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Structures and Changes of the Demersal Fish Assemblage off Greenland, 1982–96

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Abstract

The demersal fish community was found to be mainly composed of very few boreal species. Structures in the quantitative species composition were determined by geographical as well as depth effects but no persistent deliminations or boundaries in the demersal fish assemblage were defined. The species diversity ranged around similar magnitudes as observed for the subantarctic fish fauna. During the period 1982–96, survey results indicated fundamental shifts in species composition in coherence with dramatic changes in stock abundance and biomass along with significant reductions in individual size for ecologically and economically important species. Atlantic cod and golden redfish (≥17 cm) almost disappeared while American plaice, Atlantic wolffish, and starry skate displayed less pronounced declines in abundance but decreased in biomass by more than 50%. The enormous increase of deep sea redfish (≥17 cm) and unspecified juvenile redfish (<17 cm) off East Greenland was due to recruitment. The geograhical differences of trends in fish abundance, biomass and individual size off West and East Greenland were significant. Negative developments in fish abundance, biomass and size observed recently were more pronounced off West Greenland where only 5% of the fish were distributed since 1990. Average or warmer ambient temperatures were indicated from near bottom measurements and have enhanced the chance of successful recruitment. With the exception of redfish off East Greenland, the failure of recruitment might therefore be attributed to significant by-catches in the recently expanded shrimp fishery as well as the depletion of spawning stocks.

Keywords: Abundance, biomass, community, demersal, fish stocks, Greenland, survey, temperature

Introduction

Exploitation of marine fish stocks generally result in the capture of a variety of species due to the low selectivity of the fishing gear used. Recent collapses of demersal fish stocks in the Northwest Atlantic and changes of harvesting strategies in terms of effort and target species require the implementation of ecological aspects in stock assessments and resulting management strategies (Murawski *et al*., 1983; Mayo *et al*., 1992). In addition to demographical studies such aspects should cover biotic interactions and environmental effects. Therefore, the analysis of persistent spatial structures in groundfish assemblages are not only relvant to ecological studies but have implications for defining optimum managemant units and their sustainable production levels (Cohen *et al*., 1982).

Since 1982, the demersal fish assemblage off Greenland has been monitored by annual German groundfish surveys. This survey series represents the only fishery independent source of information on groundfish stocks inhabiting the shelf and continental slope off West Greenland (NAFO Div. 1B–1F) and off East Greenland (ICES Subarea XIVb) outside the 3 mile zone down to 400 m depth. Spatial distribution patterns and trends in aggregate fish abundance, biomass, and individual size as well as structures in quantitative species composition and diversity were evaluated and described in the present paper. The findings were related with available informations on the changes in environmental and harvest regimes.

Materials and Methods

Fish abundance and biomass estimates were derived from annual groundfish surveys covering shelf areas and the continental slope off West and East Greenland. The surveys commenced in 1982 and were primarily designed for the assessment of cod. The surveys were performed during autumn because of favourable weather and ice conditions, and the lack of spawning concentrations. They were carried out by the research vessel (R/V) *Walther Herwig* (*II*) throughout most of the time period. In 1984 R/V *Anton Dohrn* was used and she was replaced by the new R/V *Walther Herwig III* since 1994, respectively.

The fishing gear used was a standardized 140-ft. bottom trawl, its net frame rigged with heavy ground gear because of the rough nature of the fishing grounds. A small mesh liner (10 mm) was used inside the codend. The horizontal distance between wing-ends was 25 m at 300 m depth, the vertical net opening being 4 m. In 1994, small Polyvalent doors (4.5 m^2, 1 500 kg) were used for the first time to reduce net damages due to overspread caused by bigger doors (6 m^2, 1 700 kg), which had been used earlier. All calculations of abundance and biomass indices were based on the 'swept area' method using a 22 m horizontal net opening as trawl parameter, i.e. the constructional width specified by the manufacturer. The towing time was normally 30 min at a speed of 4.5 knots. Trawl parameters were listed in Table 1. Hauls during which the net was damaged or hungup after less than 15 min were rejected. Some hauls of the 1987 and 1988 surveys were also included, although towing time had been intentionally reduced to 10 min because of the expected large cod catches as observed from echo sounder traces.

The surveys were primarily designed for the assessment of cod. In order to reduce the error of abundance estimates, a subdivision of shelf areas and the continental slope into different geographic and depth strata was required due to a pronounced heterogeneity of cod distribution (Rätz, 1996a). The survey area was thus split into seven geographic strata. Each stratum was subdivided into two depth strata covering the 0–200 m and 201–400 m zones. All strata were restricted at the 3 mile offshore line. The names of the 14 strata, their geographic boundaries, depth ranges and areas in nautical square miles (nm^2) are illustrated in Fig. 1 and specified in Table 2.

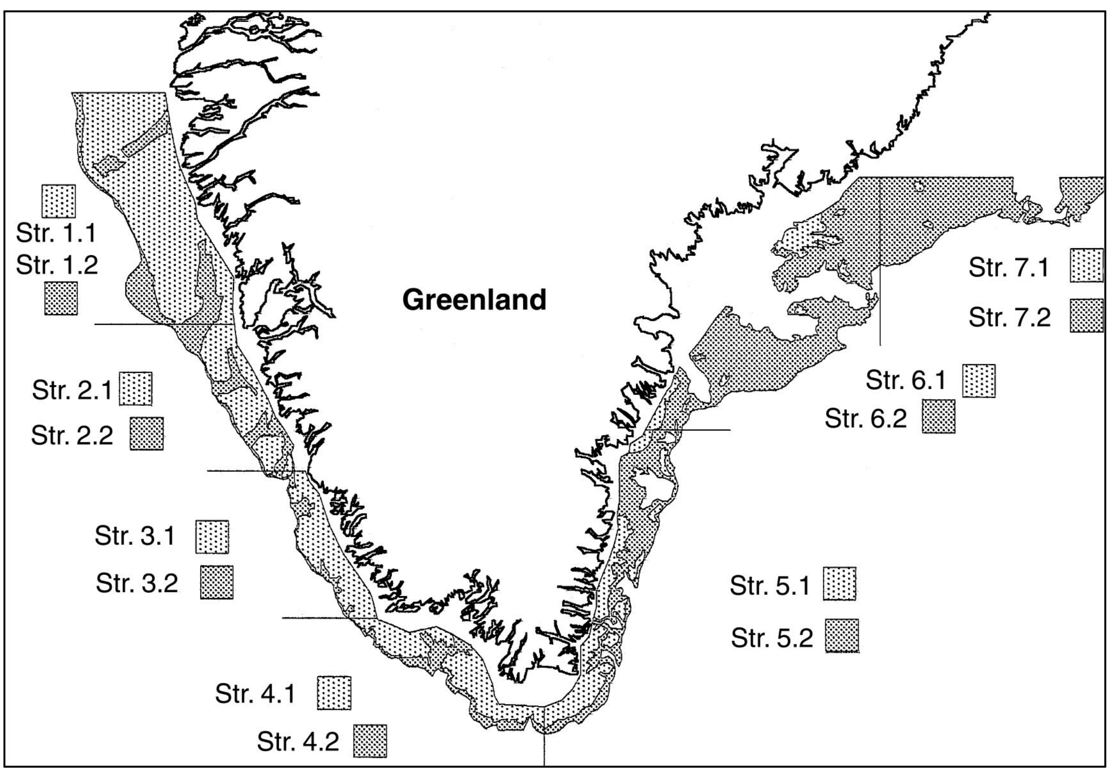

Fig. 1. Stratification scheme of the survey area as specified in Table 2.

The strategy applied included a distribution of the sampling effort according both to the stratum areas and cod abundance. Consequently, fifty percent of the hauls were allocated proportionally to strata by stratum area while the other fifty percent were apportioned on the basis of a review of historical mean cod abundance. The hauls were randomly distributed within trawlable areas of the various strata. Non-trawlable areas were mainly located inshore. During 1982–96, 2 343 successful sets were carried out. The numbers of valid sets by year and stratum are listed in Table 3. Apart from stratum 7.2 (Dohrn Bank), East Greenland strata were not covered adequately in 1984, 1992 and 1994 due to technical problems. Stratum 7.1 comprised a very small area and was therefore never covered.

Catch components were identified by species or lowest taxonomic level and their numbers and weights were recorded on a haul by haul basis. Redfish (≥17 cm) were separated into *Sebastes marinus* L. or deep sea *Sebastes mentella* Travin, whereas juvenile redfish (<17 cm) were classified as *Sebastes* spp. due to time-consuming and difficult species indentification. Total fish lengths were measured to cm below. Stratified abundance estimates were calculated from catch-per-tow data using the stratum areas as weighting factor (Cochran, 1953; Saville, 1977). Strata with less than five valid sets were rejected. The coefficient of catchability was set arbitrarily at 1.0, implying that estimates were merely indices of abundance and biomass. Respective confidence intervals (CI) were set at the 95% level of significance of the stratified mean. As a standard procedure, near bottom temperatures were measured directly before or after trawling in the vicinity of the swept area by a CTD-sonde with a precision of one hundredth degree Celsius. During the 15-year time series, a total of 1 207 measurements were conducted. Weighted mean temperature of the near bottom layers was calculated using the stratum areas as the weighting factor.

Species diversity and eveness indices were computed using the formula of Shannon and Weaver (1963) and Pielou (1966), respectively. Statistical analyses such as multidimensional scaling were performed using the CSS Statistical software in order to illustrate the similarity (or dissimilarity) between strata based on their species composition. Recently, multidimensional scaling was often applied and demonstrated as a useful tool for numeric classification of units in taxonomic and ecological studies (Sneath and Sokal, 1973). The method provides a matrix of distance estimates between various units based on their quantitative characteristics being compared by so-called similarity or dissimilarity coefficients. The present analysis

TABLE 1. Trawl parameters of the survey.

Gear	140-feet bottom trawl
Horizontal net opening	22 m
Standard trawling speed	4.5 knots
Towing time	30 min
Coefficient of catchability	1.0

TABLE 2. Specification of strata.

Stratum	Geographic boundaries South	North	East	West	Depth (m)	Area (nm^2)
1.1	64°15'N	67°00'N	50°00'W	57°00'W	1–200	6 805
1.2	64°15'N	67°00'N	50°00'W	57°00'W	201–400	1 881
2.1	62°30'N	64°15'N	50°00'W	55°00'W	1–200	2 350
2.2	62°30'N	64°15'N	50°00'W	55°00'W	201–400	1 018
3.1	60°45'N	62°30'N	48°00'W	53°00'W	1–200	1 938
3.2	60°45'N	62°30'N	48°00'W	53°00'W	201–400	742
4.1	59°00'N	60°45'N	44°00'W	50°00'W	1–200	2 568
4.2	59°00'N	60°45'N	44°00'W	50°00'W	201–400	971
5.1	59°00'N	63°00'N	40°00'W	44°00'W	1–200	2 468
5.2	59°00'N	63°00'N	40°00'W	44°00'W	201–400	3 126
6.1	63°00'N	66°00'N	35°00'W	41°00'W	1–200	1 120
6.2	63°00'N	66°00'N	35°00'W	41°00'W	201–400	7 795
7.1	64°45'N	67°00'N	29°00'W	35°00'W	1–200	92
7.2	64°45'N	67°00'N	29°00'W	35°00'W	201–400	4 589
Total						37 463

consideres the 14 strata as units and their mean log-transformed (n+1) species compositions as characteristics. The coefficient of Euclidean Distance was chosen for calculation of the distance matrix containing the individual values of dissimilarity between the strata. The method of multidimensional scaling was then applied in order to determine the relative position of each stratum in a three-dimensional space.

Results

During the period from 1982 to 1996, the total survey catch amounted to 3.3 million individuals in number and 1 100 tons in weight. A total of 66 fish species or taxa were identified. Species were ranked according to their relative importance in numbers and listed in Table 4. Results indicate that the demersal ichthyofauna off Greenland consisted of very few boreal species, while the most abundant arctic species (capelin, *Mallotus villosus*) contributed only a little more than 4% of the overall catch in numbers (Table 4, Fig. 2). Most abundant were deep sea redfish (*S. mentella*), and golden redfish (*S. marinus*), Atlantic cod (*Gadus morhua*), American plaice (*Hipplogossoides platessoides*), Atlantic wolffish (*Anarhichas lupus*) and starry skate (*Raja radiata*). Including juveniles, these six

TABLE 3. Numbers of valid hauls by year and stratum, 1982–96. Incomplete survey coverage off East Greenland in 1984, 1992 and 1994.

Year	1.1	1.2	2.1	2.2	3.1	3.2	4.1	4.2	5.1	5.2	6.1	6.2	7.1	7.2	Σ
1982	20	11	16	7	9	6	13	2	1	10	3	12	1	25	136
1983	26	11	25	11	17	5	18	4	3	19	10	36	0	18	203
1984	25	13	26	8	18	6	21	4	5	4	2	8	0	5	145
1985	10	8	26	10	17	5	21	4	5	21	14	50	0	28	219
1986	27	9	21	9	16	7	18	3	3	15	14	37	1	34	214
1987	25	11	21	4	18	3	21	3	19	16	13	40	0	18	212
1988	34	21	28	5	18	5	18	2	21	8	13	39	0	26	238
1989	26	14	30	9	8	3	25	3	17	18	12	29	0	11	205
1990	19	7	23	8	16	3	21	6	18	19	6	15	0	13	174
1991	19	11	23	7	12	6	14	5	8	11	10	28	0	16	170
1992	6	6	6	5	6	6	7	5	0	0	0	0	0	6	53
1993	9	6	9	6	10	8	7	0	9	6	6	18	0	14	108
1994	16	13	13	8	10	6	7	5	0	0	0	0	0	6	84
1995	0	0	3	0	10	7	10	5	8	6	6	17	0	12	84
1996	5	5	8	5	12	5	10	5	7	9	5	13	0	9	98
Total	267	146	278	102	197	81	231	56	124	162	114	342	2	241	2 343

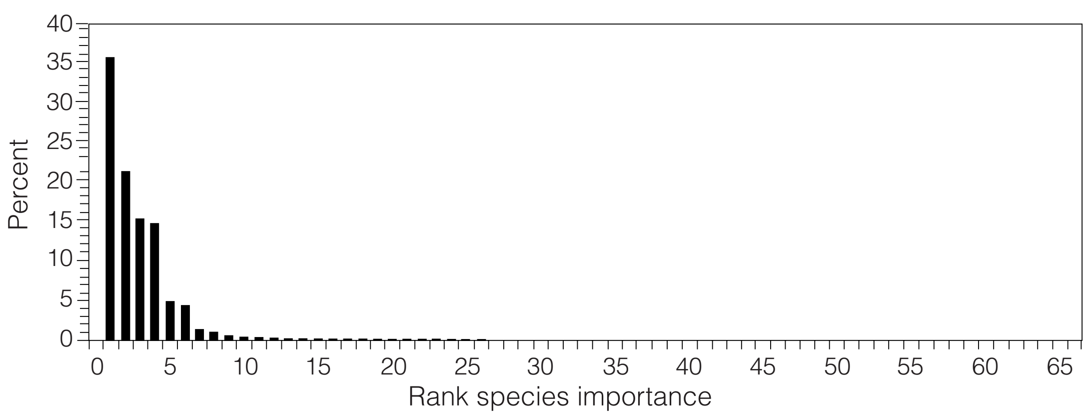

Fig. 2. Rank species importance in percent of the total catch in numbers. Species are listed in Table 4 by rank order.

TABLE 4. List of taxa, ranked by species importance based on catch in numbers as illustrated in Figure 2 and catch in weight, 1982–96.

Rank	Taxa	Catch (Numbers)	Percent	Catch (kg)	Percent
1	*Sebastes* spp. <17 cm	117 1291	35.4	26947.0	2.4
2	*Sebastes mentella* ≥17 cm	696 299	21	160495.6	14.6
3	*Sebastes marinus* ≥17 cm	499 428	15.1	296618.3	27
4	*Gadus morhua*	480 902	14.5	503240.2	45.7
5	*Hippoglossoides platessoides*	154 710	4.7	26469.1	2.4
6	*Mallotus villosus*	142 482	4.3	2366.7	0.2
7	*Anarhichas lupus*	42 063	1.3	21357.4	1.9
8	*Ammodytes* spp.	34 086	1	748.4	0.1
9	*Raja radiata*	15 351	0.5	4702.7	0.4
10	*Micromesistius poutassou*	10 901	0.3	2103.0	0.2
11	*Artediellus* spp.	8 277	0.2	139.0	0
12	*Reinhardtius hippoglossoides*	8 148	0.2	3449.7	0.3
13	*Triglops* spp.	7 154	0.2	136.0	0
14	*Triglops murrayi*	5 039	0.2	102.6	0
15	*Eumicrotremus spinosus*	3 683	0.1	157.4	0
16	*Melanogrammus aeglefinus*	3 300	0.1	820.7	0.1
17	*Lycodes* spp.	3 243	0.1	216.9	0
18	*Hippoglossus hippoglossus*	2 927	0.1	11630.5	1.1
19	*Anarhichas minor*	2 572	0.1	11250.8	1
20	*Cottunculus* spp.	2 307	0.1	102.4	0
21	*Myoxoscephalus* spp.	2 048	0.1	414.9	0
22	*Macrourus berglax*	2 046	0.1	1766.5	0.2
23	*Leptoclinus maculatus*	1 990	0.1	14.8	0
24	*Argentina silus*	1 827	0.1	1175.8	0.1
25	*Boreogadus saida*	1 705	0.1	46.9	0
26	*Anarhichas denticulatus*	1 079	0	11459.8	1
27	*Aspidophoroides monopterygus*	874	0	13.4	0
28	*Molva dipterygia*	731	0	1806.3	0.2
29	*Triglops pingeli*	673	0	13.8	0
30	*Brosme brosme*	662	0	710.3	0.1
31	*Leptagonus decagonus*	644	0	14.1	0
32	*Gadus ogac*	531	0	786.6	0.1
33	*Coryphaenoides rupestris*	531	0	255.6	0
34	*Icelus bicornis*	466	0	2.8	0
35	*Myxine glutinosa*	460	0	17.1	0
36	*Gymnelus viridis*	442	0	3.6	0
37	*Liparis* spp.	387	0	22.3	0
38	*Careproctus* spp.	357	0	18.8	0
39	*Cyclopterus lumpus*	311	0	961.6	0.1
40	*Onogadus argentatus*	226	0	13.3	0
41	*Raja fyllae*	155	0	46.9	0
42	*Sebastes viviparus*	117	0	18.5	0
43	*Raja* spp.	111	0	124.5	0
44	*Trisopterus esmarkii*	90	0	4.0	0
45	*Lumpenus lampretaeformis*	86	0	2.3	0
46	*Glyptocephalus cynoglossus*	61	0	23.8	0
47	*Myctophidae* spp.	58	0	1.0	0
48	*Serrivomer beani*	39	0	1.9	0
49	*Somniosus microcephalus*	21	0	7343.5	0.7
50	*Pollachius virens*	20	0	129.5	0
51	*Paraliparis* spp.	20	0	1.6	0
52	*Raja lintea*	20	0	16.2	0

TABLE 4. (Continued). List of taxa, ranked by species importance based on catch in numbers as illustrated in Figure 2 and catch in weight, 1982–96.

Rank	Taxa	Catch (Numbers)	Percent	Catch (kg)	Percent
53	*Onogadus ensis*	12	0	0.2	0
54	*Squalus acanthias*	11	0	21.3	0
55	*Molva molva*	11	0	25.2	0
56	*Eumesogrammus praeciosus*	10	0	0.7	0
57	*Bathyraja spinicauda*	10	0	55	0
58	*Stomias boa*	6	0	0.2	0
59	*Notacanthus chemnitzii*	4	0	10.6	0
60	*Rhinonemus cimbrius*	3	0	0.1	0
61	*Chauliodus sloani*	3	0	0.2	0
62	*Raja bathyphila*	3	0	20.2	0
63	*Microstomus kitt*	2	0	1.3	0
64	*Pholis gunellus*	2	0	0.1	0
65	*Centroscyllium farbicii*	1	0	0.2	0
66	*Nemichthys scolopaceus*	1	0	0.1	0
Total		3 313 030	100	1100421.5	99.9

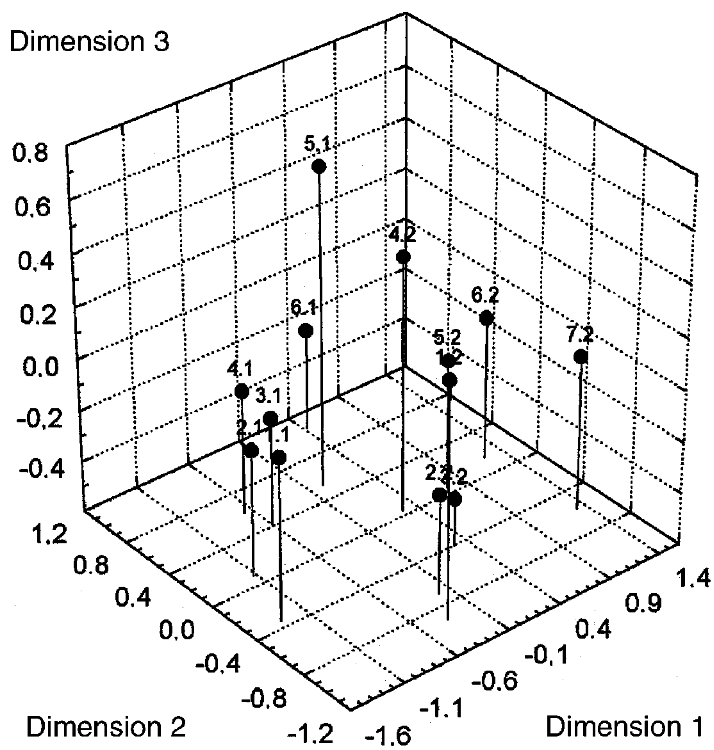

Fig. 3. Scatter plot of distances between strata (multidimensional scaling) based on log-transformed mean species composition, 1982–96. Distances are calculated applying the coefficient of Euclidean Distance.

ecologically and economically important species accounted for 92 and 96% of the overall catch in numbers and biomass, respectively.

The differences between strata based on their log-transformed mean species composition over the past 15 years are illustrated in Fig. 3 where relative positions of the strata are plotted in a three-dimensional space. Obviously, the strata are grouped into two clusters by the depth effect: all shallow strata (1–200 m) are positioned on the left hand side of the graph while deep strata (201–400 m) are located in the right part. In addition, a geographical effect seemed to contribute significantly to the relative position of the strata. All West Greenland strata are arranged in the foreground while East Greenland strata can be found in the rear.

Diversity and eveness indices of individual strata are listed in Table 5 and illustrated in Fig. 4. The eveness indices show only negligible differences and vary between 3.4 and 3.8. In contrast, the variations in species diversity among the strata are significant. Based on mean species composition over the past 15 years, the strata off West Greenland are found to be generally more diverse than the strata off East Greenland.

Summarized trends in abundance, biomass indices, and resulting mean individual weight for West and East Greenland are given in Table 6. These values are illustrated in Fig. 5, 6, and 7, respectively. Developments in total fish abundance and biomass indices are very similar. During the period from 1985 to 1987, both abundance and biomass indices increased to intermediate maxima in 1987, but decreased thereafter. Since 1993, the abundance indices exceeded the intermediate maximum by a factor of 3 to 4 due to very abundant juvenile deep sea redfish indicating successful recruitment off East Greenland. In 1996, total fish biomass increased also significantly by 48 % as compared to the mean of the decade of the 1980s. These recent positive effects were restricted to the survey area off East Greenland only, where 94% of the indivduals and 96% of the biomass was concentrated, while the stocks off West Greenland

TABLE 5. Diversity and eveness indices (Shannon and Weaver, 1963; Pilou, 1966) by stratum based on mean species composition, 1982–86.

Stratum	Diversity	Evenness
1.1	2.113	3.553
1.2	1.378	3.784
2.1	1.435	3.611
2.2	1.897	3.807
3.1	1.362	3.466
3.2	2.006	3.829
4.1	1.546	3.401
4.2	0.928	3.367
5.1	0.382	3.401
5.2	0.659	3.638
6.1	0.826	3.466
6.2	0.897	3.497
7.1	–	–
7.2	1.441	3.761

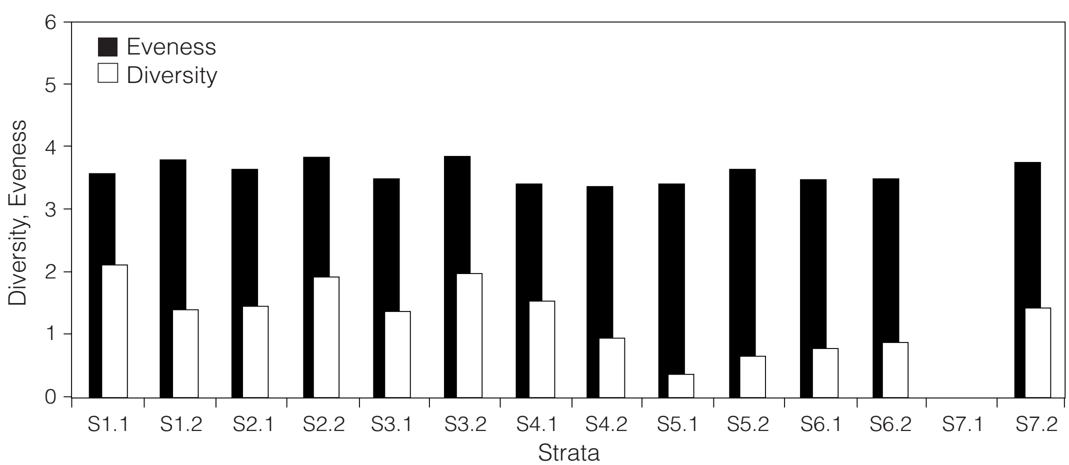

Fig. 4. Diversity and evenness indices (Shannon and Weaver, 1963; Pilou, 1966) by stratum based on mean species composition as listed in Table 5, 1982–96.

TABLE 6. Abundance (× 1 000), biomass (tons) indices, and mean individual weight (kg) aggregated for all fish species off West and East Greenland, 1982–96.

	Abundance		Biomass		Individual Weight	
Year	West	East	West	East	West	East
1982	352 616	658 706	266 146	449 802	0.755	0.683
1983	244 248	551 135	160 329	522 124	0.656	0.947
1984	180 404	207 169	71 985	126 314	0.399	0.610
1985	239 333	1 506 988	86 761	277 447	0.363	0.184
1986	600 868	707 448	147 124	430 107	0.245	0.608
1987	1 301 487	914 311	686 212	387 093	0.527	0.423
1988	884 305	525 890	652 776	316 509	0.738	0.602
1989	491 261	654 100	359 753	437 324	0.732	0.669
1990	223 097	913 629	52 888	278 120	0.237	0.304
1991	275 449	1 180 593	18 769	448 608	0.068	0.380
1992	194 756	108 910	11 155	39 013	0.057	0.358
1993	150 061	8 146 016	6 555	452 251	0.044	0.056
1994	126 677	164 907	8 196	21 150	0.065	0.128
1995	127 282	5 778 887	3 870	475 162	0.030	0.082
1996	442 702	7 362 729	13 206	979 951	0.030	0.133

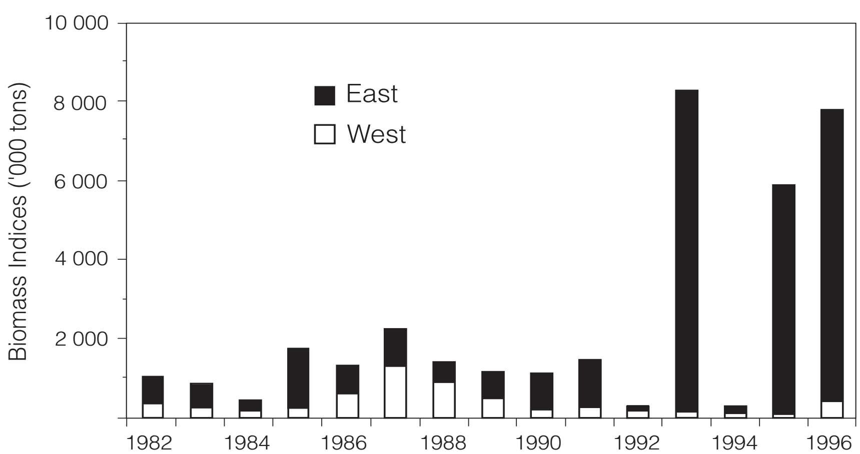

Fig. 5. Abundance indices off West and East Greenland for all fish species aggregated as listed in Table 6, 1982–96. Incomplete survey coverage off East Greenland in 1984, 1992 and 1994.

appeared to be severely depleted without any signs of recovery since 1990. During the 1980s, fish were distributed more evenly across West and East Greenland with abundances of 57% and 55%, respectively. During the 1990s, the mean individual weight showed an overall dramatic decline by 72% as compared to the mean during the 1980s. Especially during the 1990s, fish off West Greenland were found to be significantly smaller and weighed around 50 g only. Since 1994, individual weight increased to 127 g off East Greenland while fish of West Greenland did not show any growth indications.

Survey abundance, biomass estimates, and resulting mean individual weights for the seven most common fish species are listed in Tables 7, 8, and 9, respectively. Values are illustrated in Fig. 8 on a stock by stock basis. Atlantic cod was found to be the most dominant fish species in weight (46%). The increase in stock abundance and biomass during 1984–87 to 830 million individuals and 690 000 tons was due to the recruiting process of the year-classes 1984 and 1985. Until 1992, stock abundance and biomass collapsed almost completely and remained at a very low level. The mean weight of cod varied between 0.5 and 2.5 kg due to poor stock

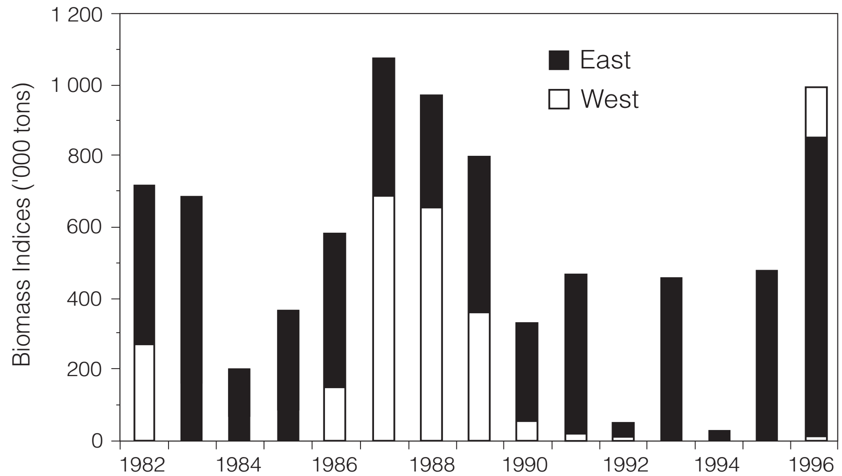

Fig. 6. Biomass indices off West and East Greenland for all fish species aggregated as listed in Table 6, 1982–96. Incomplete survey coverage off East Greenland in 1984, 1992 and 1994.

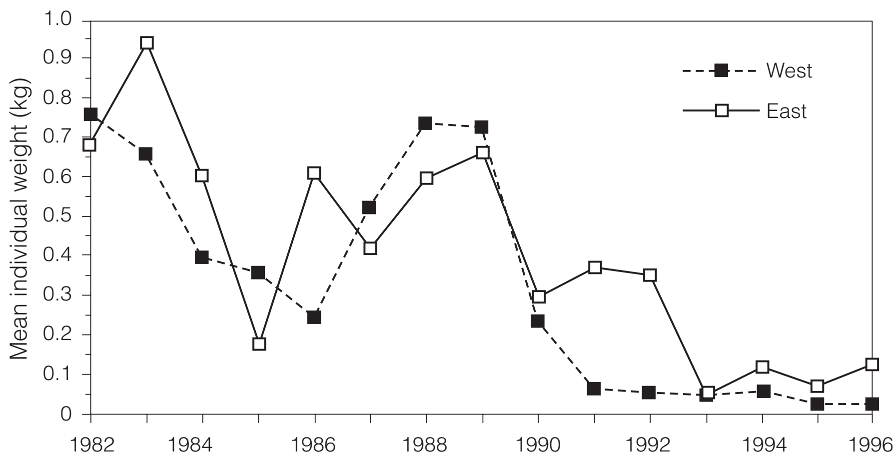

Fig. 7. Mean individual fish weight off West, East Greenland as listed in Table 6, 1982–96. Incomplete survey coverage off East Greenland in 1984, 1992 and 1994.

structure which was dominated by single year-classes only.

Abundance and biomass indices of American plaice showed a decreasing trend. During the 1990s, estimates were reduced by 54 and 65% as compared with the mean of the 1980s. In 1996, both estimates indicated a slight increase in stock abundance and biomass. The individual weight was 25% lower during the 1990s in comparison with the mean of the 1980s.

Significant losses in abundance and biomass by more than 90% were recorded for golden redfish (≥17 cm). Like Atlantic cod, the stock remained almost non-existent since 1992. Despite high variation in mean individual weight, a sharp decrease in fish size by 26% was observed (Fig. 8) when comparing the mean body weight during the 1980s and 1990s.

During the 1990s, deep sea redfish (≥17 cm) were found to be very abundant off East Greenland

TABLE 7. Abundance indices (× 1 000) by year, for Atlantic cod (*Gadus morhua*), golden redfish ≥17 cm (*Sebastes marinus*), deep sea redfish ≥17 cm (*Sebastes mentella*), juvenile redfish <17 cm (*Sebastes* spp.), American plaice (*Hippoglossoides platessoides*), Atlantic wolffish (*Anarhichas lupus*), starry skate (*Raja radiata*), other finfish species, and total, 1982–96. Confidence intervals (CI) are given at the 95% level of significance in percent of the stratified mean.

Year	Cod	CI	American plaice	CI	Golden redfish	CI	Deepsea redfish	CI	Juvenile redfish	CI	Atlantic wolffish	CI	Starry skate	CI	0thers	Total
1982	100 366	28	82 973	30	679 186	55	90 582	65	3 945	44	24 989	23	9 869	38	19 412	1 011 322
1983	58 195	25	126 805	49	449 110	53	95 475	42	7 328	56	18 795	24	6 999	87	32 676	795 383
1984	23 286	32	97 535	43	88 844	65	116 596	93	10 182	67	17 814	27	6 806	42	26 510	387 573
1985	71 747	33	80 519	23	325 216	52	172 903	47	990 128	164	25 493	19	8 061	44	72 254	1 746 321
1986	160 915	32	128 985	39	489 338	53	154 119	36	271 401	168	23 369	19	6 922	46	73 267	1 308 316
1987	828 026	59	74 049	26	609 092	39	102 810	45	264 219	87	29 525	15	3 582	30	304 495	2 215 798
1988	650 080	48	47 233	19	189 274	54	261 057	58	99 401	41	24 552	21	7 306	39	131 292	1 410 195
1989	450 459	59	49 092	28	234 706	60	298 546	60	40 486	36	19 618	21	19 647	38	32 807	1 145 361
1990	59 777	43	44 559	25	783 168	75	49 343	43	95 261	52	21 708	17	13 880	51	69 030	1 136 726
1991	15 213	29	46 125	18	111 411	51	972 431	81	238 999	38	20 005	21	5 091	26	46 767	1 456 042
1992	2 700	50	30 802	28	34 814	151	60 222	165	121 335	54	18 601	26	10 910	50	24 282	303 666
1993	4 738	36	43 029	17	66 074	93	1 384 220	86	6 681 402	111	25 403	28	4 512	39	86 699	8 296 077
1994	1 376	36	13 982	21	4 616	41	78 570	168	110 766	95	17 494	48	5 834	43	58 946	291 584
1995	7 464	93	36 801	18	43 274	97	2 505 107	55	3 188 279	106	20 717	26	970	59	103 557	5 906 169
1996	2 257	38	58 501	17	29 538	47	4 510 639	64	2 184 959	98	39 595	21	2 822	29	977 120	7 805 431

TABLE 8. Biomass indices (tons) by year, for Atlantic cod (*Gadus morhua*), golden redfish ≥17 cm (*Sebastes marinus*), deep sea redfish ≥17 cm (*Sebastes mentella*), juvenile redfish <17 cm (*Sebastes* spp.), American plaice (*Hippoglossoides platessoides*), Atlantic wolffish (*Anarhichas lupus*), starry skate (*Raja radiata*), other finfish species, and total, 1982–96. Confidence intervals (CI) are given at the 95% level of significance in percent of the stratified mean.

Year	Cod	CI	American plaice	CI	Golden redfish	CI	Deepsea redfish	CI	Juvenile redfish	CI	Atlantic wolffish	CI	Starry skate	CI	0thers	Total
1982	152 107	25	18 552	32	436 148	54	33 923	68	180	41	27 266	31	6 273	36	41 499	715 948
1983	116 531	25	25 576	41	421 283	61	46 765	47	229	51	14 661	31	2 413	34	54 995	682 453
1984	45 309	34	15 045	45	48 159	55	49 762	97	240	71	9 563	24	2 399	31	27 822	198 299
1985	69 236	39	12 037	22	141 078	35	65 972	35	23 190	142	11 314	17	2 405	23	38 976	364 208
1986	127 902	26	20 103	30	299 202	38	65 141	36	7605	168	12 377	16	2 068	28	42 833	577 231
1987	690 181	63	14 011	30	271 715	38	31 806	46	12 367	93	14 560	16	1 366	29	37 299	1 073 305
1988	660 935	46	7 785	20	158 386	60	83 711	56	4005	56	10 544	16	1 913	28	42 006	969 285
1989	573 395	46	6 934	40	108 950	47	67 392	63	1158	42	8 522	19	4 259	31	26 467	797 077
1990	100 395	34	5 713	22	181 853	45	9 010	44	1866	58	7 160	16	2 863	45	22 148	331 008
1991	37 901	36	7 463	18	110 497	98	284 509	80	2139	46	5 851	20	1 093	28	17 924	467 377
1992	1 823	69	3 054	26	13 022	130	19 889	160	1075	54	5 189	27	1 345	49	4 771	50 168
1993	5 959	41	4 880	17	24 943	68	229 352	61	177 275	90	5 682	22	841	28	9 874	458 806
1994	2 931	68	1 703	25	2 014	38	7 206	128	3569	132	4 534	43	1 959	62	5 430	29 346
1995	15 583	155	5 418	21	11 013	38	375 747	52	55 303	97	6 466	25	441	75	9 061	479 032
1996	3 973	56	8 151	22	14 926	40	877 314	59	48 007	96	11 125	19	568	44	29 093	993 157

TABLE 9. Mean individual weight (kg) by year, for Atlantic cod (*Gadus morhua*), golden redfish ≥17 cm (*Sebastes marinus*), deep sea redfish ≥17 cm (*Sebastes mentella*), juvenile redfish <17 cm (*Sebastes* spp.), American plaice (*Hippoglossoides platessoides*), Atlantic wolffish (*Anarhichas lupus*) starry skate (*Raja radiata*), other finfish species, and total, 1982–96. Confidence intervals (CI) are given at the 95% level of significance in percent of the stratified mean.

Year	Cod	Am. plaice	Golden redfish	Deepsea redfish	Juvenile Redfish	Atlantic Wolffish	Starry skate	Others	Total
1982	1.516	0.224	0.642	0.375	0.046	1.091	0.636	2.138	0.708
1983	2.002	0.202	0.938	0.490	0.031	0.780	0.345	1.683	0.858
1984	1.946	0.154	0.542	0.427	0.024	0.537	0.352	1.049	0.512
1985	0.965	0.149	0.434	0.382	0.023	0.444	0.298	0.539	0.209
1986	0.795	0.156	0.611	0.423	0.028	0.530	0.299	0.585	0.441
1987	0.834	0.189	0.446	0.309	0.047	0.493	0.381	0.122	0.484
1988	1.017	0.165	0.837	0.321	0.040	0.429	0.262	0.320	0.687
1989	1.273	0.141	0.464	0.226	0.029	0.434	0.217	0.807	0.696
1990	1.679	0.128	0.232	0.183	0.020	0.330	0.206	0.321	0.291
1991	2.491	0.162	0.992	0.293	0.009	0.292	0.215	0.383	0.321
1992	0.675	0.099	0.374	0.330	0.009	0.279	0.123	0.196	0.165
1993	1.258	0.113	0.378	0.166	0.027	0.224	0.186	0.114	0.055
1994	2.130	0.122	0.436	0.092	0.032	0.259	0.336	0.092	0.101
1995	2.088	0.147	0.254	0.150	0.017	0.312	0.455	0.087	0.081
1996	1.760	0.139	0.505	0.194	0.022	0.281	0.201	0.030	0.127

only. However, the significant decrease in mean body weight indicates that the stock is almost exclusively composed of small and juvenile fish. The overall reduction in individual weight exceeded 40%.

In terms of abundance, juvenile and unspecified redfish (<17 cm) dominate the finfish fauna by far (35%). Since 1993, juvenile redfish have become even more abundant and concentrated off East Greenland in particular. Affected by the occurrence of varying recruitment, the mean individual weight ranged from 9 to 47 g.

The stock of Atlantic wolffish has also undergone fundamental shifts in abundance and structure. During the 1990s, stock biomass was reduced by 52% as compared to the mean stock weight during the 1980s. Since 1995, the stock biomass showed a slight increase similar to American plaice. The abundance of Atlantic wolffish did not show a clear tendency; the maximum was observed in 1996. However, significant losses in mean individual weight were observed during the survey period as illustrated in Fig. 8. During the 1980s, the fish had a mean weight of 0.6 kg which was reduced by more than 50% to less than 0.3 kg during the 1990s.

Starry skate dominated the low catch of elasmobranch species. Abundance estimates varied without a clear trend but have been at a very low level since 1995. During the 1990s, starry skates showed a reduction in biomass by 55% and mean individual weight decreased by 29%, as compared to the respective values of the 1980s.

Mean near temperatures of the near bottom layer are listed in Table 10 by stratum and year. Weighted means by stratum area are also given in order to indicate the overall ambient temperature. These values are illustrated in Fig. 9 on a stratum by stratum basis. Shallow strata (1–200 m) are arranged on the left panel while deep strata (201–400 m) are illustrated on the right panel. Since 1982, the overall temperature variation ranged between 1 and 6°C. The shallow strata often showed lower temperatures as compared to the weighted means, while the deep strata appeared to be less variable and dominated by warmer conditions. A very cold event around 2°C was identifiable for the period 1982–84 followed by a warming to an overall mean of 4°C. During 1987–89, a less pronounced cooling was observed off West Greenland in particular. Subsequently, there was an increasing trend exceeding 3.5°C in the most recent years. The estimated near bottom temperature for 1996 indicates the warmest conditions during the entire survey period.

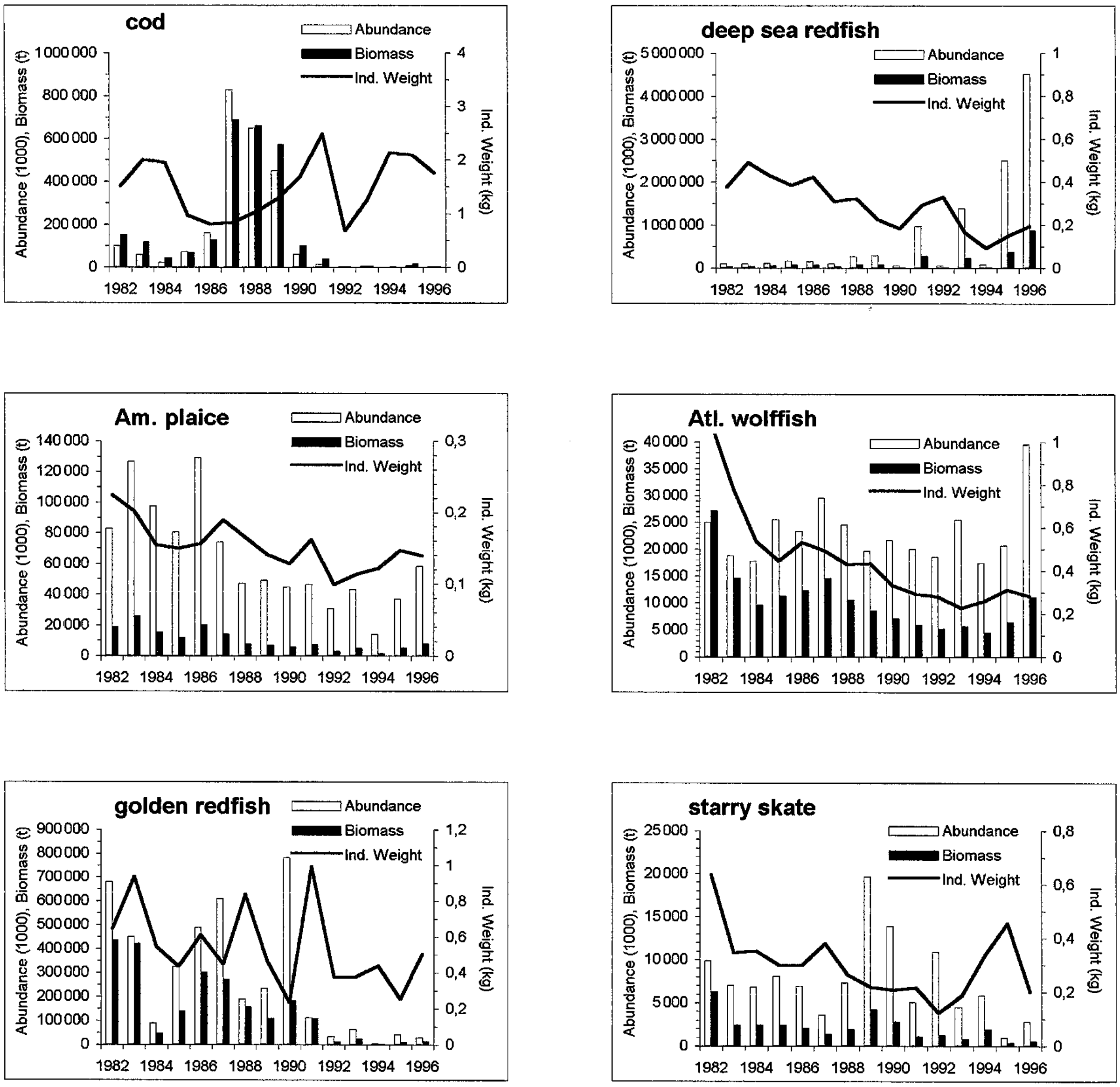

Fig. 8. Abundance, biomass indices, and mean individual weight for cod, Amercian plaice, golden redfish, deep sea redfish, Atlantic wolffish, and starry skate as listed in Tables 7–9, 1982–96.

Discussion

The demersal fish assemblage off Greenland was found to be mainly composed of a few boreal species. The six most common fish species, deep sea redfish, and golden redfish, Atlantic cod, American plaice, Atlantic wolffish and starry skate, accounted for more than 90% of the overall fish occurrence. Differences between strata based on quantitative species composition were found to be determined by geographical as well as depth effects. Species composition changed gradually from shallow to deep strata; it could also be observed that deep strata were more homogeneous than shallow strata. Inspite of significant geographical and depth patterns in quantitative species composition of the individual strata, no clear indications of persistent delimitations or boundaries in the demersal fish assemblage off Greenland were determined. However, persistent zoogeographic regions on the Grand Bank and adjacent areas were found to be strongly aligned with bottom depth (Gabriel, 1992; Gomes *et al.*, 1992). Geographical and depth effects were also decisive for the species composition of the fish fauna inhabiting the shelf areas and continental slopes in the Antartic Weddell Sea (Hubold, 1992).

TABLE 10. Mean near bottom temperature (°C) by stratum and weighted mean (by stratum area), 1982–96. Incomplete coverage of the survey area in 1982, 1984, 1991, 1992 and 1994.

Year	1.1	1.2	2.1	2.2	3.1	3.2	4.1	4.2	5.1	5.2	6.1	6.2	7.1	7.2	Weighted mean
1982	2.54	3.63	1.95	3.10	3.26	3.63	2.62							4.60	3.14
1983	2.03	3.71	1.42	3.82	2.14	4.81	2.16			4.12		4.00		2.94	3.01
1984	1.37	2.79	1.62	3.89	2.46		2.52					4.13			2.70
1985	4.19	5.15	3.12	4.61	2.61	4.34	4.44		5.04	5.19	4.42	4.30		3.30	4.18
1986	3.67	4.39	4.01	5.07	4.20	5.07	4.10			4.80	4.04	4.52		3.35	4.14
1987	3.09	4.89	3.39		3.50		3.53			4.47		4.40		3.30	3.78
1988	2.55	4.33	3.03	4.96	4.23	5.23	4.33		4.48	4.56	4.30	4.58		3.79	3.96
1989	2.32	3.95	2.72	4.53			2.58		3.39	3.74	3.65	4.06		3.15	3.30
1990	2.50	3.92	3.00	4.81	3.42		2.52		4.40	4.57	3.25	4.02		3.03	3.46
1991	3.53	4.73	3.48	4.20	3.02		3.00								3.56
1992	3.90	4.42	2.91	4.46	2.99	4.69	1.94							3.47	3.49
1993	3.01	4.00	2.36	3.36	4.71	4.96	2.77		3.77	4.06	4.33	4.39		2.82	3.60
1994	2.91	4.44	3.75	4.64	3.85	5.11	3.77								3.62
1995					4.23	4.61	3.47	4.24	2.60	3.62	3.68	4.32		3.83	3.86
1996	4.61	5.51	4.41	5.69	5.61	5.70	5.06	5.73	4.51	5.13	5.32	4.90		2.85	4.71

Measurements of species diversity and eveness indices in marine communities are highly dependent on sample gear, sample size and sample effort, as well as taxonomic expertise of scientists and technicians involved in the sampling resulting in difficulties of comparing one study with others. However, the species diversity of the Greenlandic demersal fish community had similar values as the subantarctic fish fauna around Elephant Island (Tiedtke and Kock, 1989) whereas the communities in the high Antarctic Weddell and Ross Sea and the Prydz Bay were substantially more diverse (Schwarzbach, 1988; Hubold, 1992).

During the past 15 years, the demersal fish assemblage in Greenlandic waters has undergone fundamental changes in species composition and abundance, down to the collapse of the ecologically and economically important cod and golden redfish stocks which almost disappeared from survey catches. American plaice (Lloret, MS 1996), Atlantic wolffish and starry skates displayed a less pronounced decrease in abundance but decrased in biomass by more than 50%. In comparison with the mean estimates during the 1980s, the frequent occurrence of deep sea redfish and unspecified juvenile redfish off East Greenland during recent years resulted in a compensatory increase in total fish abundance and biomass by a factor of 5 and 0.5, respectively. With the exception of cod and juvenile redfish, average individual weight in general declined by 25–50% as compared to the means of the 1980s. Since 1990, these stocks have been almost exclusively composed of small juveniles. Similar stock declines and reductions in individual size but without any clear indication for biomass compensation within the demersal fish community have been described for Div. 2J and 3KL (Atkinson, 1994).

The demersal fish assemblage off Greenland has been significantly affected by climate changes and fishing operations during the past 70 years (Hansen, 1949). After the World War II, the pertubations due to an intensive fishery reached a high catch level of 400 000 tons annually (Horsted, MS 1994). The temperature regime was dominated by persistent cool events during the early years of the 1970s and into the 1980s with an overall decreasing trend since 1960 (Buch and Stein, 1989; Stein, 1996). During the last 30 years, the productivity of the fish stocks decreased and became extremely irregular due to the depletion of the cod and redfish spawning stocks (Rätz, 1996b). In 1991, extremely low catch rates resulted in a complete discontinuation of the formerly profitable cod and redfish fishery. Recently, a shrimp fleet expanded its activities to traditional fishing grounds with unknown by-catches. Around 70 000 tons of shrimps were landed annually, especially from West Greenland (Hvingel, MS 1996; Hvingel *et al.*, MS 1996a and b) where 80% of the catches and effort were distributed. Effort distribution was consistent with the extremely poor status of the demersal fish assemblage off West Greenland which lacks any signs of recovery since 1990. Average or warmer

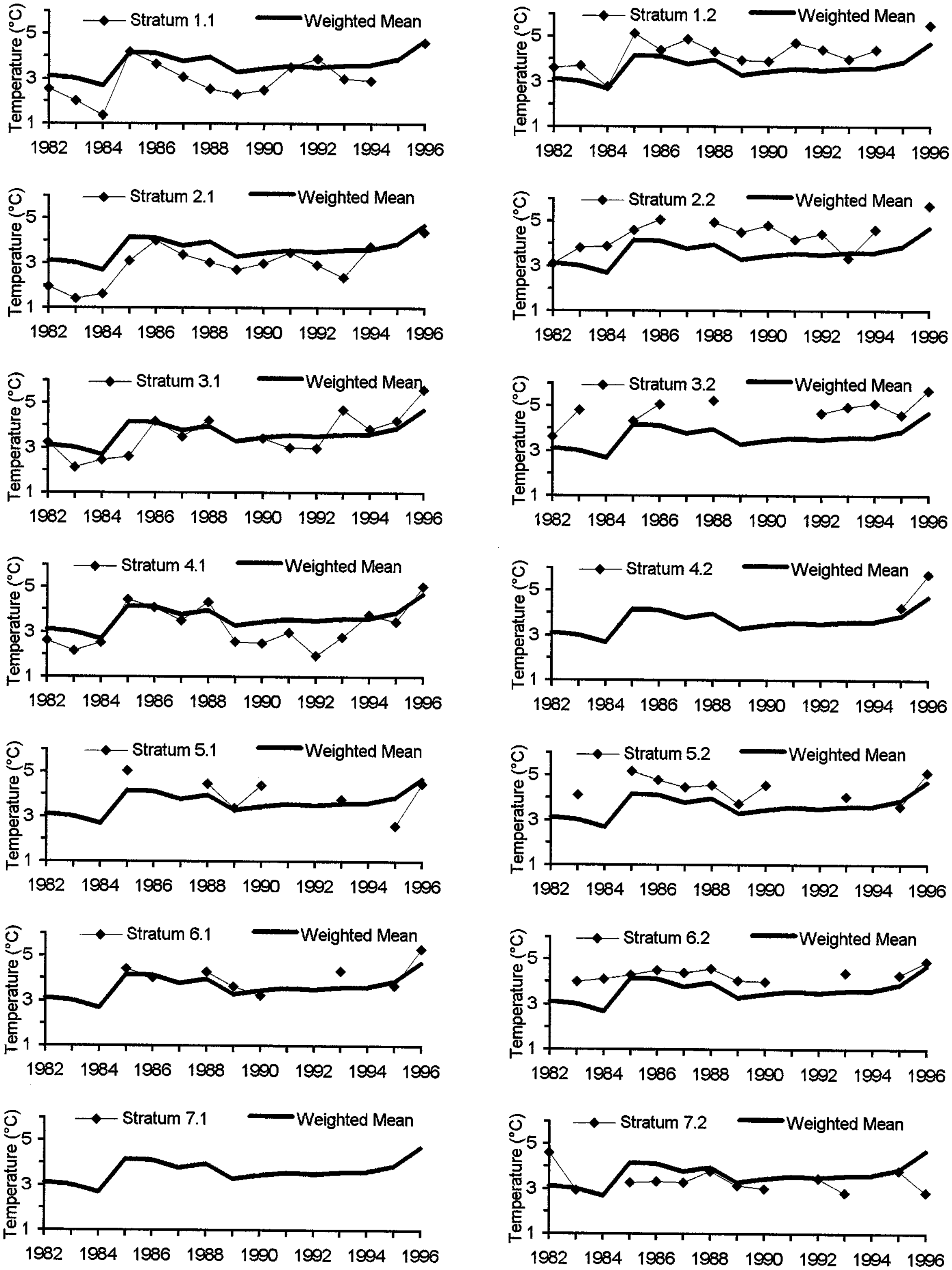

Fig. 9. Trends in mean temperature of the near bottom layer by stratum and weighted mean (by stratum area) illustrated as bold lines, 1982–96. Values are listed in Table 10.

ambient temperatures were indicated from near bottom measurements and have enhanced the chance of successful recruitment. With the exception of redfish off East Greenland, the failure of recruitment might therefore be attributed to significant by-catches in the recently expanded shrimp fishery as well as the depletion of spawning stocks. Given this scenario, a substantial recovery of the demersal fish assemblage off Greenland appeared to be unlikely within the next decade.

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References

ATKINSON, D. B. 1994. Some Observations on the Biomass and Abundance of Fish Captured During Stratified Random Bottom Trawl Surveys in NAFO Divisions 2J3KL, Autumn 1981–91. *NAFO Sci. Coun. Studies*, **21**: 43–66.

BUCH, E., and M. STEIN. 1989. Environmental Conditions off West Greenland, 1980–85. *J. Northw. Atl. Fish. Sci.*, **9**: 81–89.

COHEN, E. B., M. D. GROSSLEIN, M. P. SISSENWINE, F. STEIMLE, and W. R. WRIGHT. 1982. Energy budget of Georges Bank. *In*: Multispecies approaches to fisheries management advice. M-C. Mercer (ed.). *Can. Spec. Publ. Fish Aquat. Sci.*, **59**: 95–107.

COCHRAN, W. G. 1953. Sampling techniques. *John Wiley & Sons Inc., New York*: 330 p.

GABRIEL, W. L. 1992. Persistence of Demersal Fish Assemblages Between Cape Hatteras and Nova Scotia. *J. Northw. Atl. Fish Sci.*, **14**: 29–46.

GOMES, M. C., R. L. HAEDRICH, and J. C. RICE. 1992. Biogeography of Groundfish Assemblages on the Grand Banks. *J. Northw. Atl. Fish Sci.*, **14**: 13–27.

HANSEN, P. M. 1949. Studies on the Biology of Cod in Greenland Waters. *ICES Rapp. Proc.-Verb*, **123**: 77 p.

HVINGEL, C. MS 1996. Geograhical changes in the fishing pattern of Greenlandic shrimp trawlers in the Davis Strait, 1987–1996). *NAFO SCR Doc.*, No. 110, Serial No. N2807, 5 p.

HVINGEL, C., H. SIEGSTAD, and O. FOLMER. MS 1996a. The Greenland fishery for northern shrimp (*Pandalus borealis*) in Davis Strait in 1995 and January–October 1996. *NAFO SCR Doc.*, No. 102, Serial No. N2806, 29 p.

MS 1996b. The Greenland fishery for northern shrimp (*Pandalus borealis*) in Denmark Strait in 1995 and January–October 1996. *NAFO SCR Doc.*, No. 117, Serial No. N2814, 24 p.

HORSTED, SV. AA. MS 1994. A Review with Some Proposals for Amendments of the Catch Statistics for the Cod Fisheries in Greenland Waters Since 1911. *NAFO SCR Doc.*, No. 38, Serial No. N2407, 33 p.

HUBOLD, K. G. 1992. Ecology of Weddell sea fishes. *Ber. Polarforsch.*, **103**: 157 p.

LLORET, J. MS 1996. Population dynamics of American plaice (*Hippoglossoides platessoides*) off West Greenland (NAFO Divisions 1B–1F, 0–400 m). *NAFO SCR Doc.*, No. 5, Serial No. N2670, 10 p.

MAYO, R. K., M. J. FOGERTY, and F. M. SERCHUK. 1992. Aggregate Fish Biomass and Yield on Georges Bank, 1960–87. *J. Northw. Atl. Fish. Sci.*, **14**: 59–78.

MURAWSKI, S. A., A. M. LANGE, M. P. SISSENWINE, and R. K. MAYO. 1983. Definition and analysis of multispecies ottertrawl fisheries off the northeast coast of the United States. *ICES J. Cons.*, **41**: 13–27.

PILOU, E. C. 1966. The Measurement of Diversity in Different Types of Biological Collections. *J. Theoret. Biol.*, **13**: 131–144.

RÄTZ, H.-J. 1996a. Efficiency of Geographical and Depth Stratification in Error Reduction of Groundfish Survey Results: Case Study Atlantic Cod off Greenland. *NAFO Sci. Coun. Studies*, **28**: 65–71.

1996b. Hints at Overfishing of Demersal Fish Stocks off Greenland. *Inf. Fischwirtsch.*, **43**(1): 9–15.

SAVILLE, A. 1977. Survey methods of apprising fishery resources. *FAO Fish. Tech. Pap.*, No. 171, 76 p.

SCHWARZBACH, W. 1988. Die Fischfauna des östlichen und südlichen Weddelmeeres: geographische Verbreitung, Nahrung und trophische Stellung der Fischarten. *Ber. Polarforsch.*, **54**: 94 p.

SHANNON, C. E., and W. WEAVER. 1963. "The Mathemathical Theory of Cummunication". *Urbana, University of Illinois Press*, 117 p.

SNEATH, P. H. A., and R. R. SOKAL. 1973. Numerical Taxonomy. *Freemann & Co., San Francisco.*

STEIN, M. 1996. Climatic conditions around Greenland – 1994. *NAFO Sci Coun. Studies*, **25**: 59–65.

TIEDTKE, J. E., and K. H. KOCK. 1989. Structure and Composition of the Demersal Fish Fauna around Elephant Island. *Arch.FischWiss.*, **39**(1): 143–169.