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Relations between environment, plankton and fishery yield in ICNAF Subareas 3 and 4

by

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I - Introduction -

A prospecting cruise and a survey of herring populations were accomplished on R/V Cryos in Newfoundland, Cap Breton and Banquereau areas (divisions ICNAF 4 R, 3 P and 4 V) from 20 November-11 December 1972. During this cruise, followed by others in 1973, 1974 and 1975, data on environment, temperature, salinity and plankton production were obtained in order to connect the presence and abundance of fish to the surrounding factors. This preliminary survey of the plankton populations precedes a more important work on the dynamics of plankton in the same areas, from 1973 to 1975.

The stations are located in a geographic area limited in latitude 44° and 49° North and longitude 57° and 61° West. It can be divided into three subdivisions relatively well distinct from one another : - in the North, the Newfoundland area, west and South coasts (7 stations), - in the centre, the Cap Breton area (9 stations), separated from the preceeding one by the Laurentian Channel and in the South, the Banquereau area (3 stations), South shore near the Gullet.

II - Methods and techniques -

We compelled ourselves to use methods and techniques well adapted to this kind of survey.

The 19 plankton samples obtained during this first cruise have been towed with Hensen net with a 70 cm diameter and openings of unstrectched mesh of .333 mm. Every tow is accomplished vertically from the bottom to the surface. The nets are set out at 30-35 m/mn and retrieved at 10-15 m/mn. The samples obtained are kept on board after being preserved in 4 % formalin.

In the laboratory, the work is achieved in two phases : sorting and counting of the zooplankton, then counting of the phytoplankton. Made as it is, the Hensen net is not particularly suited to the collecting of the phytoplankton and therefore, the results obtained are spoiled by a considerable bias due to the too important selectivity of this type of gear. The results obtained have only a quantitative value.

2.1. Quantitative study.

Sorting and counting of the zooplankton is accomplished under binocular. The numerations are accomplished on either the entire sample or aliquot. Generally, the size of the study sample depends upon the importance of the catch. To count the organisms, a Dollfus squared tub is used and it is proceeded as it follows : after an homogeneization as perfect as possible of the whole sample or only part of it, a determined volume is separated and poured into the tub. The counting is expressed in terms of the zooplankton density and accomplished on either all the squares concred by the sample or only one part which varies according the case. The total is obtained from partial results by the following formula

$$N = \sum_{i} \frac{ni\ C\ V}{c.v}$$

N stands for the total number of organisms in a sample, ni the number of individuals, V the total volume of the sample, C the total number of squares of the tub, v the volume of the subsample, c the partial number of squares. From the theoretic volume of water filtered, the results are expressed in number for 100 m^3 of water filtered.

Basically, the methods used for the analysis of phytoplankton are not different. Observation is accomplished under microscope and counting with an Agasse-Laffont cell after dilution of the sample at a chosen volume. The results are obtained according the formula :

$$N = \sum_{i} \frac{ni}{c}\ kd$$

N is the total number of organisms, ni the number of individuals, c the number of counted A.L. squares, k the coefficient of the cell and d the dilution of the sample.

Results are brought to a column of water of 100 m or more generally 50 m, which approximately corresponds to the euphotic layer at this time of year. Results are expressed in number of organisms for 100 m^3 of water filtered.

2.2. Study of planktonic structures.

This study is done on quantitative and qualitative data.

2.2.1. Distribution.

In the oceans, the plankton groups (planctontes) of apparently motionless one-cell plants and restricted swimming animals seem to be spread at random. The distribution would be then the one of "POISSON" defined by the average, since $\sigma^2 = m$.

In fact, random distributions are rarely met because of antagonisms or affinities existing between organisms or groups of plankton organisms. The so-called contagious distributions are expressed by the equality $\sigma^2 = m + cm^2$ (σ^2 = variance m = average) and accordingly

$$C = \frac{\sigma^2 - m}{m^2}$$ (CASSIE, 1963 , LAMOTTE and BOURLIERE,1971).

- in a more regular distribution or underdispersion, $\sigma^2 < m$ and $c < 0$.

- in a random distribution $\sigma^2 = m$, $c = 0$

- and in a less regular distribution or overdispersion $\sigma^2 > m$, $c > 0$. In this case, we often meet big concentrations of individuals or swarms, namely with copepods, euphausids and geloplankton.

A coefficient of dispersion defined by FISHER (1958) σ^2/m shows that the quantity $(n - 1)\ \sigma^2/m$ is distributed like a χ^2 when the organisms are arranged according a law of POISSON.

2.2.2. Specific diversity.

The specific diversity which caracterizes the distribution of individuals between the species has been calculated with the MARGALEF (1956) and SHANNON indexes for the phytoplankton and only with the SHANNON index for the zooplankton.

The MARGALEF index, complicated enough to use,

$$D = \frac{1}{N} \log_2 \frac{N}{Na\,!\ Nb\,!\ \ldots\ Ns\,!}$$ is, usually for big

samples, often replaced by the following equality :

$$D = \frac{3,322}{N} \left(\log N\,! - \sum_{i=1}^{s} \log ni\,!\right)$$

in which, N equals the total number of organisms, Na, Nb, Ns equal the number of individuals of species a, b, s.

The calculations are made easier with the use of logarithmic tables of factorials (FISHER and YATES, 1963) and beyond those, the STERLING function :

$$\sigma = \sqrt{2 \pi N \ (\frac{N}{e})^N}$$

from which derives

$$\log N\,! \simeq \frac{1}{2} \log 2\pi + \frac{1}{2} \log N + N \log N - N \log e$$

i.e.

$$\log N\,! \simeq (N + 0,5 \log N) - 0,43429\ N + 0,39903 \quad \text{(TRAVERS,1971)}.$$

The specific diversity has also been calculated with the SHANNON index for the phytoplankton and the zooplankton (copepods)

$H = -\sum pi \log_2 pi$ ($\sum pi = 1$) with the use of tables by FRONTIER (1969). Whatever the index is, results are expressed in bits/individual.

2.2.3. Plankton communities (phytoplankton).

Several association coefficients, worked out enough, are set for the study of interspecific liaisons. Generally, these indexes are worked with improved calculation units. The JACCARD index (1908) is linked to the presence or absence of species (REYSSAC and ROUX,1972). It's also the case for DICE index (1945) which is used for a limited number of species for the total sample

$$SD = \frac{2\ n\ \ JK}{2\ n\ JK\ \ +\ u}$$, n JK is the number of co-occurences

of two species and u the number of times one only appears.

Another association coefficient based on two parameters, number of occurences of one specie for a total sample and total number of species, has been calculated and the results compared to the preceeding ones. The index is the summing up of the ratios of the frequency of the species to the total number of species for a considered total sample.

$$Ic = \frac{\sum fs}{S_T}$$

or, introducing the notion of abundance

$$Ic' = \frac{\sum fs}{S_T} \quad \log ni$$

This index is conceived differently from the indexes based on interspecific liaisons. Its value is tested in comparison with DICE coefficient. As for this one or the other indexes, a minimum is arbitrarily chosen to determine the species around which the communities spread. In the present case, it was used to compare the plankton populations of three geographic areas next to one another.

III - Results -

Observations were accomplished with such punctuality that it is quite impossible to prejudge the evolutive situation of the plankton sample at its taking. At best, we shall be able to try to value it by the analysis of synthetic caracteristics.

3.1. The phytoplankton.

Five taxonomic groups are represented in the 19 plankton tows, the diatoms with 35 species, the dinoflagellates with 10 species, the coccolithophorids, the silicoflagellates and the desmids with respectively 1, 2 and 3 species, say a total of 50 species.

3.1.1. Quantitative evaluation and distribution.

The results show relatively important variations from one area to another and even inside an area. To stabilize the variances, a changing of variable has been done by using the transformation $y = (\log x)^2$ (FRONTIER, 1966). The data brought to N/100 m^3 of water filtered for a 50 m column of water, are shown in table 1.

The subarea of Cap Breton generally appears richer than Newfoundland and Banquereau areas (fig. 2), taking into account the low number of samples for Banquereau bank. After analysis of the variance by the FISHER test, it appears that for F, 99 % of the results are significantly different between the three regions. Consequently, the observed incomformability between the phytoplanktonic distributions doesn't seem to exist by mere chance but would be the result of different processes.

Furthermore, the value of C shows that the phytoplankton distribution departs from a POISSON distribution and is confirmed by the quantity value $(n - 1)\ \sigma^2 / m$. In Newfoundland and Cap Breton subareas, we meet with underdispersion. On the contrary, on Banquereau the phytoplankton would be overdispersed (tabl. 1).

3.1.2. Specific diversity.

The specific diversity can be an important factor in caracterizing the stage of evolution of a phytoplanktonic succession. Because of the lack of data as regards the study area, we are unable to make any comparison or draw immediat lessons from our results. So, we only state them without trying to interpret them definitely.

In the Newfoundland area, the SHANNON index shows a small variability. Except at the station Y 528 where H = 1,56 bits, the indexes fluctuate between 2,24 and 2,81 bits. On Banquereau, the values of H are similar, from 2,17 to 2,94 bits. The variability is more important in Cap Breton area, from 1,43 to 3,02 bits, with an average value inferior to those of both other subareas (tabl. 1). There is no noticeable difference between the SHANNON and MARGALEF indexes ($\bar{D}$). The variations of $\bar{D}$ are strictly identical to those of H. The correlation directly proportional is excellent, r = 0,92 and the regression line of the type y = a + bx gives : $\bar{D}$ = 0,892 H + 0,1937.

3.1.3. Phytoplanktonic communities.

In order to increase the informations on a phytoplanktonic population at a given time, we tried, using association coefficients (Ic and Ic' - SD : DICE coefficient) to define the types of existing communities in this automnal period.

The indexes Ic and Ic', quickly and easily worked out, compared to the SD DICE index, show on one hand, an excellent correlation between SD and Ic, r = 0,99 - Ic = 0,2801 SD + 0,1673 (fig. 3). On the other hand, they also show an excellent correlation between SD and Ic', r = 0,96 - Ic' = 1,4925 SD - 0,275, taking into account the notion of abundance.

In fact, the values obtained for these indexes only back up the observations made empirically on the phytoplanktonic communities of the three areas.

In the Newfoundland area, the prevailing specie is *Rhizosolenia hebetata semispina* accompanied by *Chaetoceros decipiens*, *Chaetoceros concavicornis*, *Skeletonema costatum*, *Licmophora spp.* and *Dictyocha speculum.* In the Cap Breton area, *Coscinodiscus concinnus* and *Ceratium fusus* form the nucleus of a community to which are associated species such as *Synedra sp.*, *Licmophora sp.*, *Chaetoceros concavicornis*, *Chaetoceros decipiens*, *Thalassiosira nordenskioldii*, *Skeletonema costatum*, *Navicula sp.*, *Dinophysis norvegica*, *Chaetoceros danicus*, *Nitzschia closterium*, *Dictyocha speculum* and *Ceratium longipes*. On Banquereau, the prevailing specie as well as the morphological caracteristics of the phytoplankton community could not be determined because of the limited number of stations. In this place, the tychopelagic forms are relatively varied and abundant.

Out of the identified 50 genus and species, three only are common to the three subareas, i.e, 6 % : Coscinodiscus concinnus, Chaetoceros concavicornis and Licmophora anglica. The ratio of species common to Newfoundland and Cap Breton represents 24 % ; between Newfoundland and Banquereau, 6 % ; and between Cap Breton and Banquereau 14 %. It seems then, there is a North-South evolution and that we are facing here a retrogressive communal stage following a stage towards the standardization of the phytoplankton populations, for the entire considered area. The comparison between the association coefficients by the F test shows significant differences for $Ic = \frac{\sum fs}{S_T}$ with $p = 1\ \%$ and for $Ic' = \frac{\sum fs}{S_T} \cdot \log ni$, $p = 0{,}1\ \%$

3.2. The zooplankton.

Numerous taxa form the zooplankton. The copepods are specifically the most abundant. But groups such as euphausids, amphipods or geloplankton, comprising animals having a gelatinous appearance or rich in mesoglea, can cover a volume equal or superior to the copepods one, though having a more restricted number of individuals.

A selection of samples by strata would have been necessary for the structural study of zooplankton populations. As a matter of fact, vertical hauls with Hensen net can go through various strata having their own physical caracteristics and which can be as many different ecological broods. Besides, the vertical distribution of the zooplankton is not uniform. It varies in relation of the more or less pronounced, positive or negative phototropism of many animals. It also varies in relation of time, some species having a nycthemeral rhythm that brings them near the surface at night while they stay in deeper strata during sunny periods of day.

Most of the stations being located on platforms and generally near enough coasts, the fauna is mainly composed of epiplanktonic and mesopelagic species and, in lower proportion infrapelagic species.

Raw results of the numerations expressed in $N/100\ m^3$ of water filtered after changing of variable by the transformation $y = (\log x)^2$ show that the above three areas differ from one another. The Newfoundland area is the poorest, the average for all the stations being 13,83. The Cap Breton area is the richest, $\overline{m} = 23{,}11$ and Banquereau area ranges between the other two with $\overline{m} = 17{,}32$. The F test gives a significant difference between the 3 areas for $p = 0{,}1\ \%$ (fig. 4).

Distribution is close to a POISSON distribution around Cap Breton. There is even a subdispersion in the other two subareas ; for Newfoundland $c = -0{,}07$; Cap Breton $c = 0{,}002$ and Banquereau $c = -0{,}05$.

The H diversity index has been calculated for the copepods only. There is no noticeable significant difference. However, an evolution of the average index can be noticed, H = 1,49 bits for Cap Breton area, H = 1,50 for Newfoundland and H = 2,19 for Banquereau.

Because of the large diversity of zooplankton groups in a sample, it isn't interesting to calculate an index of biotic diversity.

For already mentioned reasons, we found no interest in calculating an association coefficient for the zooplankton. It is likely that animals communities establish themselves according to their ecological requirements. Under these conditions, the distribution of strongly linked species must develop on an horizontal plane, i.e, there is probably a stratification of groups. Therely, it is impossible with vertical hauls to get an idea of the structure of such groups for there is inevitably a mixing of several communities.

Some species are quite ubiquitous since they can be found in the whole overhauled area. It is the case for Calanus finmarchicus, Pseudocalanus minutus elongatus, Oithona similis, Limacina retroversa, Sagitta elegans and appendiculars. Many other species are frequently found in the 0-100 metres stratum, namely copepods such as Temora longicornis, Tortanus discaudata, Oithona plumifera, Centropages typicus, Metridia lucens, Calanus hyperboreus, Pareuchaeta norvegica (copepod stages), Scolecithricella minor, euphausids such as Meganyctiphanes norvegica, Thysanoessa inermis, amphipods such as Parathemisto abyssorum, Parathemisto gaudichaudi, a mainly epiplanktonic cladocera : Evadne nordmanni, and lastly belonging to various groups : Limacina helicoïdes, Aglantha digitale, Aulacantha scolymantha.

In strata under 100 metres and down to 200 metres, copepods are met, Acartia longiremis, Clausocalanus arcuicornis, Mecynocera clausi, Aetideus armatus, Pleuromamma robusta, Undeuchaeta plumosa and for the other groups, Thysanoessa longicaudata, Sagitta serratodentata on Banquereau bank, Tomopteris septentrionalis, Coelodendrum ramosissimum, Aulacantha scolymantha, Aulosphaera sp. and also tintinnids, Parafavella gigantea, P. denticulata and Acanthostomella norvegica.

During a seasonal cycle, phytoplankton and zooplankton vary normally in the opposite direction, under the action of grazing or control of the plant productivity by the herbivora, then under the action of predation or control of herbivora by predators of first degree, which allows a new growth of phytoplankton. From observations, it appears first there is almost a consecutive balance for both plankton groups ; secondly, after the appearance of predators of first degree limiting the herbivora growth, there is a regression of the phytoplankton production due to grazing and the decaying optimal state of the surrounding. This situation leads to a general stabilization of productivity. For Newfoundland, Cap Breton and Banquereau subareas, the phyto-zooplankton relations determined by the regressions of log Z (zooplankton) and log P (phytoplankton) respectively gave the following equations :

$$Z = 351,9654\ P^{0,2623}$$

$$Z = 3,3869\ P^{0,7920}$$

$$Z = 1\ 541,7005\ P^{0,1944}$$

From this assumption we can infer that the phyto-zooplankton relations are directly proportional at a given time in a determined space. In a milieu abounding in phytoplankton there is a more considerable zooplankton productivity. This was noticed in the considered geographic area where the calculated regression line gives $Yz = 1,0168\ xp - 6,5624$ for a correlation coefficient $r = 0,996$.

3.3. Quantitative evaluation of plankton by volumes.

Results confirm the previous observations. Cap Breton area is richer than Newfoundland and Banquereau areas. Average volumes expressed in cm^3 for 100 m^3 of water filtered are respectively for each subarea : 14,96 , 3,97 and 1,87 cm^3. The variation coefficient is higher in Cap Breton area (Cv = 67,1 %) where values are ranging between 2,5 and 36 cm^3 (fig.5).

3.4. Hydrography and plankton environment relations.

It seems impossible to set forth valuable relations on plankton productivity from bottom salinities and surface and bottom temperatures only.

On the Newfoundland coasts, temperatures vary from 1°37 to 3°97 C at the surface. Waters are hardly less cold on the West coast (3°03 to 3°97 C) than on the South coast (1°37 to 2°23 C). Furthermore, temperatures are generally higher at the surface than at the bottom (0°95 to 3°46 C). Salinities vary from 32,4 to 33,6 %.

In Cap Breton waters, temperatures are higher except at station Y 522, nothermost (0°89 C). Surface temperatures are ranging between 2°90 and 5°39 C and bottom ones between 1°24 and 4°49 C. Salinities are lower 30,1 to 32,8 %.

On Banquereau bank, temperatures and salinities are superior to those of the other two zones, T° C : 4°80 to 5°90 at the surface, 2°68 to 5°43 at the bottom ; salinities : 33,1 to 34,8 ‰.

The respective general means for Newfoundland, Cap Breton and Banquereau : 2°43, 3°13 and 4°69 C show a small gradient according to latitude. The Newfoundland area is under the influence of Labrador current ; the Cap Breton area is bathed with mixed waters as the relatively low salinities indicate. The Banquereau zone is under the influence of Atlantic waters.

The plankton-environment correlations are not evident. Newfoundland waters which are the least productive are also the coldest but on the Banquereau bank where the plankton biomass is less important than in Cap Breton area, temperatures are higher. It is likely that this phenomena in Cap Breton waters is due to a more important enriching in biogen material than anywhere else.

3.5. Catches and yields.

Captures of fish were accomplished with two bottom trawls : one of the Lofoten type 31,20-17,70 and a semi-pelagic one of the type 35-42. Hawls were of 30 minute duration. The results can be expressed either in kgs/half-hour, or in kgs per 100 m^3 of water filtered by the fishing gear.

It is plain that these bottom trawls only capture demersal or benthic species occupying a high position in the food chain and very little plankton-eater pelagic species such as herring. However in addition to inherent errors in the sampling methods, an important bias can be brought with the difference of capture densities for each zone : 3 trawls for Newfoundland, 18 for Cap Breton and 5 for Banquereau. The efficiency difference of both used trawls, fish shunning and escaping are other causes for errors. Lastly, the conversion of raw results into weight per 100 m^3 of water filtered can lead to an overestimate of the captures.

However, plankton biomass and fishery yields can be indirectly linked by a trophic relation. Generally, demersal or benthic fish which accomplish most of their cycle in a restricted area, often are plankton-eaters during their larval and juvenile periods or, in their mature state, 2nd or 3rd degree predators of preys which also depend on plankton for feeding. Under these conditions, it is likely that areas with large plankton production also are high yields areas.

Anyway, Cap Breton area, the richest in plankton, appears more productive and has higher mean yields.

	Newfoundland	Cap Breton	Banquereau
Total catch weight (kgs)	765,5	8 386,5	1 654
Mean weight	255,2	465,9	413,5
Mean weight per N kgs/100 m^3	0,20	0,36	0,18

Plankton-eater fish such as herring (<u>Clupea harengus</u>) were captured in Cap Breton area only, say 65,5 kg ($\overline{m}$ = 11,25 kg). The stomach contents of some samples were analysed and appeared to be exclusively composed of plankton food varied enough : copepods, amphipods, chaetognatha, larvae of decapods, euphausids (PAULMIER and DECAMPS, 1973).

The exponential relations between fish weight (W) and zooplankton biomass (Z) and, between fish weight (W) and plankton volume (V) are calculated with the equation $Y = ax^b$ in which $\log Y = \log a + b \log X$. The results are :

$$W = 0{,}1865 \quad Z^{0{,}0326}$$

$$W = 0{,}1404 \quad V^{0{,}3499} \quad \text{(fig. 6)}$$

IV - <u>Conclusion</u> -

As it has been already noted, it is difficult to caracterize the evolution degree of plankton populations on a sampling serie only. Seasonal observations done at adequate intervals would have been necessary to obtain a complete scheme of the plankton cycle in the study area.

However, through the study of the synthetic caracteristics of the plankton groups, some features come out allowing to define approximately the evolution state of plankton populations during the period november-december 1972.

Generally, the plankton is quantitatively poor. It is composed of automnal phytoplankton species of small multiplication capability. Quantitative data, values of biotic diversity indexes and communities constitution show a phytoplankton being probably at the end of the cycle and at the 3rd stage of a succession.

The zooplankton still has a remarkable enough development though having probably gone beyond its optimal stage. The copepods, relatively numerous, represent in many cases, most of the biomass. The phyto-zooplankton ratios show tendency towards a balance stage defined by a zooplankton biomass in appearance superior to the phytoplankton one.

The whole of the hydrographical and biological observations allow to divide the study area into 3 distinct zones caracterized by the oligotrophic degree of the milieu. In the North, the Newfoundland area, West and South coasts, is the poorest. The plankton density is low, the volumes unimportant and the climatic and hydrographical conditions unfavourable to plankton growth. In the South, the Banquereau area is richer than the preceeding one, and the surrounding factors more favourable. In the centre, the Cap Breton area, the richest, profits, may be more and for a longer period than the other two areas, from eutrophising waters coming from St Laurent.

These observations are confirmed by the fishery yields, though being small generally. Catch tonnage is more important in Cap Breton area than around Newfoundland and on the Banquereau.

Yet, demersal or pelagic species seem more or less dispersed, namely plankton-eaters such as herring : 69,5 kg for 13 trawl stations. It seems that for food-seeking these fish must swim long distances.

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Table 1. Synthetic characteristics of plytoplankton.

	Nombre unités morphologiques (log.)[2]			Valeur de c $\left(c = \dfrac{\sigma^2 - \bar{m}}{\bar{m}^2}\right)$	Valeur de $(n-1)\,\sigma^2/\bar{m}$	P = 0,05	Indice diversité $\bar{H}$ / $\bar{m}$
	moyenne	variance	écart-type				
Terre-Neuve	19,80	4,44	2,11	-0,04	1,35	significatif	2,46
Cap Breton	28,97	14,76	8,84	-0,02	4,08	"	2,07
Banquereau	23,95	31,73	5,63	0,01	2,66	"	2,56

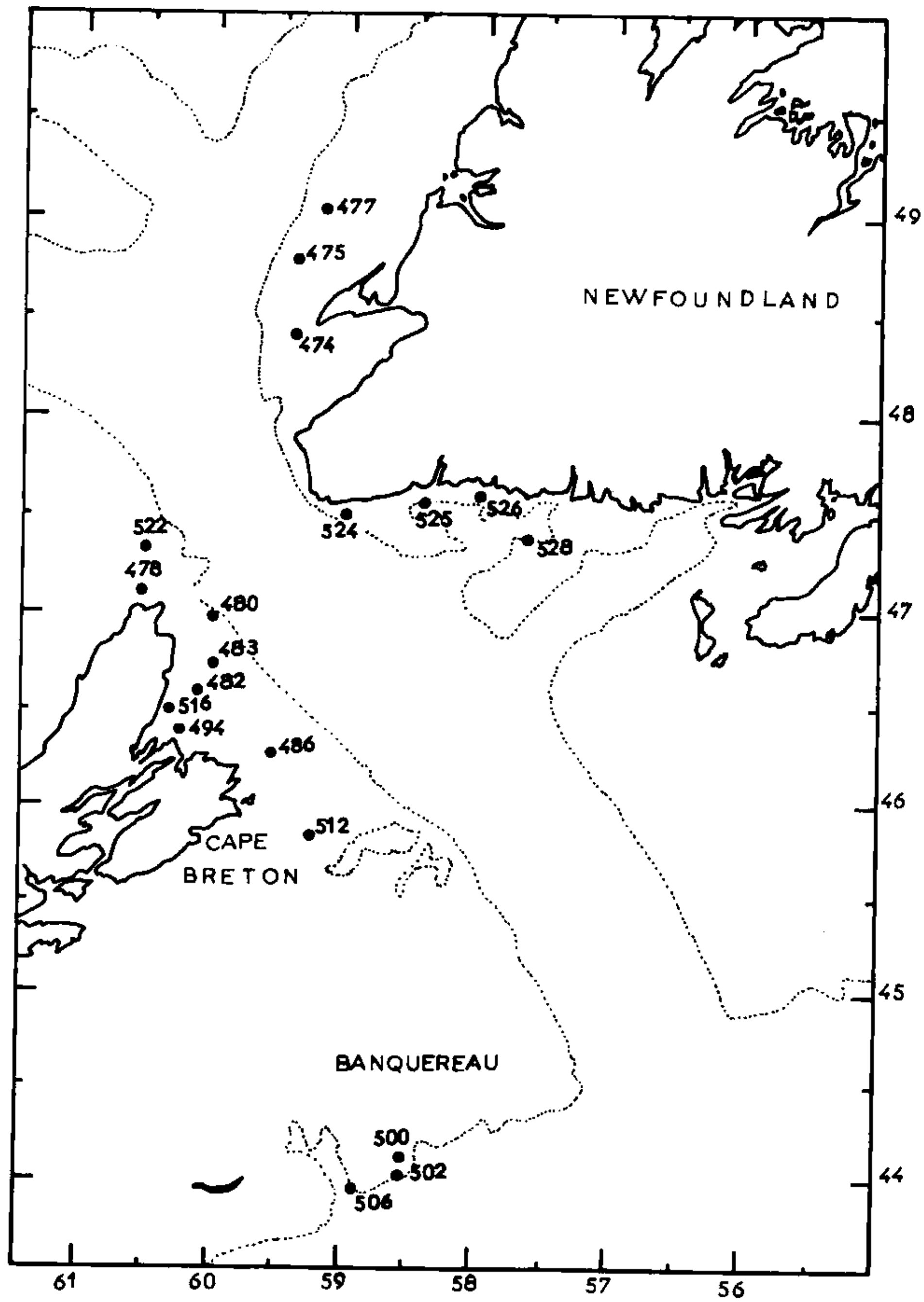

Fig. 1. Geographical situation of planktonic stations.

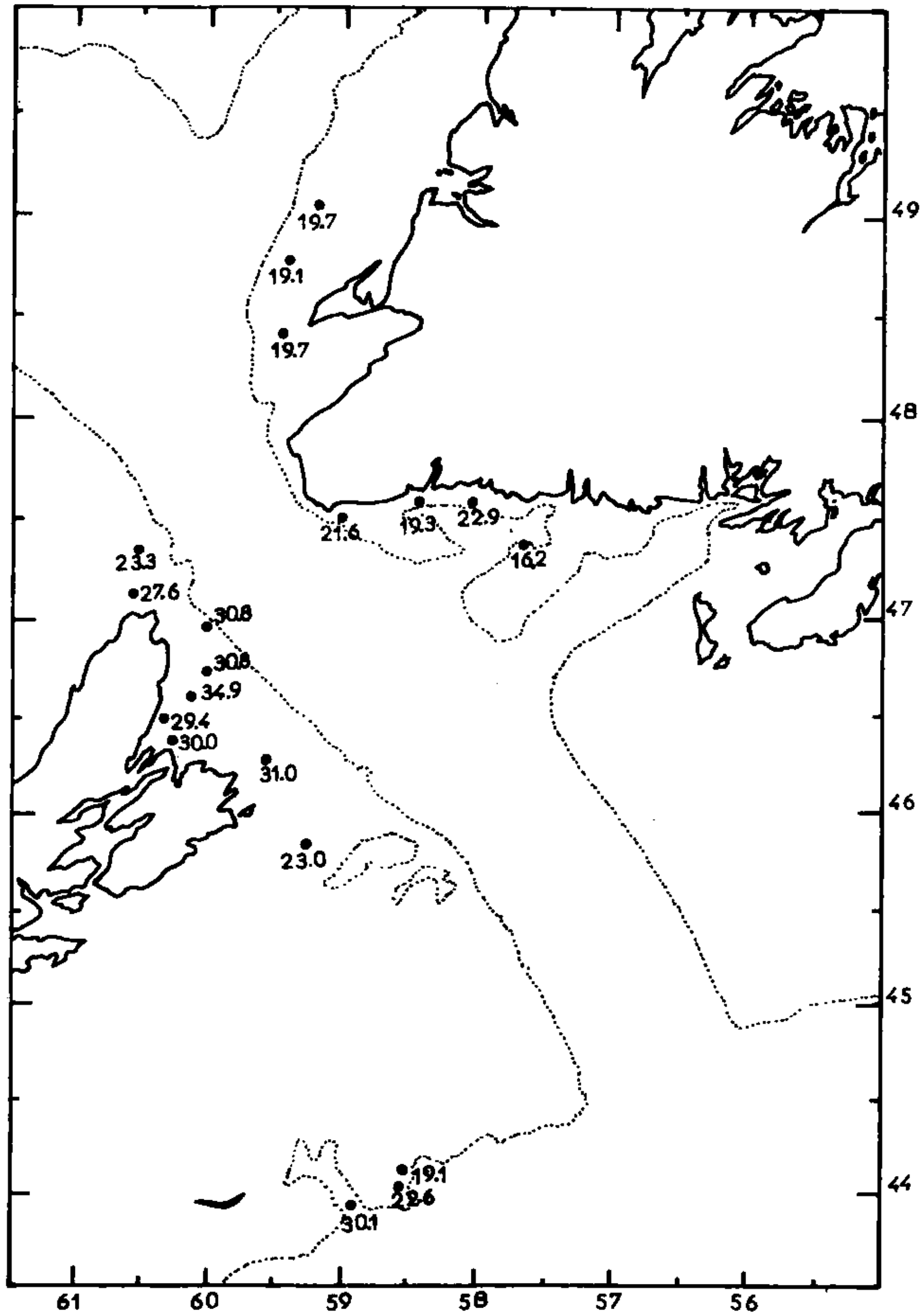

Fig. 2. Quantitative distribution of plytoplankton per 100 m^3 of filtered water (log)^2.

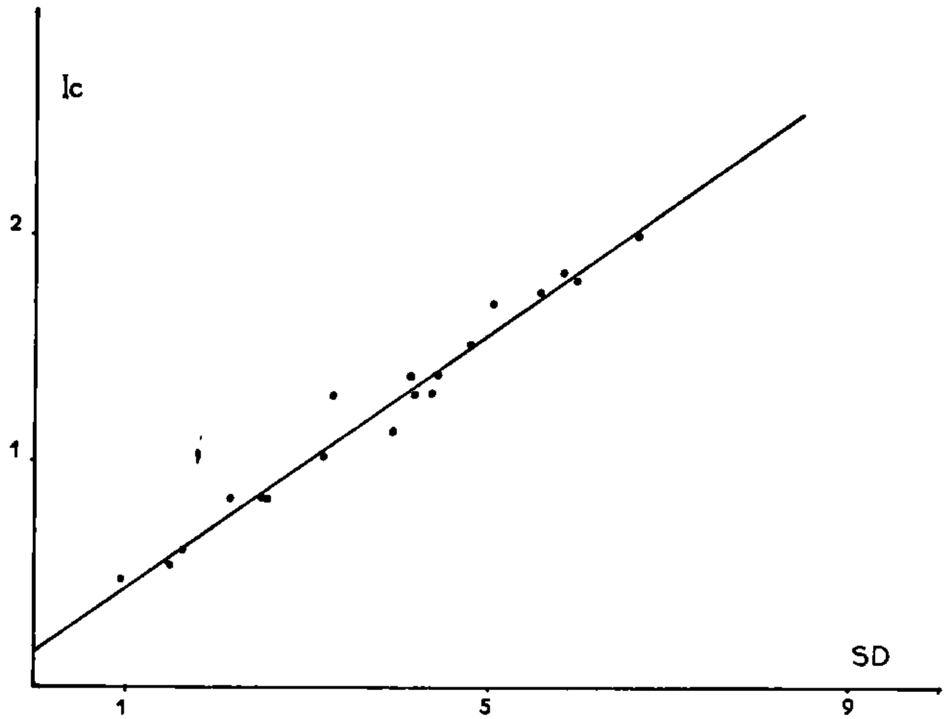

Fig. 3. Relationship between SD and IC coefficient of association.

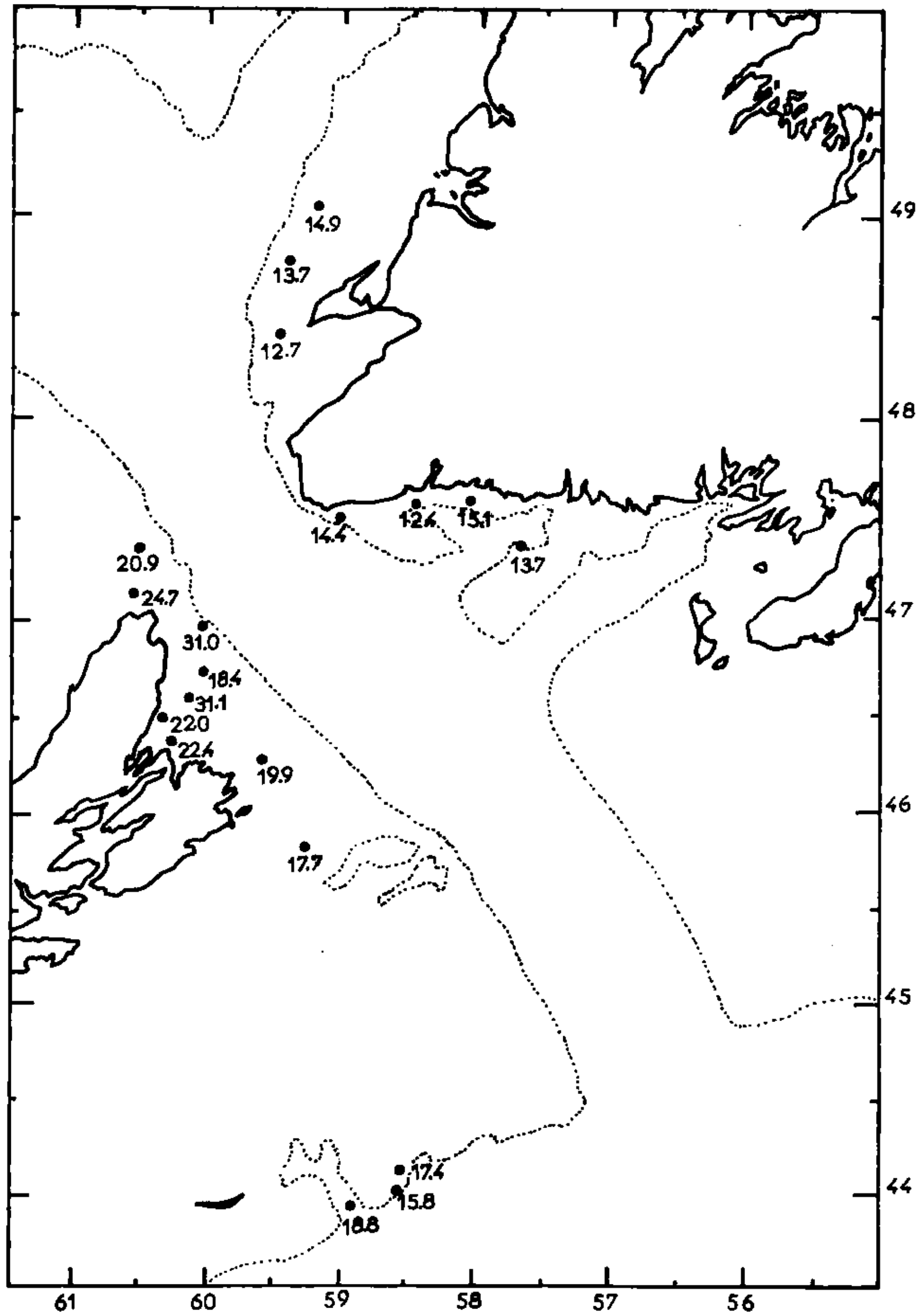

Fig. 4. Quantitative Distribution of zooplankton per 100 m^3 of filtered water (log)^2.

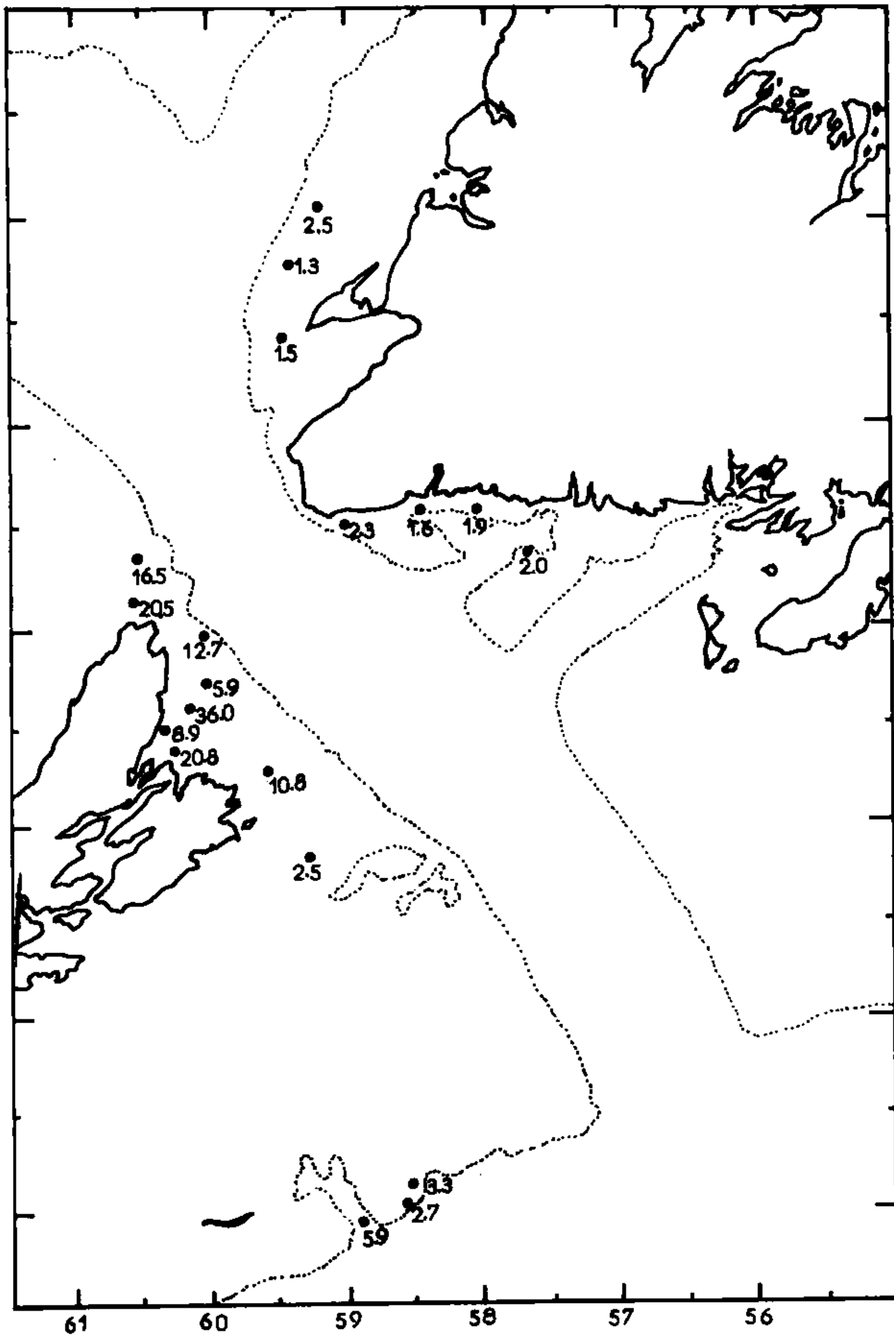

Fig. 5. Volume of plankton distribution per 100 m^3 of filtered water.

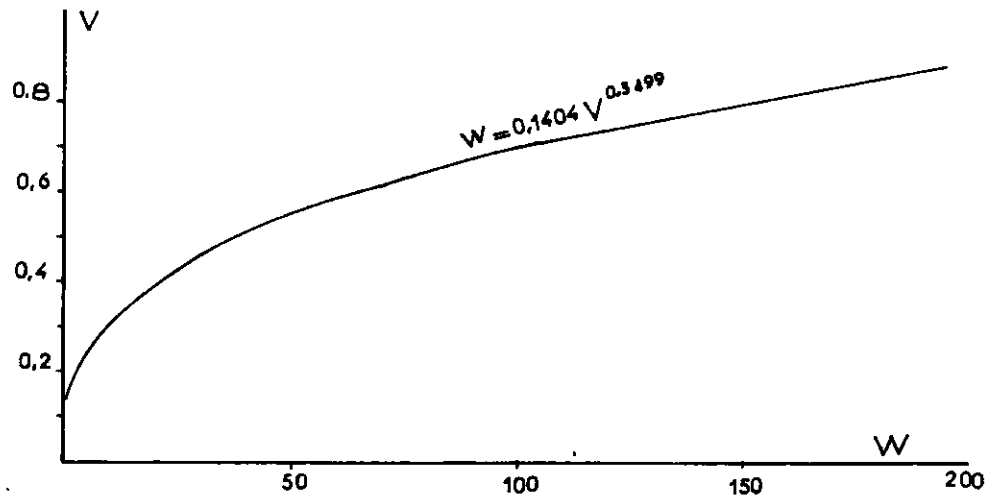

Fig. 6. Relationship between catches and volume of plankton.