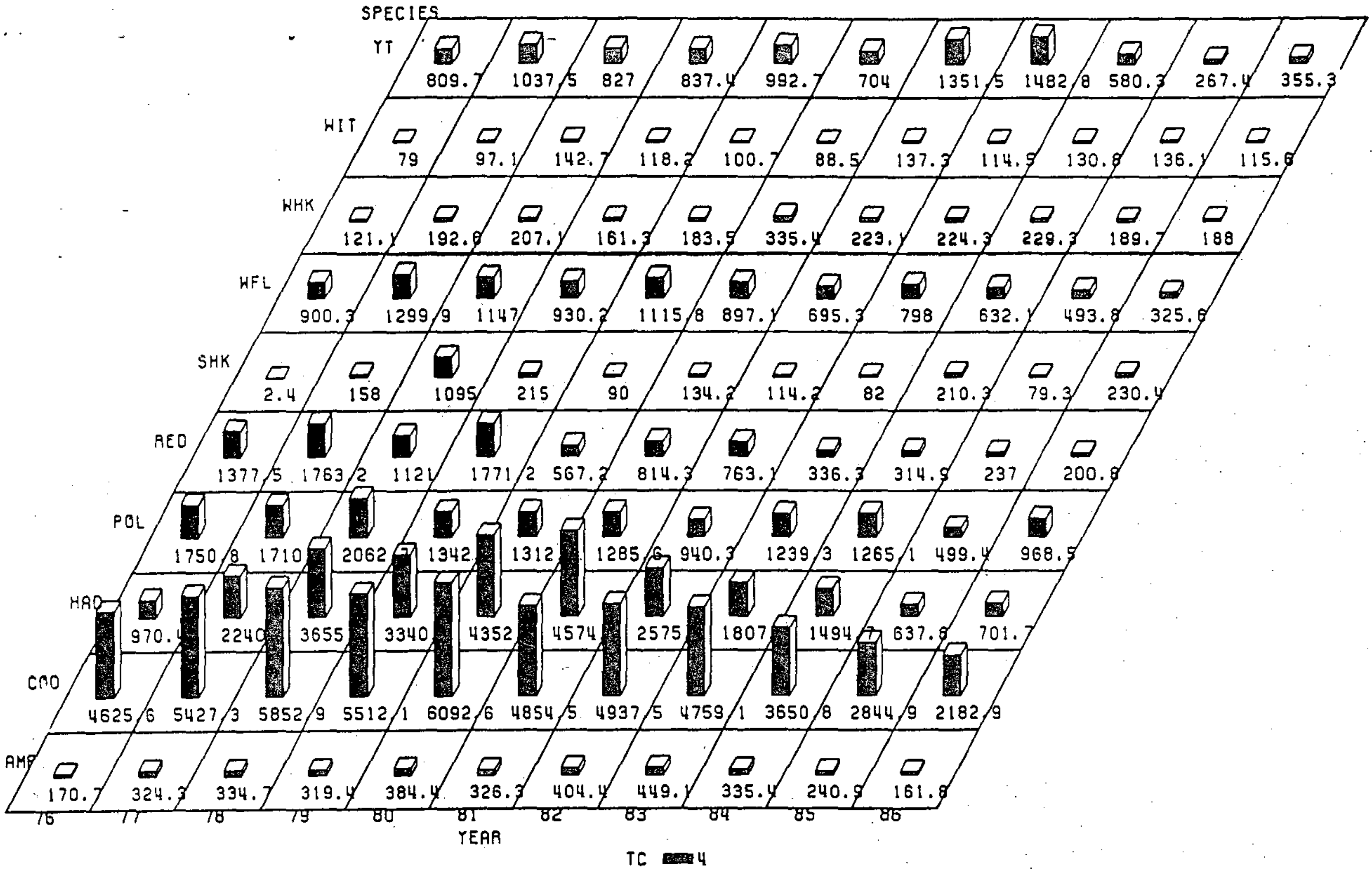

Figure 5. Landings per standardized day fished (pounds) for 10 important demersal fish species by class 4 trawlers (151-500 GRT) on Georges Bank, 1976-1986. Species are YT=yellowtail flounder, WIT=witch flounder, WHK=white hake, WFL=winter flounder, SHK=silver hake, RED=redfish, POL=pollock, HAD=haddock, COD=cod, AMP=American plaice.

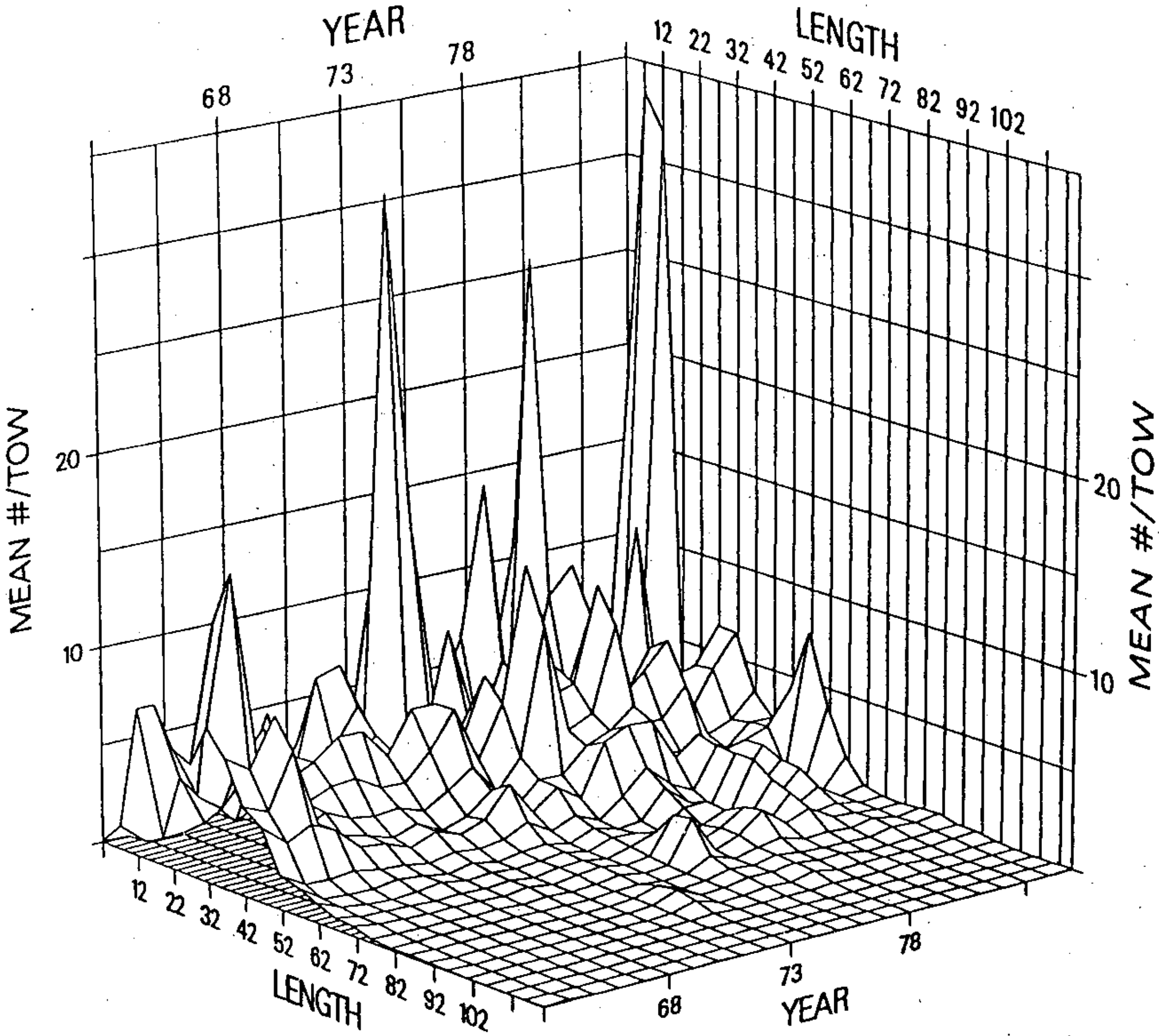

Figure 6. Stratified mean number per tow at length of finfishes taken in autumn bottom trawl surveys of Georges Bank, 1963-1985. Catch data are aggregated into 5 cm length intervals.

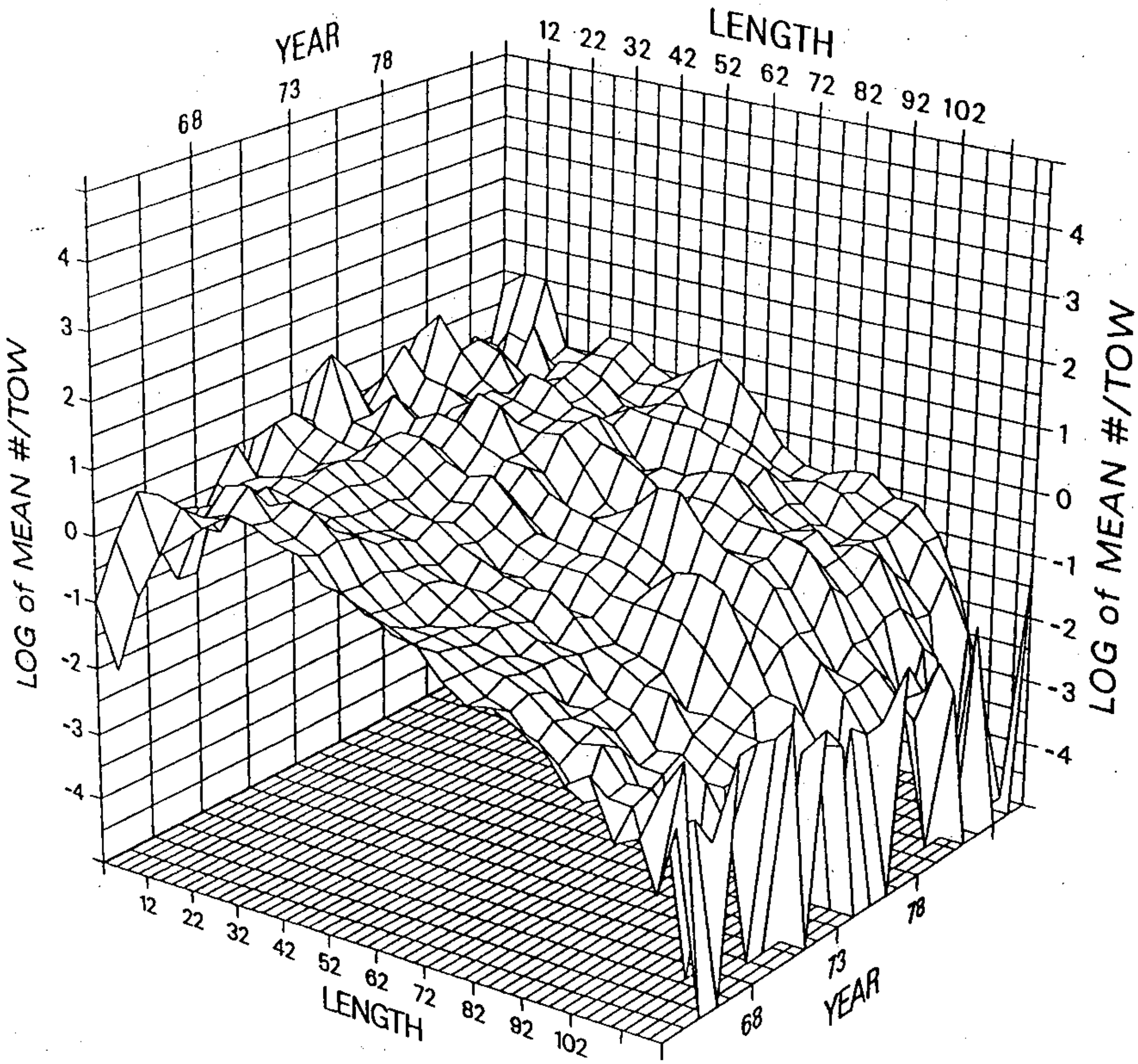

Figure 7. Log mean number per tow at length of finfishes taken in autumn bottom trawl surveys of Georges Bank, 1963-1985. Catch data are aggregated into 5 cm length intervals.