Scientific Excellence • Resource Protection & Conservation • Benefits for Canadians
Excellence scientifique • Protection et conservation des ressources • Bénéfices aux Canadiens

Analysis of Continuous Plankton Recorder Data in the Northwest Atlantic 1959-1992

R. A. Myers, N. J. Barrowman, G. Mertz, J. Gamble, and H. G. Hunt

Science Branch
Department of Fisheries and Oceans
Northwest Atlantic Fisheries Centre
P.O. Box 5667
St. John's, Newfoundland
A1C 5X1

1994

Canadian Technical Report of Fisheries and Aquatic Sciences 1966

Fisheries and Oceans Pêches et Océans

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1–456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457–714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715–924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of
Fisheries and Aquatic Sciences 1966

1994

Analysis of Continuous Plankton Recorder Data in the Northwest Atlantic 1959 – 1992

by

Ransom A. Myers
Northwest Atlantic Fisheries Centre, Science Branch
P.O. Box 5667, St. John's, NF, A1C 5X1 Canada

Nicholas J. Barrowman
Seaconsult Ltd., P.O. Box 2035, Station C,
200 White Hills Road, St. John's, NF, A1C 5R6 Canada

Gordon Mertz
Northwest Atlantic Fisheries Centre, Science Branch
P.O. Box 5667, St. John's, NF, A1C 5X1 Canada

John Gamble and Harold G. Hunt
The Sir Alister Hardy Foundation for Ocean Science
c/o Plymouth Marine Laboratory
Prospect Place, The Hoe, Plymouth PL1 3DH, U.K.

Cat. No. Fs 97-6/1966E ISSN 0706-6457

Correct citation for this publication:
Myers, R. A., N. J. Barrowman, G. Mertz, J. Gamble, and H. G. Hunt. 1994. Analysis of Continuous Plankton Recorder Data in the Northwest Atlantic 1959–1992. Can. Tech. Rep. Fish. Aquat. Sci. 1966: iii + 246 p.

ABSTRACT

Myers, R. A., N. J. Barrowman, G. Mertz, J. Gamble, and H. G. Hunt. 1994. Analysis of Continuous Plankton Recorder Data in the Northwest Atlantic 1959–1992. Can. Tech. Rep. Fish. Aquat. Sci. 1966: iii + 246 p.

Data from the Continuous Plankton Recorder (CPR) surveys in the Northwest Atlantic were examined to determine seasonal cycles and long-term trends. This report provides maps of abundance by year, month, and species. In addition, sub-regions are defined and the data analyzed for the presence of seasonal cycles and interannual variability. Particular attention is paid to three plankton categories: Phytoplankton colour index, *Calanus* stages I-IV, and *Calanus* stages V-VI. The seasonal cycle and long term trends of each of the species that have been consistently processed are included. The decline in phytoplankton and zooplankton seen in the Northeast Atlantic from the 1950's to 1979 is seen throughout the region for most species.

RESUME

Myers, R. A., N. J. Barrowman, G. Mertz, J. Gamble, and H. G. Hunt. 1994. Analysis of Continuous Plankton Recorder Data in the Northwest Atlantic 1959–1992. Can. Tech. Rep. Fish. Aquat. Sci. 1966: iii + 246 p.

On a étudié les données des enquêtes "Continuous Plankton Recorder" (CPR) dans l'Atlantique nord-ouest pour déterminer les cycles saisonniers et les tendances à long-terme. On a groupé les cartes d'abondance par an, par mois, et par espèce. En plus, on a défini des sous-regions et analysé les données pour voir les cycles saisonniers et la variabilité entre années. On a étudie en particulier trois catégories de plancton: l'index de couleur de phytoplancton, les stages I-IV de *Calanus*, et les stages V-VI de *Calanus*. On a inclu le cycle saisonnier et les tendances à long-terme pour chaque espèce qui a été analysé régulièrement. On voit le déclin de phytoplancton et de zooplancton dans l'Atlantique nord-est des années cinquante à 1979 à travers cette région pour la plupart des espèces.

INTRODUCTION

The Continous Plankton Recorder (Hardy 1939), or CPR, is one of the most important methods for assessing long term biological changes in the ocean. The extensive data collected in the Northeast Atlantic have been analyzed in detail (Colebrook 1978, 1982, 1986). The purpose of this report is to examine the data from the Northwest Atlantic. We will determine if the long-term trends detected in the Northeast Atlantic are apparent in the Northwest.

Coverage of the Northwest Atlantic by the CPR began in 1959 and continued until 1986. Coverage was renewed in 1991 with one transect through the region approximately once a month. Although the coverage in the Northwest is not as extensive as it is in the Northeast, it still represents an enormous number of samples – over 17000 samples west of 40°, each of which represents approximately 3 cubic meters of water filtered (Jossi and Goulet, 1993). This should be sufficient to detect long-term changes.

Colebrook (1978) reported negative trends in the principal component scores for phytoplankton and zooplankton over the north-east Atlantic and the North sea until 1979, when the trend reversed. Jossi and Goulet (1993) reported positive trends for *Calanus finmarchicus* in the Gulf of Maine, but found no consistent trends in other copepod species.

The CPR has been used in long-term surveys in the North Atlantic since 1948 (Glover 1967). The recorder is towed by merchant ships and weather ships along a number of standard routes. It travels at a nominal standard depth of about 10 m; the true average depth is 6.7 ± 1.7 m (Hays and Warner, 1993). Water is sampled through an aperture and suspended organisms are then trapped in a slowly moving band of silk. A sample is obtained from a section of the silk representing 18.5 km (10 nautical miles; represents $3m^3$ of water filtered) of towing which is examined microscopically to identify and count the trapped organisms (Edinburgh, Oceanographic Laboratory, 1973).

In a description of standard CPR data processing, Colebrook (1975, pp.126,128) noted that

> Most organisms are identified at the level of species, some as varieties or sub-species, others at coarser levels such as genus or family; some of the counts are summed to produce estimates of, for example, total copepods, and total phytoplankton is estimated from the green colour of the collecting silks.

These groupings are referred to as taxa (singular: taxon) throughout this report.

DATA AND METHODS

The data analyzed in this report extend from 1959 to 1992. For several reasons, the sampling was uneven on both spatial and temporal scales. These reasons include the very nature of the CPR survey, variation in shipping routes, and funding difficulties. In particular, there was little sampling in the Northwest Atlantic during the period 1979-1990. Sampling also tended to be sparse during the winter months.

In other reports (e.g. Edinburgh, Oceanographic Laboratory, 1973), the CPR counts were transformed logarithmically [$y = \log_{10}(x + 1)$], and geometric means were used. However, because of the arbitrary addition of 1 in the above transformation, the transformed abundance does not scale with the true abundance. In this report we avoid this potential difficulty by using the un-transformed counts and arithmetic means.

Colebrook (1986) used principle component analysis to determine trends in abundance of a large number of species. We have not used such an exploratory analysis because our purpose is to test an *a priori* hypothesis: that the trends seen in species in the northwest Atlantic are also seen in the northeast Atlantic.

Although over 300 different taxa were tabulated in the CPR survey; we analyze only about 50 standard taxa. Many of the others are extremely rare and/or were tabulated irregularly. These standard taxa were taken (with some changes) from "A list of the species and other entities selected for routine annual data processing" (Table II, Colebrook 1975).

SEASONAL CYCLES

For a given taxon, let the the number of samples in year y and month m be n_{ym}, and let the i-th observed count be Y_{ymi}. The mean count in month m is denoted $\bar{Y}_m$. That is,

$$\bar{Y}_m = \frac{\sum_{yi} Y_{ymi}}{\sum_y n_{ym}}. \tag{1}$$

The set of monthly means $\{\bar{Y}_1, \ldots, \bar{Y}_{12}\}$ is refered to as the seasonal cycle.

LONG-TERM TRENDS

Long-term trends in abundance were analyzed using a weighted least-squares regression. For each taxon in each sub-region, anomalies were obtained by subtracting the seasonal cycle from the observed counts. Let the the number of samples in year y and month m be n_{ym}, and let the i-th observed count be Y_{ymi}. The corresponding anomaly A_{ymi} is given by

$$A_{ymi} = Y_{ymi} - \bar{Y}_m. \tag{2}$$

The mean anomaly for year y is then given by

$$\bar{A}_y = \frac{\sum_{mi} A_{ymi}}{\sum_m n_{ym}}. \tag{3}$$

To aid in the interpretation of these anomalies, they were standardized by dividing by their standard deviations, i.e.

$$S_y = \bar{A}_y / \mathrm{SD}(\bar{A}). \tag{4}$$

The standardized annual mean anomaly was modelled as a linear function of year,

$$S_y = \mu + \beta y + \varepsilon \tag{5}$$

where μ is the overall mean, β is the regression coefficient for year, and ε is a noise term; with weights given by the number of samples in each year, i.e.

$$w_y = \sum_m n_{ym}. \tag{6}$$

The sign of β gives the direction of long-term change in abundance, and the corresponding t-statistic gives the significance of the trend.

Weighted regressions as described above were performed for all of the standard taxa in all of the standard sub-regions for the range of years with the most concentrated sampling, 1959-1978 (Table 1).

To test the hypothesis that the long-term trend has been negative, one-sided p-values may be combined across k regions or taxa using Fisher's method (Fisher 1954).

Since the p-values from the regressions relate to the test of the null hypothesis that $\beta = 0$ versus the alternative hypothesis that $\beta \neq 0$ (i.e. a two-sided test), the p-values must first be transformed so as to represent the test with alternative hypothesis that $\beta < 0$ (i.e. a one-sided test). Therefore

$$p_{\text{one-sided}} = \begin{cases} \frac{1}{2} p_{\text{two-sided}} & \text{if } \beta < 0 \\ 1 - \frac{1}{2} p_{\text{two-sided}} & \text{if } \beta \geq 0 \end{cases} \tag{7}$$

The one-sided p-values may now be combined using Fisher's method (Fisher 1954). We compute

$$X^2 = -2 \sum \ln p \tag{8}$$

which has, as null distribution, χ^2 with $2k$ degrees of freedom. Thus a combined p-value is readily obtained.

GEOGRAPHICAL SUB-REGIONS DEFINED FOR THE ANALYSIS

Several geographical sub-regions were defined for the analysis presented here (Fig. 1). Sub-regions on the continental shelf were based on the divisions defined by the Northwest Atlantic Fisheries Organization (NAFO). However, unlike the NAFO divisions, the sub-regions were truncated so as not to extend beyond the shelf. Several offshore sub-regions were also defined; their extent and locations were determined in part by the density of sampling (Fig. 1).

RESULTS

CPR sampling of the Northwest Atlantic was uneven and often sparse (Fig. 1, Fig. 4). A number of regions were not sampled, in particular those outside of commercial shipping lanes. Sampling was most intense during the mid to late 1960's.

Observed seasonal cycles vary considerably between sub-regions and species (Fig. 2 and 5). Some cycles exhibit single peaks (e.g. *Thalassiosira* spp in sub-region 3K), while others show multiple peaks (e.g. *Thalassiosira* spp. in sub-region 3K, *Calanus* V-VI in sub-region 3Ps). The seasonal cycles of Phytoplankton colour index, *Calanus* stages I-IV, and *Calanus* stages V-VI vary considerably between regions (Fig. 4). There is also evidence of interannual variability (Fig. 5).

SEASONAL CYLES

Phytoplankton

The variability in the seasonal cycle of phytoplankton can be broken into three categories:

(1) A single sharp spring peak with a smaller fall peak. This is the most common pattern observed. (2) A single broad peak with a maximum in the spring. This pattern is seen in the tidally mixed 4X region. It is also seen in the tidal regions of the North Sea (Gieskes and Kraay 1977, Colebrook 1982a). (3) A strong double peak in which the fall peak is as large or larger than the spring peak. This is seen in 2J and 3K, and possibly in OS3 and 5Y.

The spring peak is nearly always dominated by diatoms, and the summer minimum and fall peak are usually dominated by dinoflagelates. An exception to this pattern is seen in the Northern shelf regions, 2J and 3K, where the fall peak appears to be composed mainly of diatoms. Note the strong fall bloom of the genus *Thalassiosirsa* in the northern shelf region, i.e. 2J and 3L.

LONG-TERM TRENDS

Phytoplankton

In this section we examine long term trends from 1959 to 1978. We will refer to recent changes in some cases.

Phytoplankton colour shows no long-term changes that are consistent

in all regions. OS3 shows a nominally significant increase (p=0.005). The colour index has been very high in the 90's in most regions.

When all diatoms are combined, i.e. individual diatom species counts are summed, there is a negative trend in most shelf regions. The combined significance test for a general decrease in diatoms for the shelf regions is very strong. There is virtually no trend in the offshore regions. The increase in ocean colour in OS3 is not reflected in the diatoms.

The diatom *Skeletonema costatum* shows a negative trend in all shelf regions except 3L. The trend is very significant overall when the shelf regions are combined.

The diatom *Thalassiosirsa* decreases in all regions with the exception of 4X; again the trend is significant when combined. There are a few years that appear to be exceptional, e.g. an increase in 1991 in 3L.

The diatom *Dactyliosolen mediterraneus* is generally too sparse to examine trends in most regions; however, there appears to be a general decrease in the offshelf regions.

Diatoms of the genus *Rhizosolenia* do not show any strong trends that are consistent in all regions. However, there is a general decrease.

Diatoms of the genus *Chaetoceros* generally show a decrease over the period in most regions, but with a return to average or above average conditions in recent years.

The diatoms *Thalassiothrix longissima*, *Thalassionema nitzchioides*, *Nitzschia seriata*, *Navicula planamembranacea* show negative trends overall.

Eight dinoflagelates of the genus *Ceratium* were consistently sampled. This genus is seen mainly during the summer and fall. There appear to be relatively few strong long term trends in these series although most of the

slopes are negative.

There are patterns that are not readily explainable. There was an increase in phytoplankton colour in OS3 from 1963 to 1973, and yet most of the individual plankton species for the region decreased during this period in OS3. It is unclear how to interpret this increase in colour. It may be that the increase is caused by species that are not normally identified in the CPR analysis.

Zooplankton

Total copepods show a negative trend in all of the shelf sub-regions except the northern sub-region 2J. There is also a strong negative trend in OS3. The negative trend in total copepods is caused by a decrease in the common genera of *Pseudocalanus, Paracalanus* and *Temora* . The copepod *Pseudocalanus elongatus* shows a negative trend in all regions except 2J; the trend is statistically significant in two regions. A similar trend is seen in the earier stages, the combined genus *Pseudocalanus* and *Paracalanus*, in which the two genera cannot be separated.

Temora longicornis has a significantly negative decrease overall, and separately in 3L, 3Ps, and 4V.

The copepod *Calanus finmarchicus* shows a negative trend in the northern regions, a slight positive trend in the south, and no major trends in between. None of these trends are statistically significant.

No consistent trends were seen in the copepods *Centropages typicus*, *Euchaeta norvegica*, *Metridia lucens*, and *Acartia.*

Species of the copepod genera, *Pleuromamma*, *Neocalanus*, *Rhinocalanus*, and *Candacia* appear to have decreased in each of the off shelf regions during the 1960's and 70's.

Euphausiacea appears to have declined in the north (2J, 3K, 3L, LS1) and shows no other consistent trends except perhaps an increase in 3N) during the 1979's.

The cladocean genera, *Podon* and *Evadne* decreased in most regions; however, these changes were small.

The amphipod family, *Hyperiidea*, the pelagic gastropod, *Clione limacina,* and *Chaetognatha*'s shows no long term trend that is consistent over a wide geographic region.

DISCUSSION

LONG TERM TRENDS

Many patterns of long-term variability in plankton are detectable across the North Atlantic. It appears that the plankton part of the ecosystem may be responding to large-scale changes in the environment. Diatoms have decreased in the North Sea and the northeast Atlantic from approximately the mid 1960's to the mid 1980's, with an increase in recent years (Reid et al. 1990). This basic pattern is also seen in the Northwest Atlantic where the major diatom species, e.g. *Thalassiosirsa* and *Chaetoceros*, have decreased.

The dinoflagelates of the genus *Ceratium* show little relationship with the patterns in the diatoms in the northeast Atlantic, and do not show the long-term decline. This is also consistent with our results for the northwest Atlantic.

Phytoplankton colour shows little evidence for long-term trends in the northeast Atlantic except for an increase in the southern North sea (Reid et al. 1990). This again is consistent with our results. We had little evidence of trends except for OS3, which is south of Flemish Cap. In the North Sea

the changing ratio of "colour" to diatoms is caused by a relative increase in phytoplankton groups that contribute to the colouration of the silk but are not recorded in the CPR analysis (e.g. microflagellates, small or fragile diatoms, Gieskes and Kraay 1977).

Colebrook has analyzed temporal trends in zooplankton in the Northeast Altantic and North Sea in a long series of papers (Colebrook 1986). In general, he finds a decrease until approximately 1980, and then an increase. Our analysis clearly shows that the decrease in total copepods in the North Sea and northeast Atlantic is also seen in the northwest Atlantic (Table 1). The total copepod count is dominated in most shelf regions by *Pseudocalanus* and *Paracalanus*. These species show the largest declines in both the Northwest and the Northeast (Colebrook 1982) of any copepod. Jossi and Goulet (1993) found no trend in Pseudocalanus for the Gulf of Maine and southern Nova Scotia shelf. In these southern regions (4X and 5Y) our trends were not statistically significant and appeared to have no trend in the overlapping period; thus, our results are not inconsistent with theirs.

The copepod *Calanus finmarchicus* shows strong negative trends in the North sea (Colebrook 1985), positive trends in the Gulf of Maine and southern Nova Scotia shelf Jossi and Goulet (1993). There was no consistent trend or significant trends in our study region.

The decline in total copepods is not seen for the copepod genus *Acartia* either in the North sea (Colebrook 1985) or the Northwest Atlantic.

Colebrook (1985) found a negative trend in the amphipod family, *Hyperiidea*, *Euphausiacea* and in the North Sea and Northwest Atlantic, whereas we find no significant trends in the Northwest Atlantic expect for a negative trends in the offshore region for *Euphausiacea* and a positive trend for *Euphausiacea* in 3NO and 3Ps, and a positive trend in 3Ps for *Chaetognaths*.

MECHANISMS

The mechanisms responsible for these trends are far from clear. The trends in the northeast Atlantic appear to be correlated with "westerly weather" over Britain (Colebrook 1986) or "North winds" (Dickson et al. 1988). Neither correlation is fully satisfactory. The relationship with westerly weather has high coherence only at low frequencies, where there are inherently few degrees of freedom. If the correlation is caused by a simple causal relationship we would expect the coherence to exist at all frequencies below the annual period. There has been no link with the observations of ocean structure that would allow us to reject any of the proposed mechanisms. Furthermore, neither explanation accounts for the observation that the CPR estimation of ocean colour, which is correlated with chlorophyl (Hays and Lindley 1994), has not decreased. Thus, any mechanism that explains the decline in diatoms must also explain why other phytoplankters have not declined.

For example, Dickson et al. (1988) suggested the main mechanism controlling plankton abundance is the degree of stratification that controls the timing of the spring bloom. This mechanism requires several "tight" linkages between weather, nutrients, diatoms, and zooplankton. First, windstress must control the degree of spring stratification. Second, the degree of spring stratification must control the spring bloom of diatoms. Third, the spring bloom of diatoms must control the production of several species of zooplankton.

The Colebrook (1986) theory offers a different hypothesis: that the diatom bloom is controlled by the zooplankton abundance. That is, Colebrook suggests a top-down control of the ecosystem as opposed to bottom-up control. He suggest that the key mechanism that controls zooplankton abundance is the survival of the overwintering population.

There are several questions that remain unanswered about the trends seen in the CPR data set. Mann (1993) has argued that the interannual variability in survival of young marine fish is controlled primarily through the food chain. If this is so, the long-term trends seen in the CPR data

should be reflected in fish production; however, no such firm links have yet been established (Brander 1992).

ACKNOWLEDGEMENTS

The data were provided by the Sir Alister Hardy Foundation for Ocean Science. We thank the Northern Cod Science program for financial assistance.

REFERENCES

Aebischer, N.J., Coulson, J.C. and Colebrook, J.M. 1990. Parallel long-term trends across four marine trophic levels and weather. Nature 347: 753-755.

Brander, K. 1992. A re-examination of the relationship between cod recruitment and Calanus finmarchicus in the North Sea. ICES mar. Sci. Symp., 195: 393-401.

CPR Survey Team, the. 1992. Continuous plankton records: the North Sea in the 1980s. - ICES mar. Sci. Symp., 195: 243-248.

Colebrook, J.M. 1960. Continuous plankton records: methods of analysis, 1950-59. Bull. Mar. Ecol., 5: 51-64.

Colebrook, J.M. and Robinson, G.A. 1965. Continuous plankton records: seasonal cycles of phytoplankton and copepods in the north-eastern Atlantic and North Sea. Bull. Mar. Ecol., 6: 123-139.

Colebrook, J.M. 1975. Continuous plankton recorder survey: Automatic data processing methods. Bulletin of Marine Ecology, 8: 123-142.

Colebrook, J.M. 1975. Continuous plankton recorder survey: computer simulation studies of some aspects of the design of the survey. Bull. mar. Ecol., 8: 143-166.

Colebrook, J.M. 1978. Continuous plankton records: Zooplankton and environments, North- East Atlantic and North Sea, 1948-1975. Oceanologica Acta, 1: 9-23.

Colebrook, J.M. 1982a. Continuous plankton recrods:seasonal variations in the distribution and abundance of plankton in the North Atlantic Ocean and the North Sea. J. Plank. Res. 4:435-462.

Colebrook, J.M. 1982b. Continuous plankton records: Phytoplankton, zooplankton and environment, North-East Atlantic and North Sea, 1958-1980. Oceanologica Acta, 5: 473-480.

Colebrook, J.M. 1986. Environmental influences on long-term variability in marine plankton. Hydrobiologia, 142: 309-325.

Colebrook, J.M., Reid, P.C., and Coombs, S.H. 1978. Continuous plankton records: a change in the plankton of the southern North Sea between 1970 and 1972. Mar. Bio., 45: 209-213.

Colebrook, J.M. and Taylor, A.H. 1984. Significant time scales of long-term variability in the plankton and the environment. Rapp, P-v. Reun. Cons. Int. Explor. Mer, 183: 20-26.

Cushing, D.H. 1984. The gadoid outburst in the North Sea. J. Cons. int. Explor. Mer, 41: 159-166.

Cushing, D.H. 1989. A difference in structure between ecosystems in strongly stratified waters and in those that are only weakly stratified. J. plank. Res., 11(1): 1-13.

Cushing, D.J. 1990. Plankton production and year-class strength in fish populations: an update of the match/mismatch hypothesis. Adv. Mar. Biol., 26: 249-293.

Dickson, R.R., Kelly, P.M., Colebrook, J.M., Wooster, W.S., and Cushing, D.H. 1988. North winds and production in the eastern North Atlantic. J. Plank. Res., 10: 151-169.

Dickson, R.R., Colebrook, J.M., and Svendsen, E. 1992. Recent changes in the summer plankton of the North Sea. ICES mar. Sci. Symp., 195: 232-242.

Edinburgh, Oceanographic Laboratory, 1973. Continuous Plankton Records: A Plankton Atlas of the North Atlantic and the North Sea. Hull Bull. mar. Ecol., 7, 1-174.

Fisher, R.A. 1954. Statistical Methods for Research Workers, 12th edition., Oliver and Boyd, Edingburgh. 356 pp.

Hardy, A. C. 1939. Ecological investigations with the Continuous Plankton Recorder: object, plan and methods. Hull Bull. mar. Ecol., 1, 1-57.

Hays, G. C. and J. A. Lindley. 1994. Estimating chlorophyll *a* abundance from the 'phytoplankton colour' recorded by the Continuous Plankton Recorder survey: validation with simultaneous flurometry. J. Plankton Research 16: 23-34.

Hays, G. G. and A. J. Warner. 1993. Consistency of towing speed and sampling depth for the Continuous Plankton Recorder. J. mar. biol. Ass. U.K., 73, 967-970.

Gieskes, W.W. and Kraay, G.W. 1977. Continuous plankton records: changes in the plankton of the North Sea and its eutrophic southern bight from 1948 to 1975. Neth. J. Sea Res., 11: 334-364.

Glover, R. S. 1967. The Continuous Plankton Recorder Survey of the north Atlantic. Symp. Zool. Soc. Lond., 19, 189-210.

Jossi, J.W., and Goulet, J.R. 1993. US north-east shelf ecosystem and adjacent regions differ from north-east Atlantic and North Sea - ICES J. mar. Sci., 50: 303-313.

Mann, K. H. 1993. Physical oceanography, food chains, and fish stocks: a review. ICES J. mar Sci. 50: 105-119.

Rae, K. M. 1952. Continuous Plankton Records: explanation and methods, 1946–1949. Hull Bull. mar. Ecol., 3, 135-155.

Reid, P.C. 1975. Large scale changes in North Sea phytoplankton. Nature, 257: 217-219.

Reid, P.C. 1977. Continuous plankton records: changes in the composition and abundance of the phytoplankton of the north-eastern Atlantic Ocean and North Sea, 1958-1974. Mar. Biol., 40: 337-339.

Reid, P.C. 1978. Continuous plankton records: large-scale changes in the abundance of phytoplankton in the North Sea from 1958 to 1973. Rapp. P.-v. Reun. Cons. Int. Explor. Mer, 172: 384-389.

Reid, P.C., Robinson, G.A. and Hunt, H.G. 1987. Spatial and temporal patterns of marine blooms in the Northeastern Atlantic and North Sea from the continuous plankton recorder survey. Rapp P.-v. Reun. Cons. Int. Explor. Mer, 187: 27-37.

Robinson, G.A. 1961. Continuous Plankton Records: contributions towards a plankton atlas of the north-eastern Atlantic and North Sea. Part I Phytoplankton. Bull. mar. Ecol., 42(V): 81-89 plus plates XV-XX.

Robinson, G.A. 1970. Continuous Plankton Records: variation in the seasonal cycle of phytoplankton in the North Atlantic. Bull. Mar. Ecol., 4: 333-345.

Robinson, G.A. and Hiby, A.R. 1978. The Continuous Plankton Recorder survey. In Sournia, A. (ed.), Phytoplankton Manual. UNESCO, Paris, pp. 59-63.

Robinson, G.A., Aiken, J. and Hunt, H.G. 1986. Synoptic surveys of the western English Channel. The relationships between plankton and hydrography. J. Mar. Biol. Assoc. UK, 66: 201-218.

Saetre, R., Aure, J., and Ljoen, R. 1988. Wind effects on the lateral extension of the Norwegian Coastal Water. Cont. Shelf Res., 8(3): 239-253.

Sherman, K., Green, J.R., Goulet, J.R., and Ejsymont, L. 1983. Coherence in zooplankton of a large Northeast Atlantic ecosystem. Fishery Bulletin, US, 81: 855-862.

Svendsen, E., and Magnusson, A.K. 1991. Climatic variability in the North Sea. ICES Variability Symp. Paper No. 10/Session 1.

Taylor, A.H., Colebrook, J.M., Stephens, J.A. and Baker, N.G. 1992. Latitudinal displacements of the Gulf Stream and the Abundance of plankton in the north-east Atlantic. J. Mar. Biol. Assoc. UK. 72: 919-921.

Taylor, A.H., Harbour, D.S., Harris, R.P., Burkhill, P.H. and Edwards, E.S. 1993. Seasons succession in the pelagic ecosystem of the North Atlantic and utilization of nitrogen. J. Plankton Res., 15: 875-891.

Tables

Table 1. Scaled slopes of weighted regressions of standardized annual mean anomaly versus year (1959-1978) by region and taxon. The slopes were scaled by a factor of 1000; thus a scaled slope gives the change in abundance in thousandth's of a standard deviation per year. (*significant that slope = 0 at $p < 0.1$; **significant that slope = 0 at $p < 0.05$; ***significant that slope = 0 at $p < 0.01$) Also: combined significance levels for the hypothesis that the slope is > 0 by taxon for shelf sub-regions (2J, 3K, 3L, 3NO, 3Ps, 4V, 4W, 4X, and 5Y), offshelf sub-regions (LS1, OS2, and OS3), and for all sub-regions. Note that the combined significance tests use one-sided p-values, whereas the individual significance tests are two-sided.

	2J	3K	3L	3NO	3Ps	4V	4W	4X	5Y	LS1	OS2	OS3	shelf	offshelf	all
Phytoplankton colour	-44	62*	10	38	-81	18	54	25	-17	24	15	233***	0.695	0.952	0.884
Skeletonema costatum	-40	-17	22	-8	-122*	-138**	-112**	-77	-21				0.001		0.001
Thalassiosira spp.	-103**	-25	-77*	-33	-129**	-4	-2	7	-97	-62	-24	-46	0.001	0.151	0.001
Dactyliosolen mediterraneus			29		-120*						-80	-144	0.091	0.037	0.020
Rhizosolenia imbrica. shrubsolei			47										0.892		0.892
Rhizosolenia styliformis	-25	27	-7	-58	-68	-2		-67		-21	47	-30	0.208	0.611	0.317
Rhizosolenia hebetata semispina	-19	83	56	115*	17	-89	-108	11	-52	35	1	42	0.429	0.842	0.631
Rhizosolenia alata alata	-52	55	-99*	-31	-33			-98		29		-209**	0.037	0.089	0.017
Rhizosolenia alata inermis	-77**		-38							5		110	0.034	0.811	0.150
Chaetoceros(Hyalochaete) spp.	-94**	-19	13	-18	-156***	-110*	-139*	-109*	-138*	-20	-2	62	0.000	0.636	0.000
Chaetoceros(Phaeoceros) spp.	-2	66	61	-37	-145***	-22	19	-16	-106	40	22	47	0.067	0.926	0.198
Thalassiothrix longissima	-43	7	2	85	-88*	-89	-127*	-70	-107	-24	49	82	0.006	0.801	0.024
Thalassionema nitzschioides	-9	33	-64	-93	-131**	-131***	-80	-12	-151**	-54	-98**	25	0.000	0.067	0.000
Nitzschia seriata	-81*	-70**	-55	94	-31	-120**	-155**	-152*		-111*		-39	0.000	0.072	0.000
Nitzschia delicatissima	-89	-109*	11	45	-52			-206***		52	-24	-175*	0.002	0.123	0.001
Navicula planamembranacea	-88		-146**							52	39		0.005	0.959	0.048
Diatoms	-107***	-15	-17	11	-145***	-57	-45	-32	-122*	-13	6	7	0.000	0.624	0.001
Ceratium fusus	41	66*	-76	-5	19	-60	-14	-58	-39	-34	65	21	0.401	0.659	0.521
Ceratium furca					18	61		-65					0.556		0.556
Ceratium lineatum								-84	18			-124	0.240	0.116	0.133
Ceratium tripos	40		-13	15	-34	52	75	-24	-78		-20	-95	0.705	0.204	0.556
Ceratium macroceros			11				4	112*				6	0.874	0.522	0.879
Ceratium horridum			15	10	-16	-84	39	-57				-136	0.395	0.106	0.249
Ceratium longipes	26	-10	-79*	-74	-22	-44	-43	-99	29		-23	-71	0.085	0.294	0.084
Ceratium arcticum	-27	-118**	-50	-28	-3	33	-75	94		-55	80*	109	0.115	0.719	0.225
Ceratia	-5	-93*	-96**	-18	-28	-17	35	-41	-41	-51	47	-41	0.082	0.472	0.117
Total Copepods	42	-10	-102**	-131	-129**	-95	-69	-61	-66	45	43	-216**	0.001	0.134	0.000
Calanus fin. finmarchicus	-32	-25	-39	-42	84	61	17	86	2	-20	-31	56	0.746	0.440	0.720
Calanus helgolandicus												-12		0.460	0.460
Calanus fin. glacialis	-51	104	-21	-169	-10	26	61	11	-120	32	6	90	0.228	0.892	0.440
Calanus I-IV	52	-4	-58	-57	-31	74	-34	-83	-70	56	43	-202*	0.108	0.260	0.097
Calanus V-VI Total	-33	-25	-34	-42	84	62	17	86	1	-20	-29	59	0.762	0.460	0.743
Neocalanus gracilis												-96		0.153	0.153
Rhincalanus nasutus												-78		0.193	0.193
Pseudocalanus elongatus Adult	25	-76	-45	-150**	-114**	-89	-96*	-96	-55			-179**	0.000	0.021	0.000
Para-pseudocalanus spp.	95**	39	-42	-140*	-115**	-59	-63	-107*	-83	6	-4	-158	0.004	0.240	0.005
Temora longicornis		38	-88**	-43	-170***	-108**	-91	-107*	51			26	0.000	0.591	0.000
Acartia spp.	12	-8	11	-3	0	16	-42	103	2	37	-13	-8	0.853	0.708	0.900
Centropages typicus			-2	-54	-9	78*	92*	102	-23			-22	0.902	0.423	0.893
Euchaeta norvegica	-30	55	14	51	-8	-63		8	10	-91*	-29	22	0.755	0.099	0.430
Metridia lucens	19	77	18	68	87	-59	94	33	-50	37	-58	103	0.941	0.435	0.902
Pleuromamma robusta											-93**	-55		0.041	0.041
Pleuromamma borealis											-90**	-123		0.013	0.013
Pleuromamma gracilis												-1		0.496	0.496
Candacia armata								-100				-116	0.072	0.101	0.043
Podon spp.			-21	-108	-110*	32	-33	42	42				0.187		0.187
Evadne spp.			-76**	-77	-148**	-49	-44	-56	-34			-48	0.003	0.336	0.004
Clione limacina	38	2	-11	59	83	-79		-125*		0	-34	116	0.408	0.594	0.510
Hyperiidea	13	34	47	-65	107*	-32	-17	-122*	-68	-6	-50	86	0.373	0.321	0.338
Euphausiacea Total	-40	41	42	208**	167***	-8	-38	-17	107	-141***	-46	91	0.927	0.001	0.135
Chaetognatha Eyecount	17	-10	80	109	140**	2	-69	-102*	-40	-23	-48	33	0.466	0.223	0.350

Table 2. Scaled means of seasonal cycles by region and taxon. The means were scaled by a factor of 1000; a scaled mean gives the average number of organisms sampled from approximately 3000 m^3 of water.

	2J	3K	3L	3NO	3Ps	4V	4W	4X	5Y	LS1	OS2	OS3
Phytoplankton colour	762	440	958	1005	756	571	652	419	157	164	310	468
Paralia sulcata	11	9	4	0	7	7	4	8	0	0	0	0
Skeletonema costatum	58	97	146	79	169	202	166	67	95	0	3	12
Thalassiosira spp.	6076	2256	4750	2861	2463	3013	2609	1356	478	1001	1056	1536
Dactyliosolen antarcticus	1	5	3	0	3	0	0	0	0	0	0	1
Dactyliosolen mediterraneus	4	9	14	6	74	11	0	3	4	10	22	48
Rhizosolenia imbrica. shrubsolei	4	4	6	18	39	12	8	16	15	3	3	16
Rhizosolenia styliformis	342	177	107	97	73	37	43	23	6	227	318	138
Rhizosolenia hebetata semispina	330	139	186	386	466	305	300	144	119	375	185	139
Rhizosolenia alata indica	19	1	6	9	13	7	0	0	0	10	0	11
Rhizosolenia alata alata	43	19	12	73	59	36	27	42	95	12	10	73
Rhizosolenia alata inermis	25	11	12	13	21	30	16	8	17	14	13	19
Chaetoceros(Hyalochaete) spp.	1961	993	1853	1791	1754	1119	832	609	106	263	308	569
Chaetoceros(Phaeoceros) spp.	2921	1344	2676	2378	1639	903	785	432	176	534	967	552
Thalassiothrix longissima	538	815	1918	3204	1041	404	165	34	82	388	761	451
Thalassionema nitzschioides	214	240	410	476	470	617	633	368	146	223	152	80
Nitzschia seriata	179	192	61	64	233	122	64	68	110	34	21	35
Nitzschia delicatissima	98	55	38	83	115	17	25	34	48	124	78	108
Navicula planamembranacea	15	16	13	4	9	14	0	0	3	128	58	10
Diatoms	12557	6161	11776	11209	8390	6751	5433	3097	1490	3295	3864	3733
Ceratium fusus	47	67	940	806	1089	858	867	556	624	22	81	634
Ceratium furca	6	3	6	17	28	23	20	21	14	0	9	12
Ceratium lineatum	1	0	9	79	62	5	7	28	31	1	5	56
Ceratium tripos	8	11	85	346	717	617	683	777	322	3	19	92
Ceratium macroceros	1	3	8	26	19	27	58	176	17	2	0	151
Ceratium horridum	8	9	41	51	71	24	48	52	21	0	3	18
Ceratium longipes	178	168	958	978	1074	791	1044	931	272	11	68	106
Ceratium arcticum	980	1572	1566	331	386	270	139	93	33	61	81	51
Ceratia	1024	1525	3059	2352	2961	2220	2420	2253	1199	97	252	992
Total Copepods	352714	267903	451115	353429	372299	358540	480660	474432	568879	285923	271251	202643
Calanus fin. finmarchicus	45624	37336	22248	12280	8470	15588	15911	24030	43721	83768	46289	17153
Calanus helgolandicus	0	0	3	2	1	3	15	7	2	0	12	1175
Calanus fin. glacialis	708	995	440	73	24	120	40	76	58	229	53	55
Calanus I-IV	218515	152832	145810	72097	42512	73256	103437	108938	223199	109934	141323	87673
Calanus V-VI Total	48492	37794	22372	12300	8468	15628	16032	24055	43834	83838	46530	18299
Neocalanus gracilis	0	0	4	0	0	0	0	0	0	0	1	85
Rhincalanus nasutus	0	0	1	0	0	0	0	1	0	0	0	52
Pseudocalanus elongatus Adult	3658	3896	42488	35419	48065	51420	73411	66652	31098	41	329	1897
Para-pseudocalanus spp.	27298	21746	127492	120341	137659	133232	174917	188386	120134	1929	8774	26712
Temora longicornis	35	1905	64229	94800	86293	87162	94714	31783	6776	155	0	1535
Acartia spp.	2951	2371	7172	3095	4249	4967	4607	4777	14418	397	620	2295
Centropages typicus	98	46	608	16528	3195	15900	47868	94698	135642	0	40	588
Oithona spp.	40331	32890	78944	43458	77738	39282	46276	35605	33303	9275	21345	23573
Euchaeta norvegica	769	333	119	121	75	180	14	41	610	2037	1431	638
Metridia lucens	44	58	63	68	311	396	1367	2226	2966	78	469	921
Pleuromamma robusta	2	1	3	5	1	2	15	3	3	16	48	205
Pleuromamma borealis	0	0	17	18	0	0	1	11	3	12	80	3395
Pleuromamma gracilis	0	0	3	0	0	0	0	1	0	1	2	414
Candacia armata	0	0	0	19	1	4	5	79	4	0	4	136
Podon spp.	0	0	2095	4594	3631	1623	3712	3221	1424	58	186	485
Evadne spp.	32	0	19078	20129	26958	10224	11223	10289	12332	38	159	1173
Clione limacina	80	45	75	67	62	23	60	27	14	61	51	18
Hyperiidea	3203	3511	1553	1563	317	502	438	457	273	2742	3202	1448
Euphausiacea Total	3750	2067	3341	3064	2052	2083	4943	5150	2611	14430	13143	4553
Chaetognatha Eyecount	199	251	620	1690	836	460	1209	1253	79	590	933	2174

Figures

Figure 1. Sub-regions used in the analysis. The sub-regions on the continental shelf are named after the corresponding NAFO divisions; note, however, that unlike the NAFO regions, they do not extend beyond the shelf. Three "offshelf" sub-regions were also defined: LS1 (Labrador Sea), OS2 (Offshelf 2), and OS3 (Offshelf 3). Overplotted are locations of CPR samples in the Northwest Atlantic from 1959 to 1992. Each dot represents the centre of a 10-mile tow section. Note the concentrated sampling along standard routes.

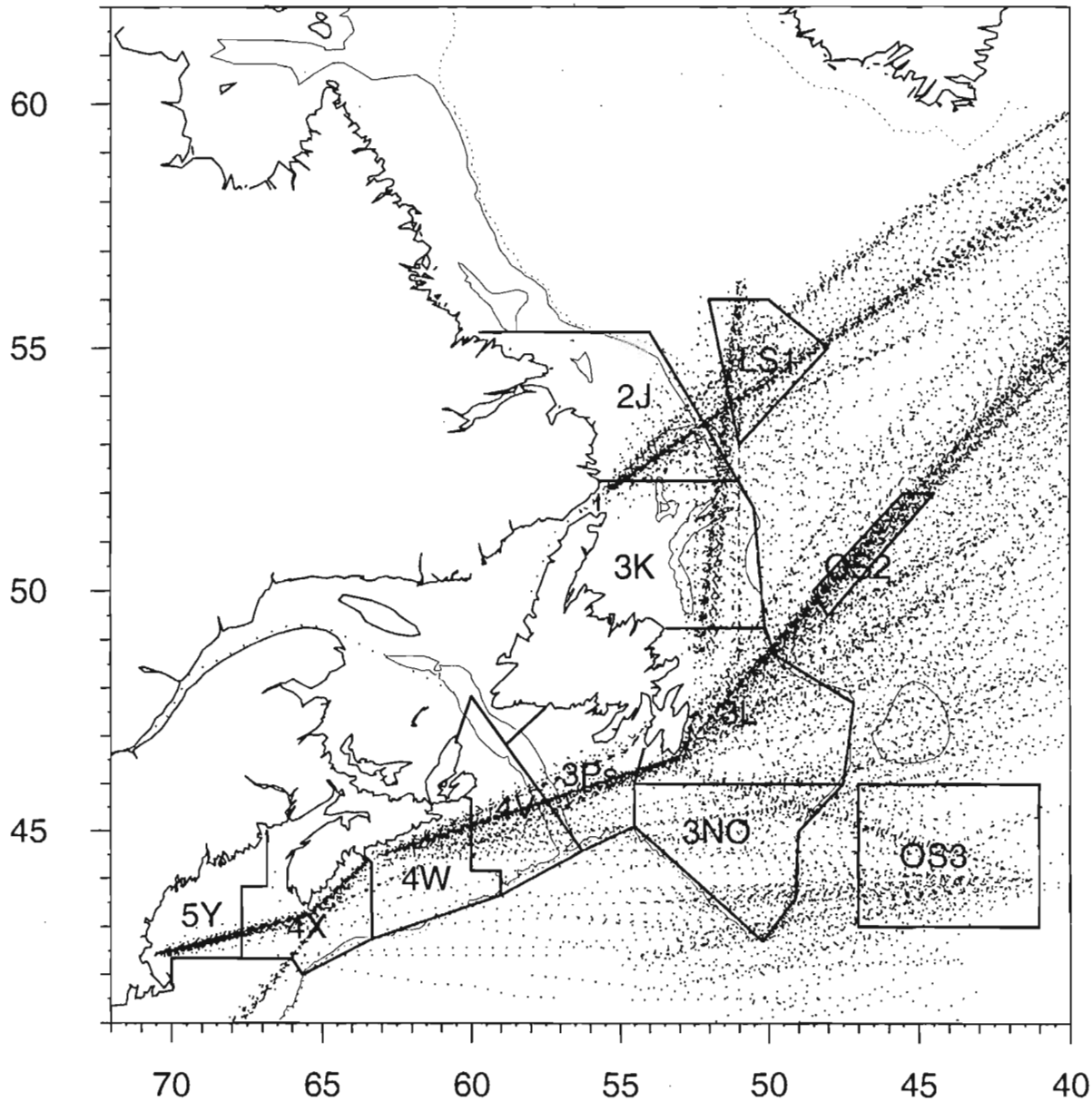
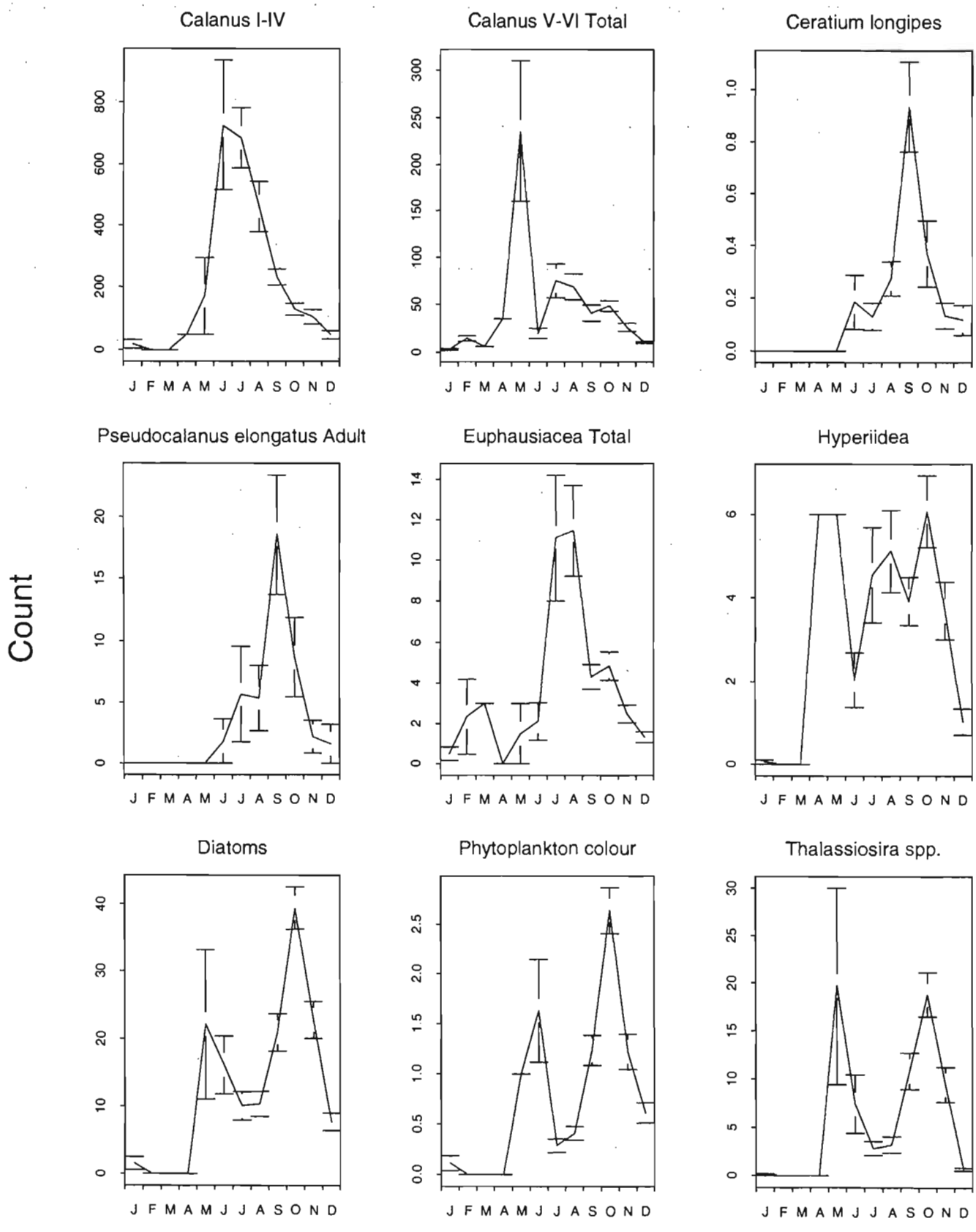
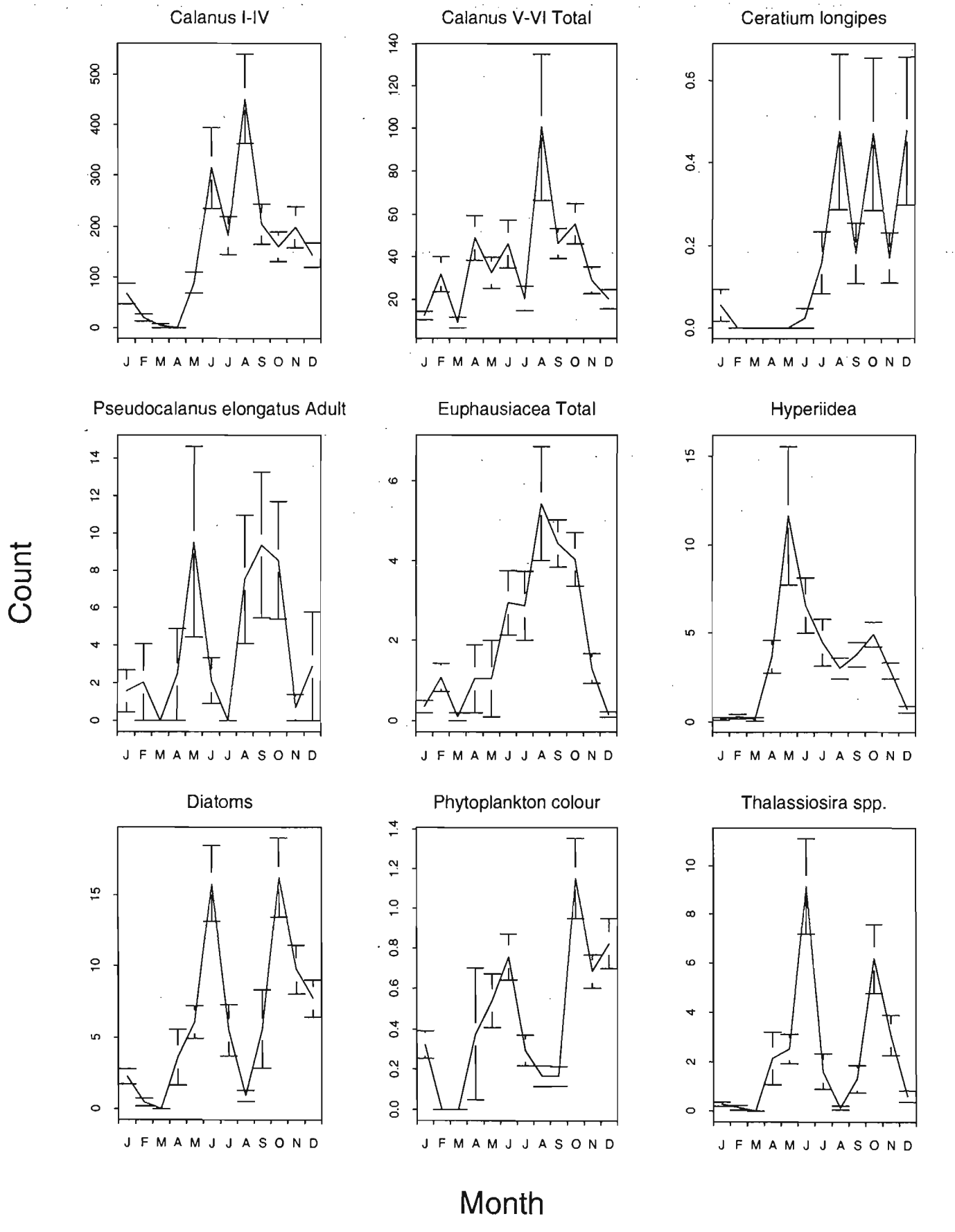

60
55
50
45
70
65
60
55
50
45
40
2J
3K
3L
3Ps
3NO
4W
4X
5Y
OS1
OS2
OS3

Figure 2. Seasonal cycles (over all years) for selected taxa in each subregion. Each figure consists of 9 panels, each of which represents a particular taxon; the name of the taxon is given above the panel. In each panel, monthly means are connected by a solid line. The standard error of each mean is represented by pointwise error bars.

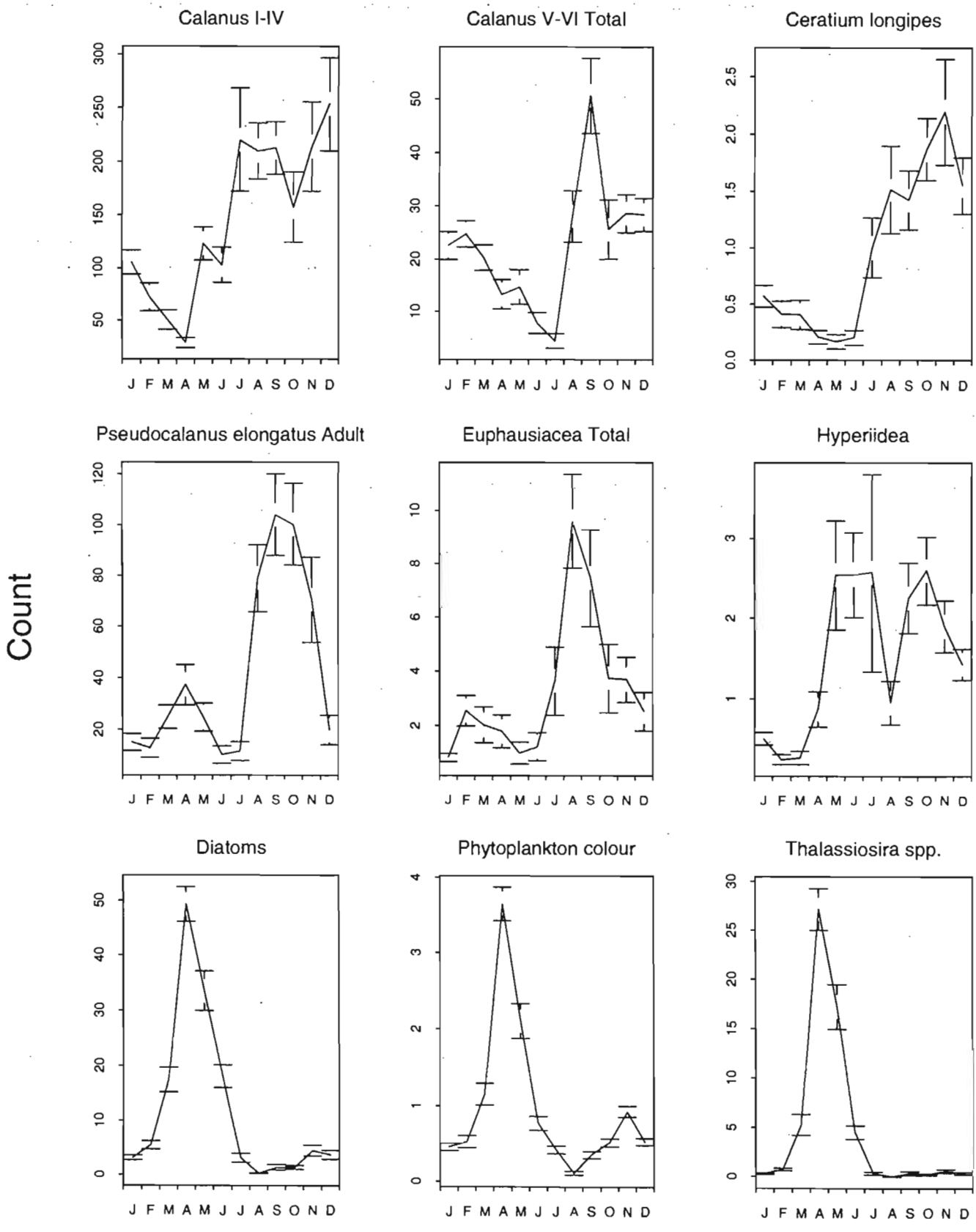
2J


Calanus I-IV
Calanus V-VI Total
Ceratium longipes
Pseudocalanus elongatus Adult
Euphausiacea Total
Hyperiidea
Diatoms
Phytoplankton colour
Thalassiosira spp.
Count
Month
J F M A M J J A S O N D

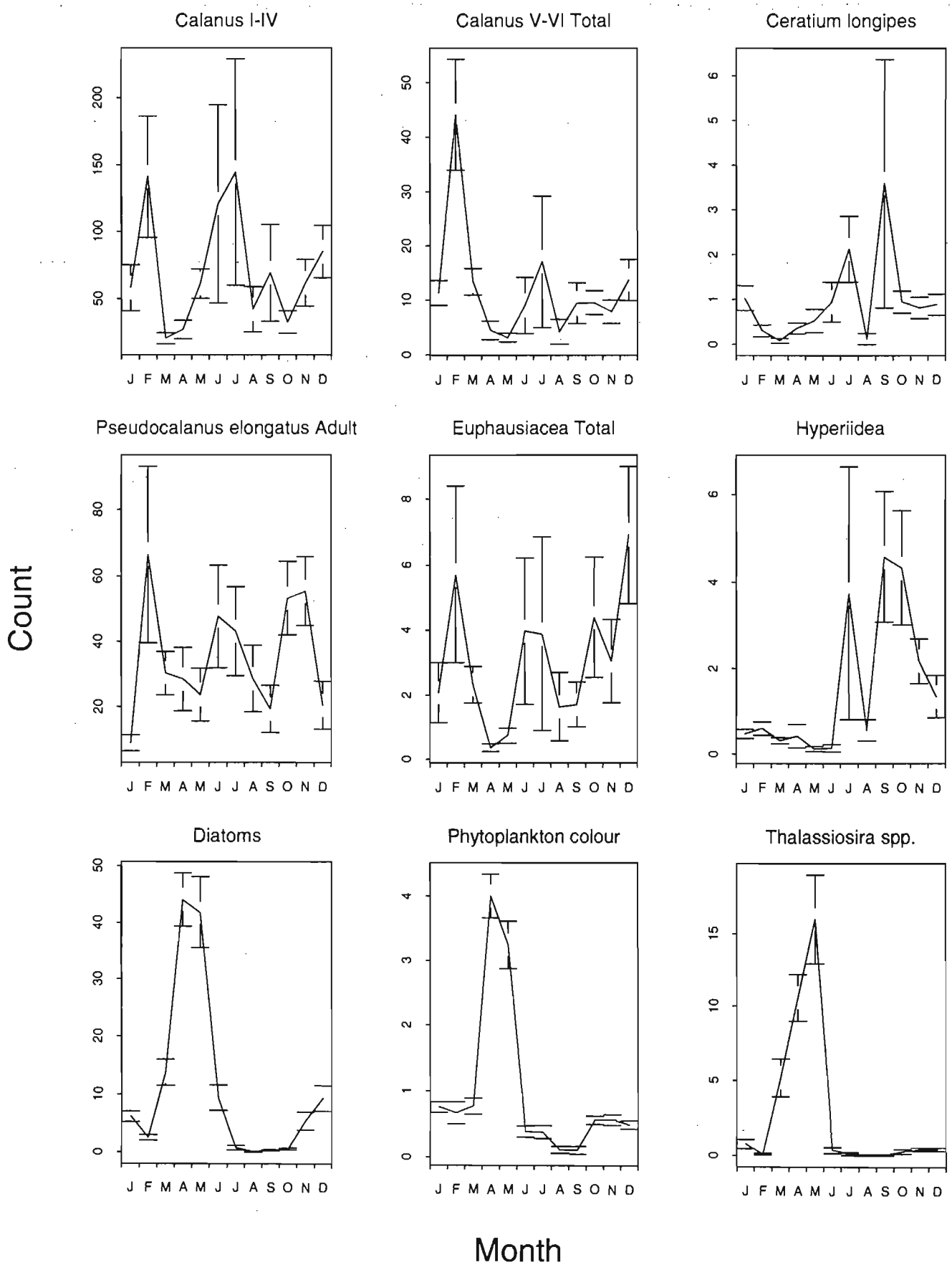
3K


Calanus I-IV
Calanus V-VI Total
Ceratium longipes
Pseudocalanus elongatus Adult
Euphausiacea Total
Hyperiidea
Diatoms
Phytoplankton colour
Thalassiosira spp.
Count
Month
J F M A M J J A S O N D

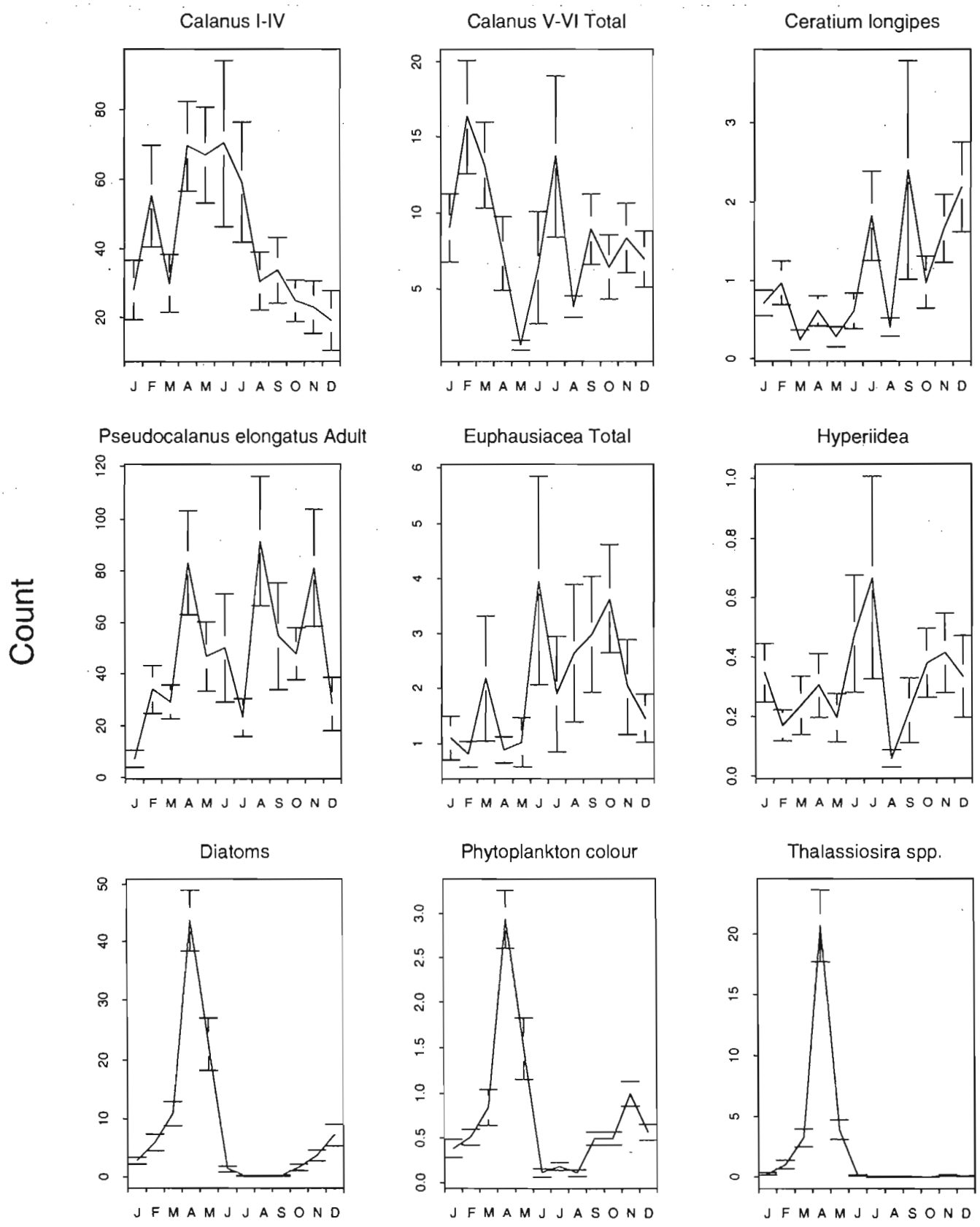
3L


Calanus I-IV
Calanus V-VI Total
Ceratium longipes
Pseudocalanus elongatus Adult
Euphausiacea Total
Hyperiidea
Diatoms
Phytoplankton colour
Thalassiosira spp.
Count
J F M A M J J A S O N D
Month

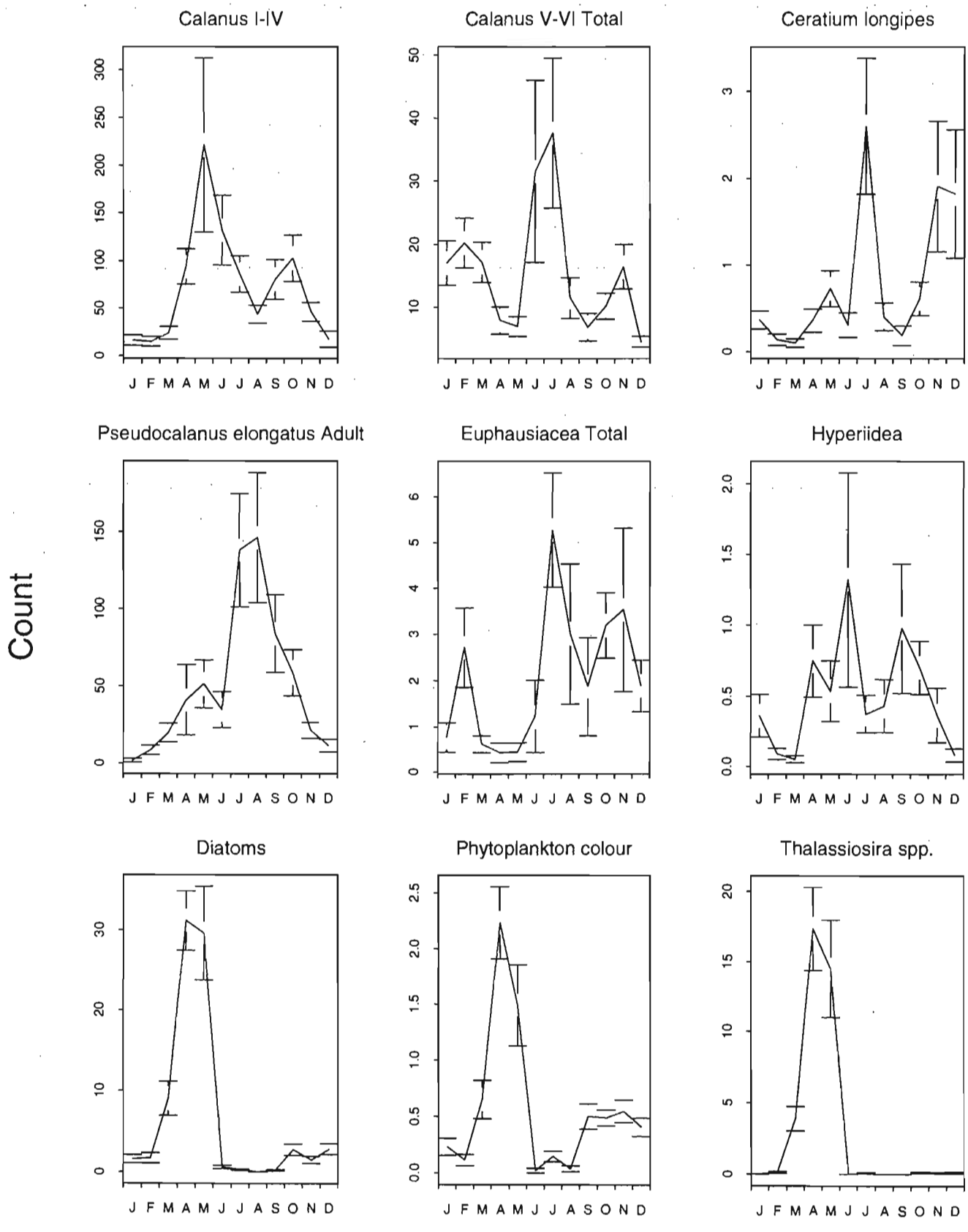
3NO


Calanus I-IV
Calanus V-VI Total
Ceratium longipes
Pseudocalanus elongatus Adult
Euphausiacea Total
Hyperiidea
Diatoms
Phytoplankton colour
Thalassiosira spp.
Count
J F M A M J J A S O N D
Month

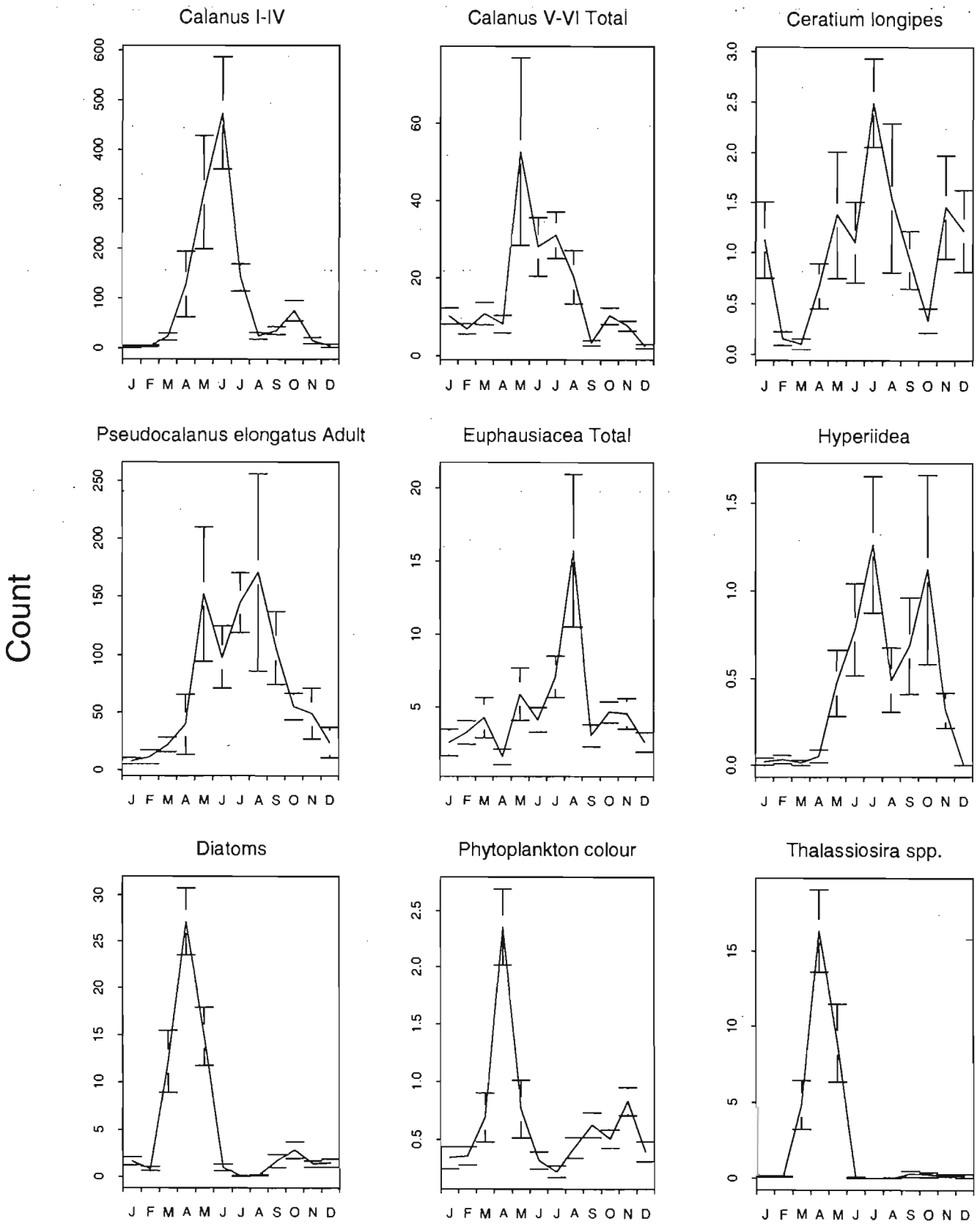
3Ps


Calanus I-IV
Calanus V-VI Total
Ceratium longipes
Pseudocalanus elongatus Adult
Euphausiacea Total
Hyperiidea
Diatoms
Phytoplankton colour
Thalassiosira spp.
Count
Month
J F M A M J J A S O N D

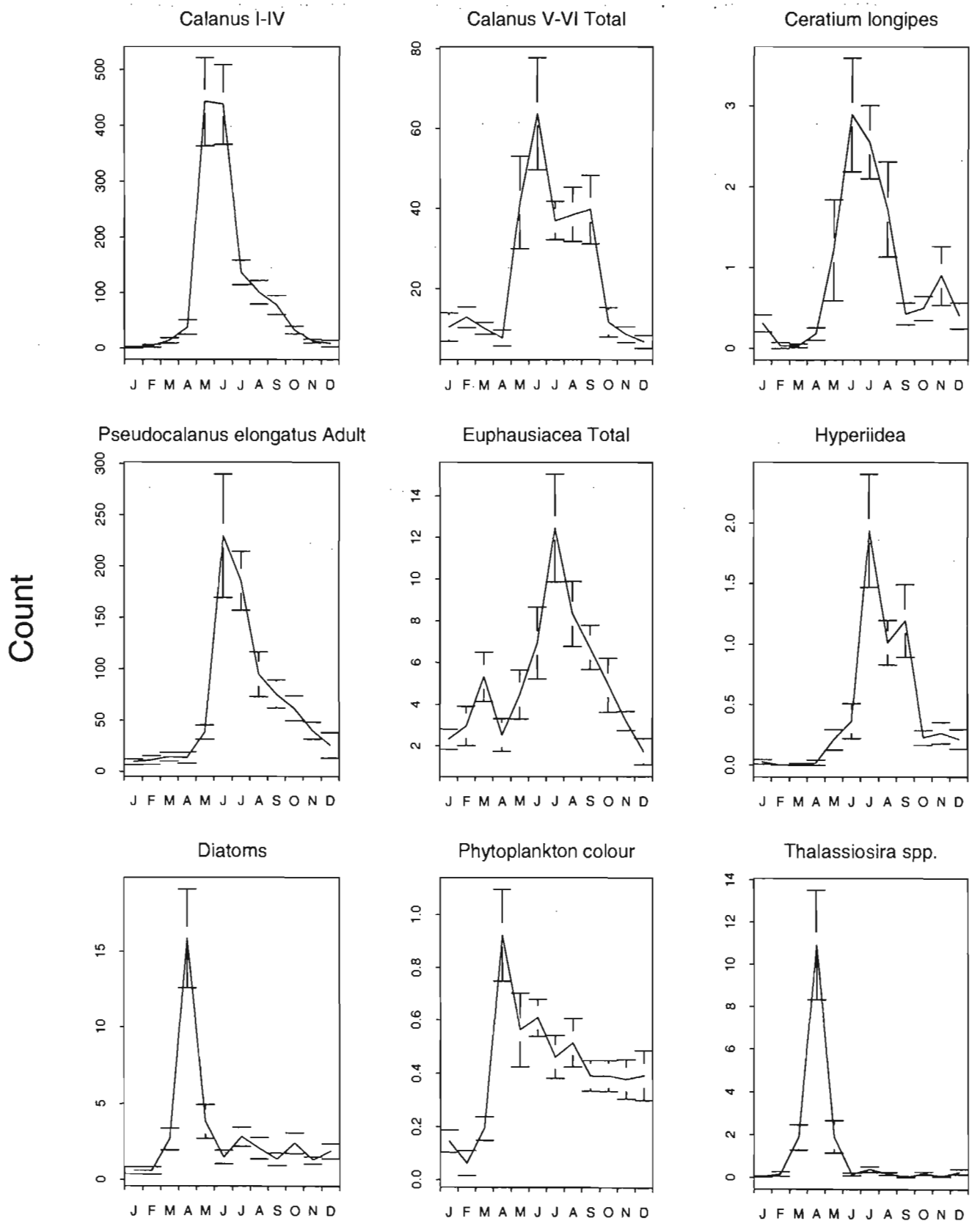
4V


Calanus I-IV
Calanus V-VI Total
Ceratium longipes
Pseudocalanus elongatus Adult
Euphausiacea Total
Hyperiidea
Diatoms
Phytoplankton colour
Thalassiosira spp.
Count
J F M A M J J A S O N D
Month

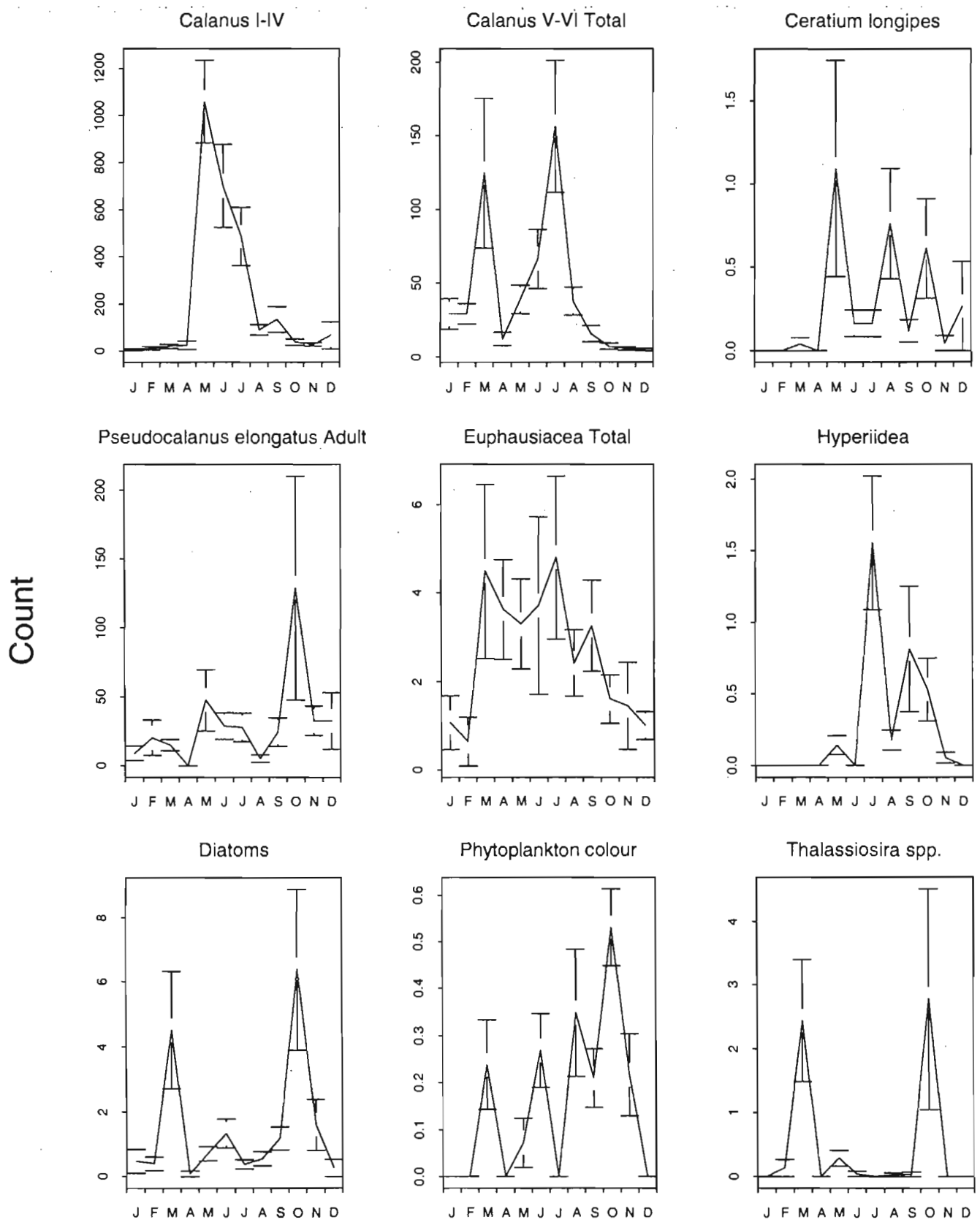
4W


Calanus I-IV
Calanus V-VI Total
Ceratium longipes
Pseudocalanus elongatus Adult
Euphausiacea Total
Hyperiidea
Diatoms
Phytoplankton colour
Thalassiosira spp.
Count
J F M A M J J A S O N D
Month

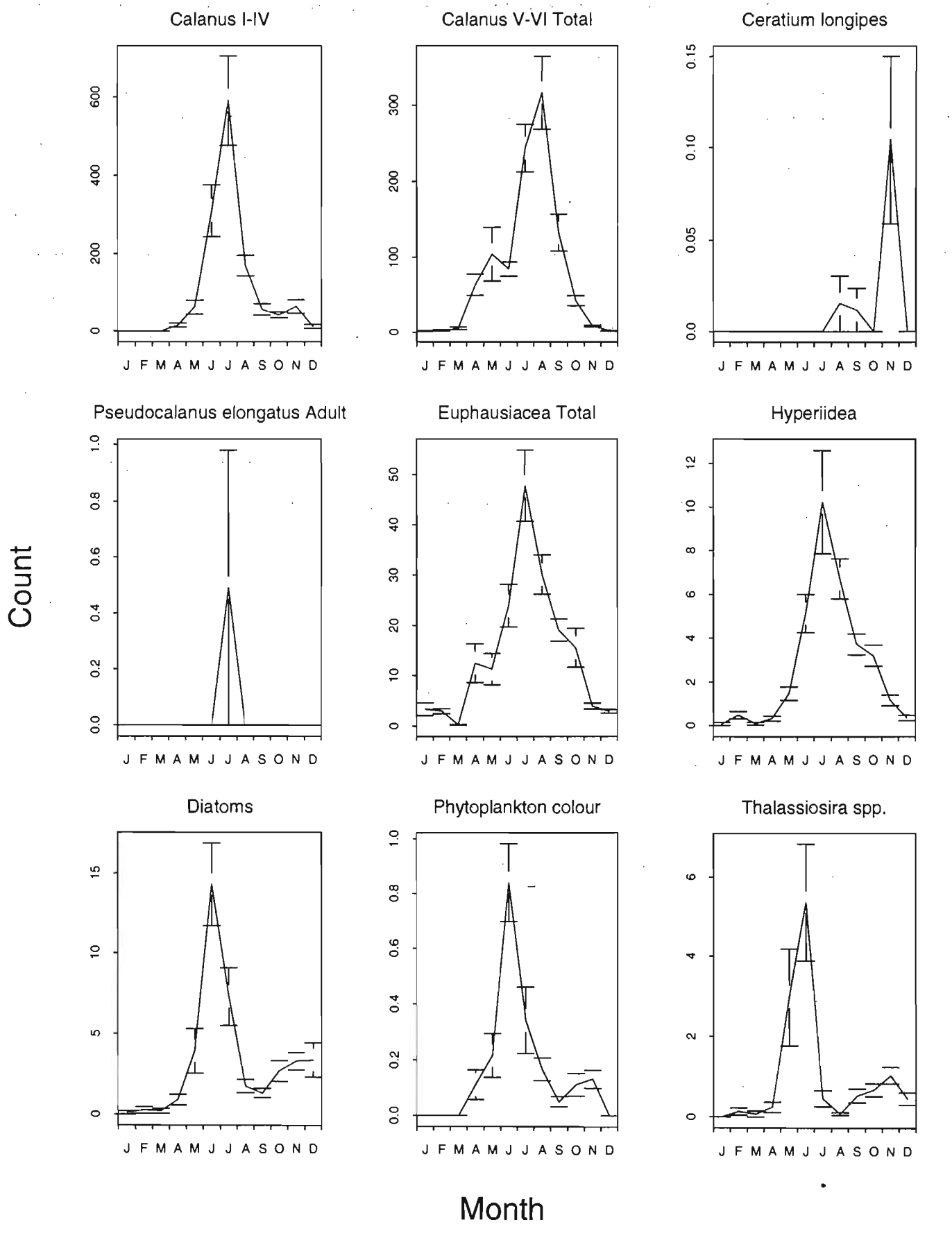
4X


Calanus I-IV
Calanus V-VI Total
Ceratium longipes
Pseudocalanus elongatus Adult
Euphausiacea Total
Hyperiidea
Diatoms
Phytoplankton colour
Thalassiosira spp.
Count
J F M A M J J A S O N D
Month

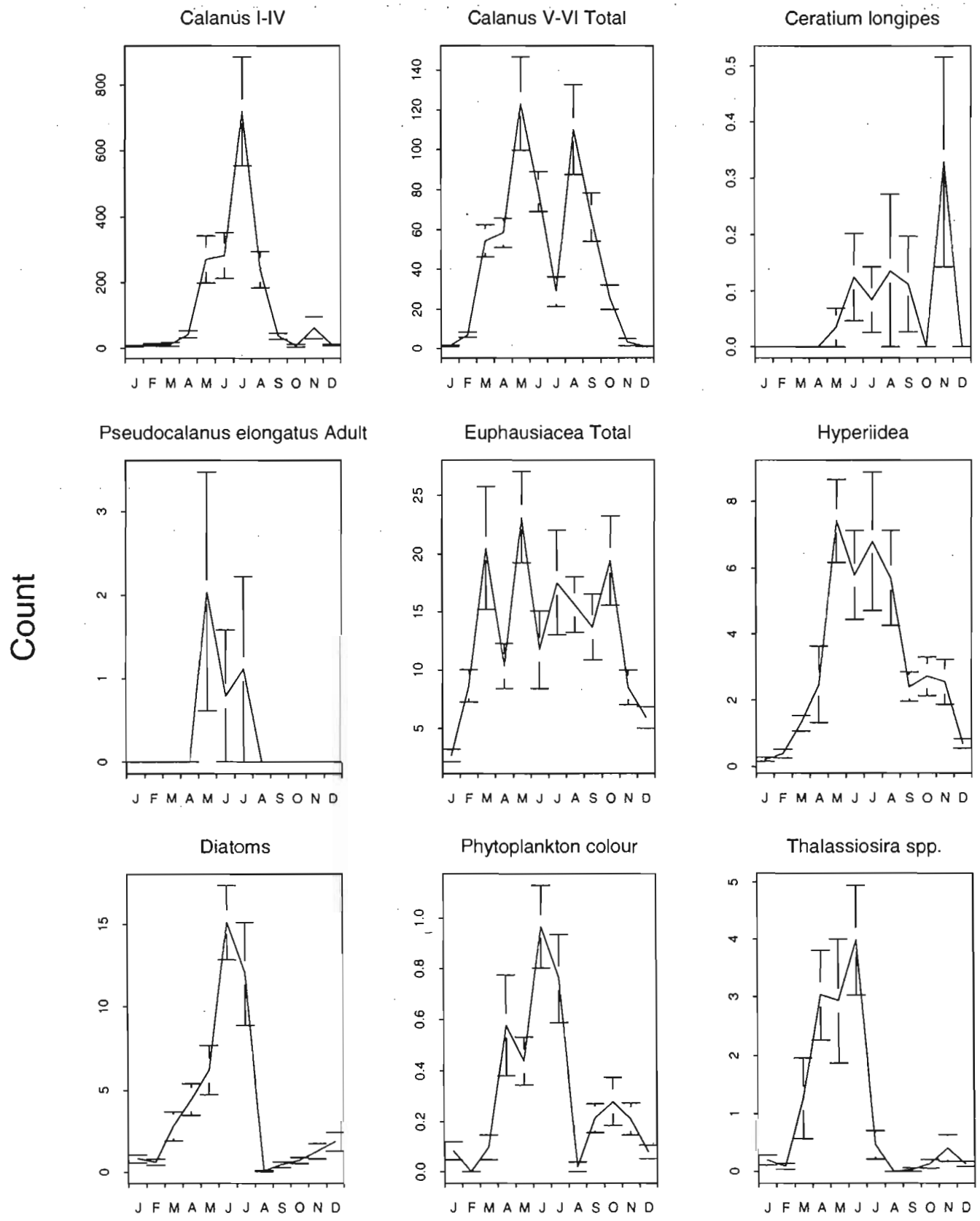
5Y


Calanus I-IV
Calanus V-VI Total
Ceratium longipes
Pseudocalanus elongatus Adult
Euphausiacea Total
Hyperiidea
Diatoms
Phytoplankton colour
Thalassiosira spp.
Count
J F M A M J J A S O N D
Month

LS1


Calanus I-IV
Calanus V-VI Total
Ceratium longipes
Pseudocalanus elongatus Adult
Euphausiacea Total
Hyperiidea
Diatoms
Phytoplankton colour
Thalassiosira spp.
Count
Month
J F M A M J J A S O N D

OS2


Calanus I-IV
Calanus V-VI Total
Ceratium longipes
Pseudocalanus elongatus Adult
Euphausiacea Total
Hyperiidea
Diatoms
Phytoplankton colour
Thalassiosira spp.
Count
Month
J F M A M J J A S O N D

OS3

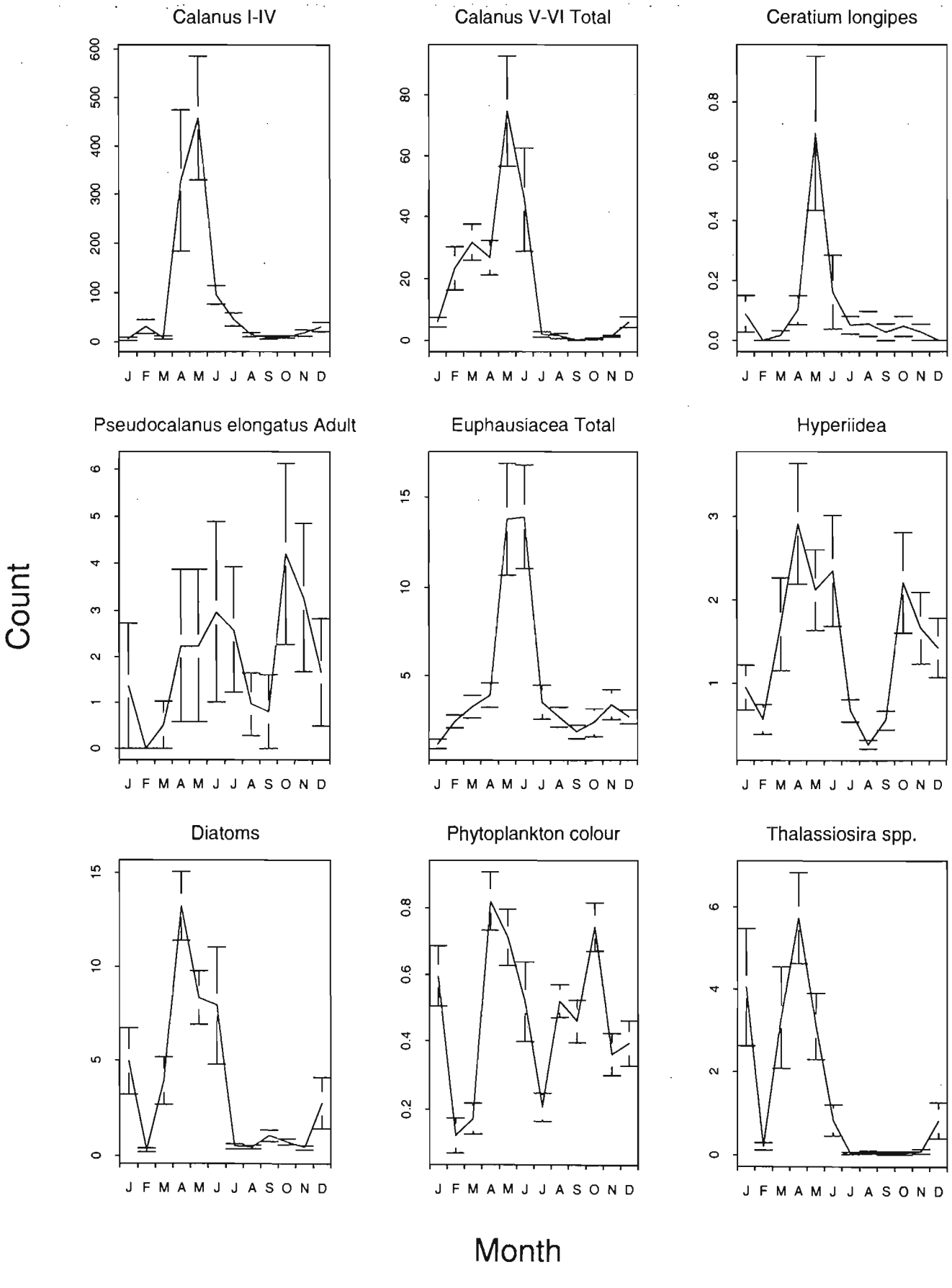
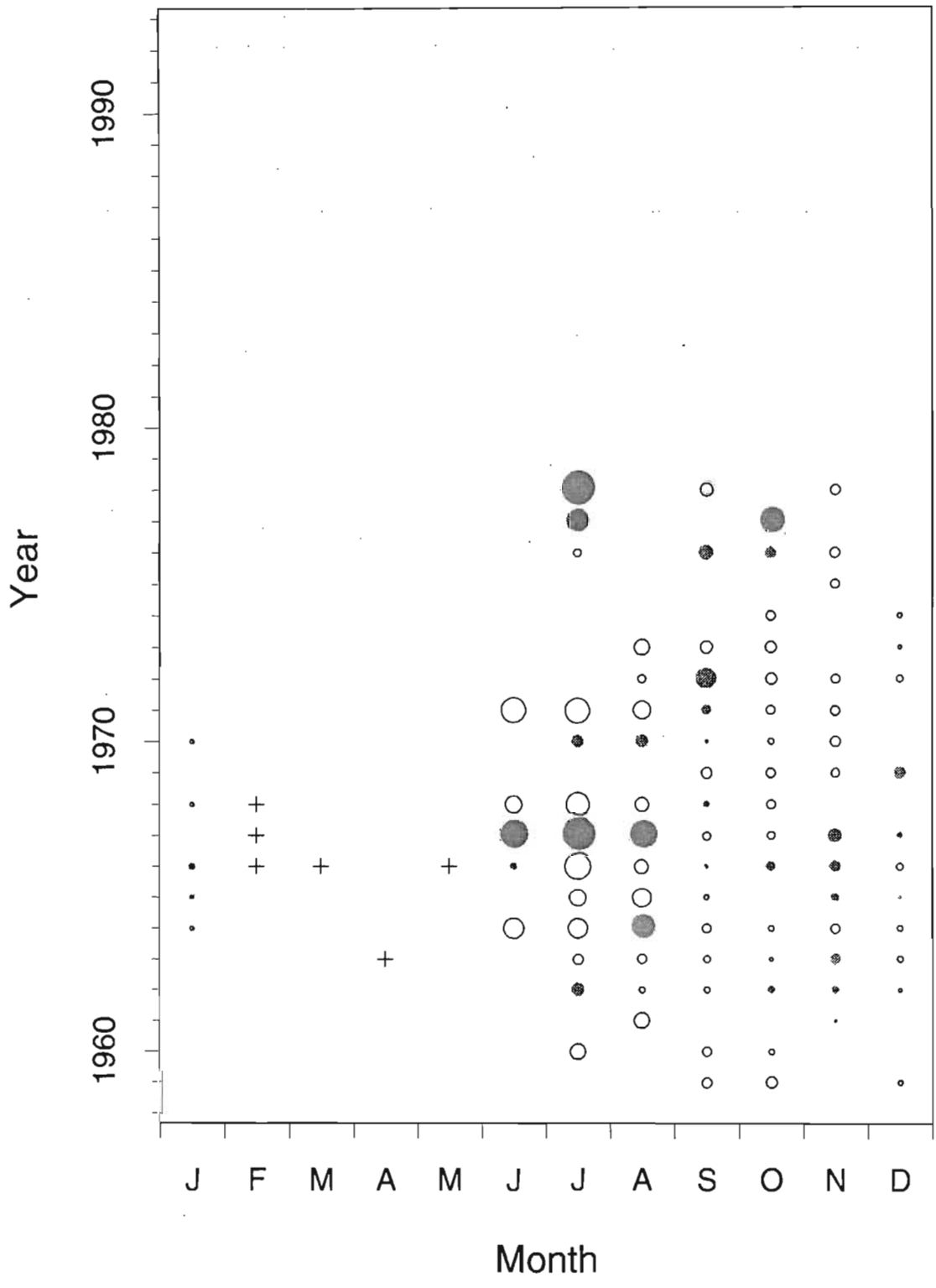

Calanus I-IV
Calanus V-VI Total
Ceratium longipes
Pseudocalanus elongatus Adult
Euphausiacea Total
Hyperiidea
Diatoms
Phytoplankton colour
Thalassiosira spp.
Count
Month
J F M A M J J A S O N D

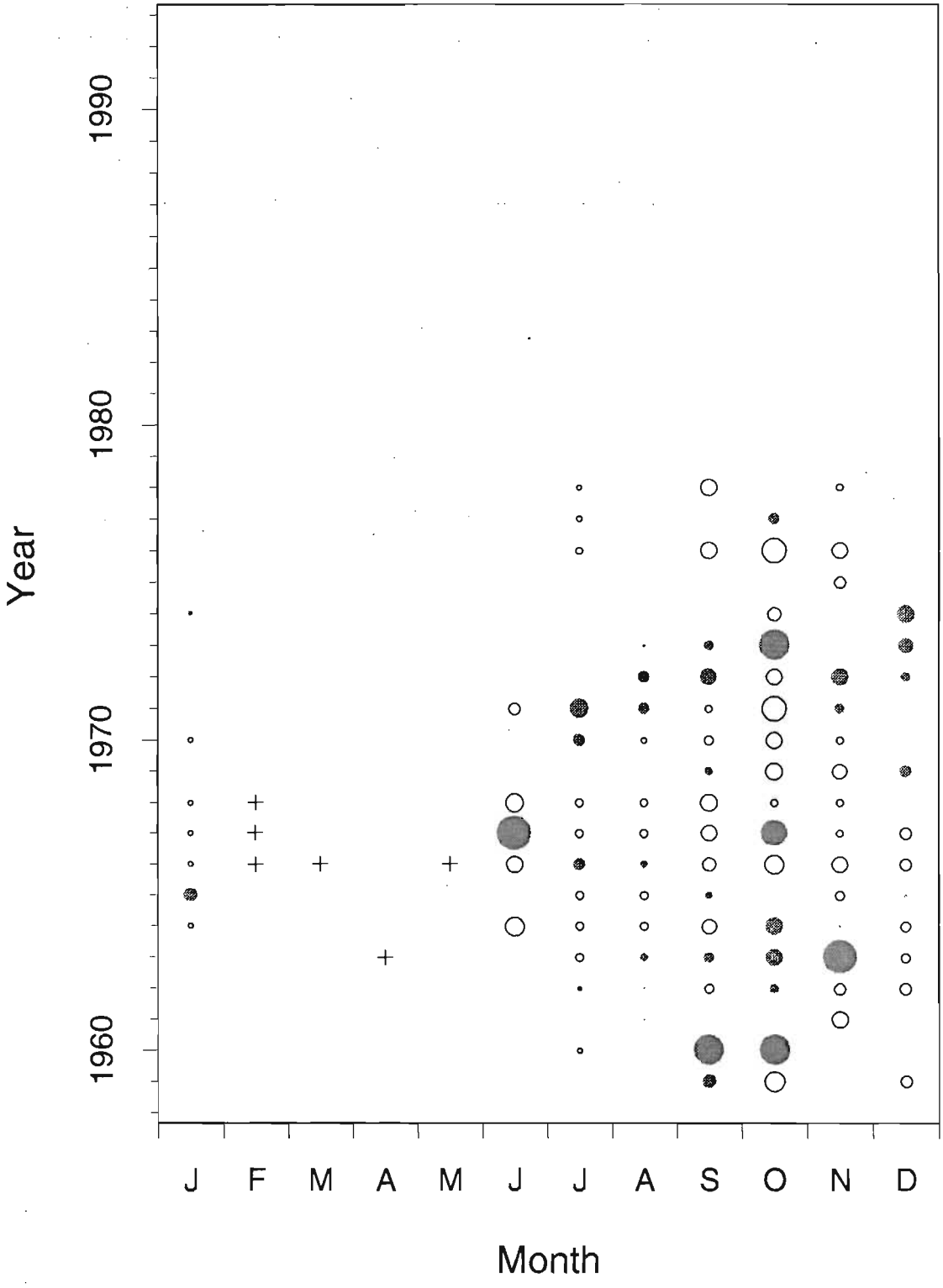
Figure 3. Average plankton abundance anomalies (observed counts minus monthly means) for each year and month, for given sub-region and taxon. The title gives the sub-region and taxon. Expanding symbols represent the magnitude of the anomalies: the anomaly is proportional to the area of the symbol. Shaded circles represent positive anomalies; open circles represent negative anomalies. The scaling is given below the figure (in terms of the largest observation). Zero's are represented by crosses (+).

2J : Calanus I-IV



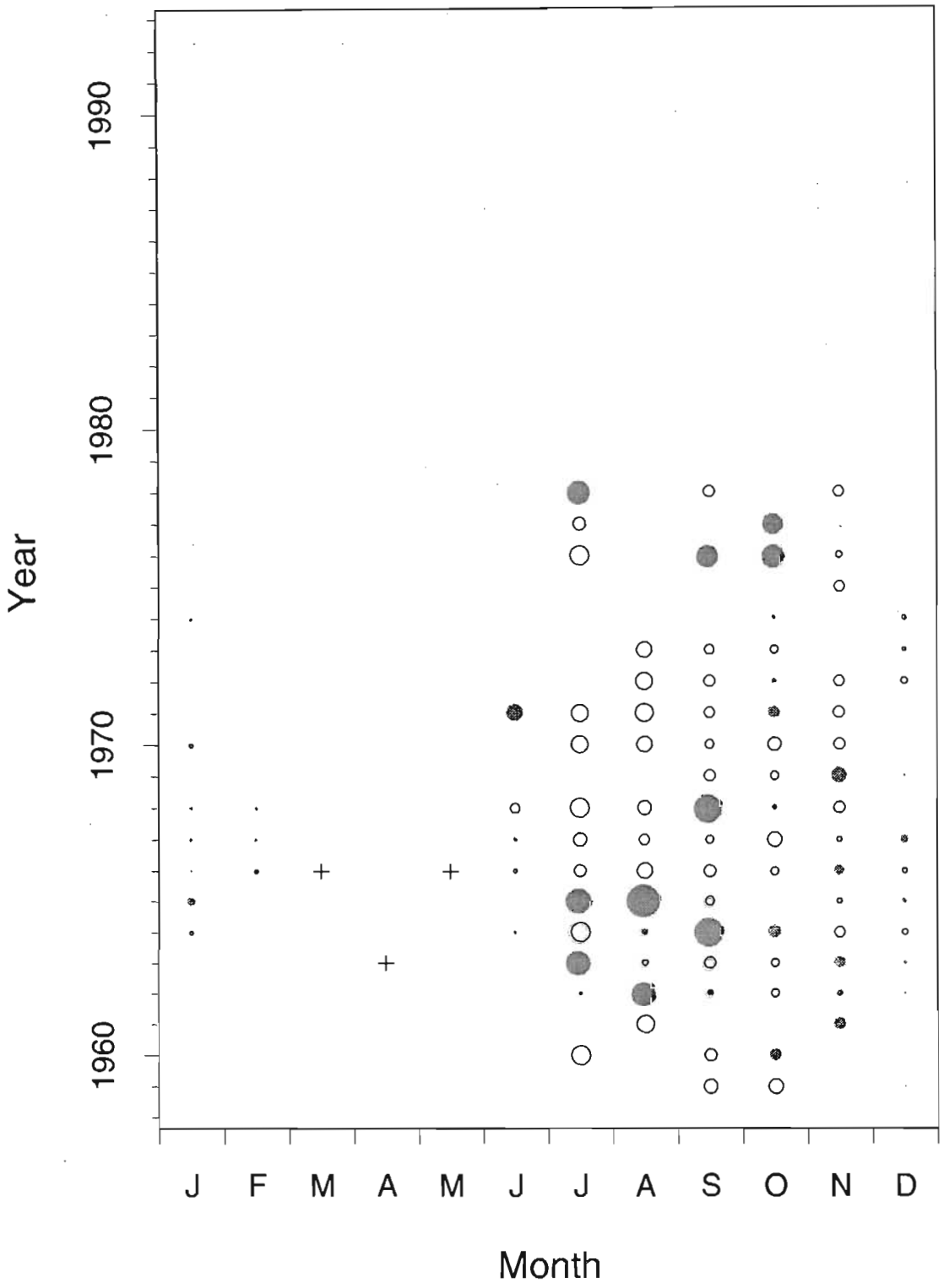
Largest circle represents an absolute anomaly of 1063.

2J : Phytoplankton colour



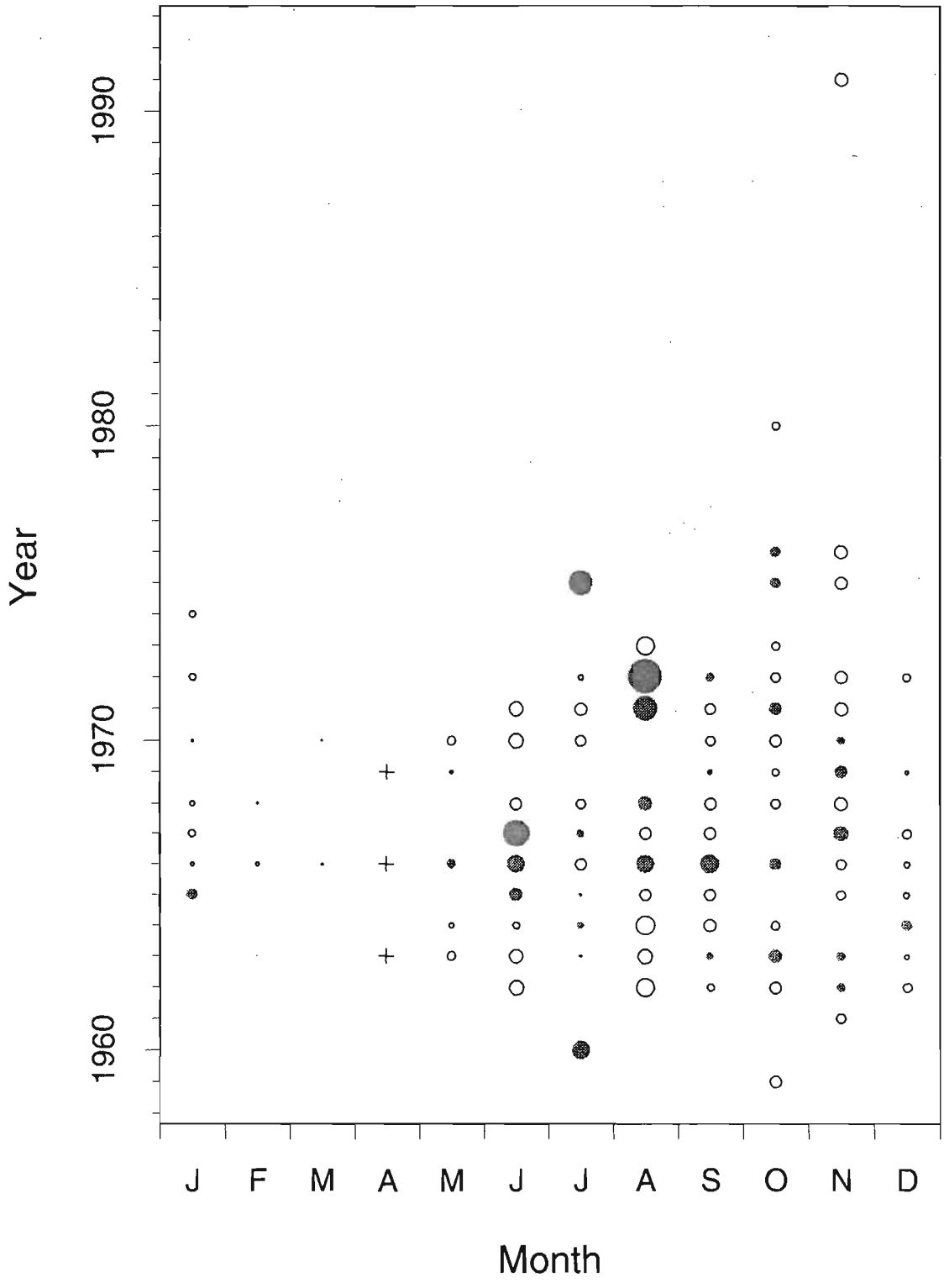
Largest circle represents an absolute anomaly of 4.9.

2J : Calanus V-VI Total



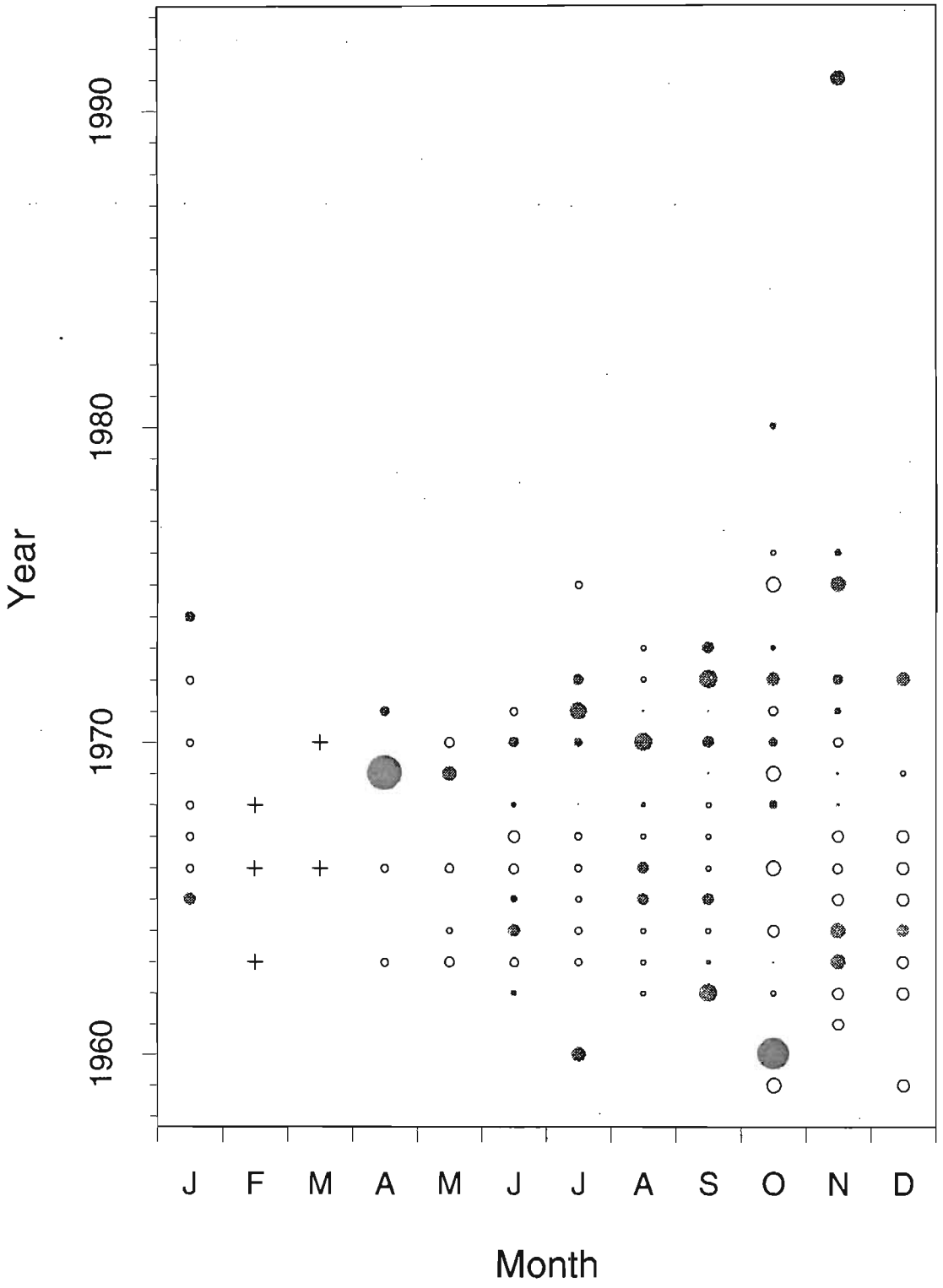
Largest circle represents an absolute anomaly of 215.

3K : Calanus I-IV



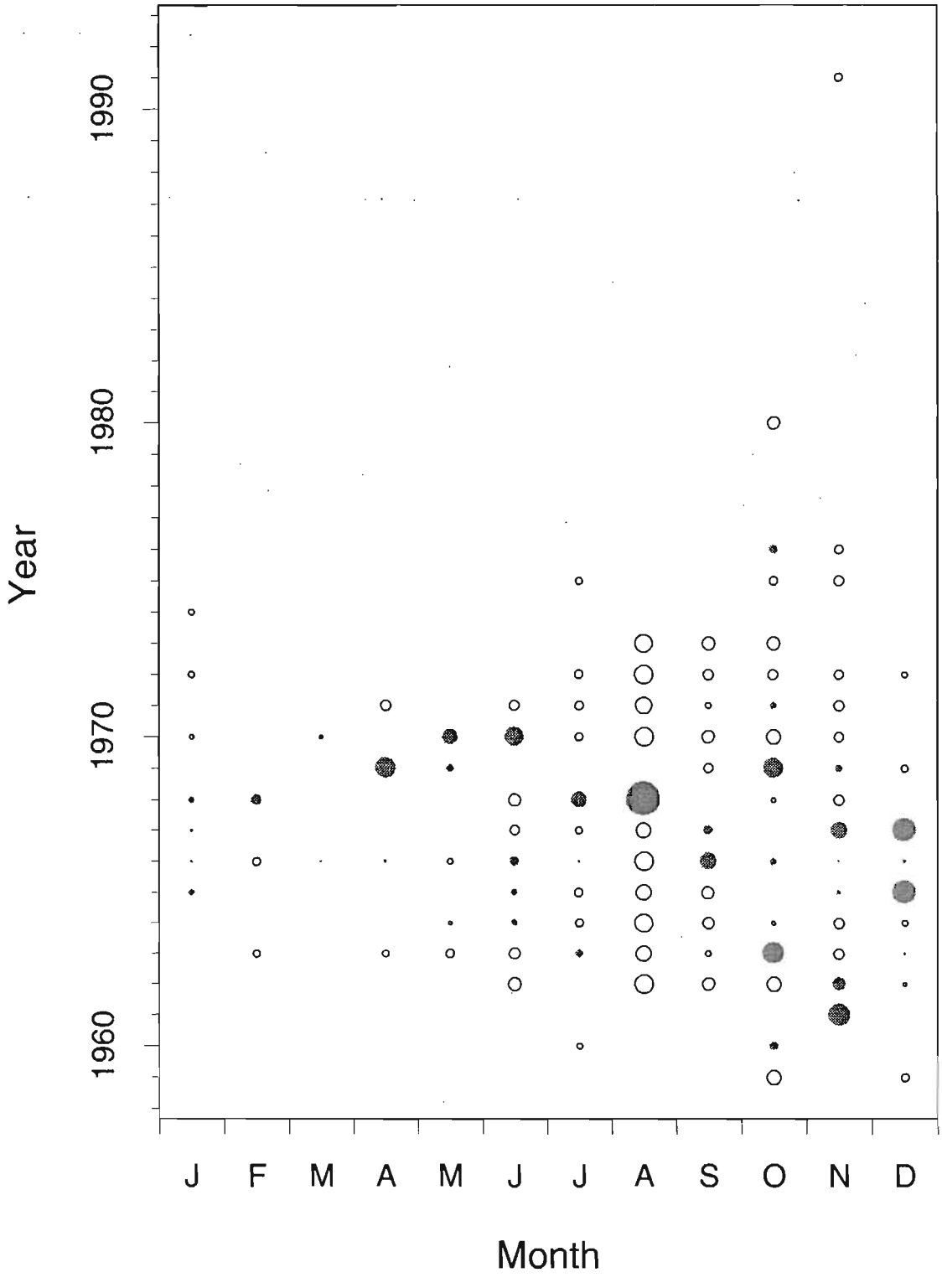
Largest circle represents an absolute anomaly of 1264.

3K : Phytoplankton colour



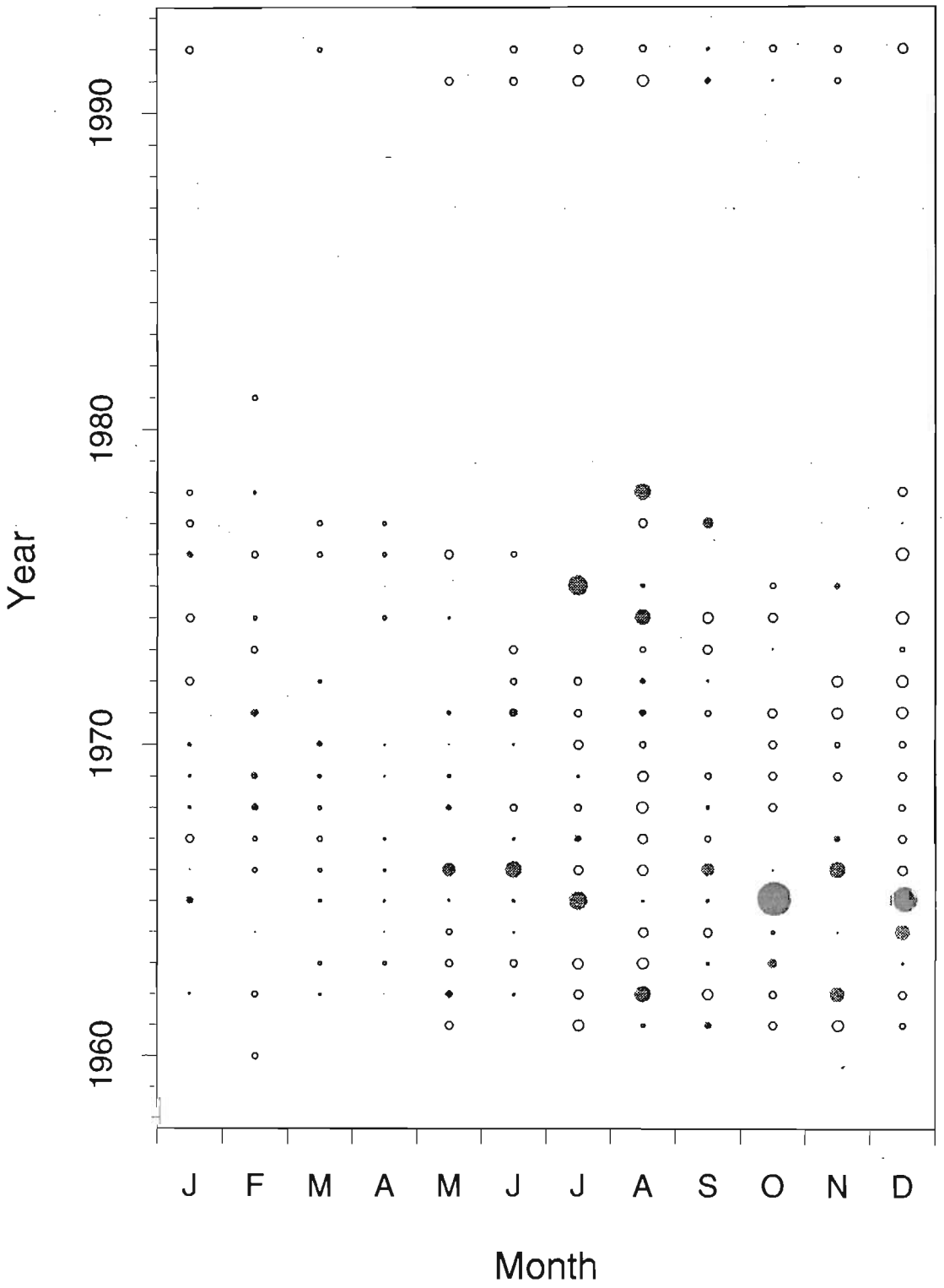
Largest circle represents an absolute anomaly of 6.1.

3K : Calanus V-VI Total



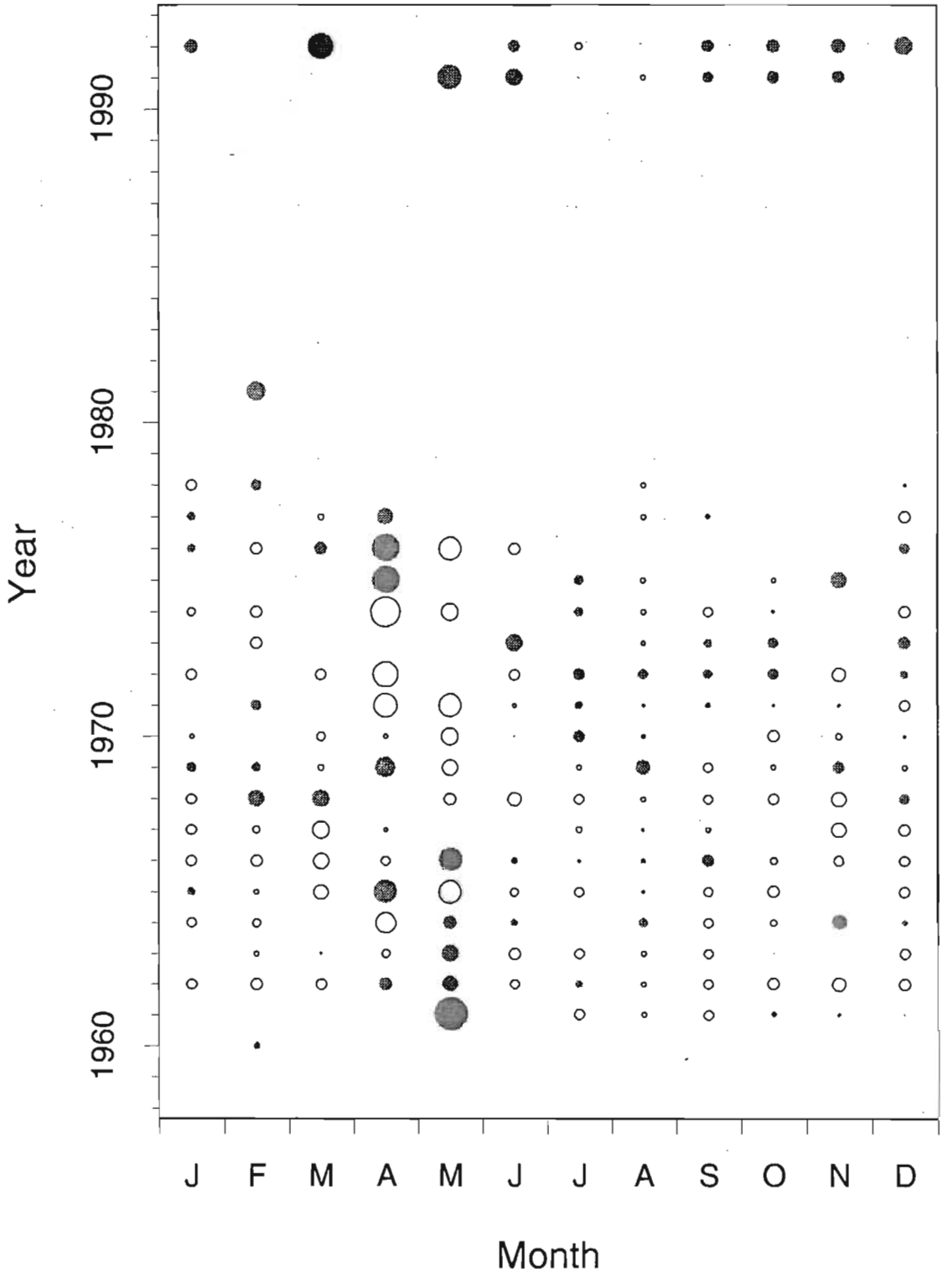
Largest circle represents an absolute anomaly of 292.

3L : Calanus I-IV



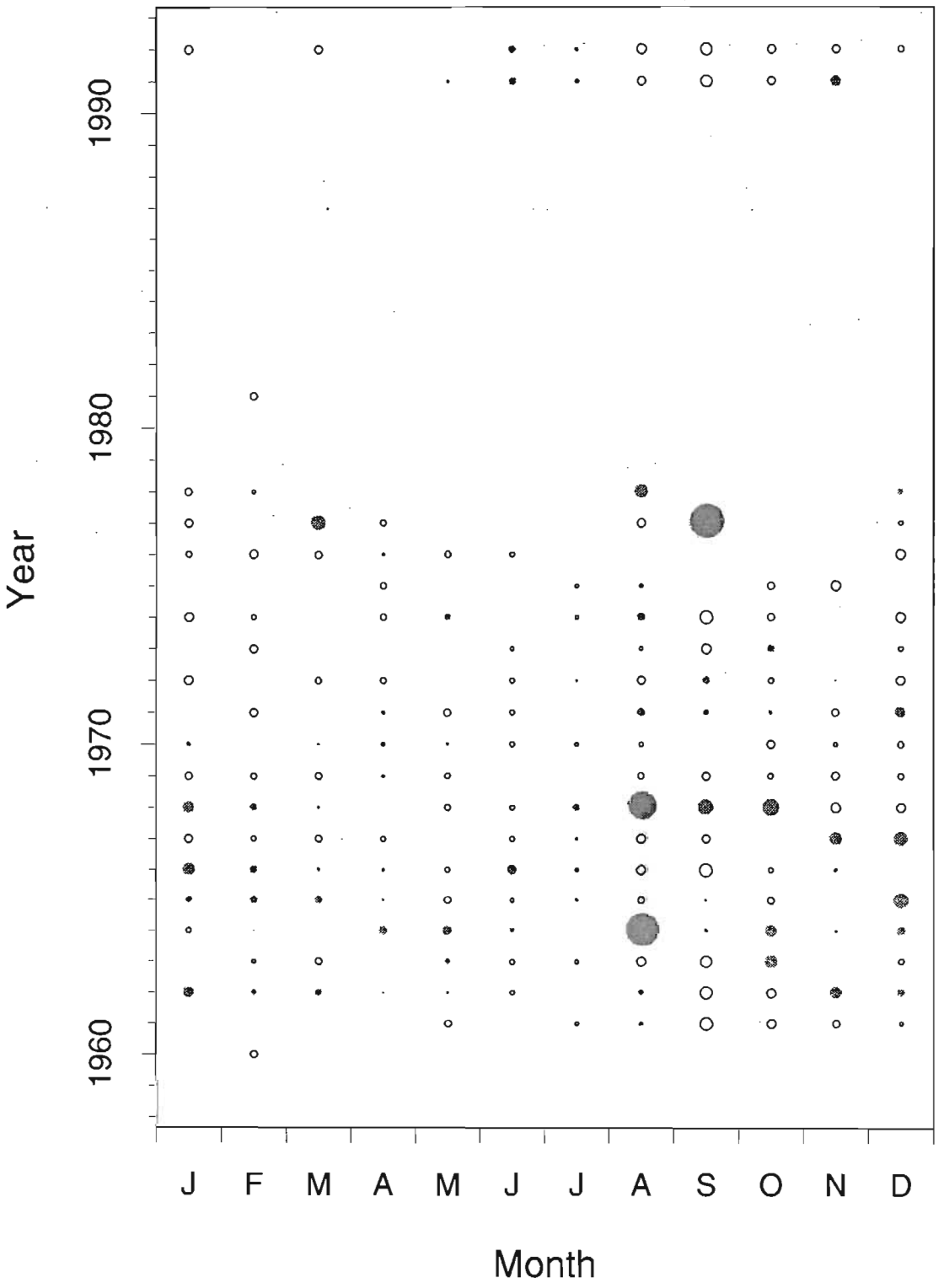
Largest circle represents an absolute anomaly of 1827.

3L : Phytoplankton colour



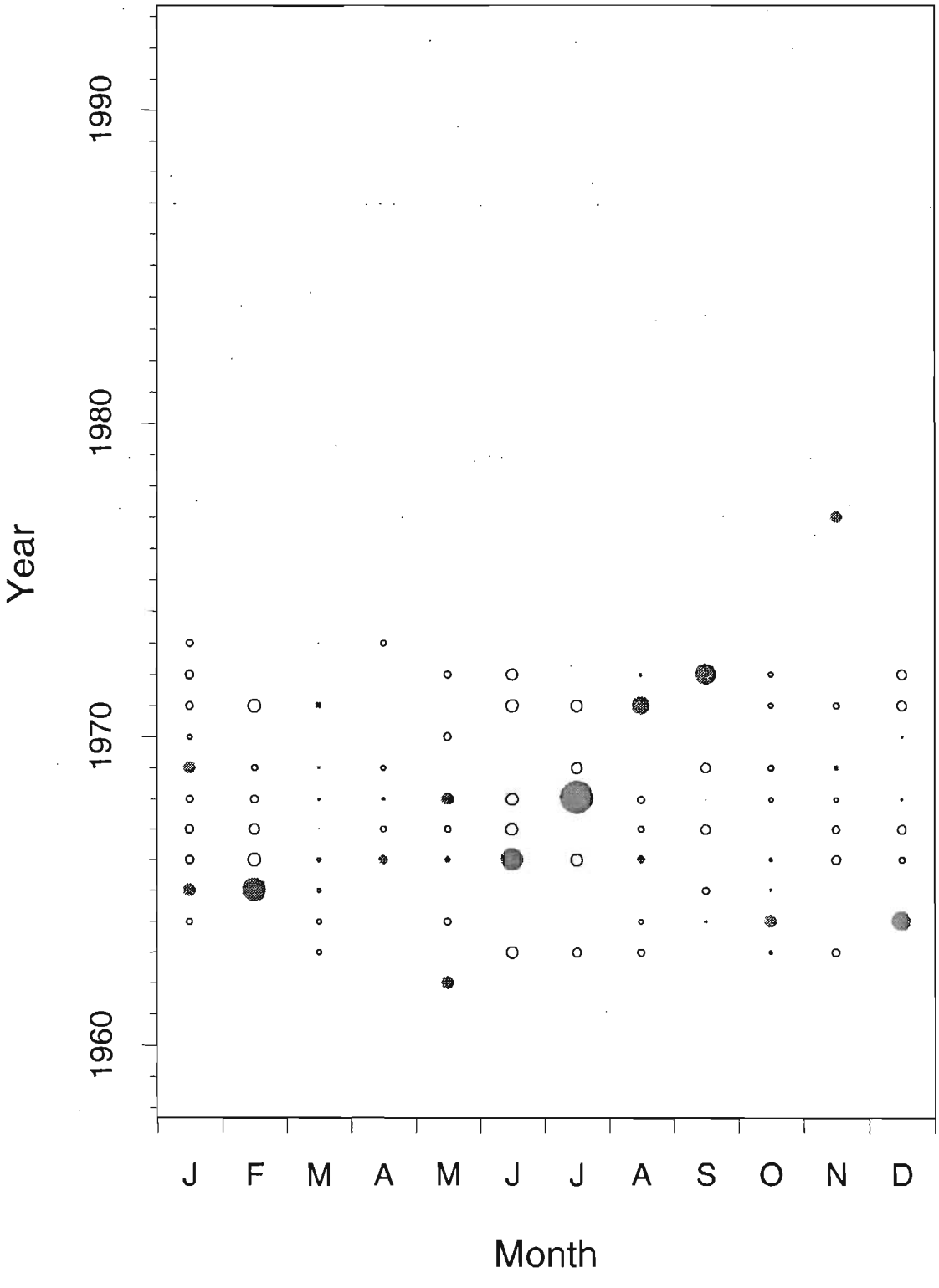
Largest circle represents an absolute anomaly of 4.4.

3L : Calanus V-VI Total



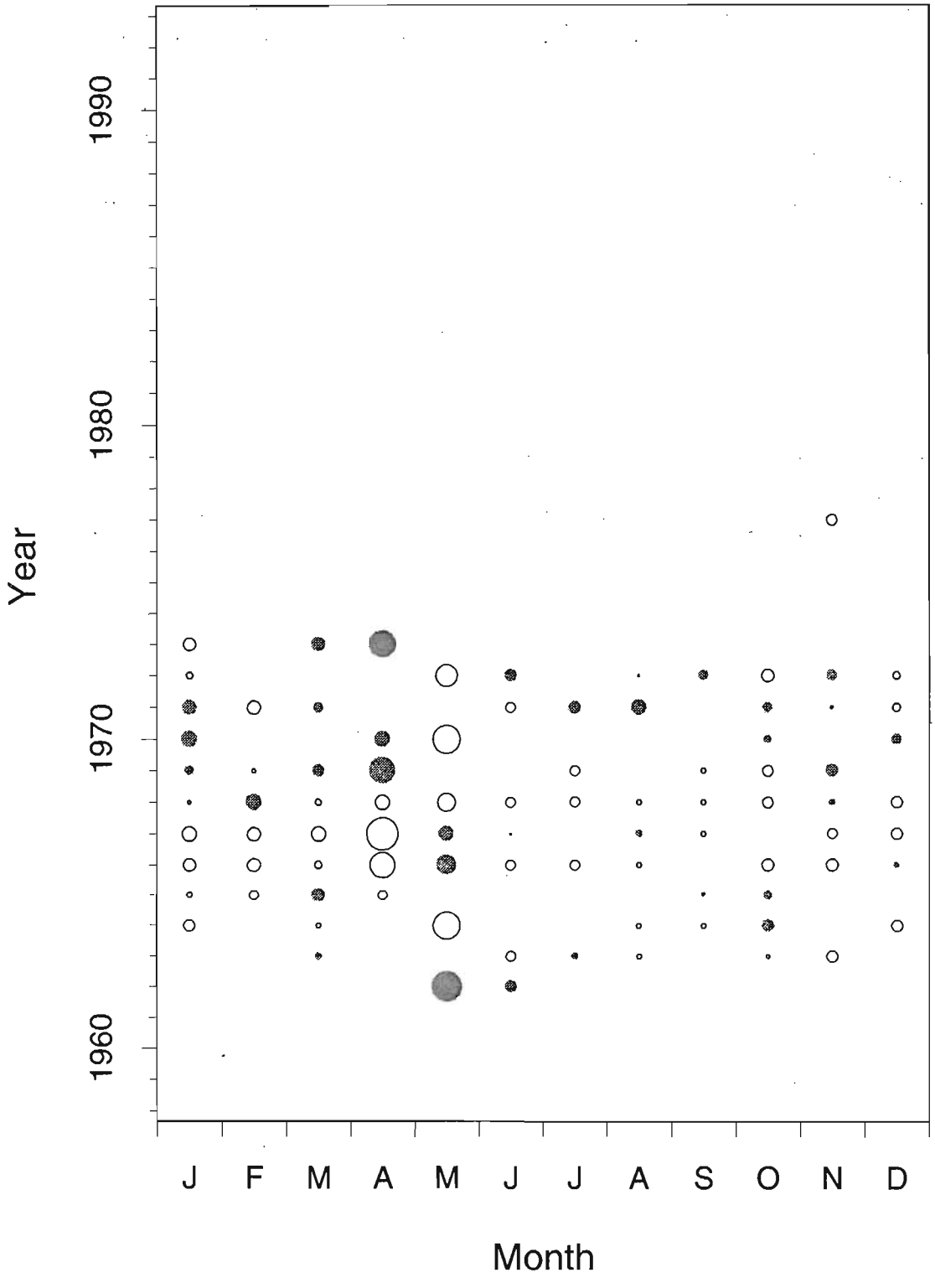
Largest circle represents an absolute anomaly of 304.

3NO : Calanus I-IV



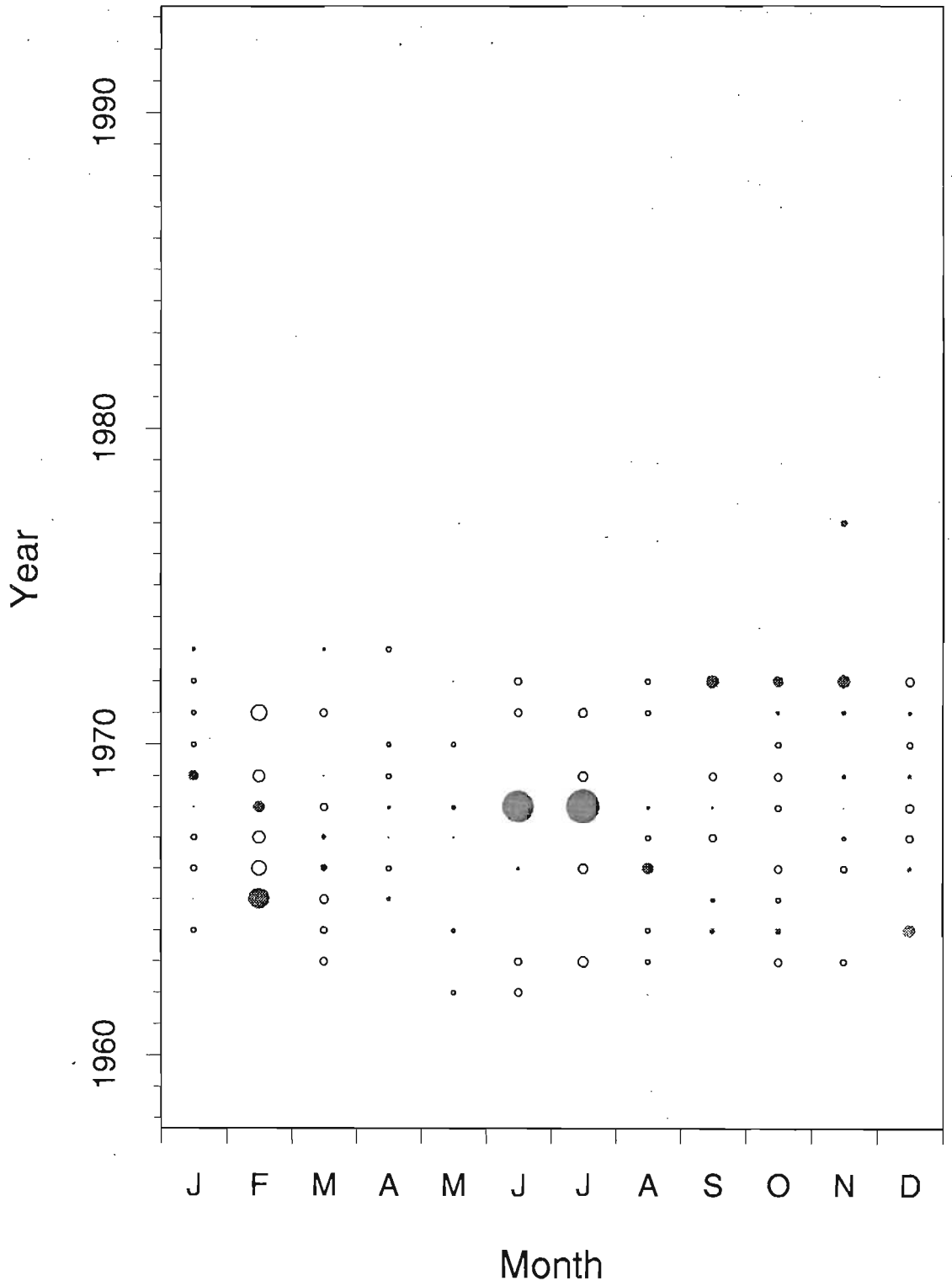
Largest circle represents an absolute anomaly of 860.

3NO : Phytoplankton colour



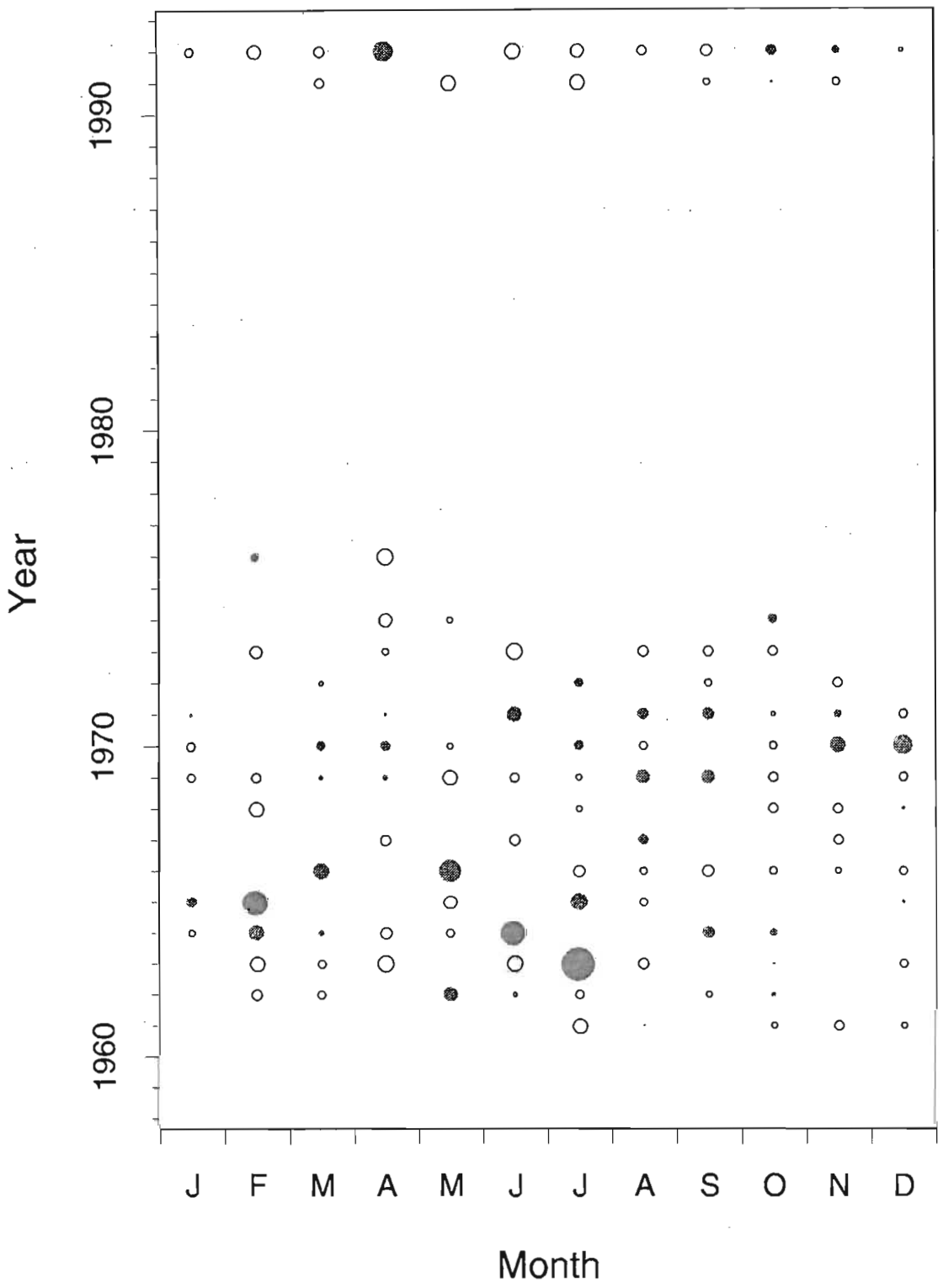
Largest circle represents an absolute anomaly of 4.

3NO : Calanus V-VI Total



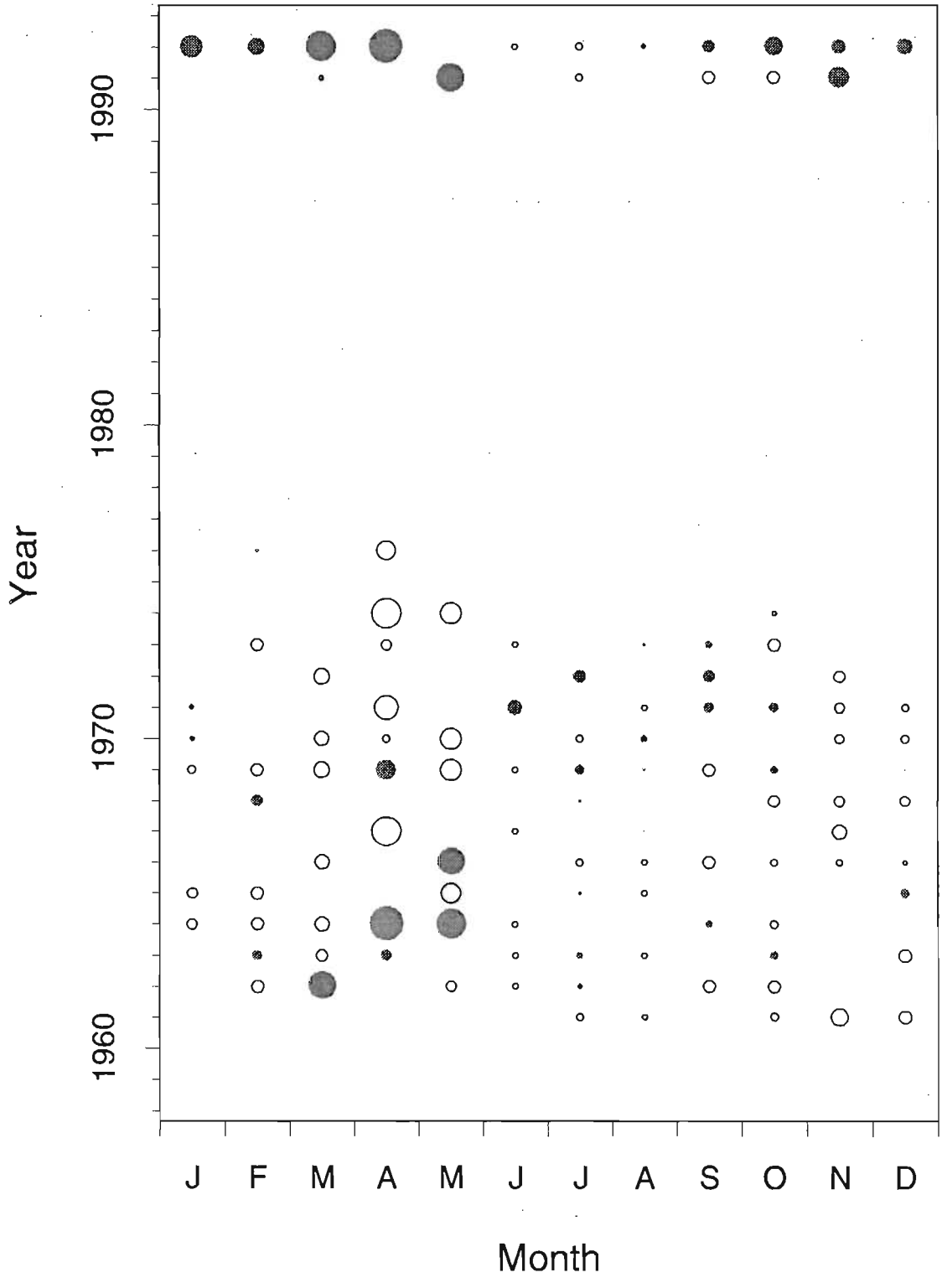
Largest circle represents an absolute anomaly of 175.

3Ps : Calanus I-IV



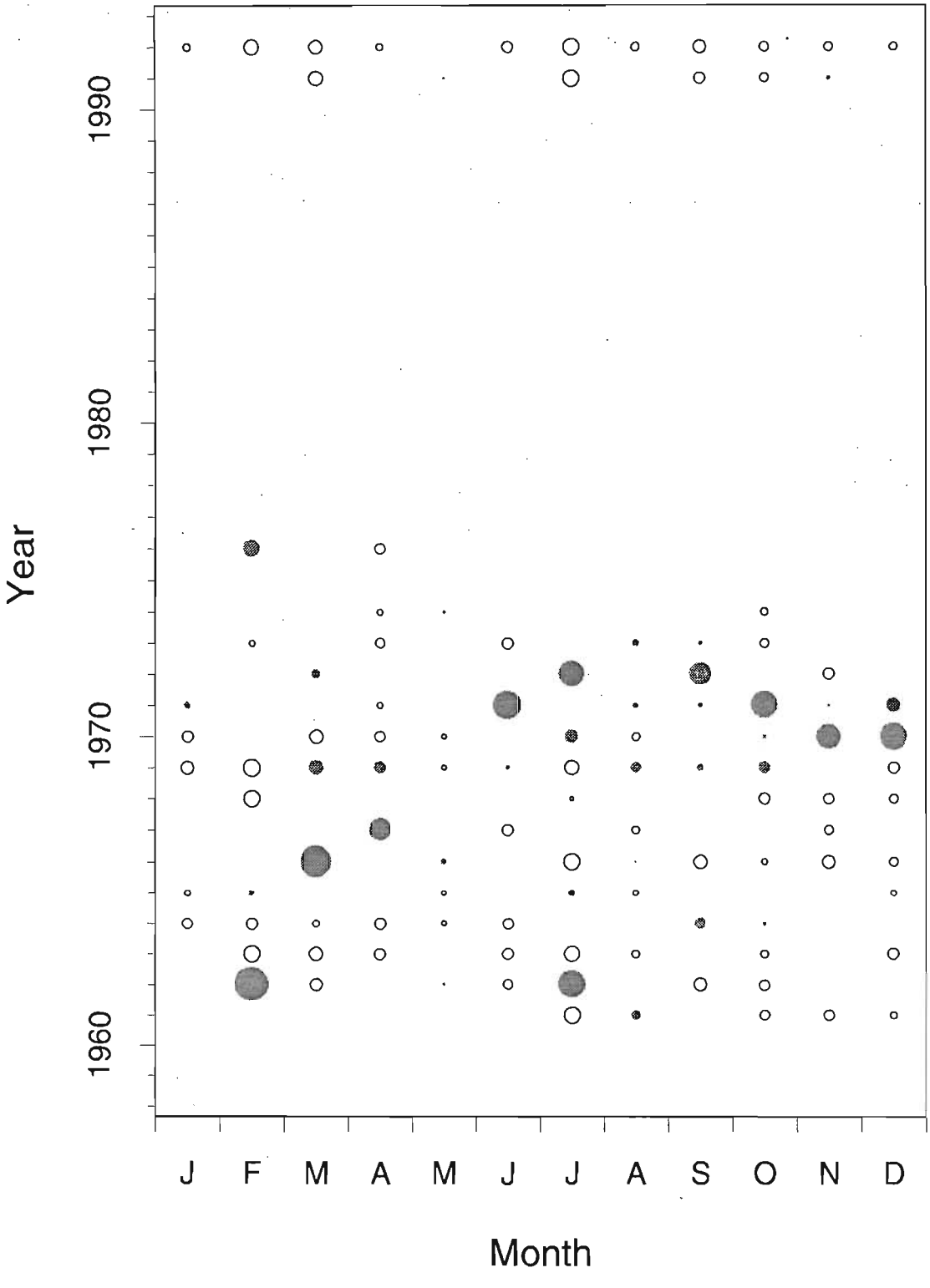
Largest circle represents an absolute anomaly of 284.

3Ps : Phytoplankton colour



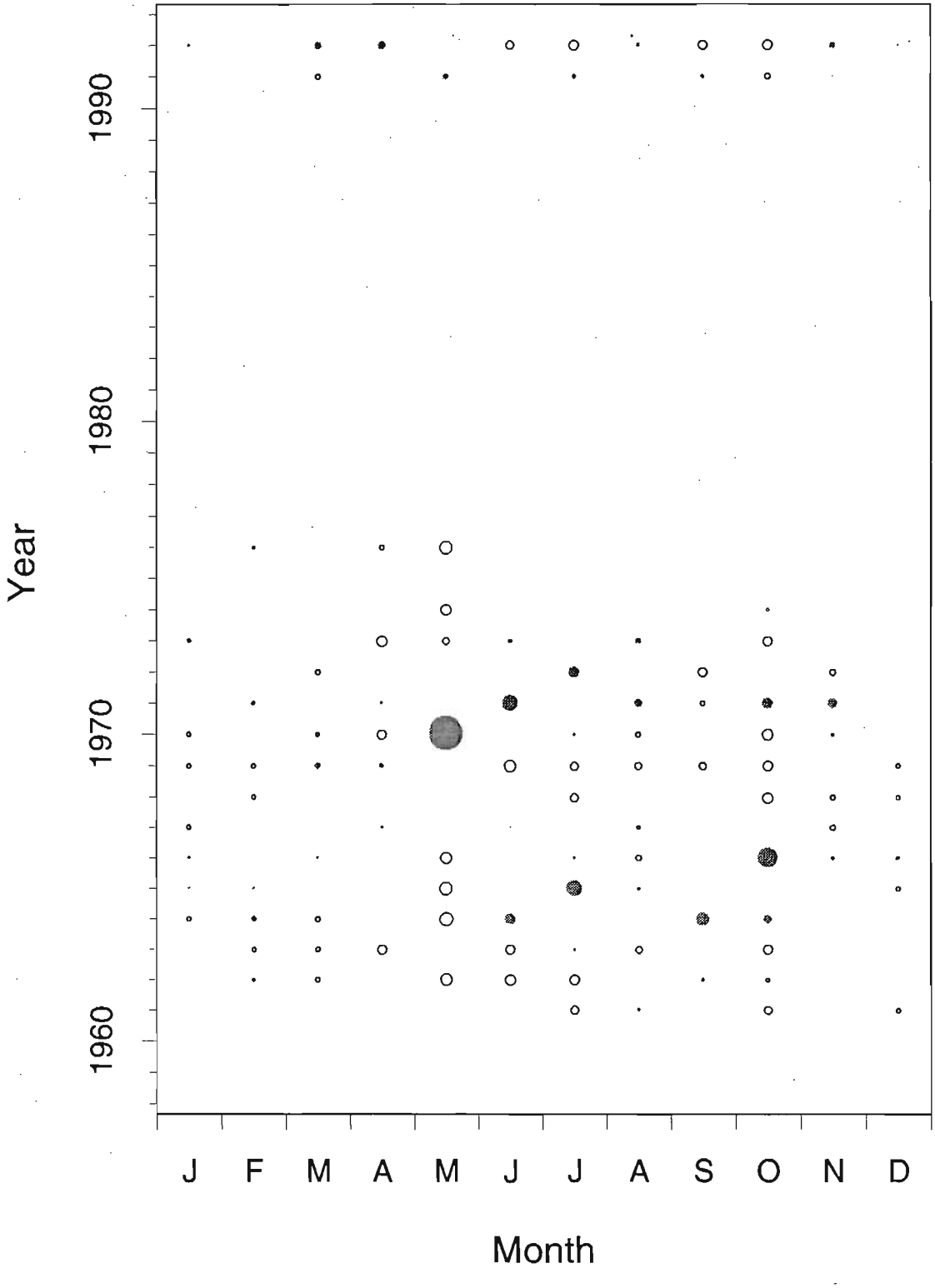
Largest circle represents an absolute anomaly of 3.6.

3Ps : Calanus V-VI Total



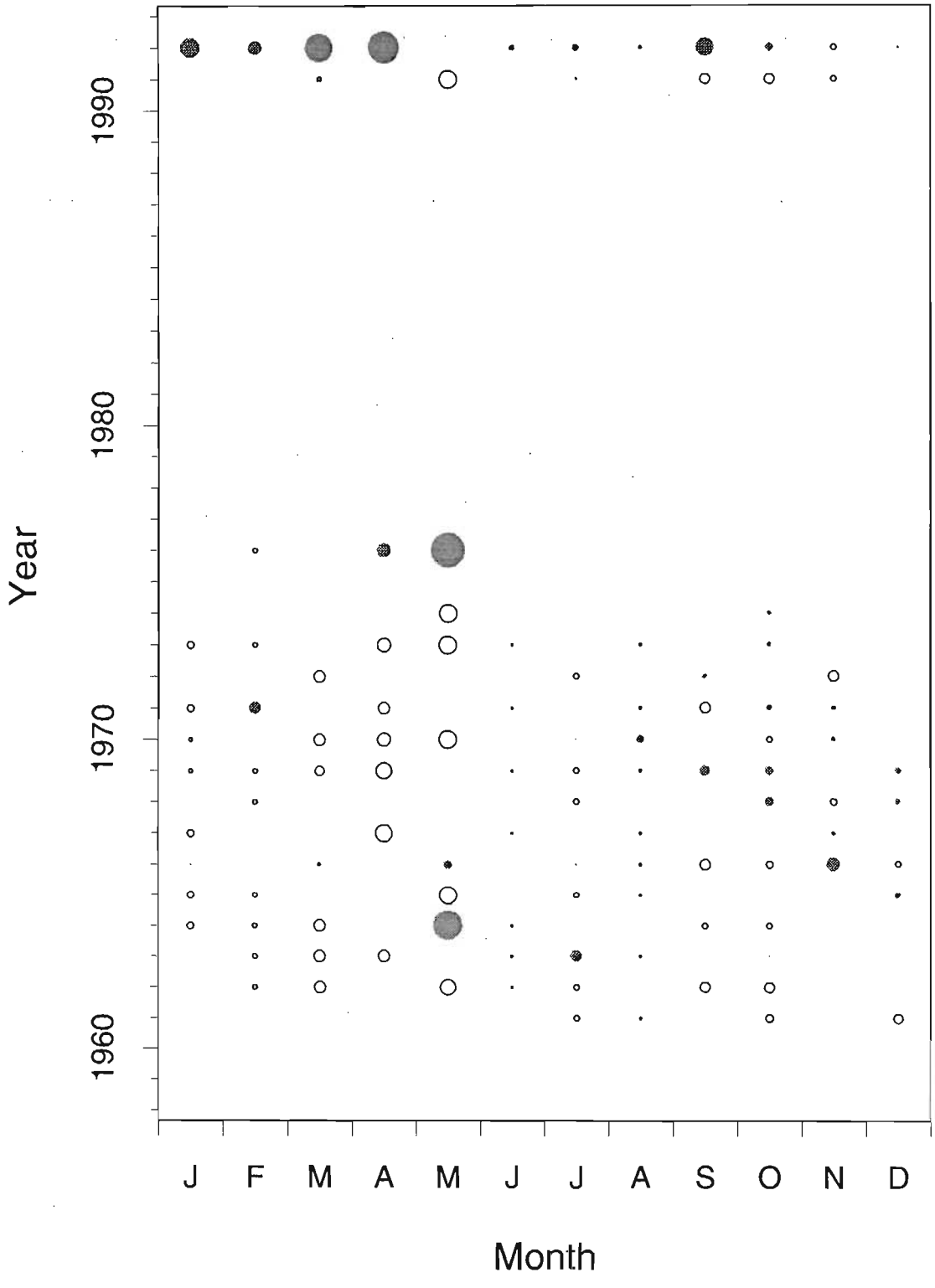
Largest circle represents an absolute anomaly of 55.

4V : Calanus I-IV



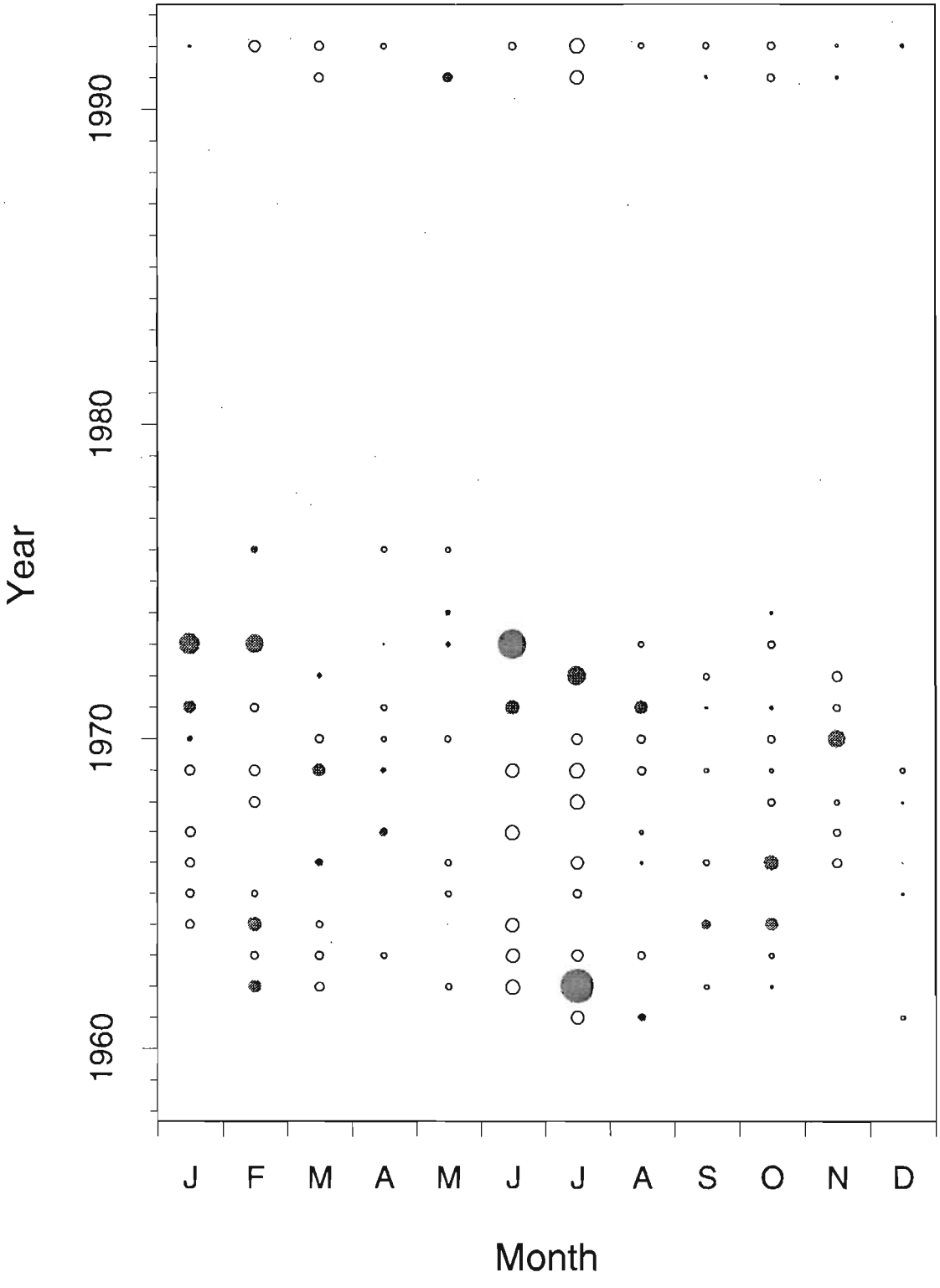
Largest circle represents an absolute anomaly of 930.

4V : Phytoplankton colour



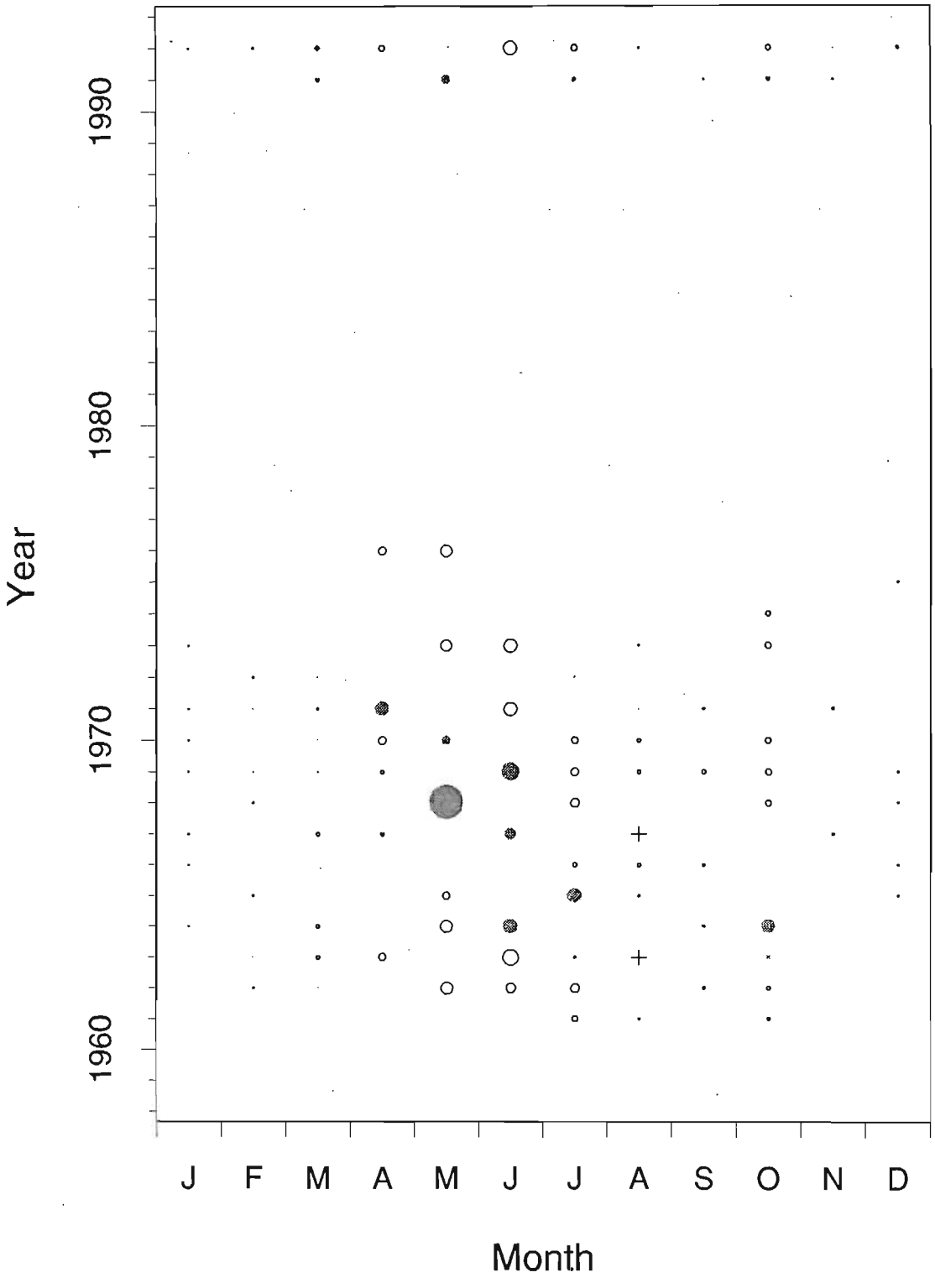
Largest circle represents an absolute anomaly of 5.

4V : Calanus V-VI Total



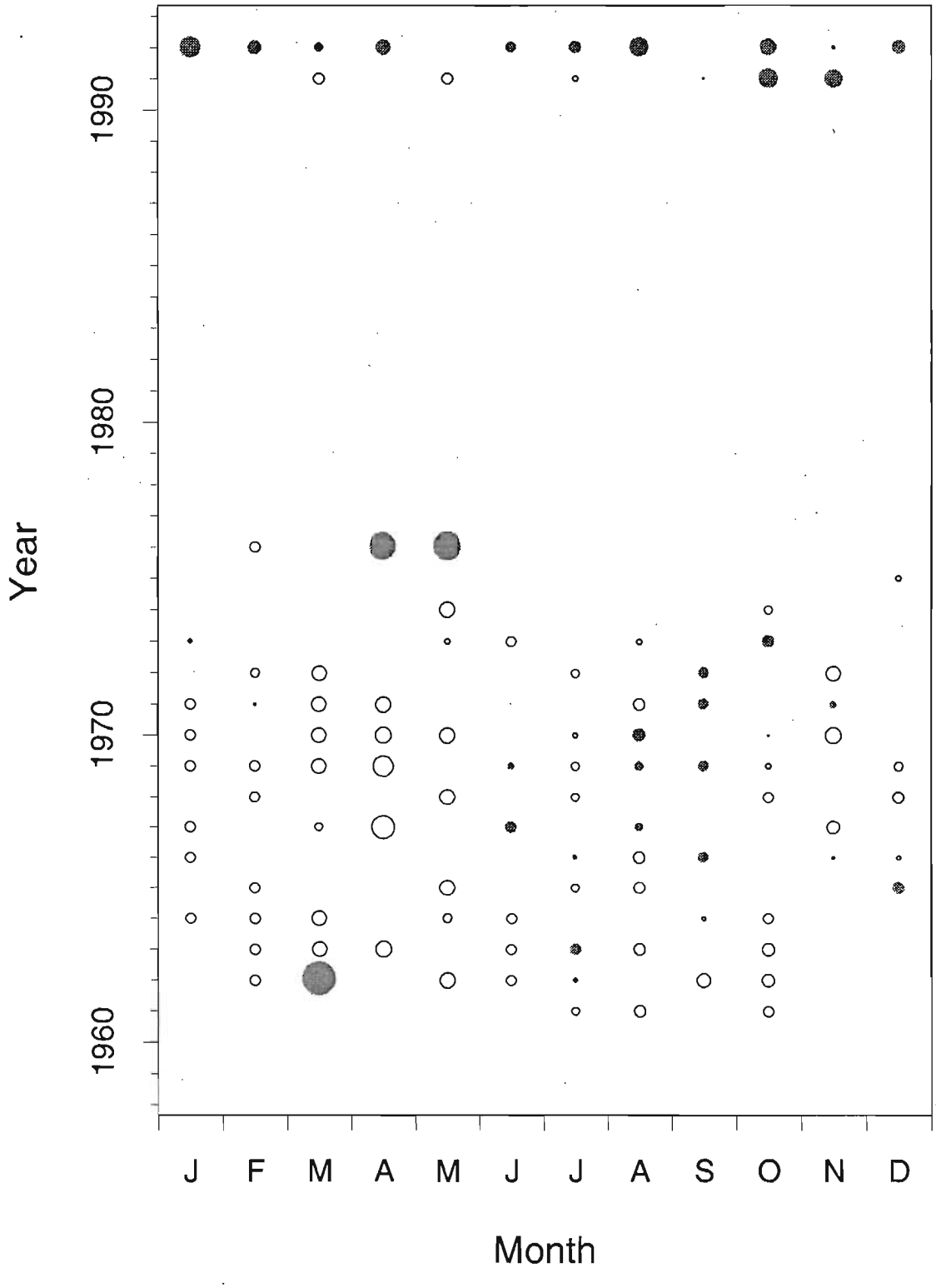
Largest circle represents an absolute anomaly of 178.

4W : Calanus I-IV



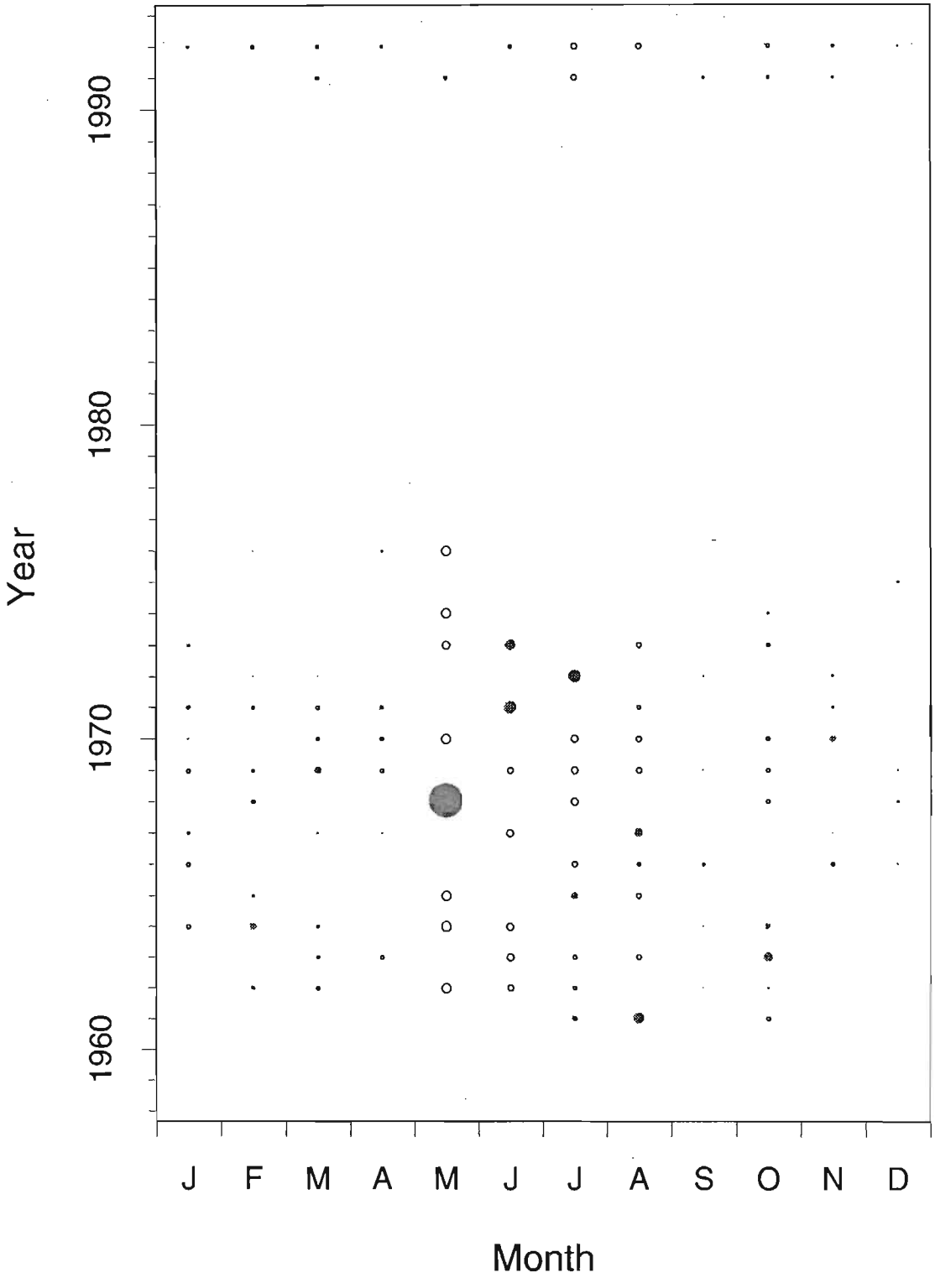
Largest circle represents an absolute anomaly of 1940.

4W : Phytoplankton colour



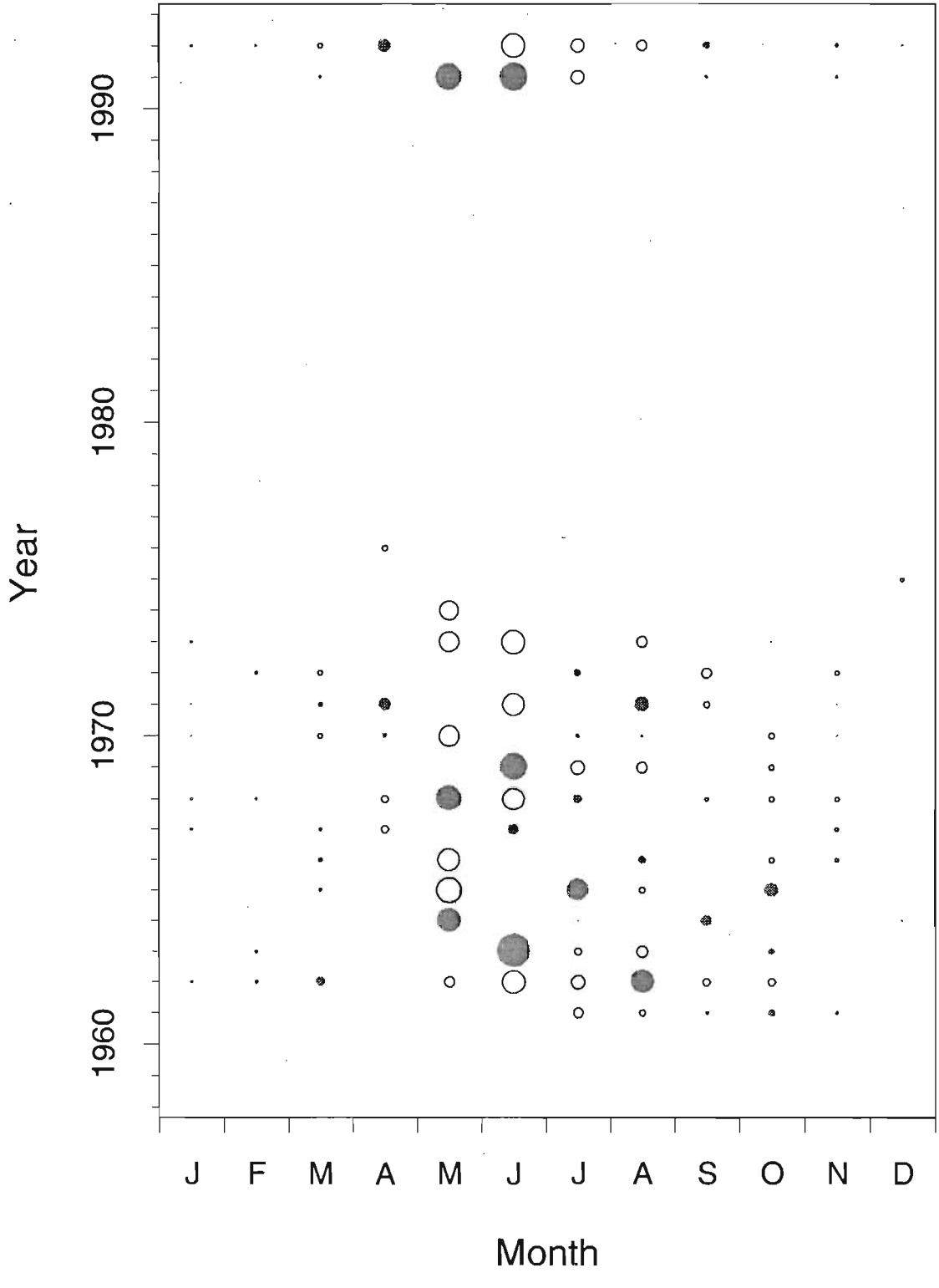
Largest circle represents an absolute anomaly of 3.4.

4W : Calanus V-VI Total



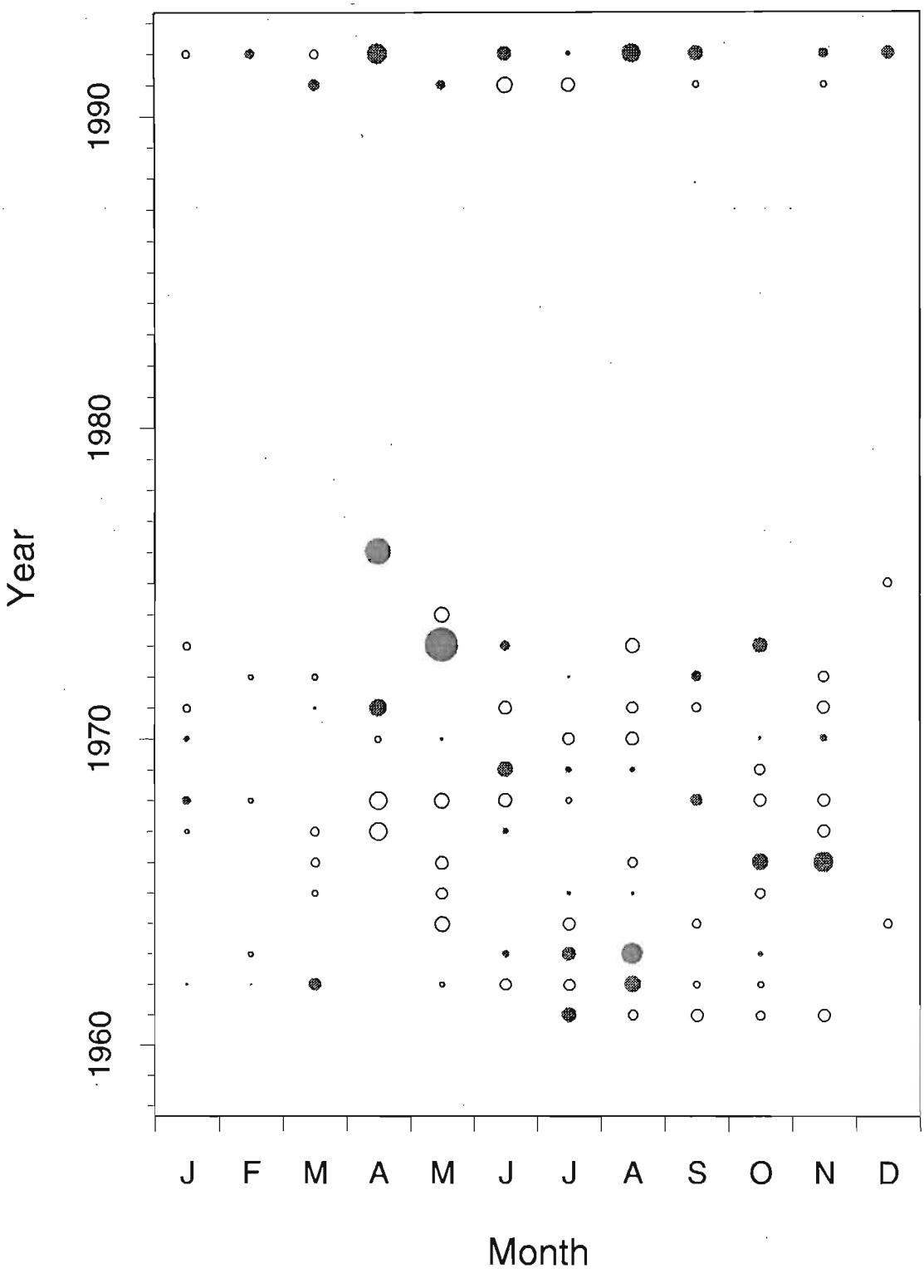
Largest circle represents an absolute anomaly of 587.

4X : Calanus I-IV



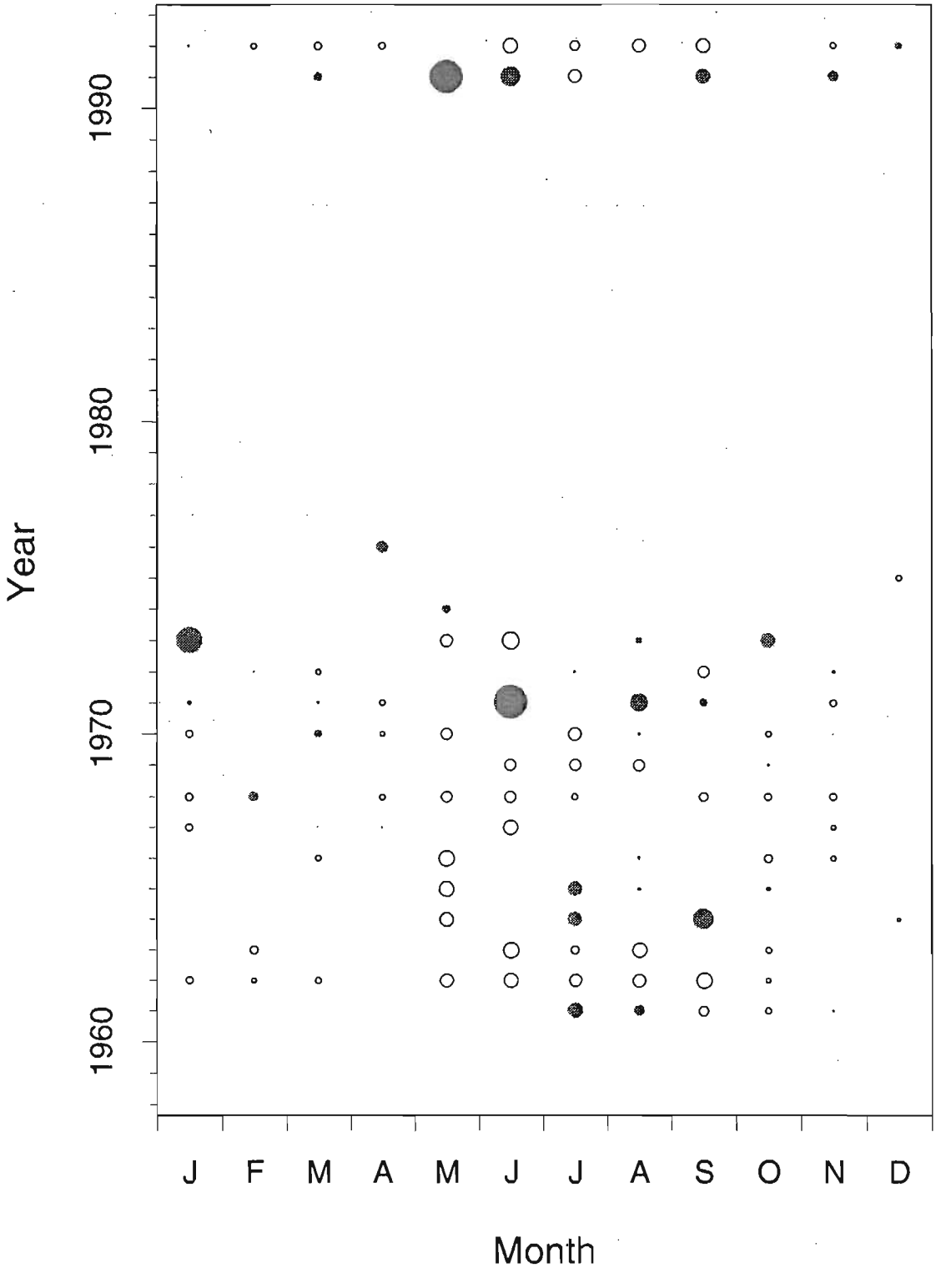
Largest circle represents an absolute anomaly of 689.

4X : Phytoplankton colour



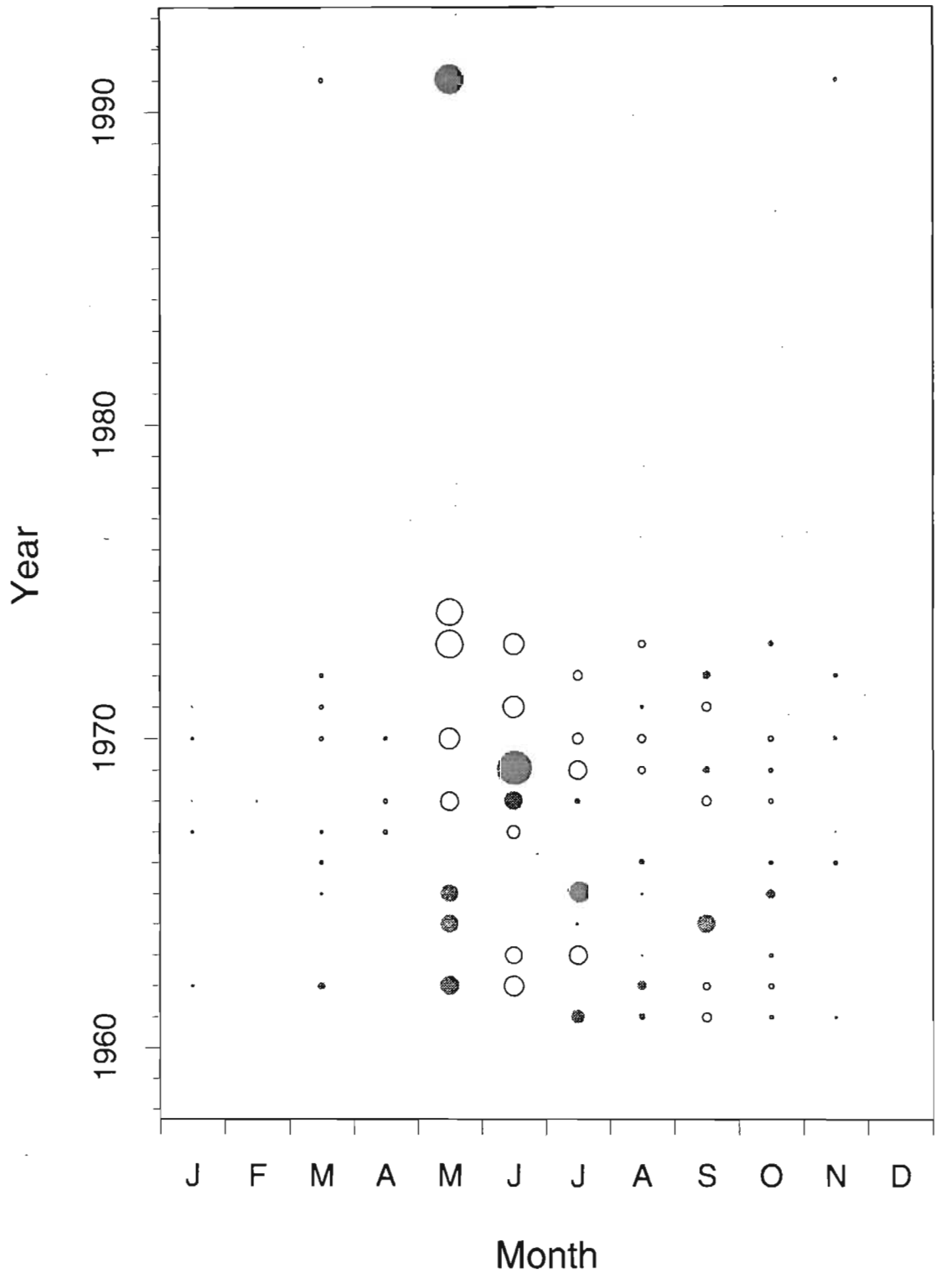
Largest circle represents an absolute anomaly of 2.7.

4X : Calanus V-VI Total



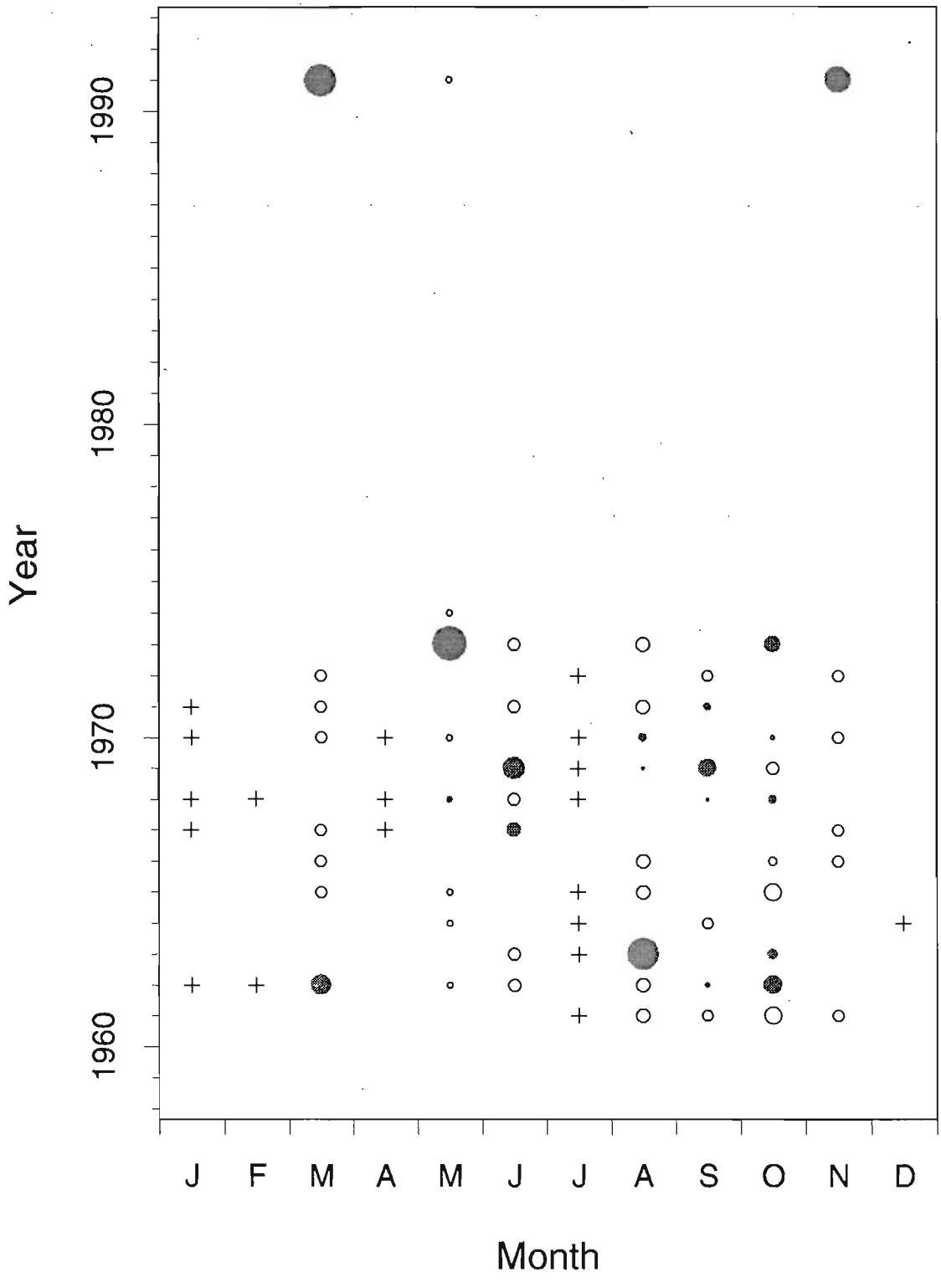
Largest circle represents an absolute anomaly of 174.

5Y : Calanus I-IV



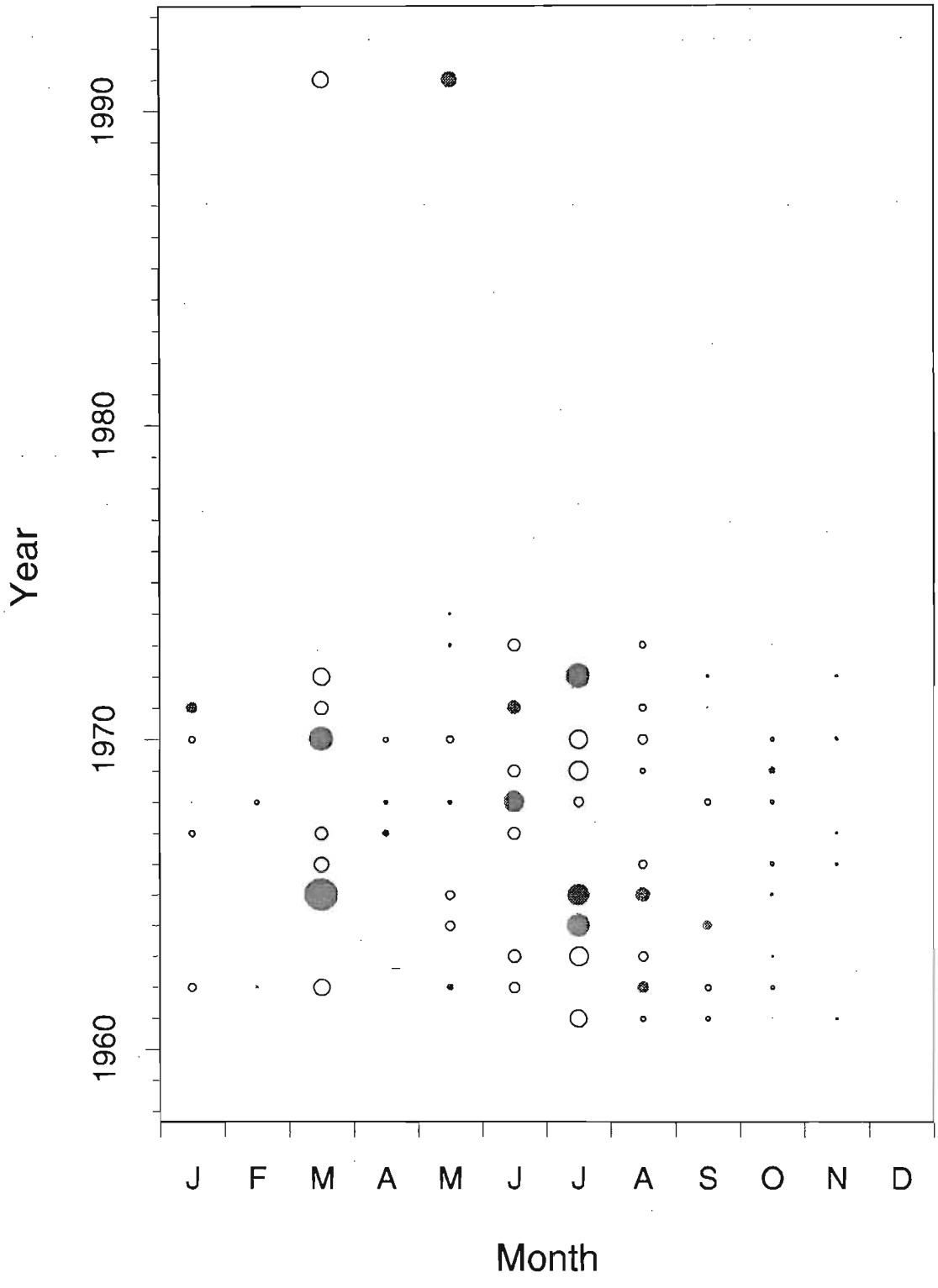
Largest circle represents an absolute anomaly of 1520.

5Y : Phytoplankton colour



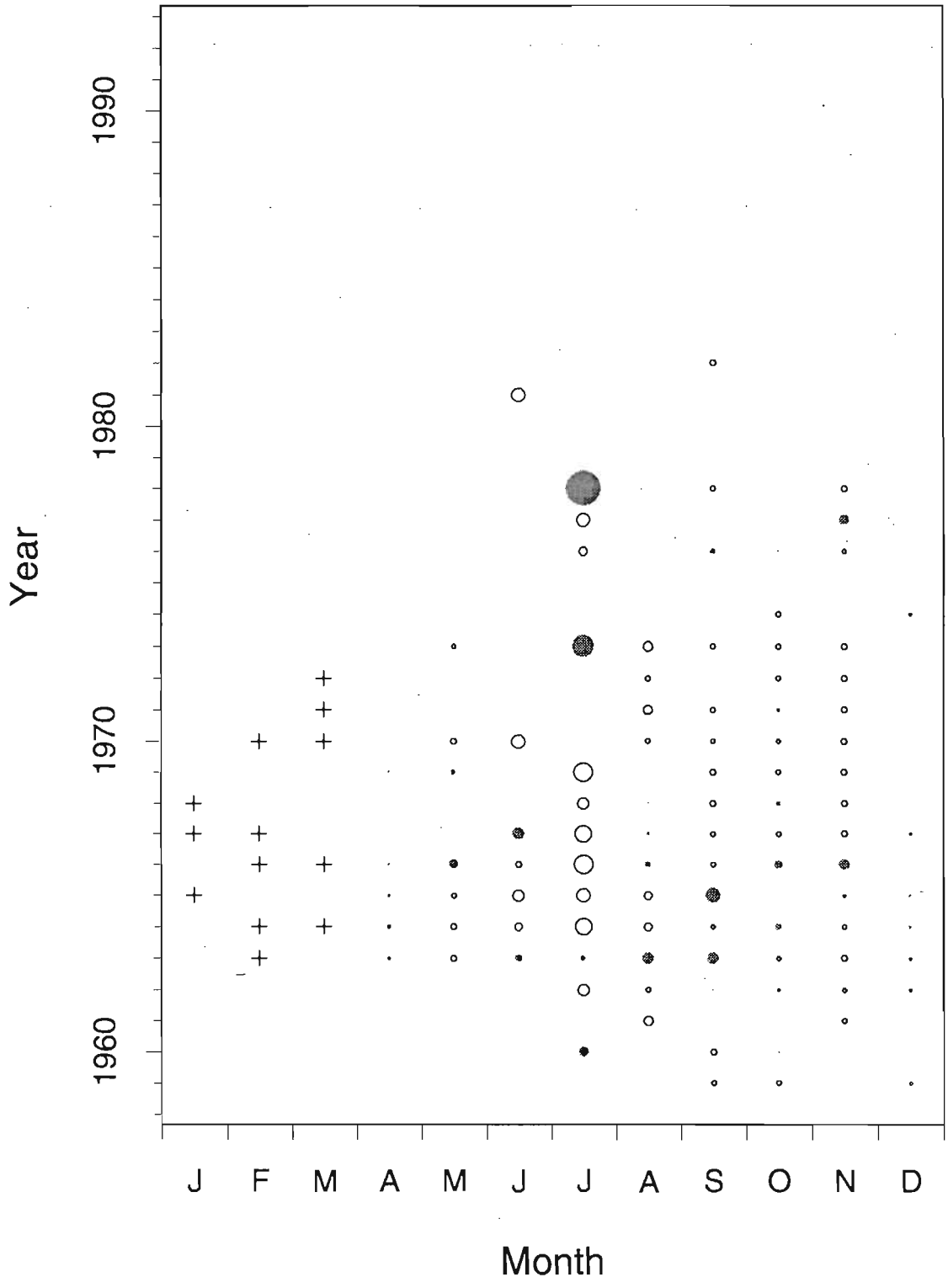
Largest circle represents an absolute anomaly of 1.9.

5Y : Calanus V-VI Total



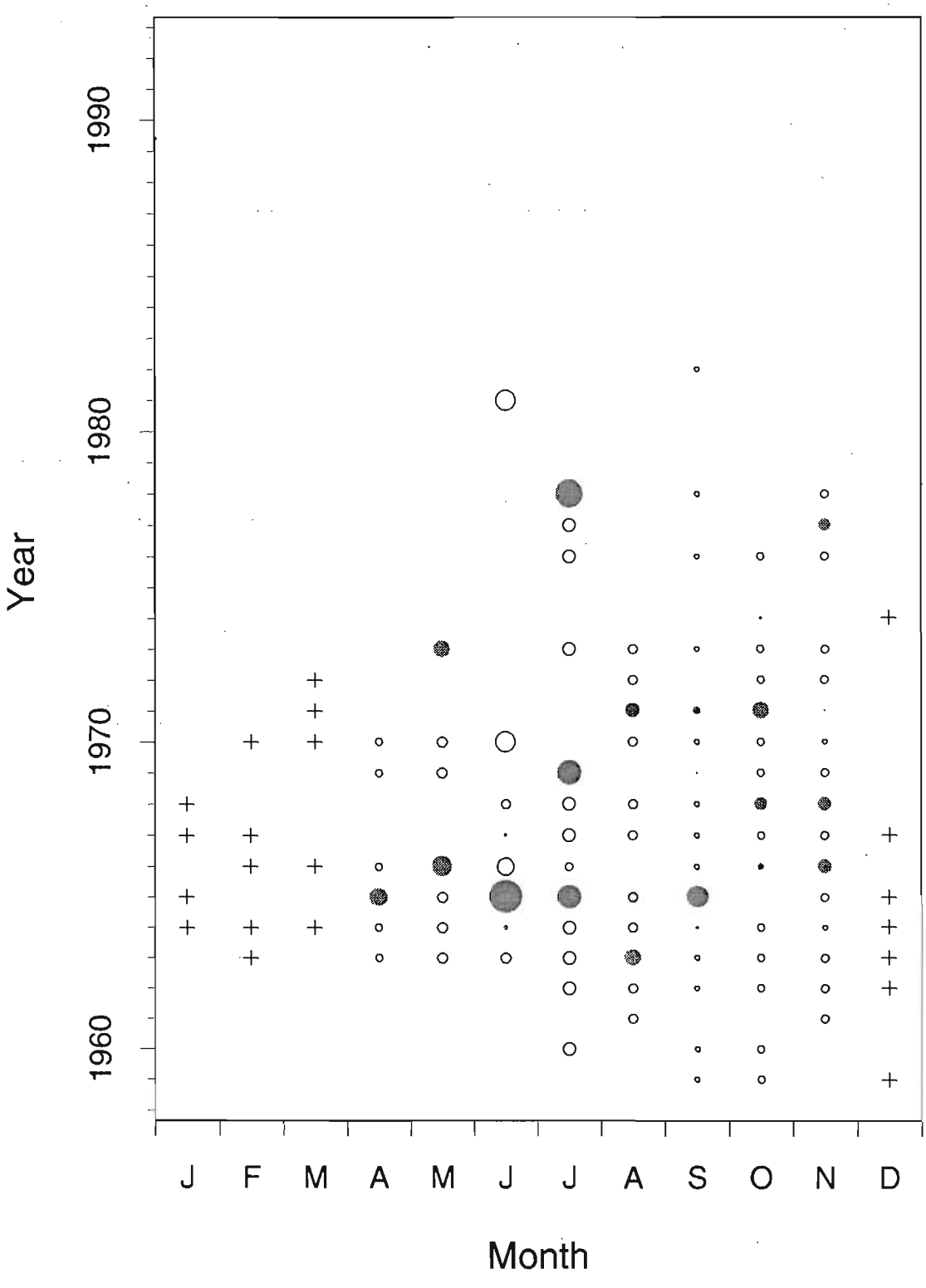
Largest circle represents an absolute anomaly of 450.

LS1 : Calanus I-IV



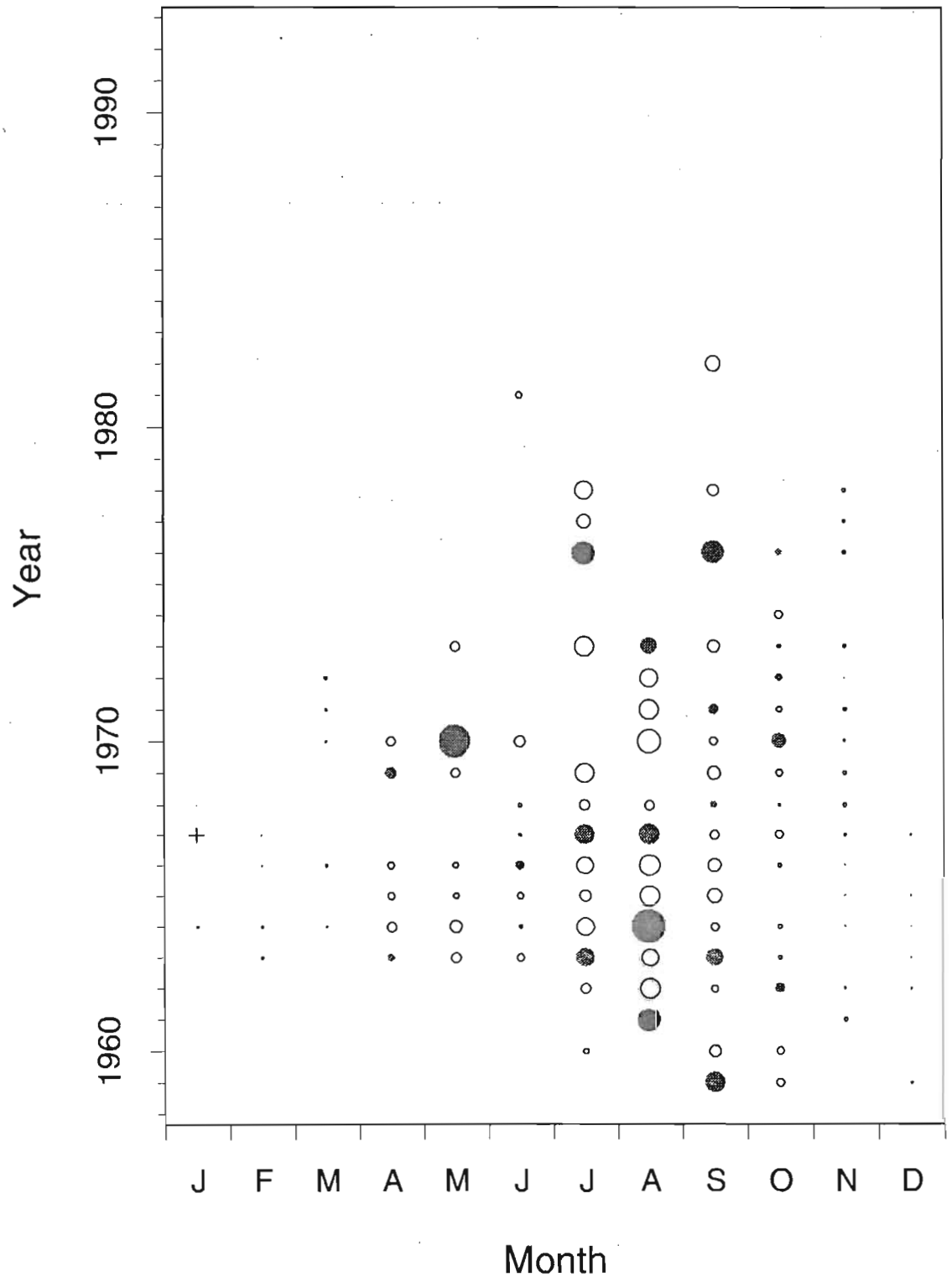
Largest circle represents an absolute anomaly of 1774.

LS1 : Phytoplankton colour



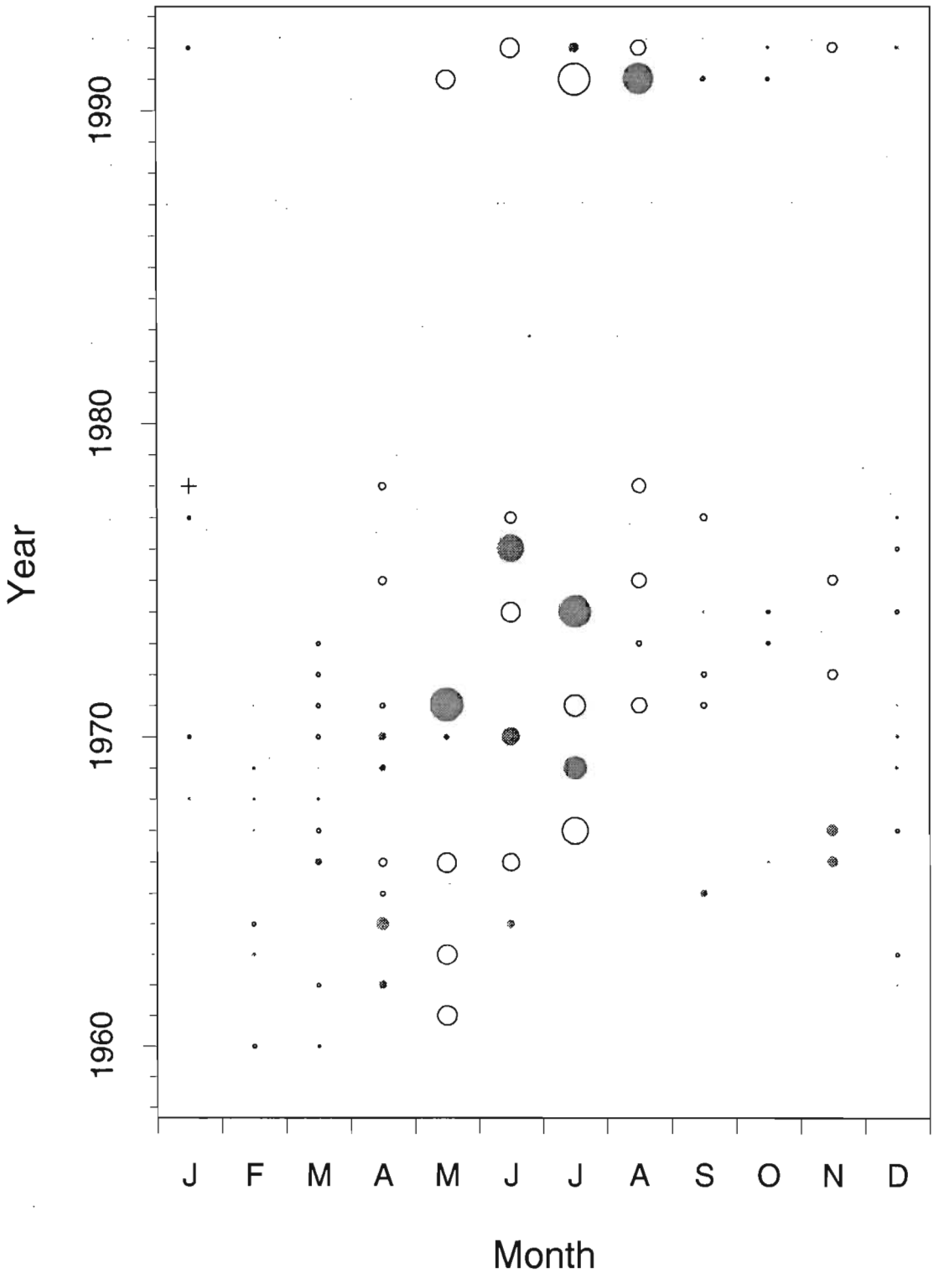
Largest circle represents an absolute anomaly of 2.2.

LS1 : Calanus V-VI Total



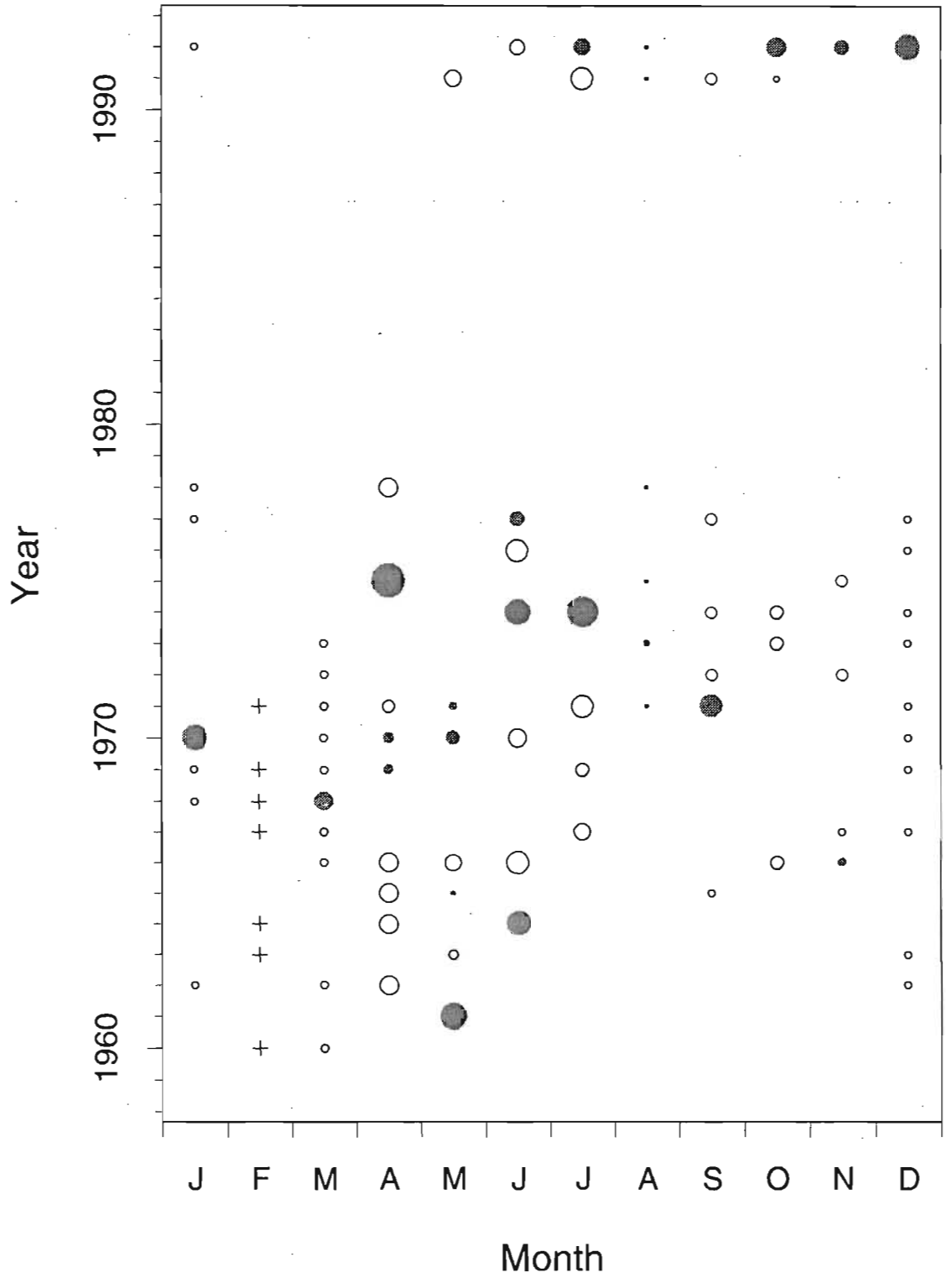
Largest circle represents an absolute anomaly of 626.

OS2 : Calanus I-IV



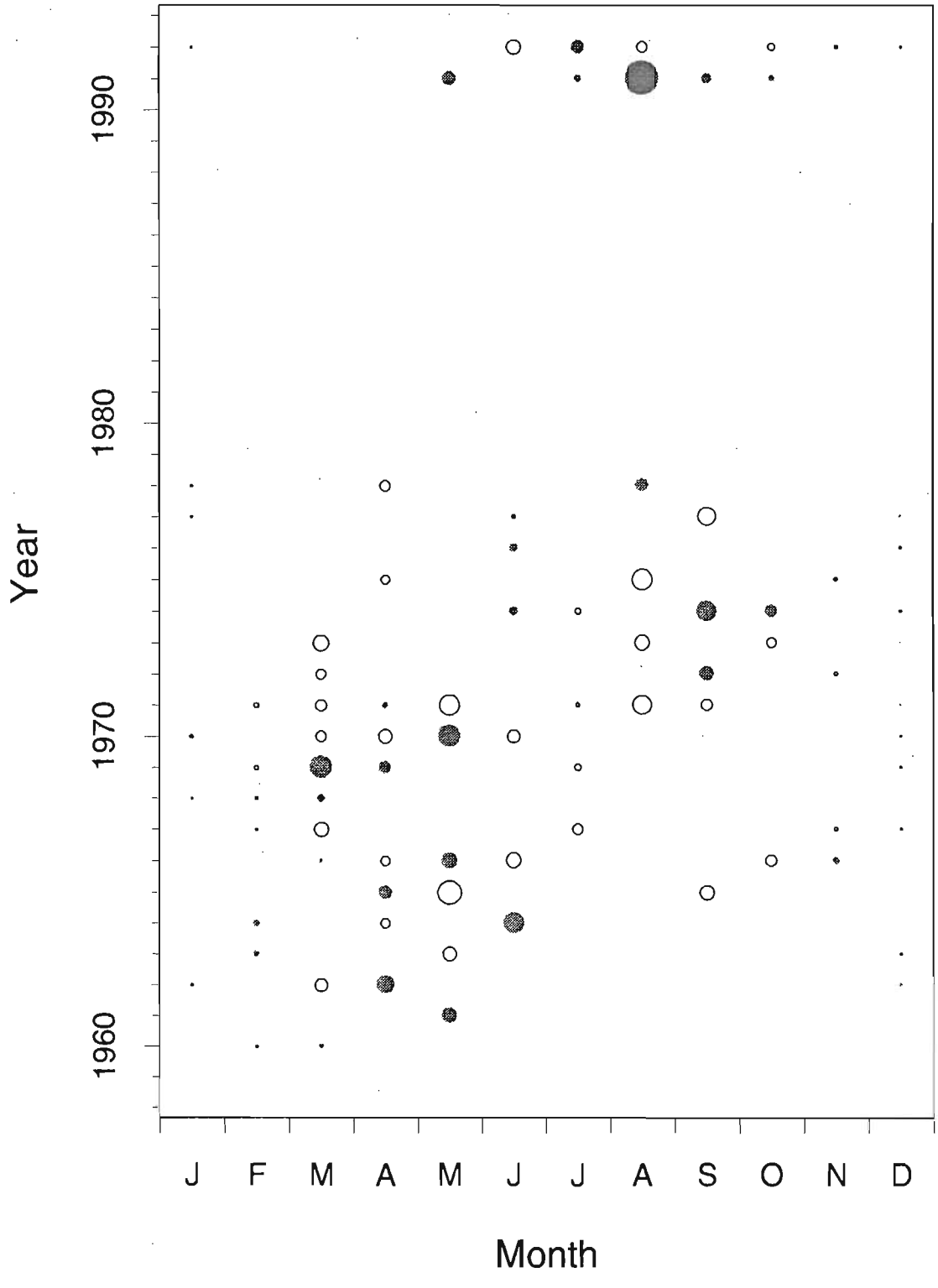
Largest circle represents an absolute anomaly of 677.

OS2 : Phytoplankton colour



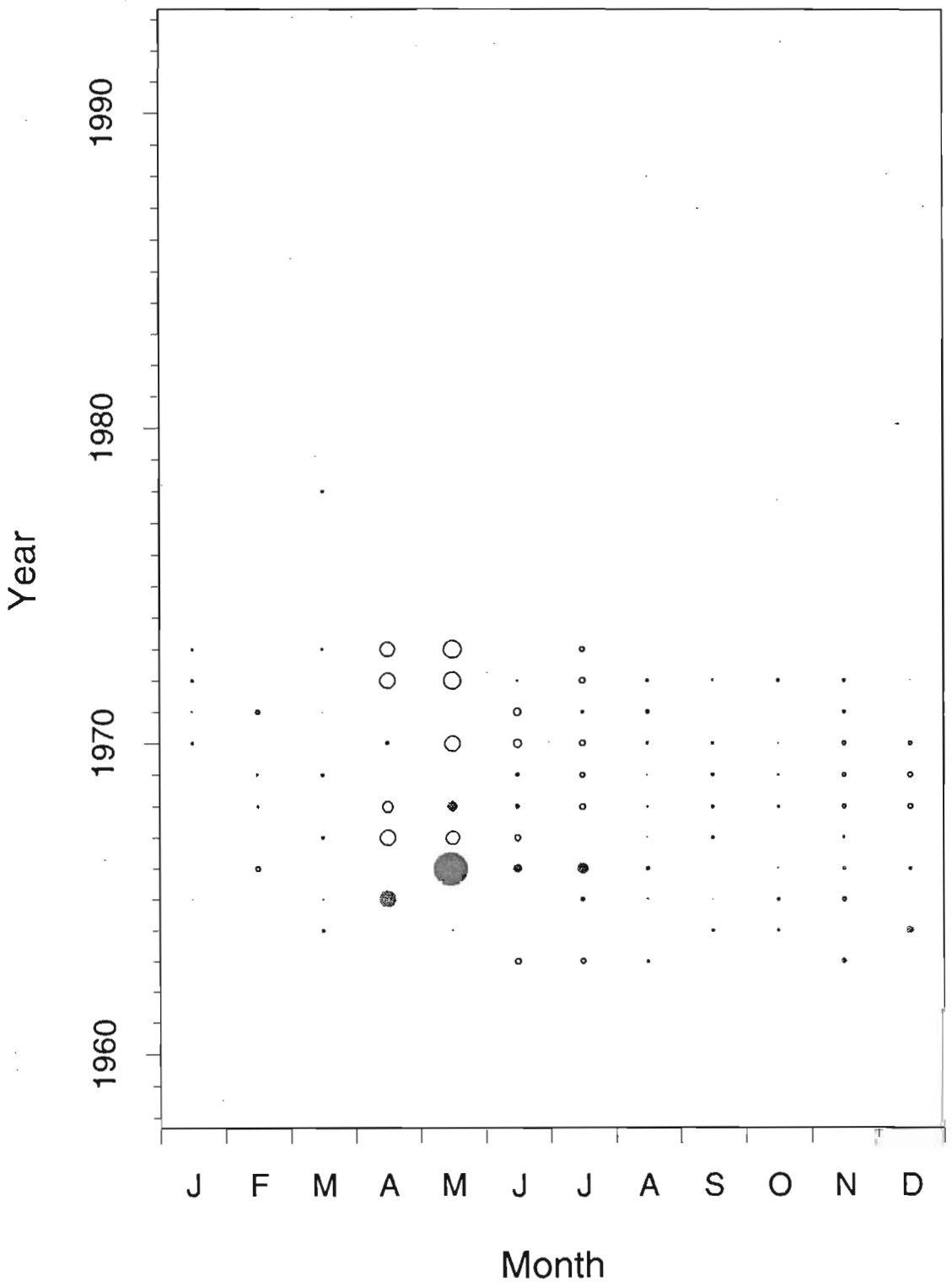
Largest circle represents an absolute anomaly of 1.7.

OS2 : Calanus V-VI Total



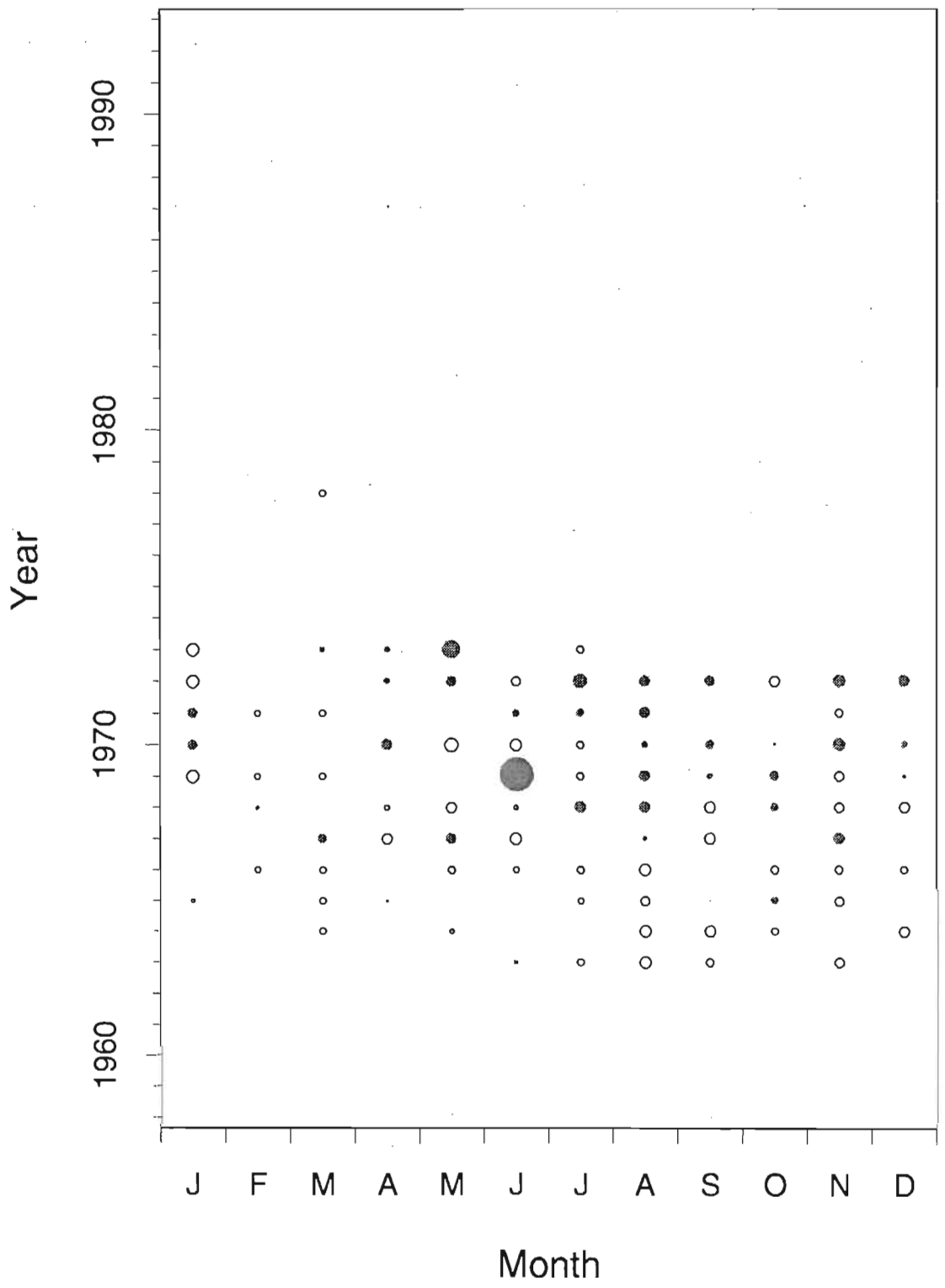
Largest circle represents an absolute anomaly of 216.

OS3 : Calanus I-IV



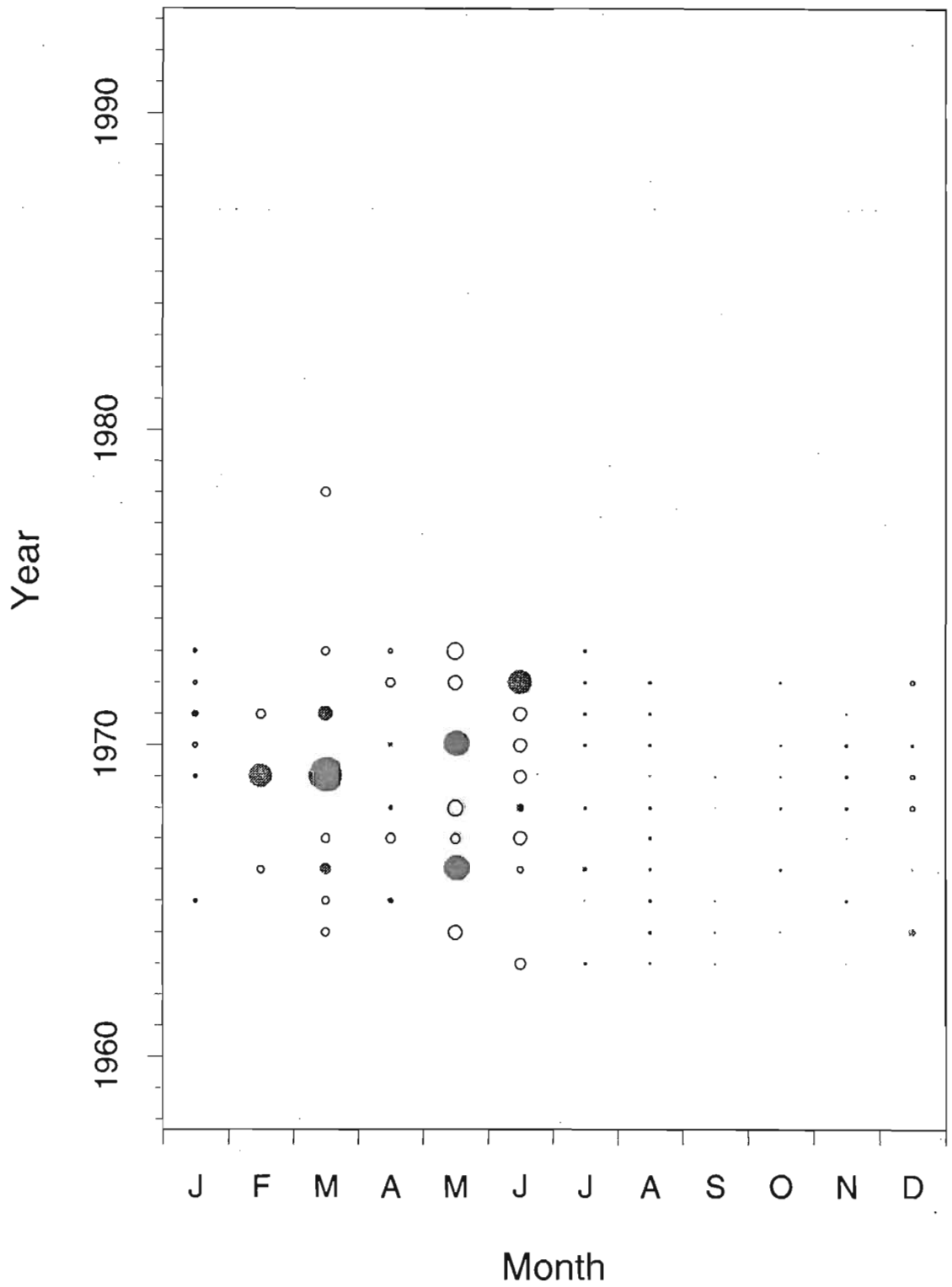
Largest circle represents an absolute anomaly of 1462.

OS3 : Phytoplankton colour



Largest circle represents an absolute anomaly of 4.1.

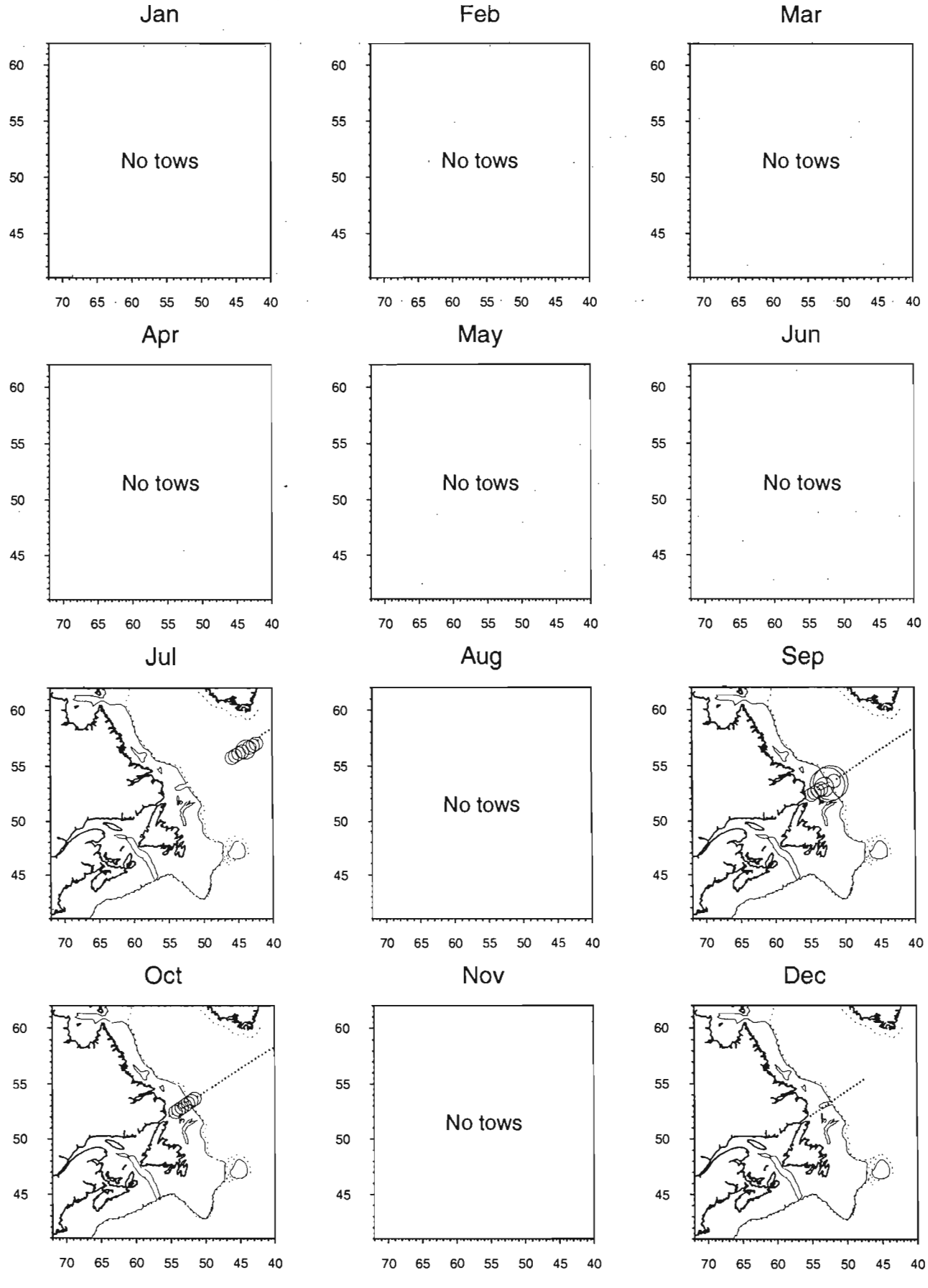
OS3 : Calanus V-VI Total



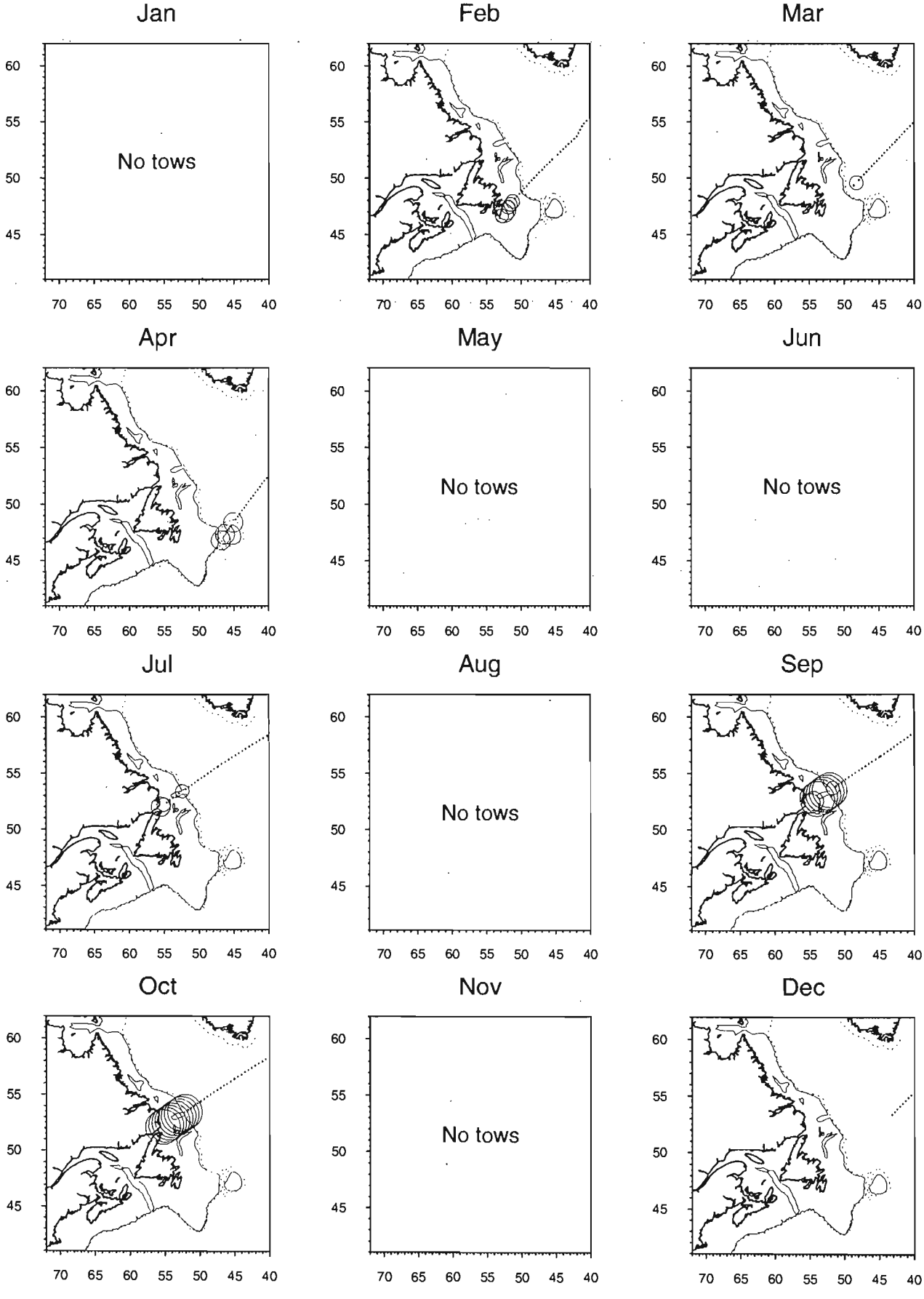
Largest circle represents an absolute anomaly of 278.

Figure 4. Monthly maps of CPR sampling and plankton abundance for Phytoplankton colour index, and *Calanus* stages V-VI. The title of each page indicates the year and taxon. In each map, expanding circles represent the abundance of the taxon in the sample. The scaling for each taxon is constant between maps: the area of the circle is proportional to the observed count, with the largest observation represented by a circle with $\frac{1}{2}$-inch diameter. For Phytoplankton colour index the largest observation is 6.5. For *Calanus* stages V-VI the largest observation is 2690. Samples in which there was no observation of the taxon in question are denoted by a cross (+).

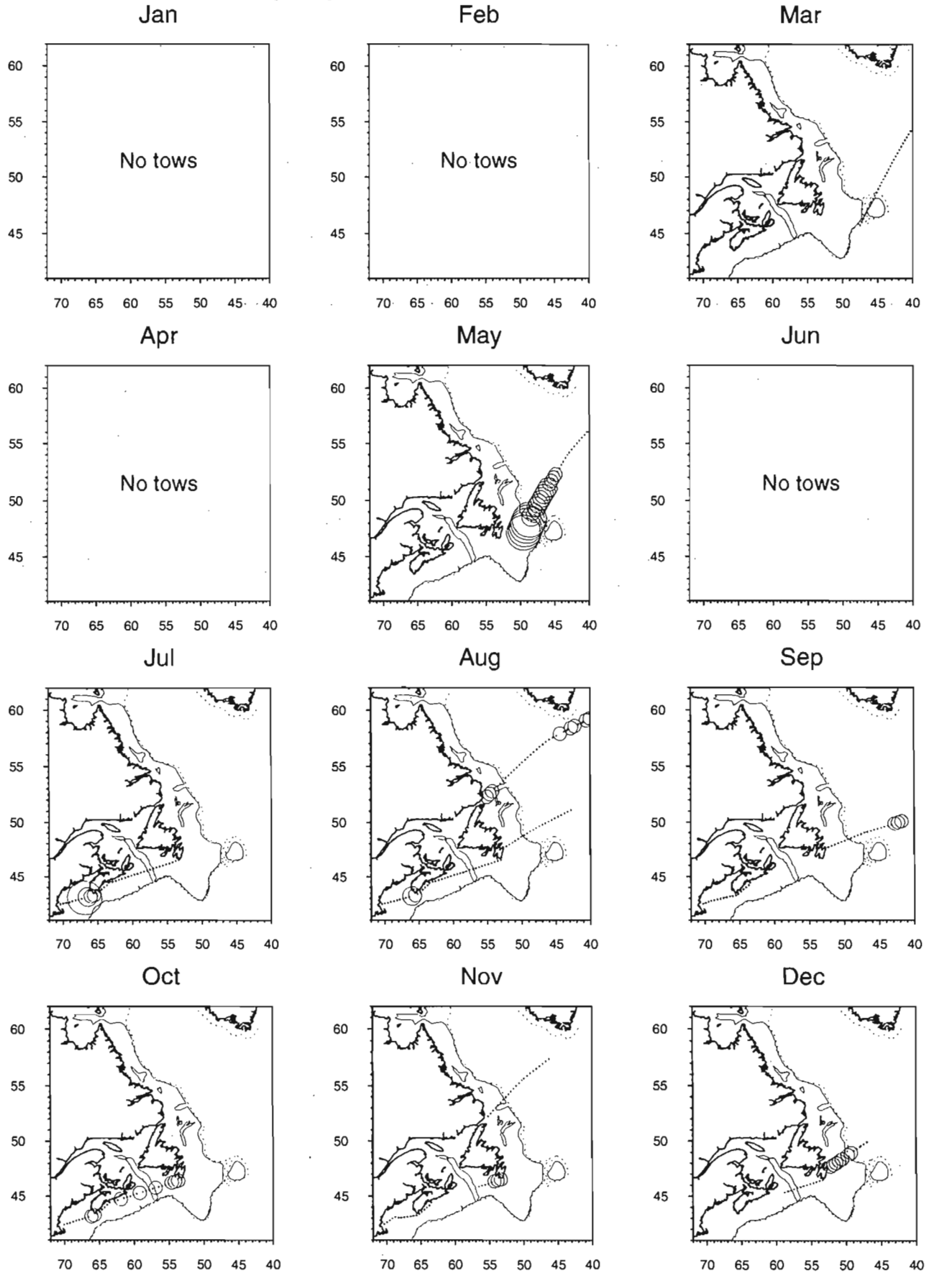
Phytoplankton colour : 1959



Phytoplankton colour : 1960

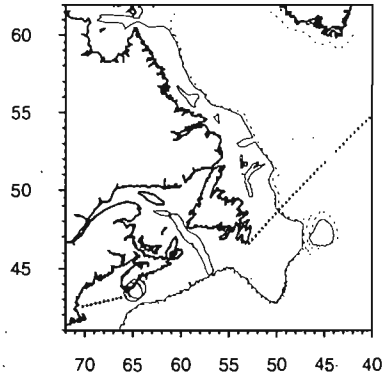


Phytoplankton colour : 1961

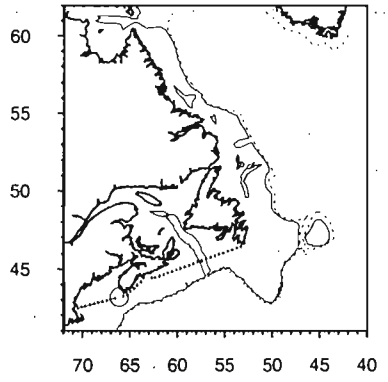


Phytoplankton colour : 1962

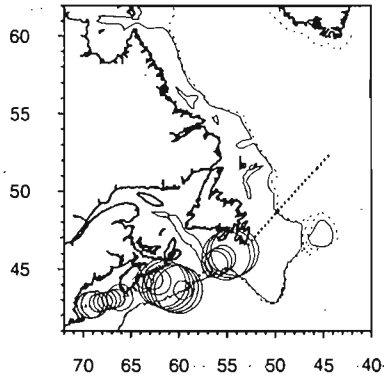
Jan



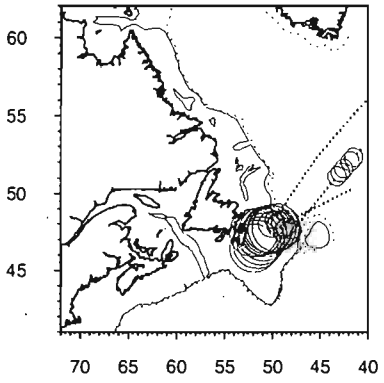
Feb



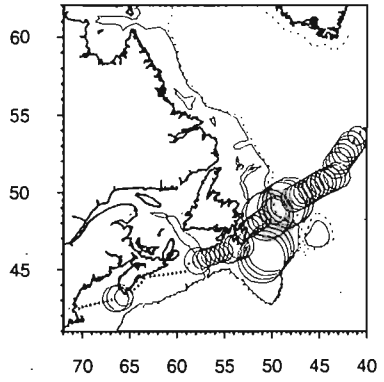
Mar



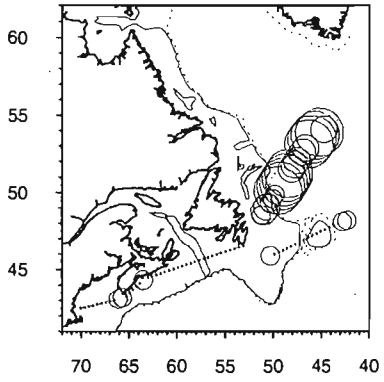
Apr



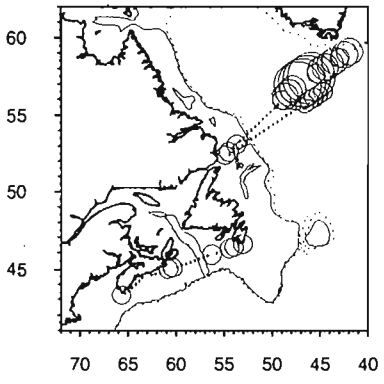
May



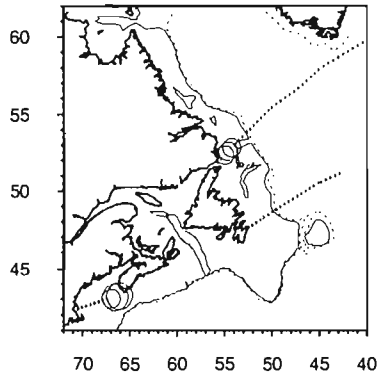
Jun



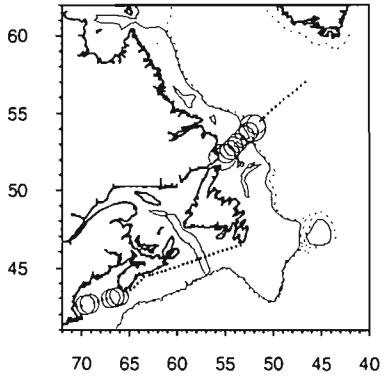
Jul



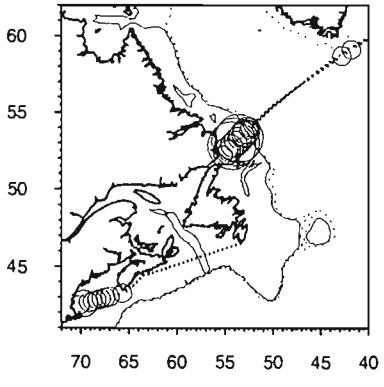
Aug



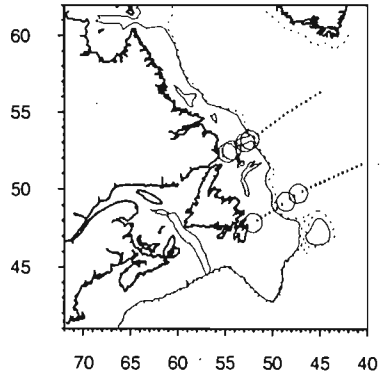
Sep



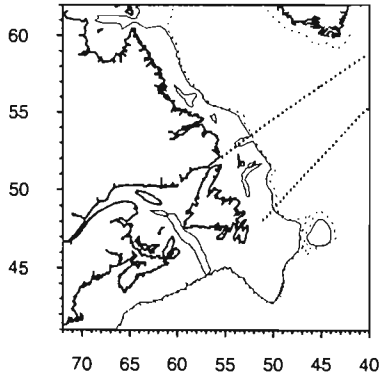
Oct



Nov

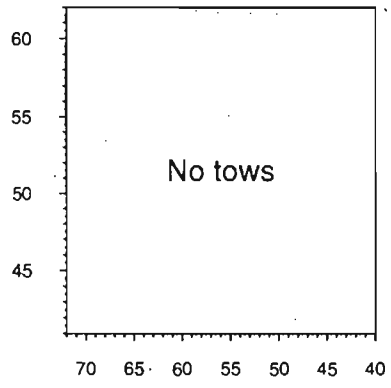


Dec

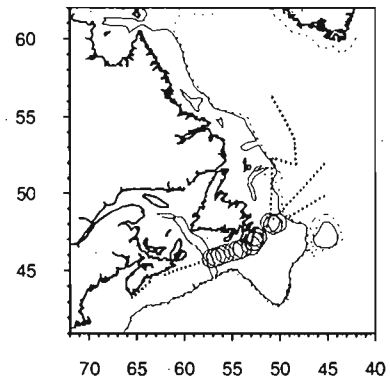


Phytoplankton colour : 1963

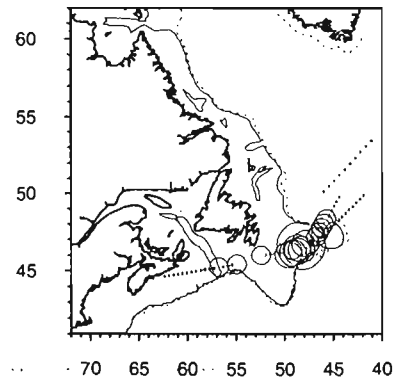
Jan



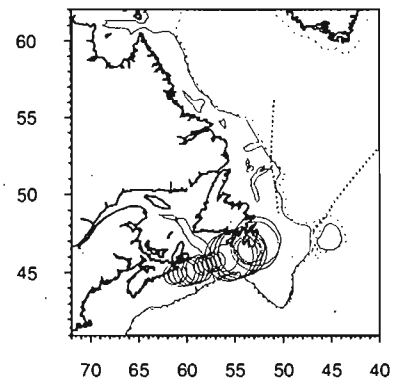
Feb



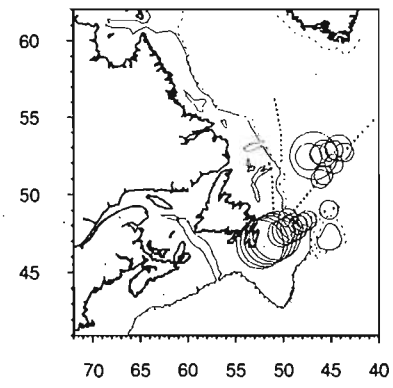
Mar



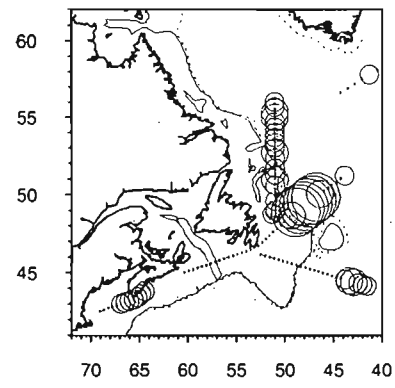
Apr



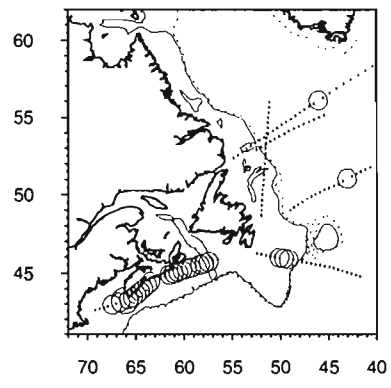
May



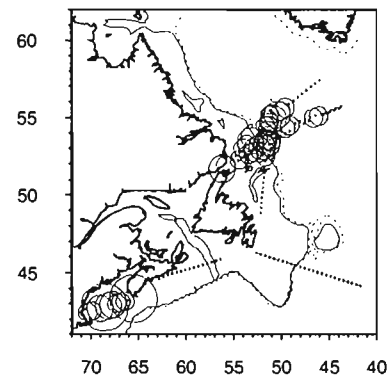
Jun



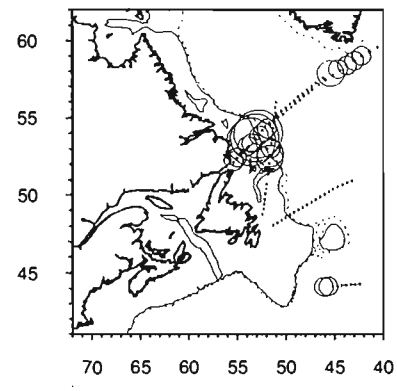
Jul



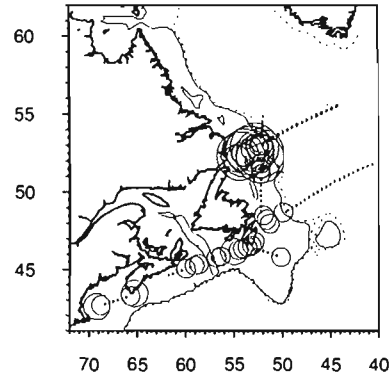
Aug



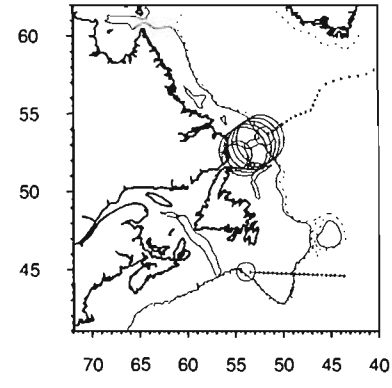
Sep



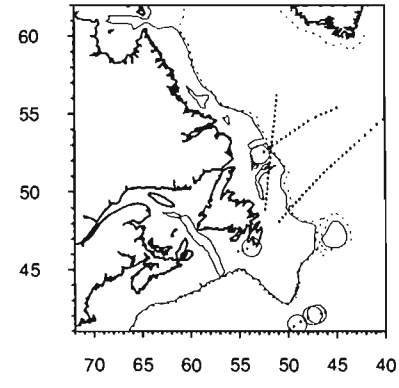
Oct



Nov

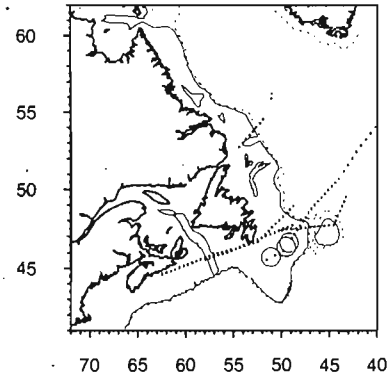


Dec

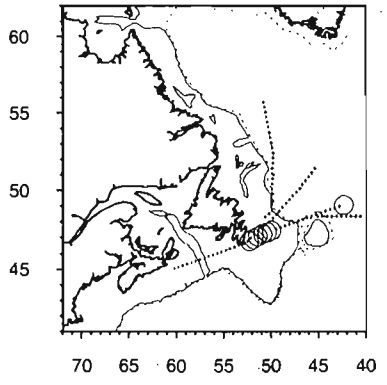


Phytoplankton colour : 1964

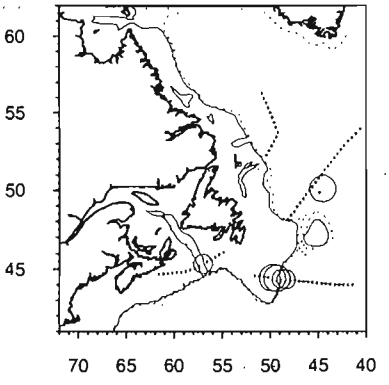
Jan



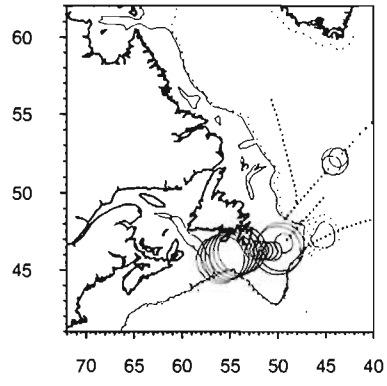
Feb



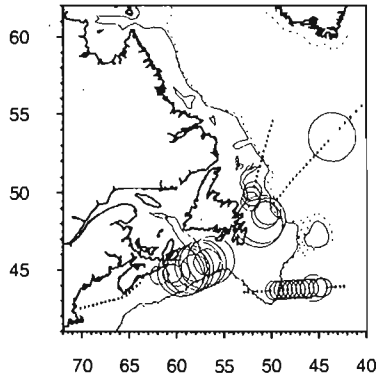
Mar



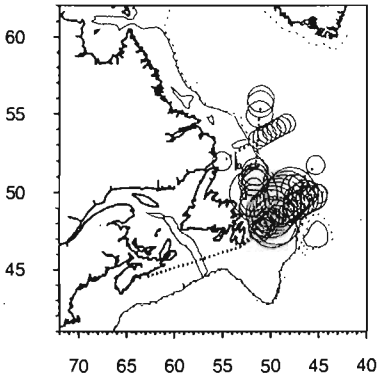
Apr



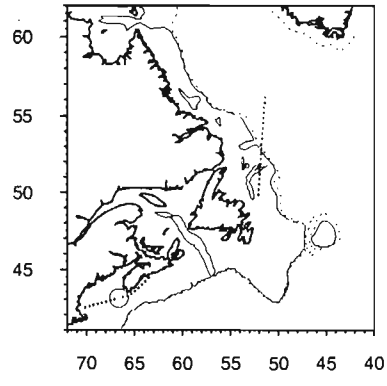
May



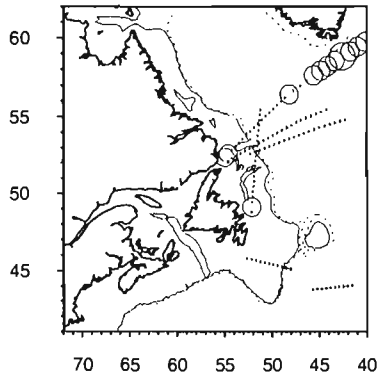
Jun



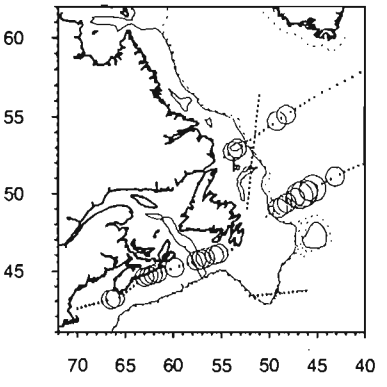
Jul



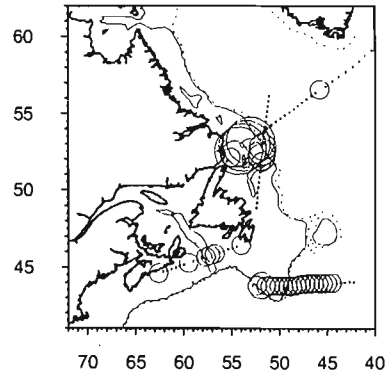
Aug



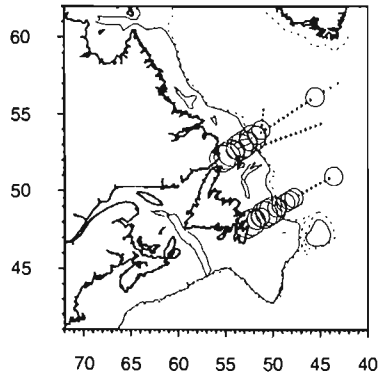
Sep



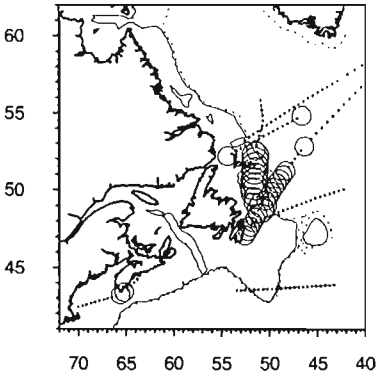
Oct



Nov

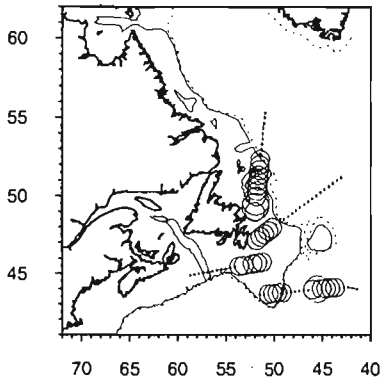


Dec

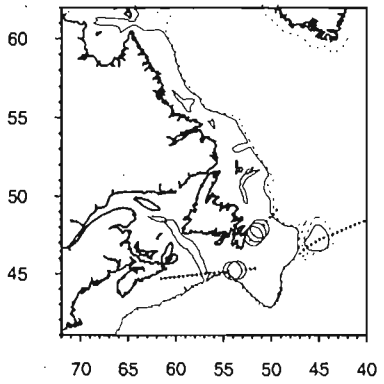


Phytoplankton colour : 1965

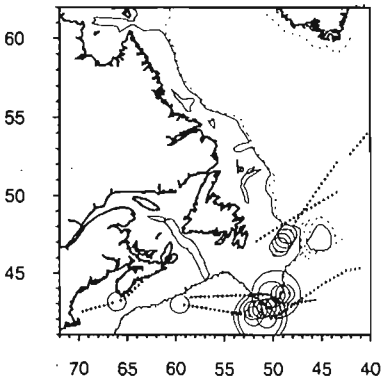
Jan



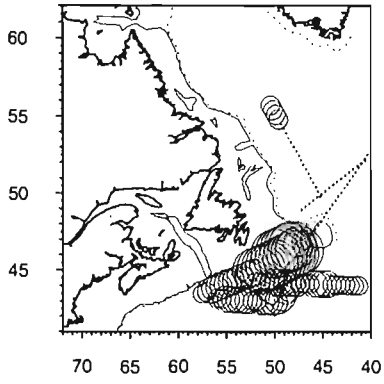
Feb



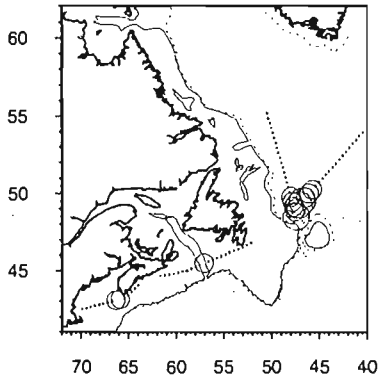
Mar



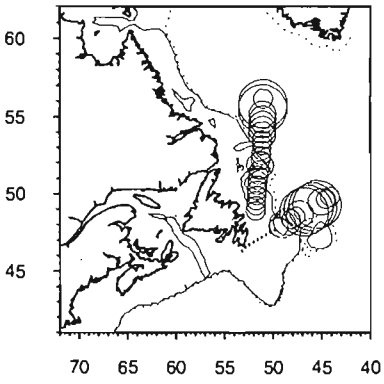
Apr



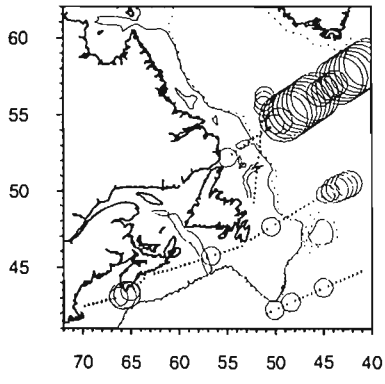
May



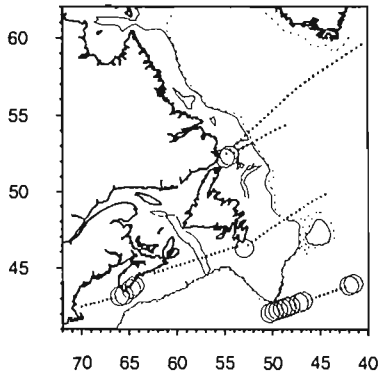
Jun



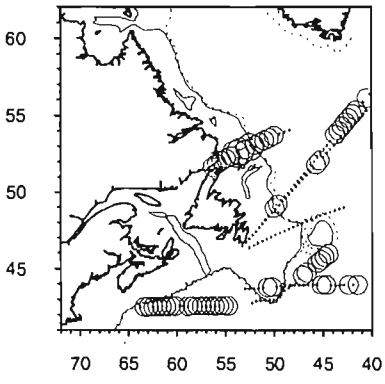
Jul



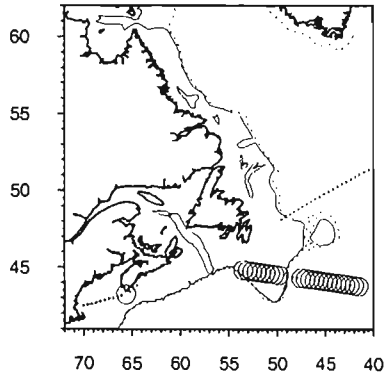
Aug



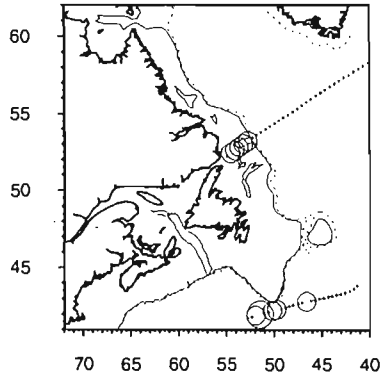
Sep



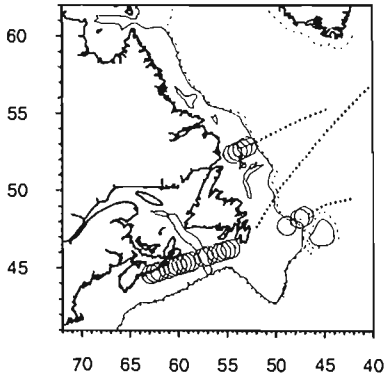
Oct



Nov

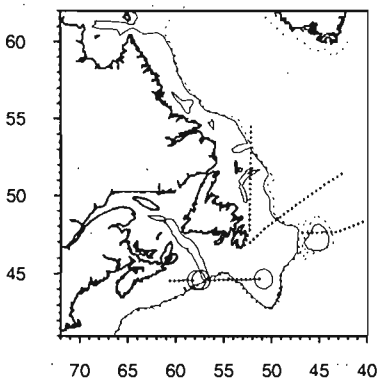


Dec

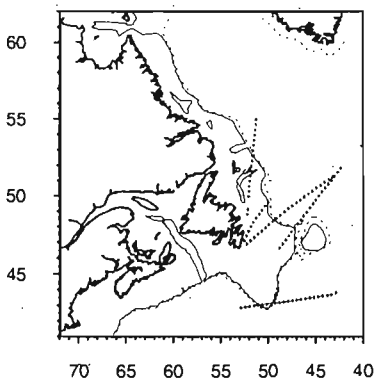


Phytoplankton colour : 1966

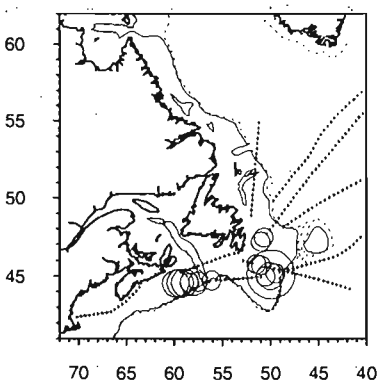
Jan



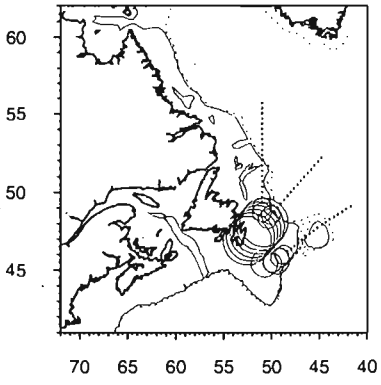
Feb



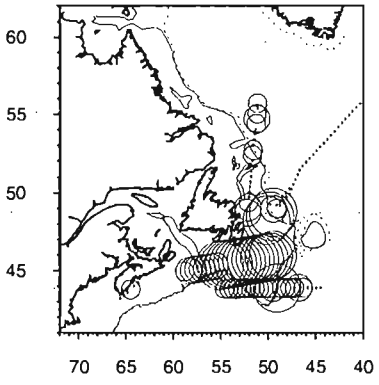
Mar



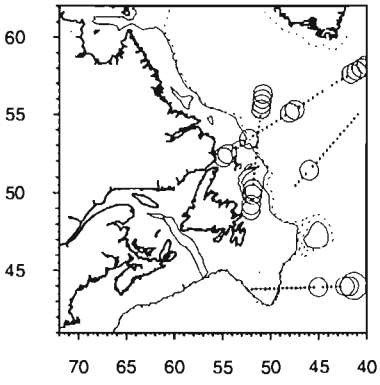
Apr



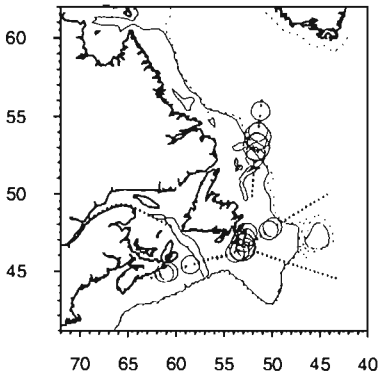
May



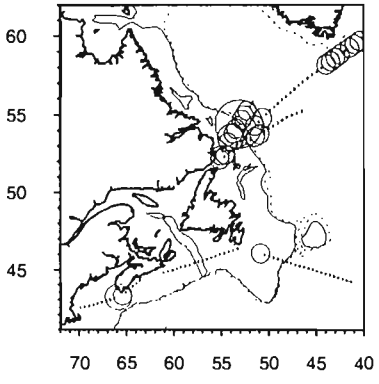
Jun



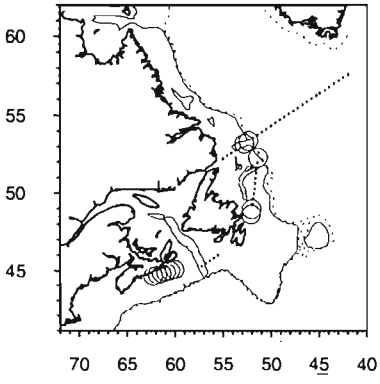
Jul



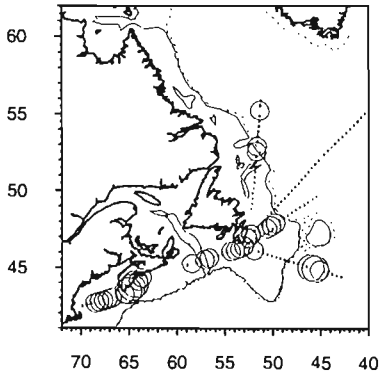
Aug



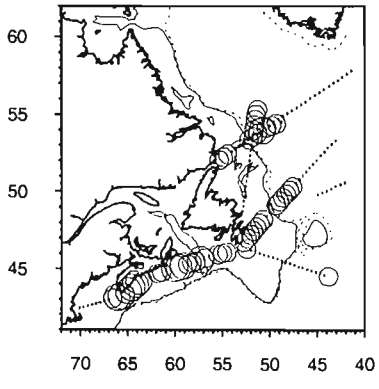
Sep



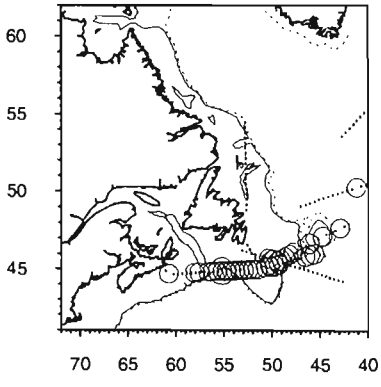
Oct



Nov

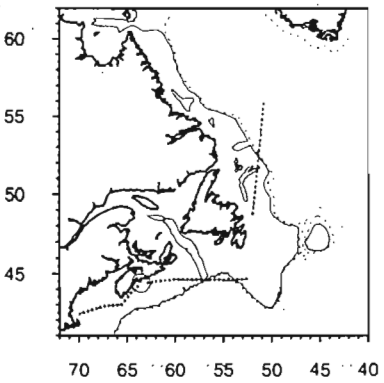


Dec

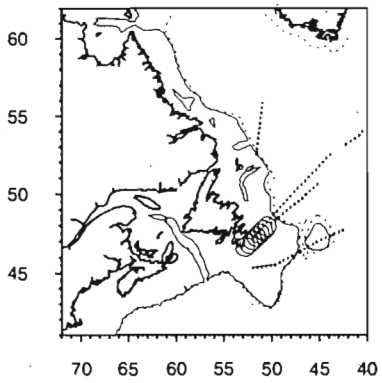


Phytoplankton colour : 1967

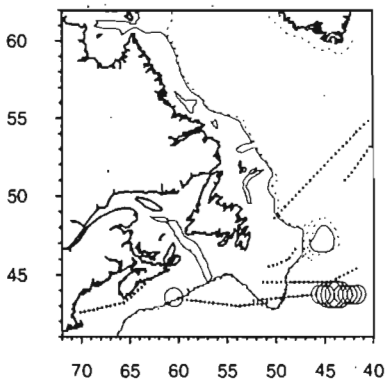
Jan



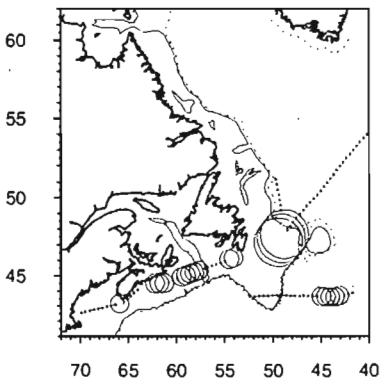
Feb



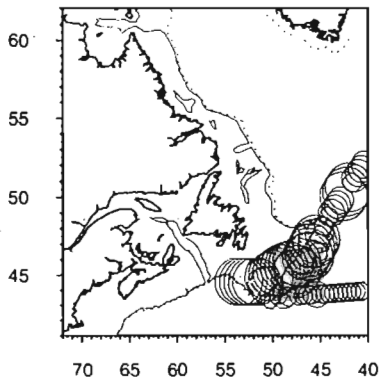
Mar



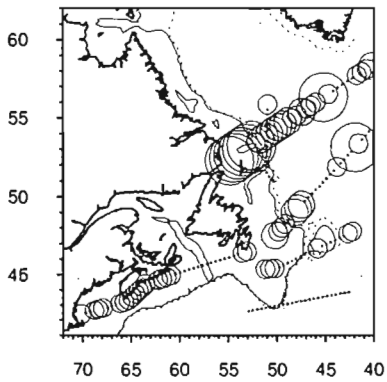
Apr



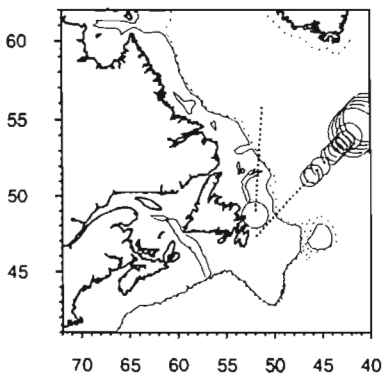
May



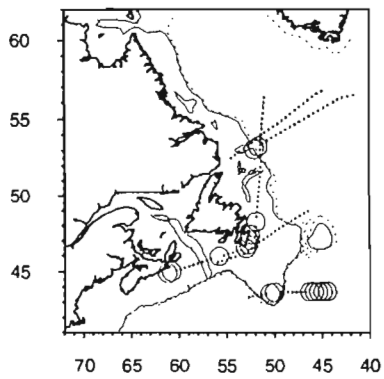
Jun



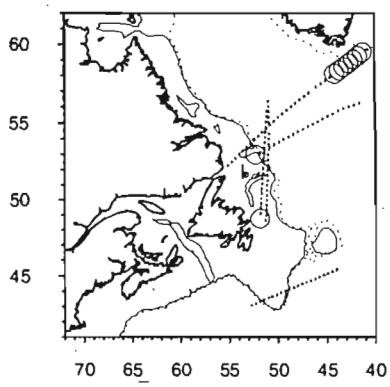
Jul



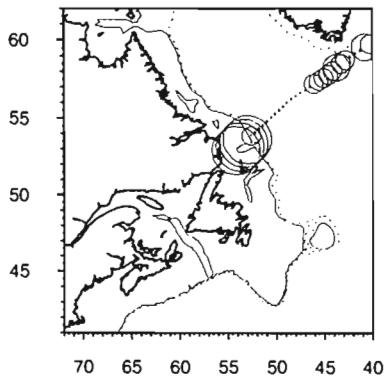
Aug



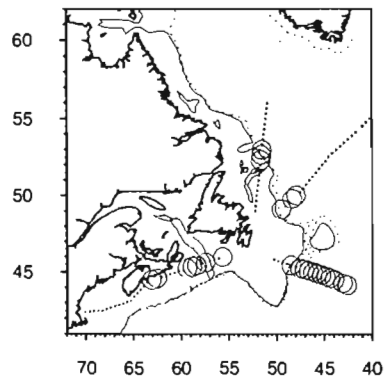
Sep



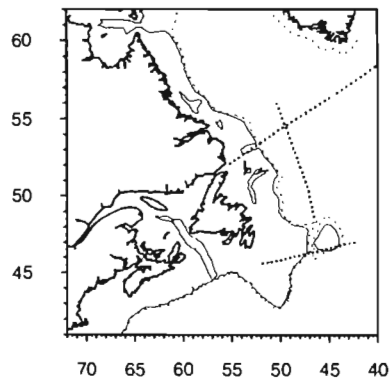
Oct



Nov

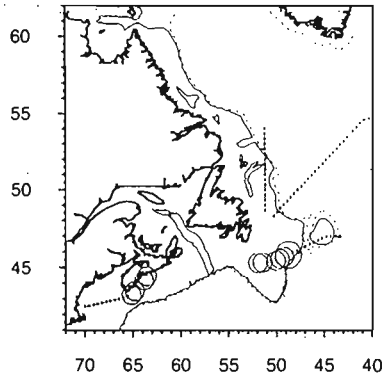


Dec

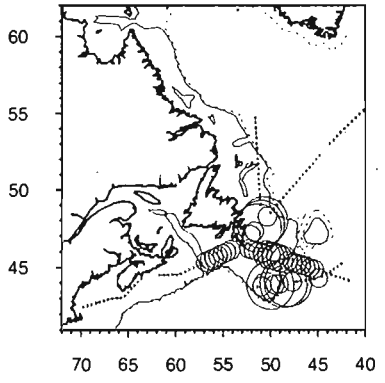


Phytoplankton colour : 1968

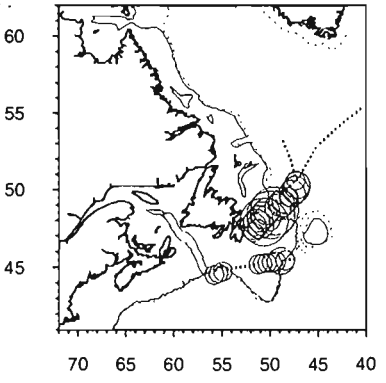
Jan



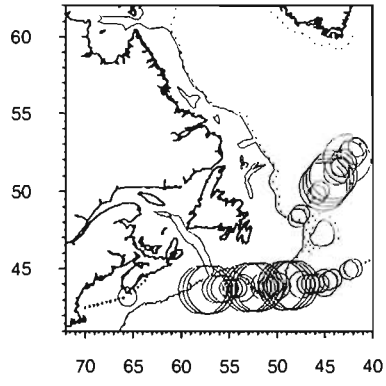
Feb



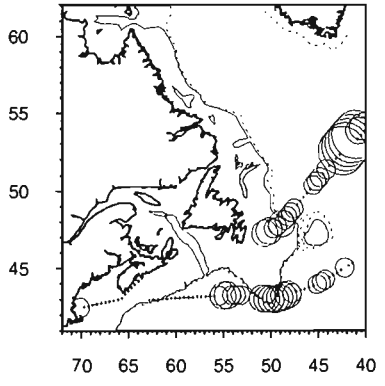
Mar



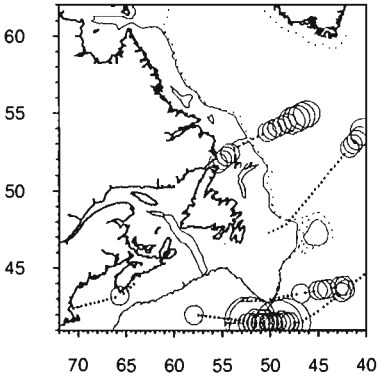
Apr



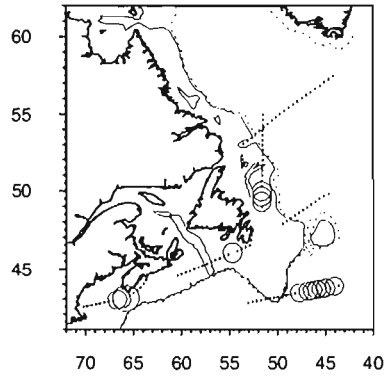
May



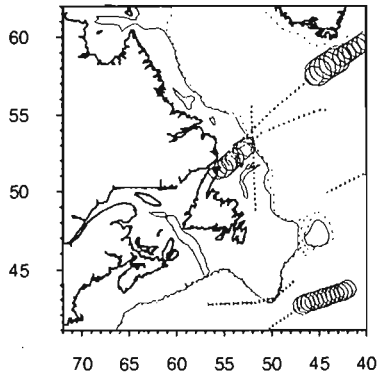
Jun



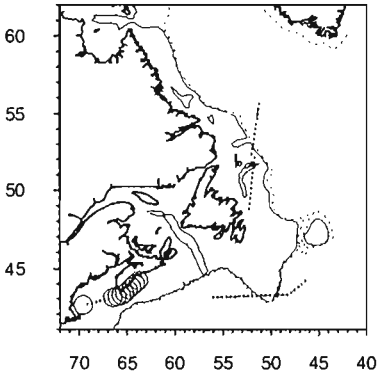
Jul



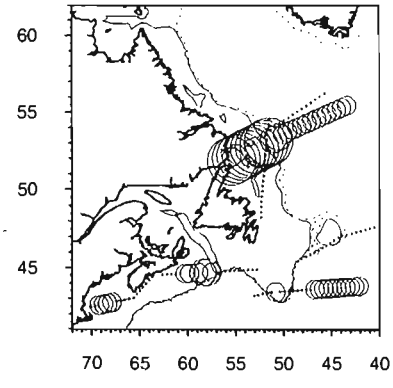
Aug



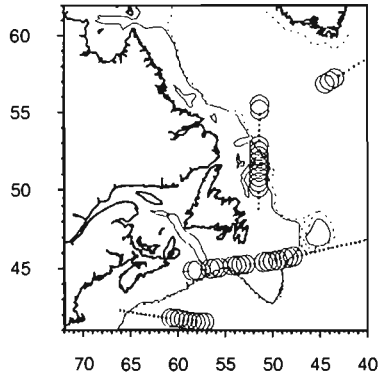
Sep



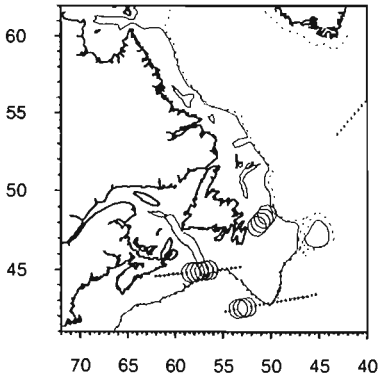
Oct



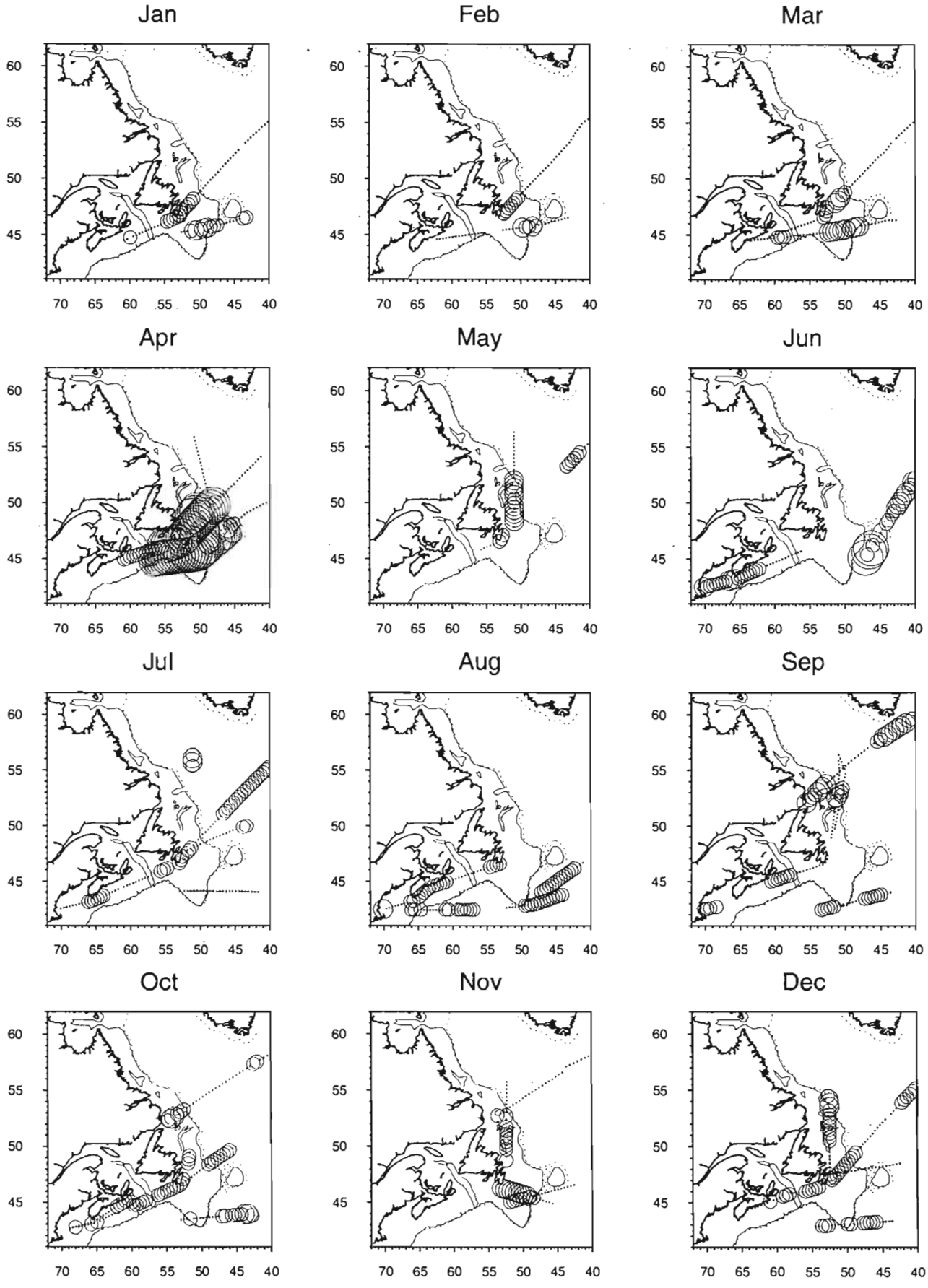
Nov



Dec

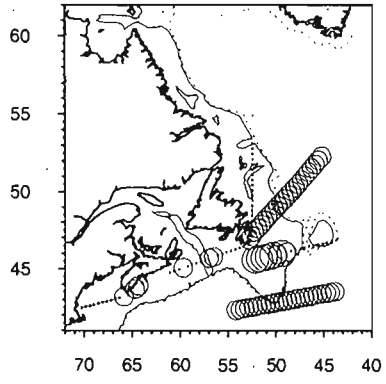


Phytoplankton colour : 1969

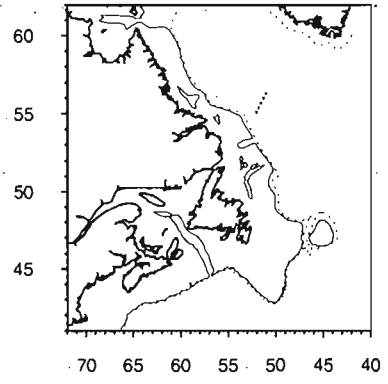


Phytoplankton colour : 1970

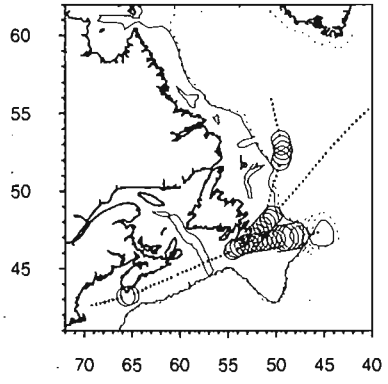
Jan



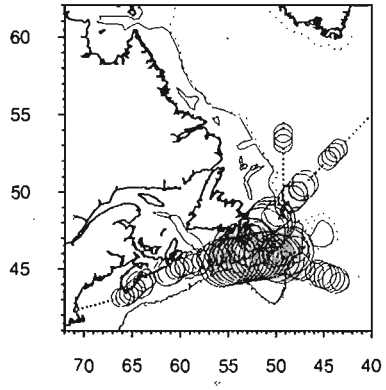
Feb



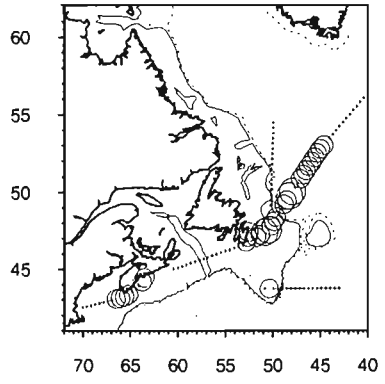
Mar



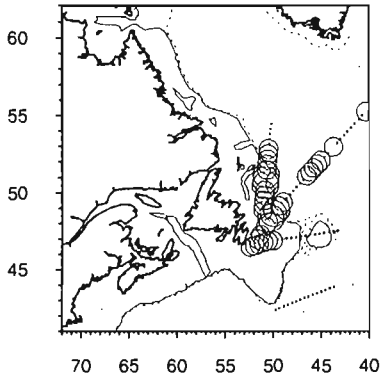
Apr



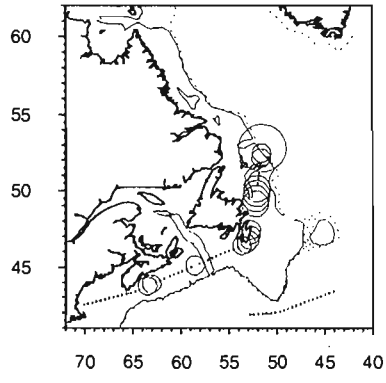
May



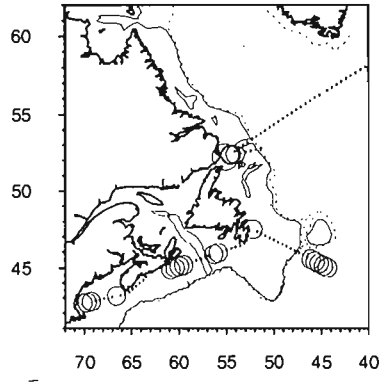
Jun



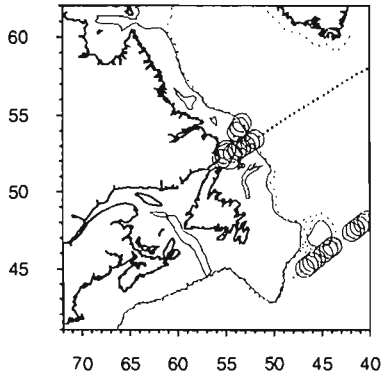
Jul



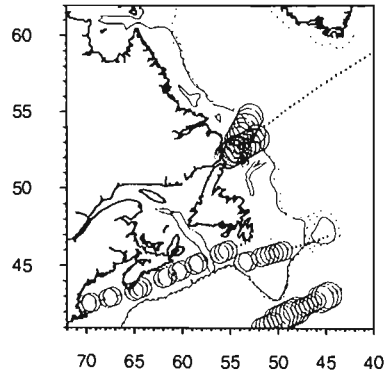
Aug



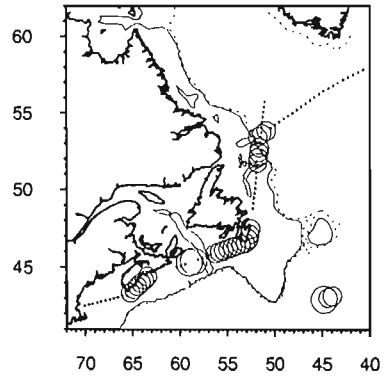
Sep



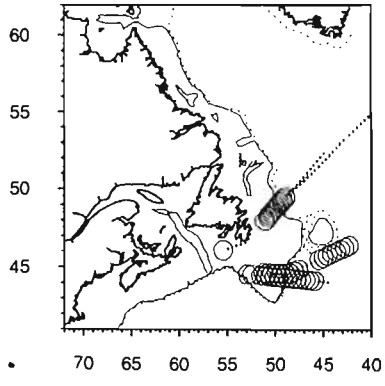
Oct



Nov

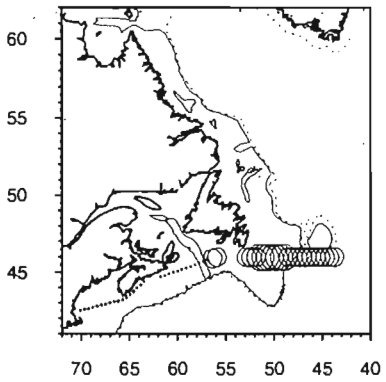


Dec

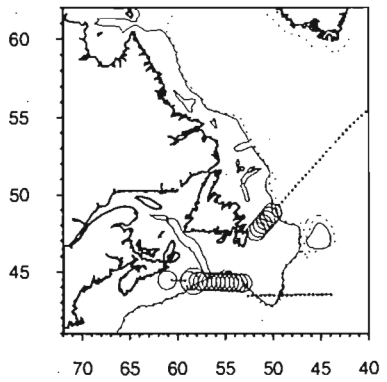


Phytoplankton colour : 1971

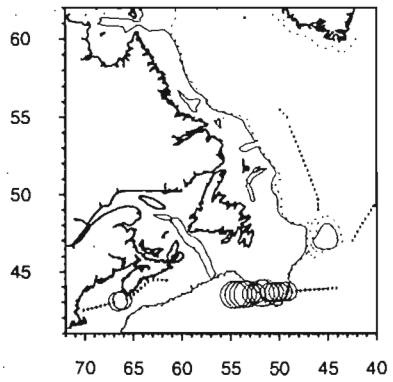
Jan



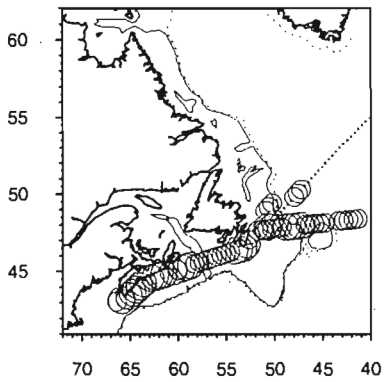
Feb



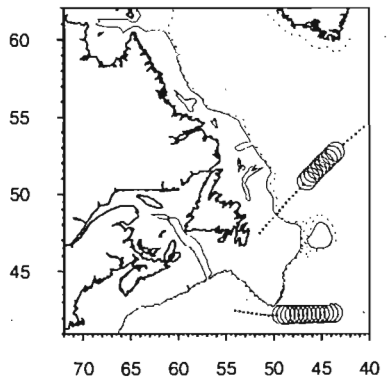
Mar



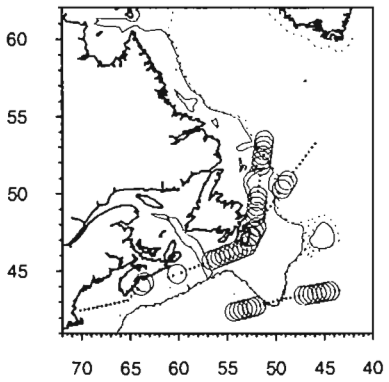
Apr



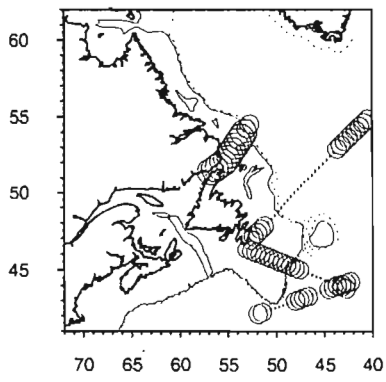
May



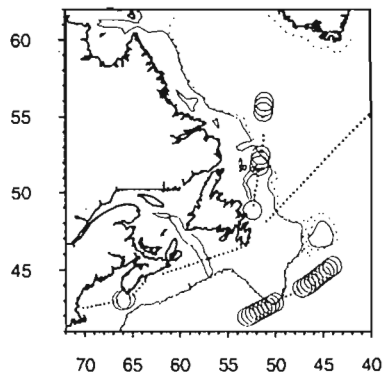
Jun



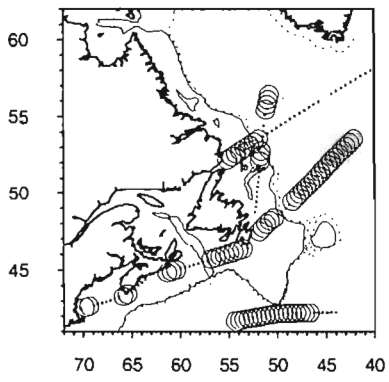
Jul



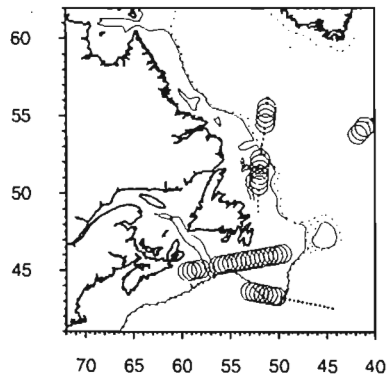
Aug



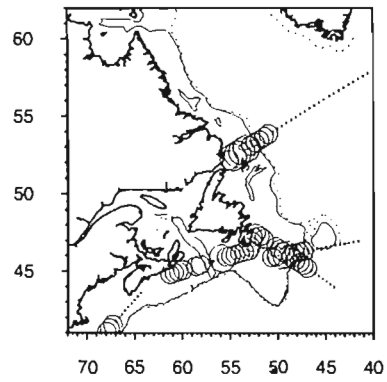
Sep



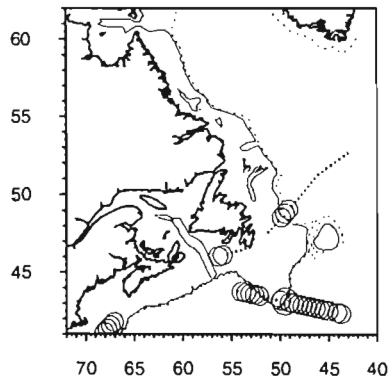
Oct



Nov

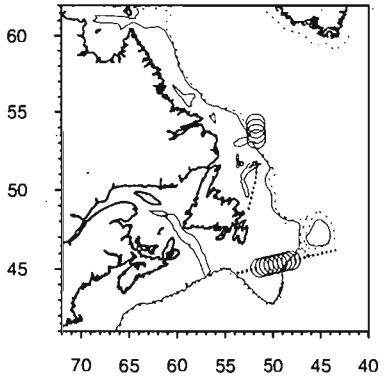


Dec

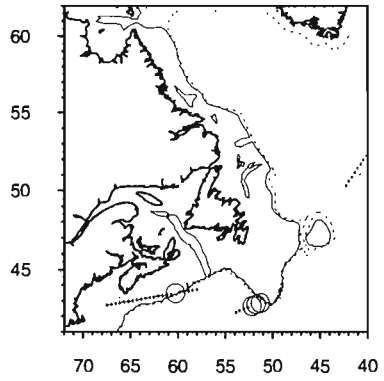


Phytoplankton colour : 1972

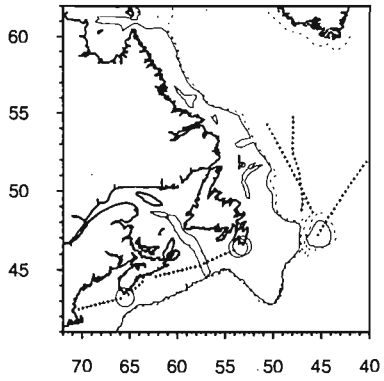
Jan



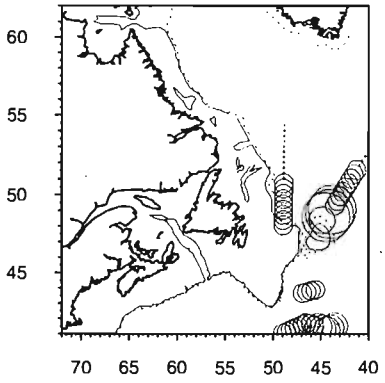
Feb



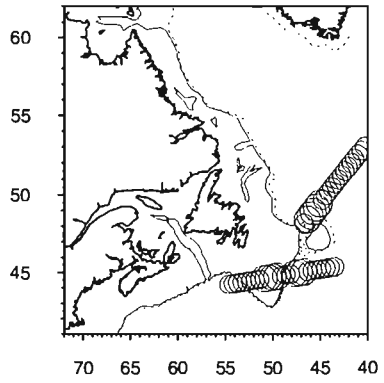
Mar



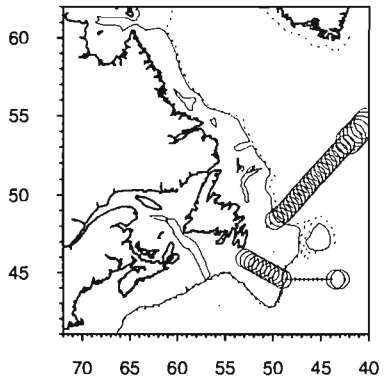
Apr



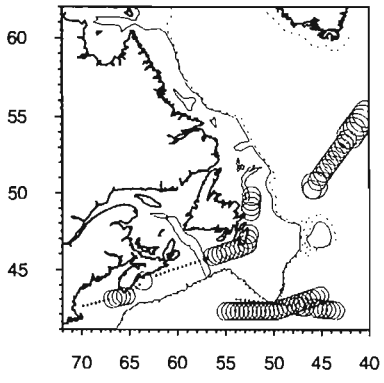
May



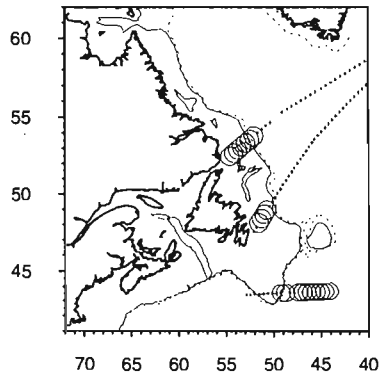
Jun



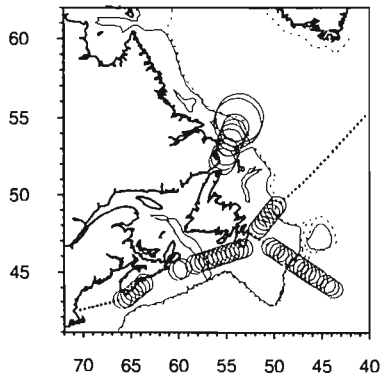
Jul



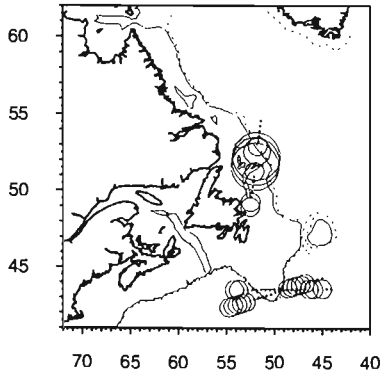
Aug



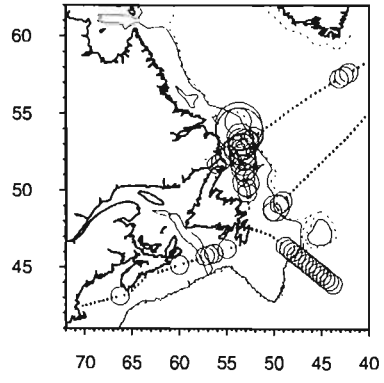
Sep



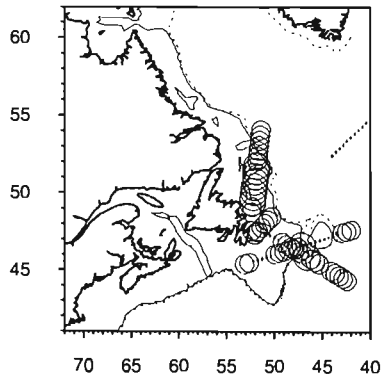
Oct



Nov

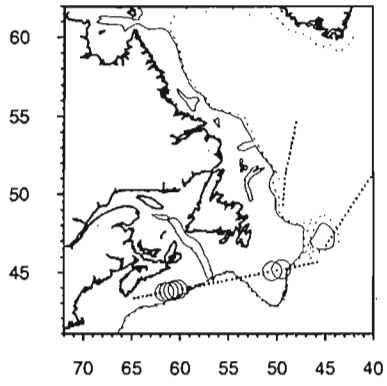


Dec

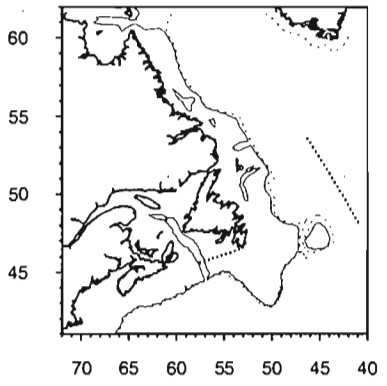


Phytoplankton colour : 1973

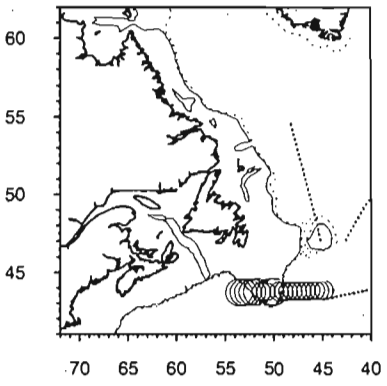
Jan



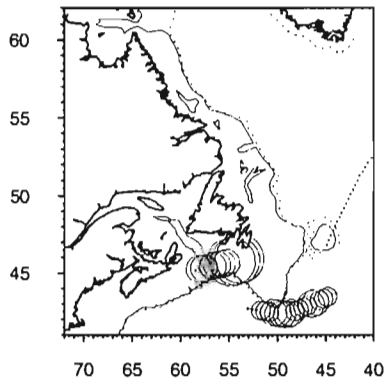
Feb



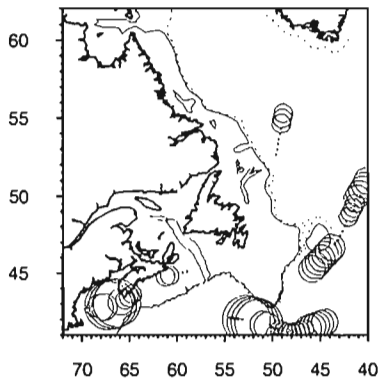
Mar



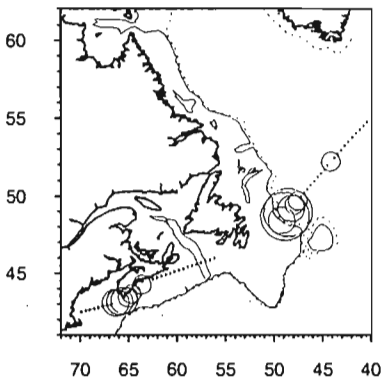
Apr



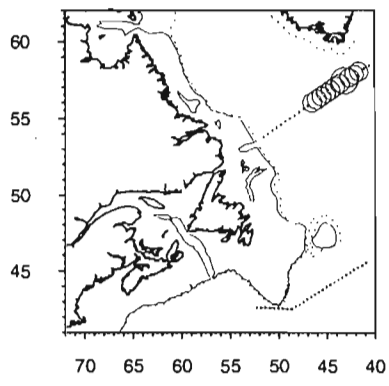
May



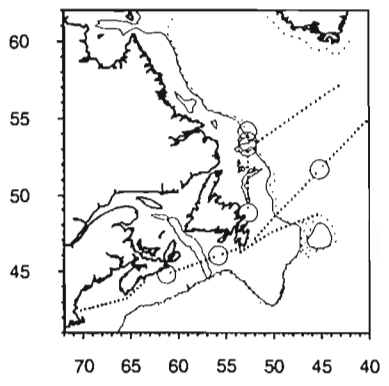
Jun



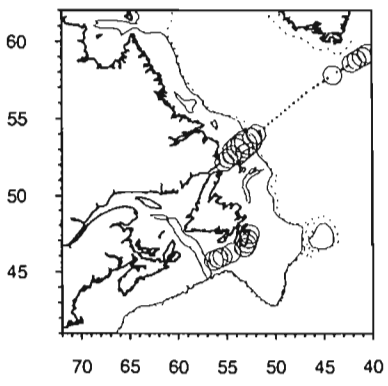
Jul



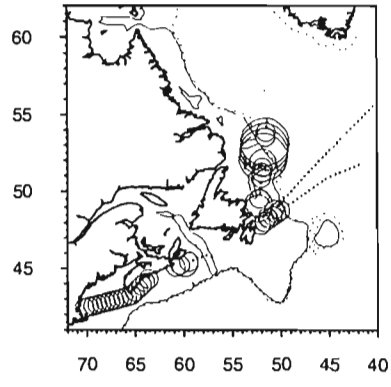
Aug



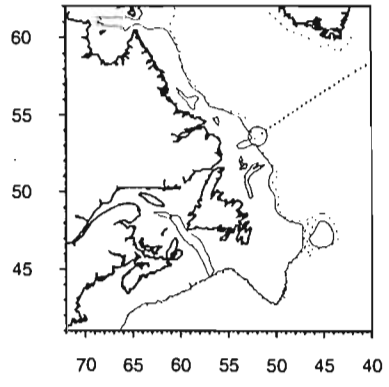
Sep



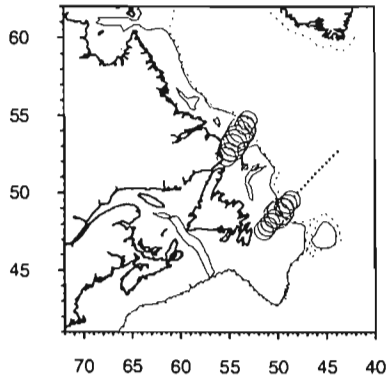
Oct



Nov

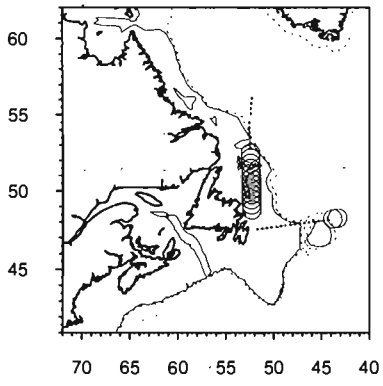


Dec

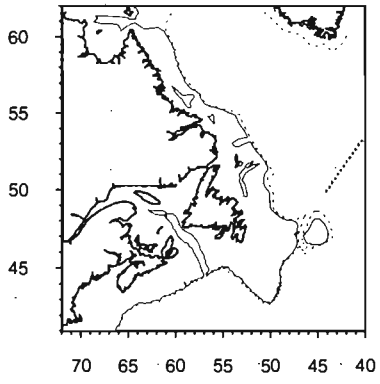


Phytoplankton colour : 1974

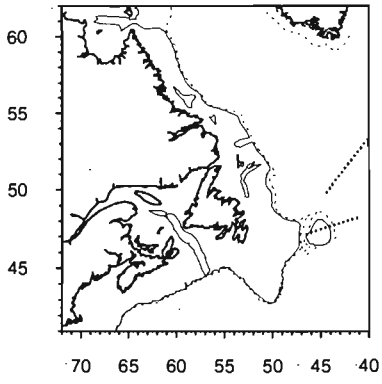
Jan



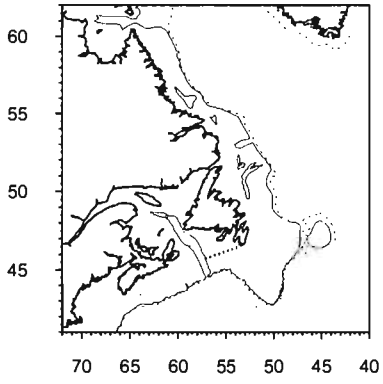
Feb



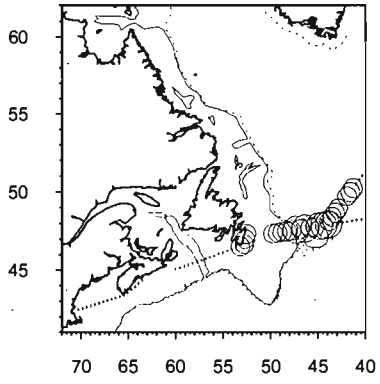
Mar



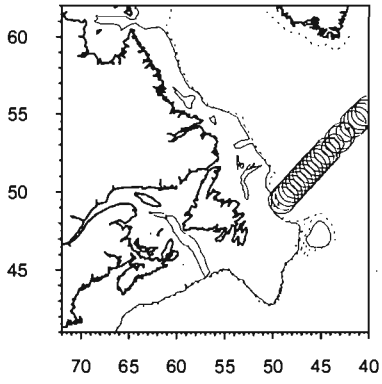
Apr



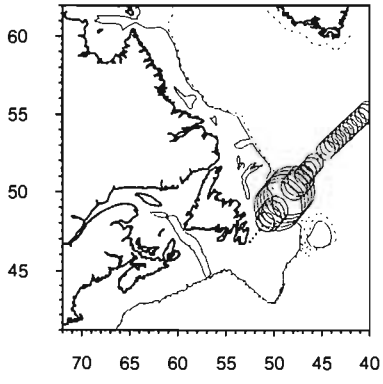
May



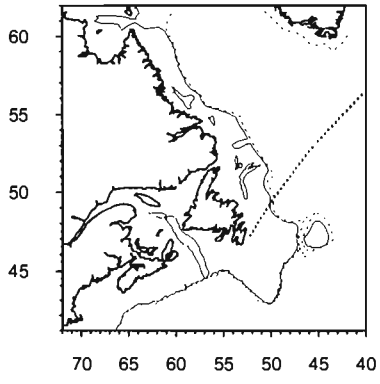
Jun



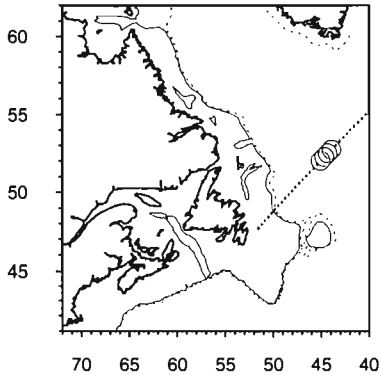
Jul



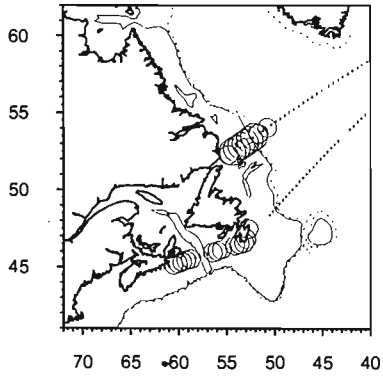
Aug



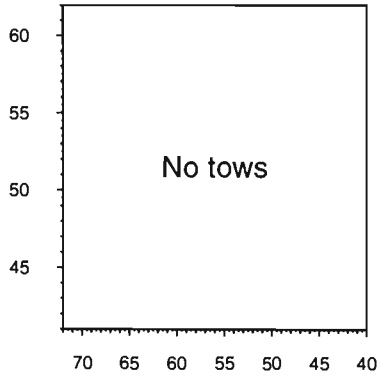
Sep



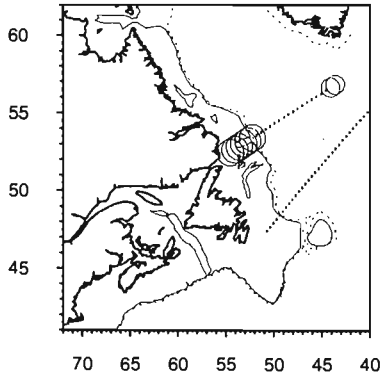
Oct



Nov

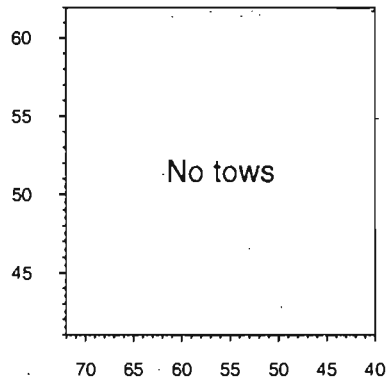


Dec

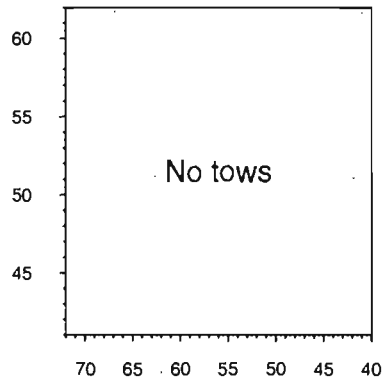


Phytoplankton colour : 1975

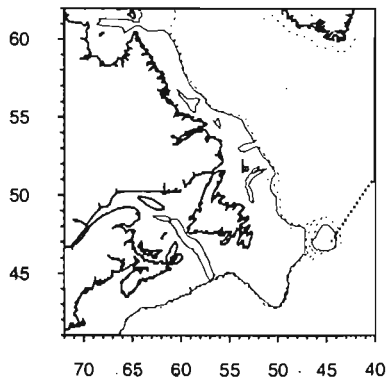
Jan



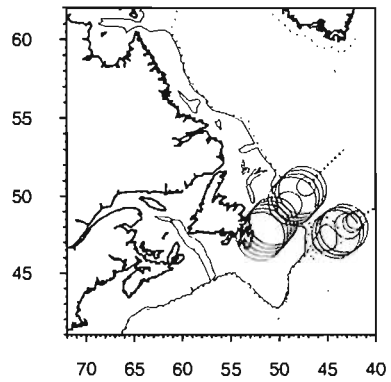
Feb



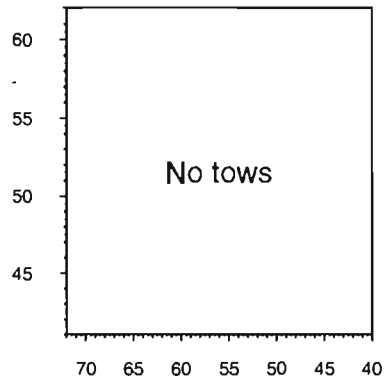
Mar



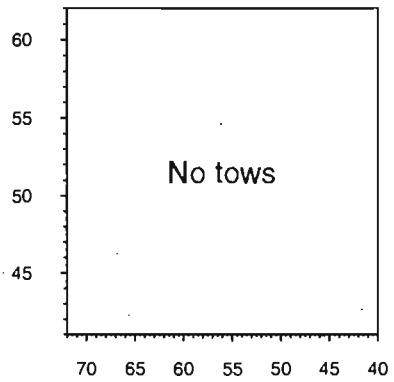
Apr



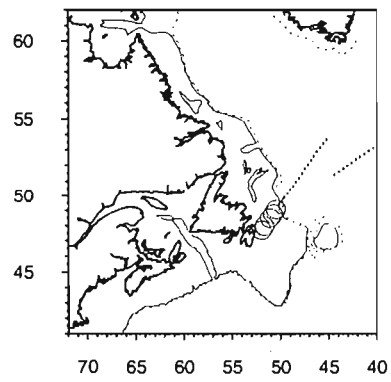
May



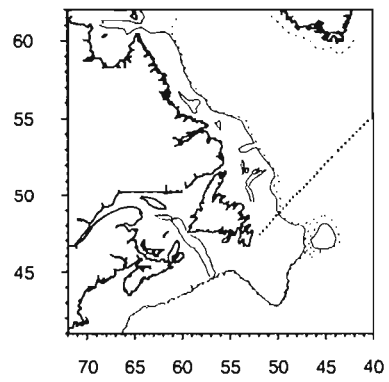
Jun



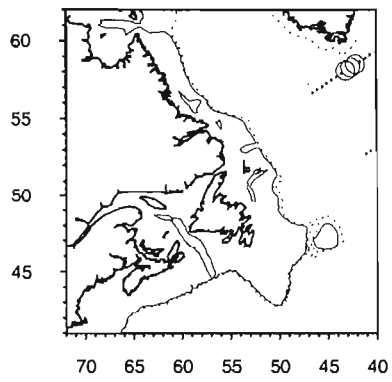
Jul



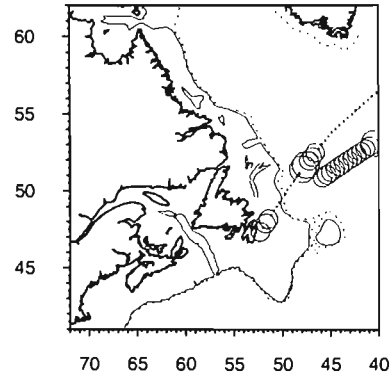
Aug



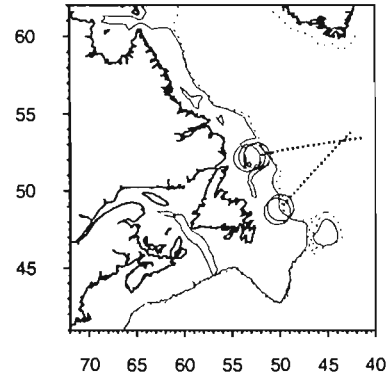
Sep



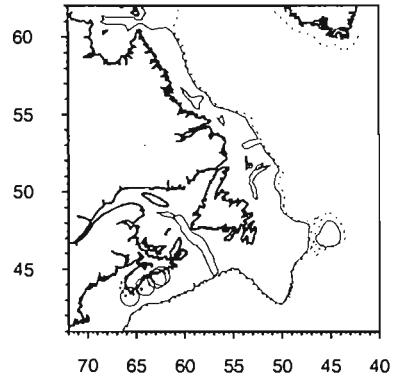
Oct



Nov

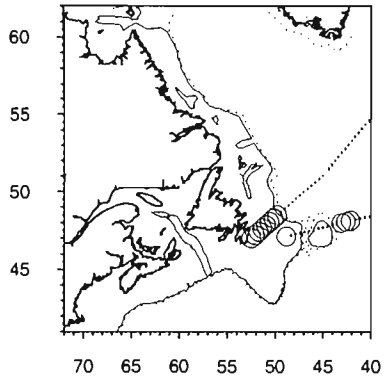


Dec

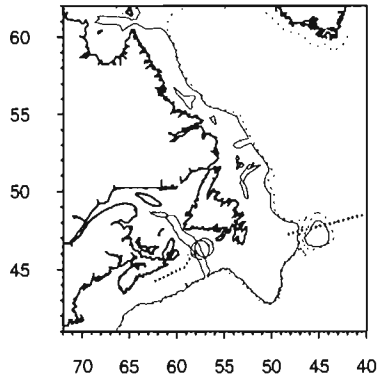


Phytoplankton colour : 1976

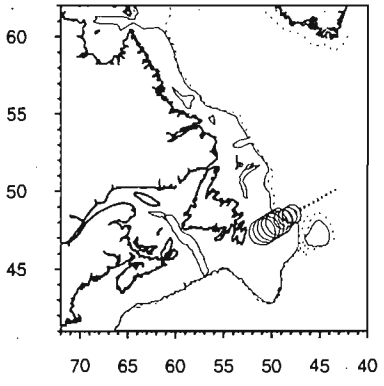
Jan



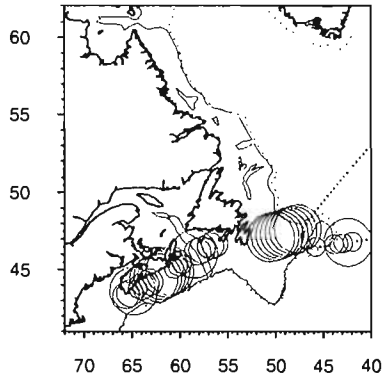
Feb



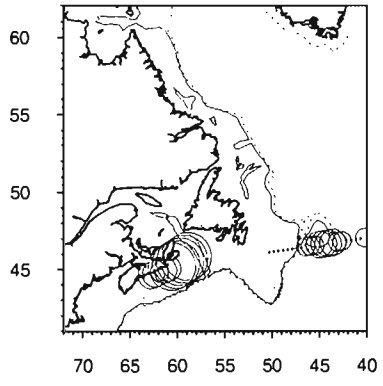
Mar



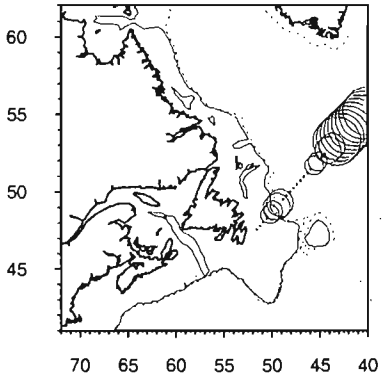
Apr



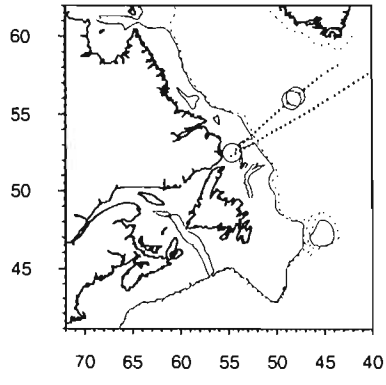
May



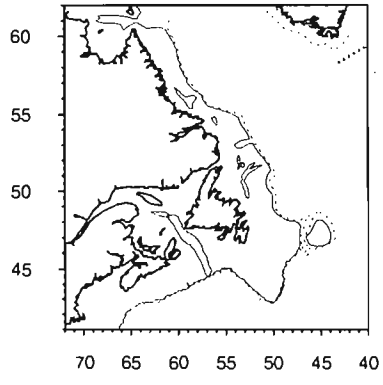
Jun



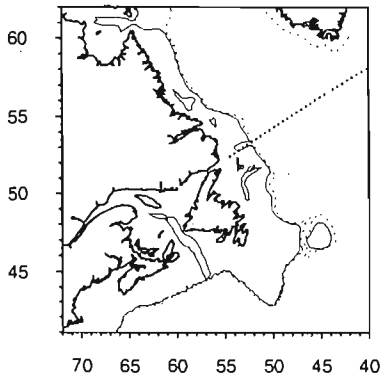
Jul



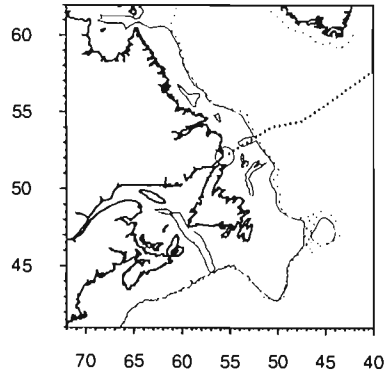
Aug



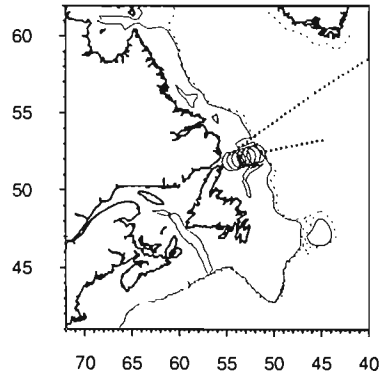
Sep



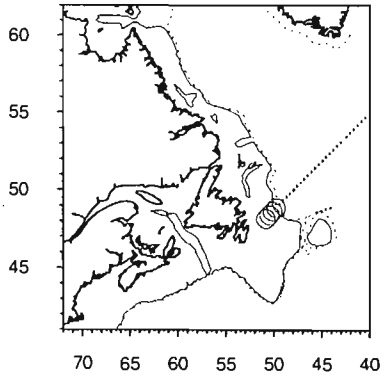
Oct



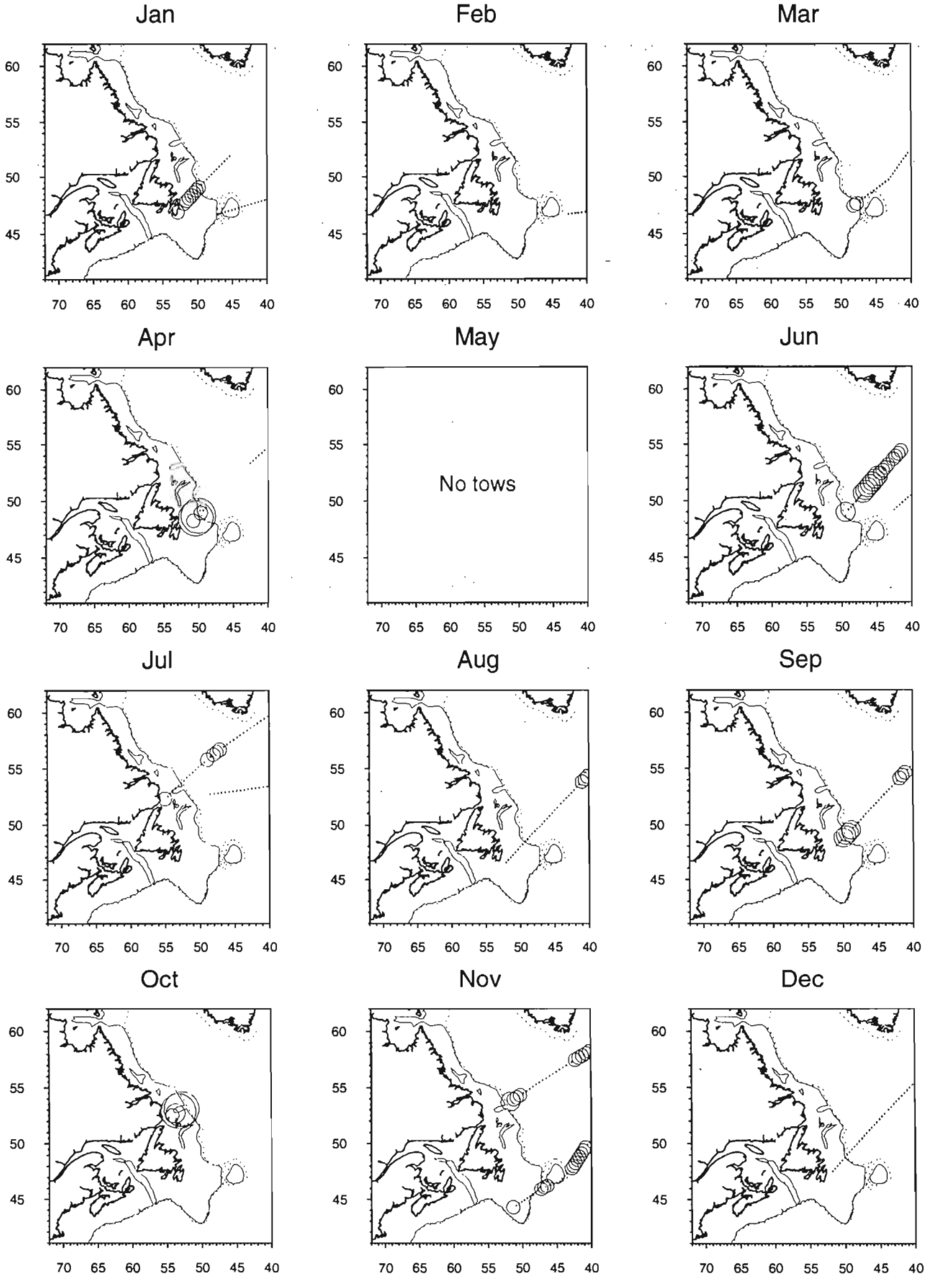
Nov



Dec

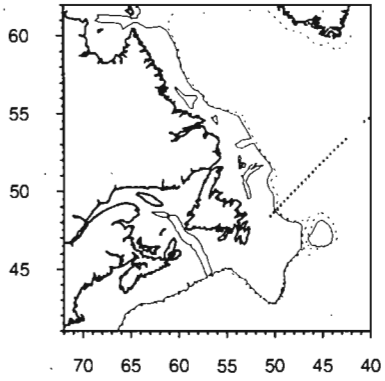


Phytoplankton colour : 1977

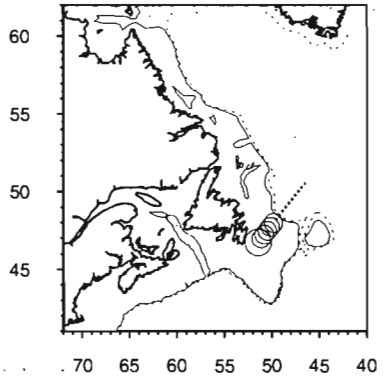


Phytoplankton colour : 1978

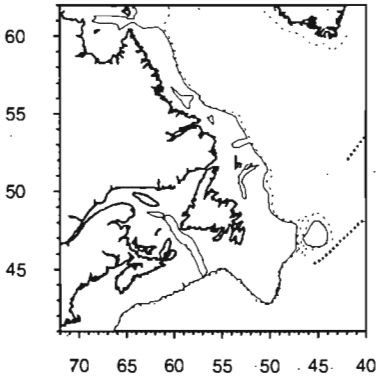
Jan



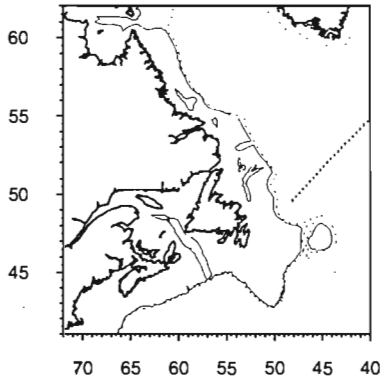
Feb



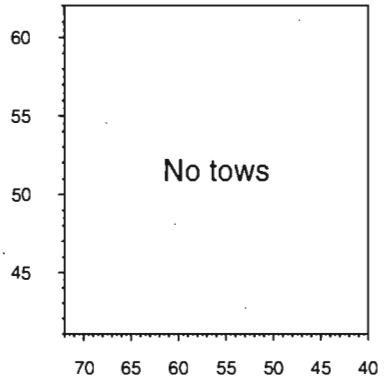
Mar



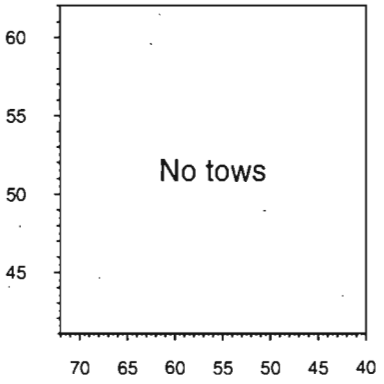
Apr



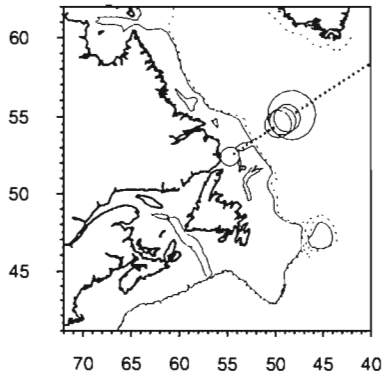
May



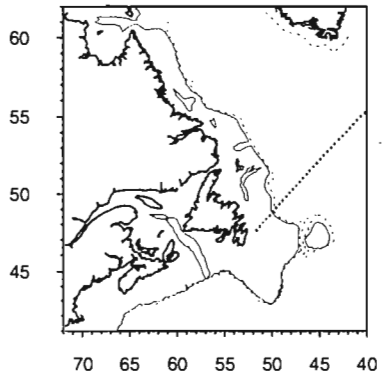
Jun



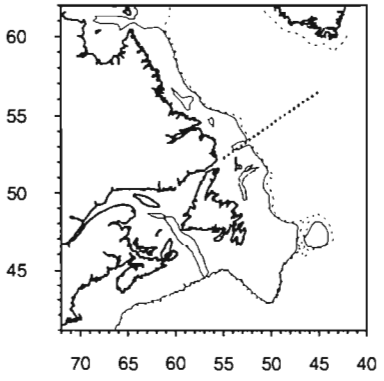
Jul



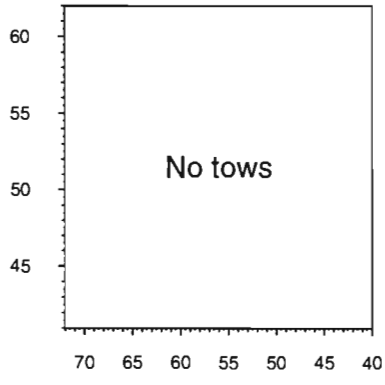
Aug



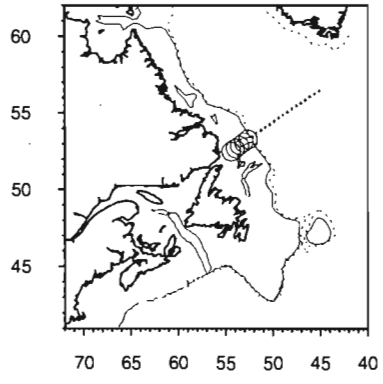
Sep



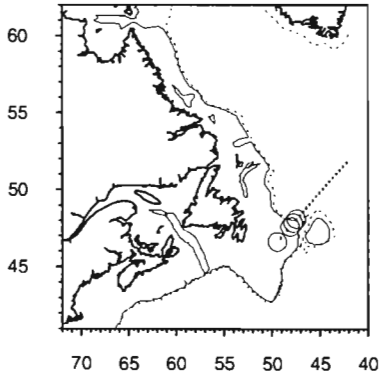
Oct



Nov

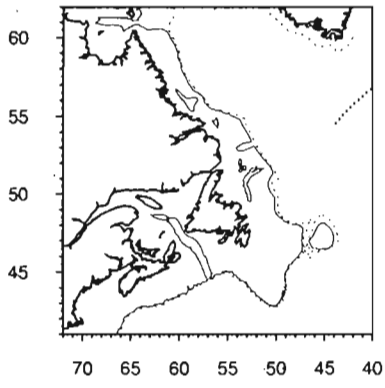


Dec

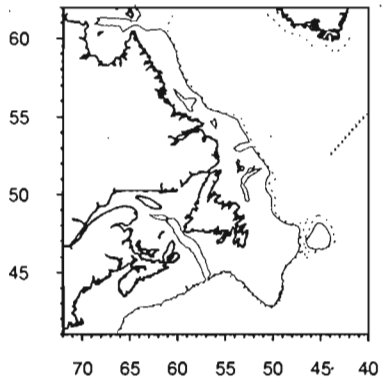


Phytoplankton colour : 1979

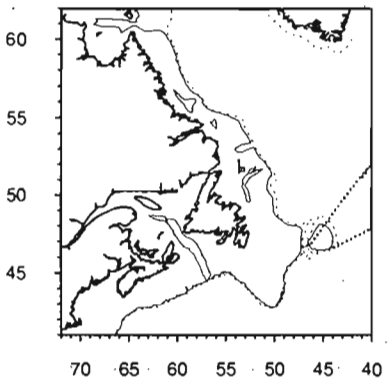
Jan



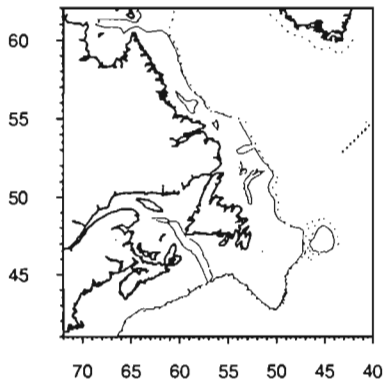
Feb



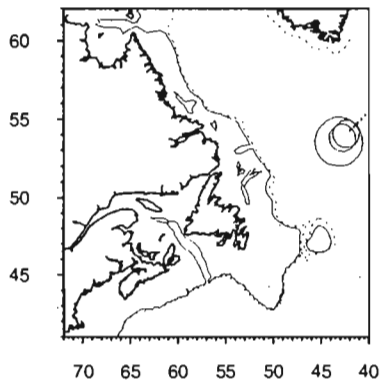
Mar



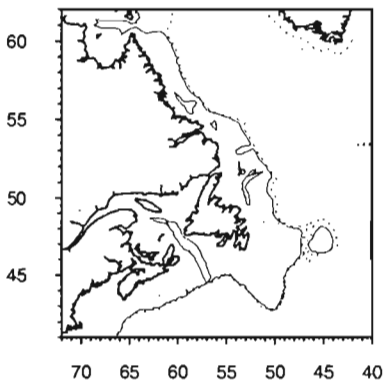
Apr



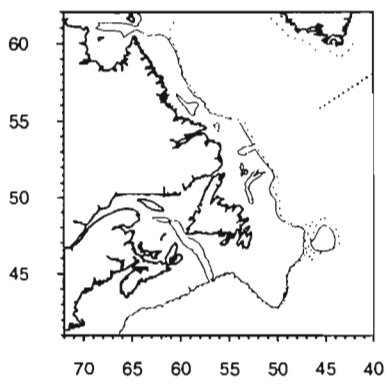
May



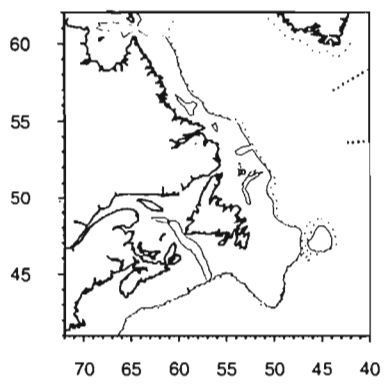
Jun



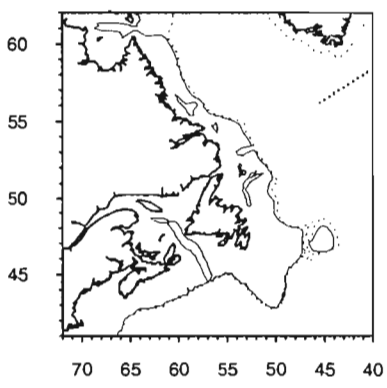
Jul



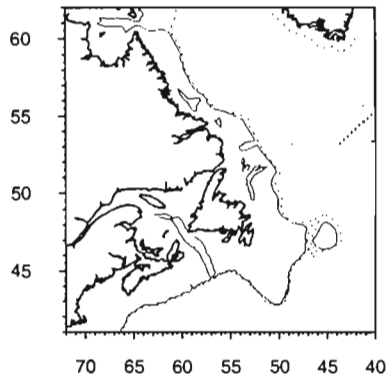
Aug



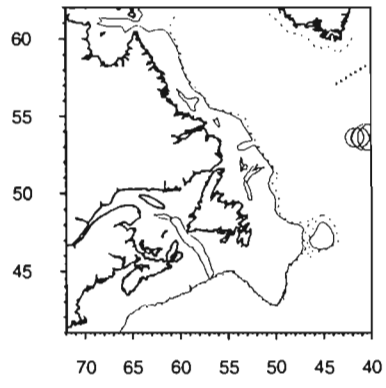
Sep



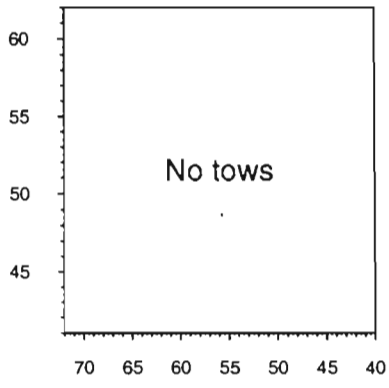
Oct



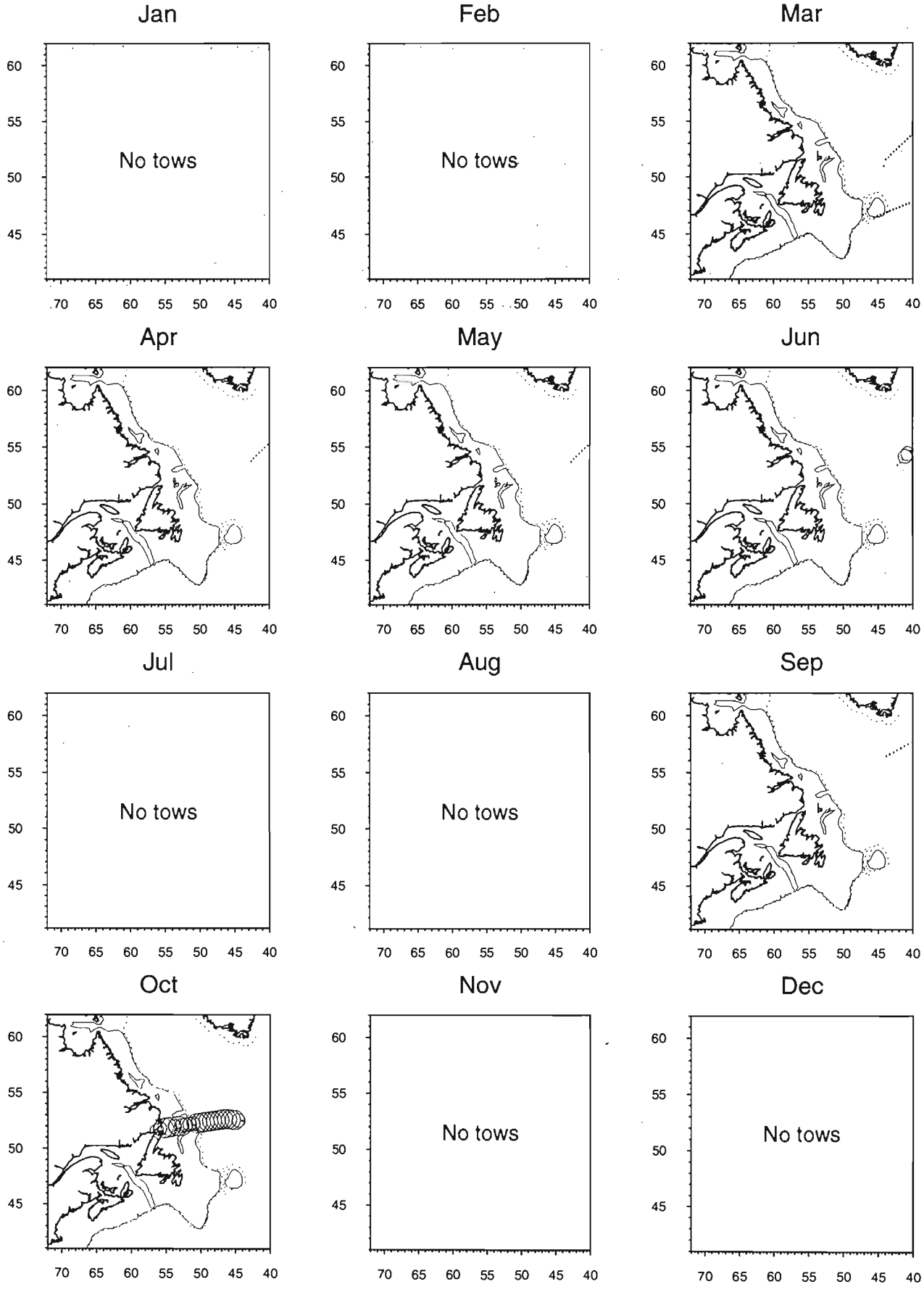
Nov



Dec

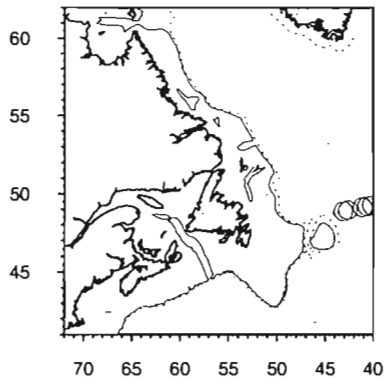


Phytoplankton colour : 1980

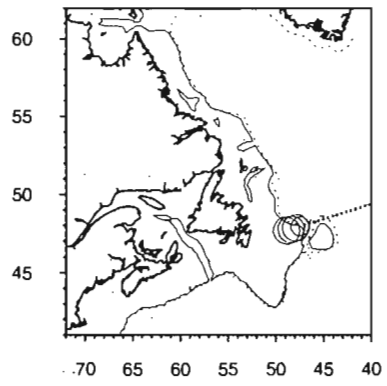


Phytoplankton colour : 1981

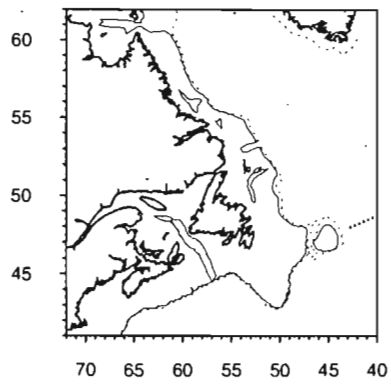
Jan



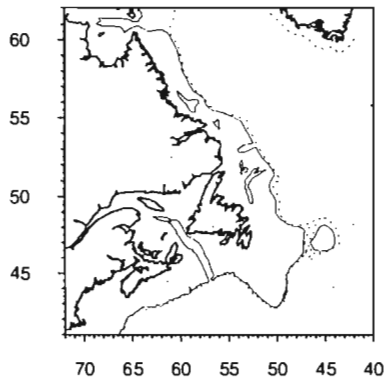
Feb



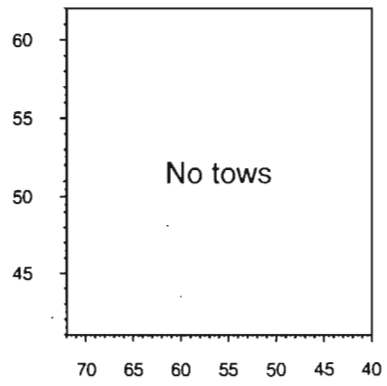
Mar



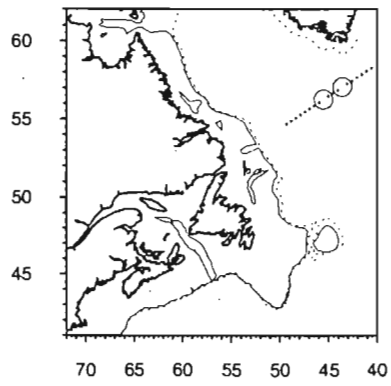
Apr



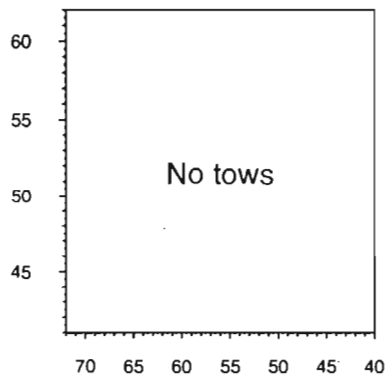
May



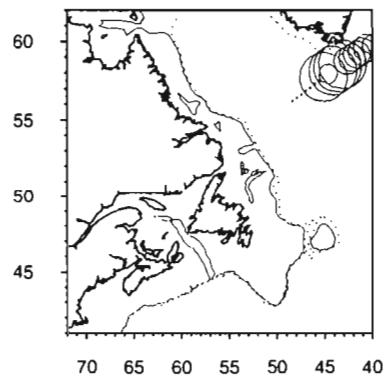
Jun



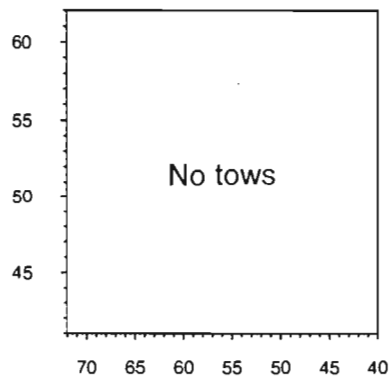
Jul



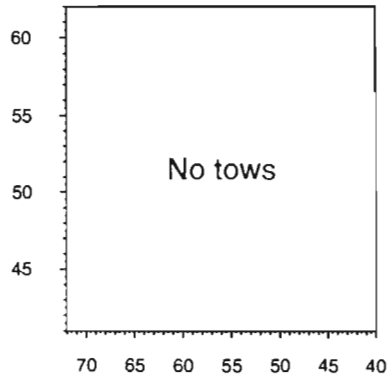
Aug



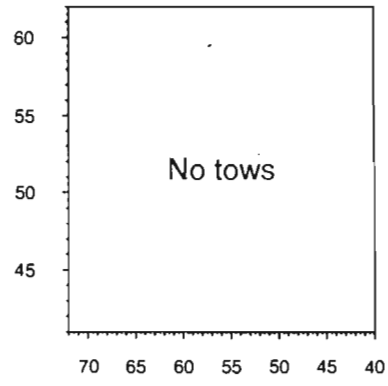
Sep



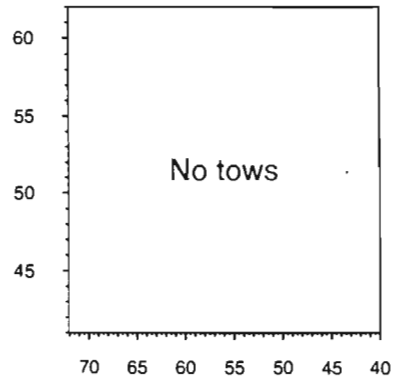
Oct



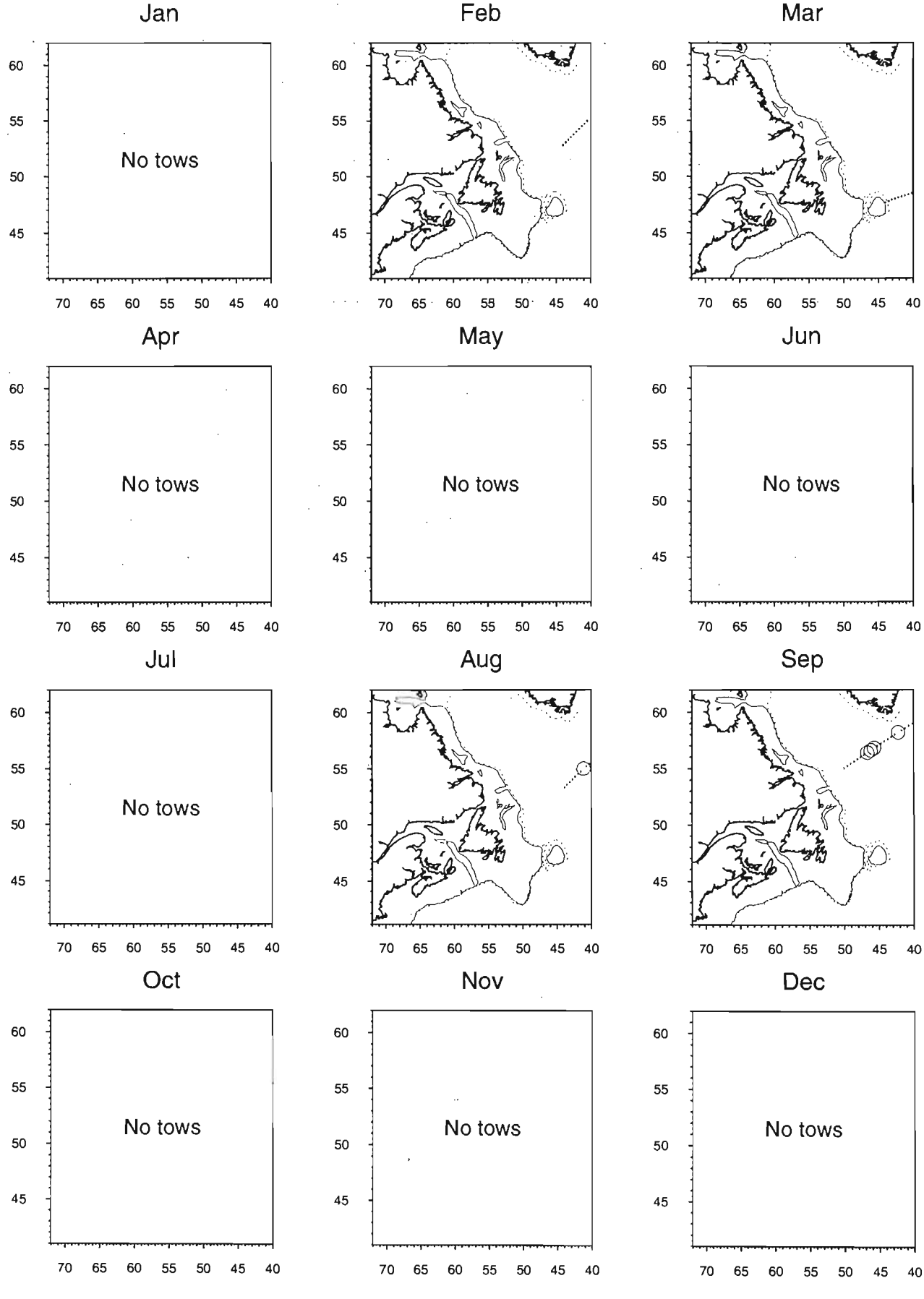
Nov



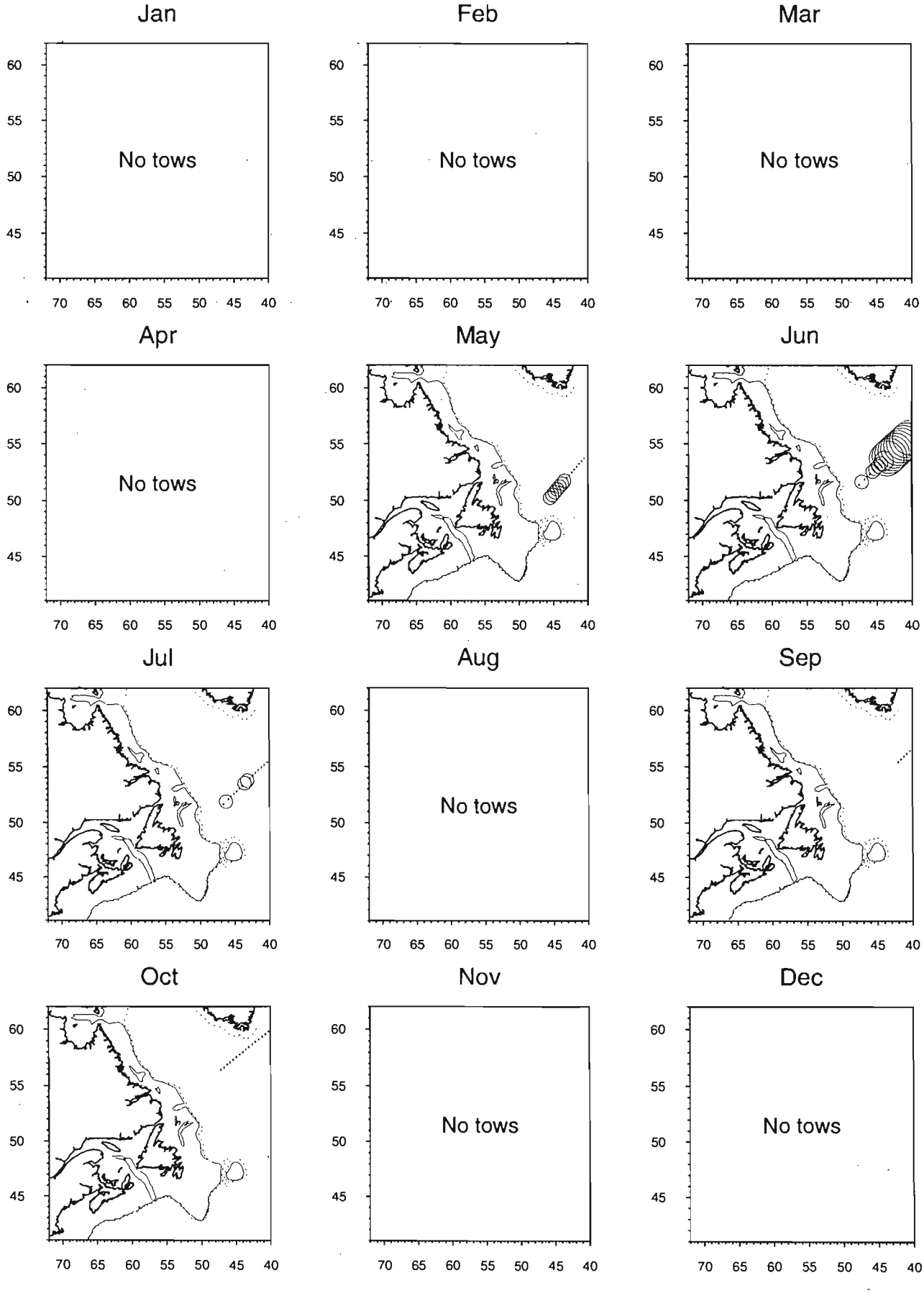
Dec



Phytoplankton colour : 1982

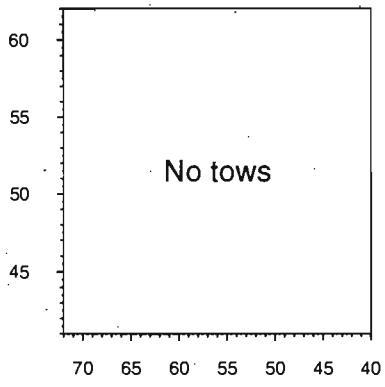


Phytoplankton colour : 1983

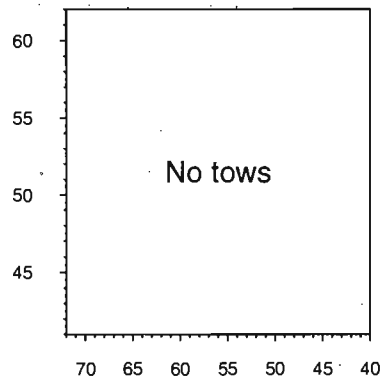


Phytoplankton colour : 1984

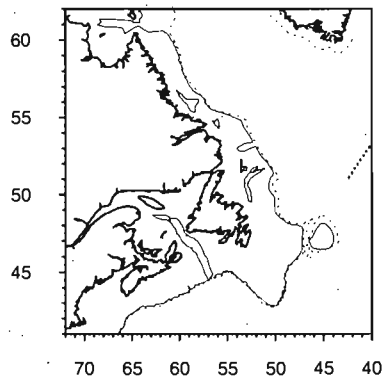
Jan



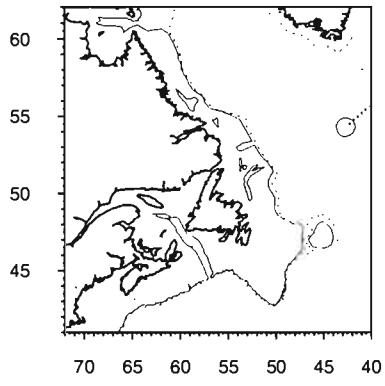
Feb



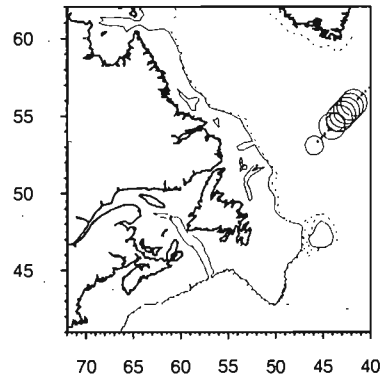
Mar



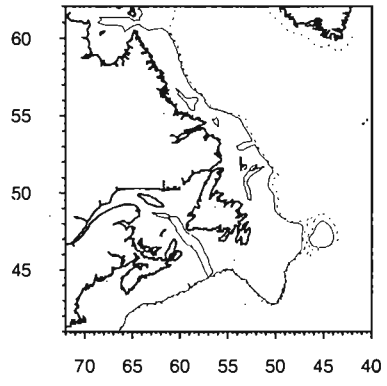
Apr



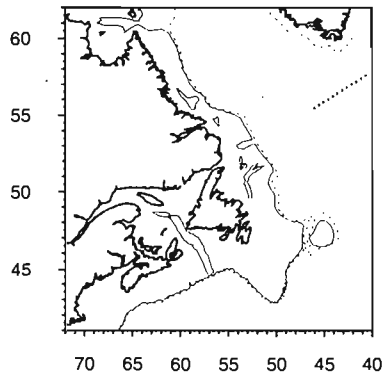
May



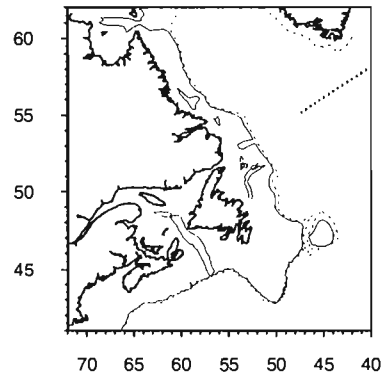
Jun



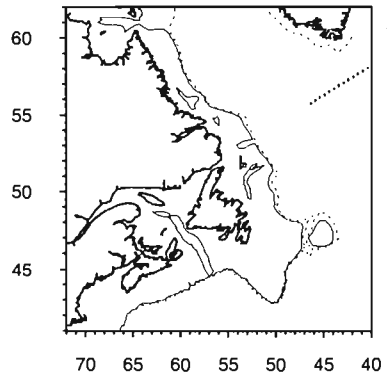
Jul



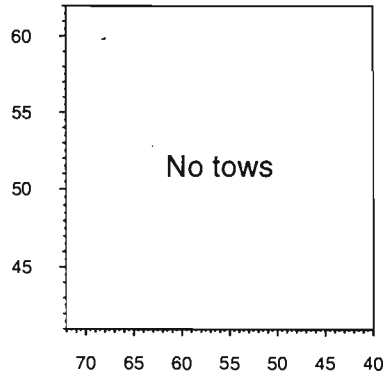
Aug



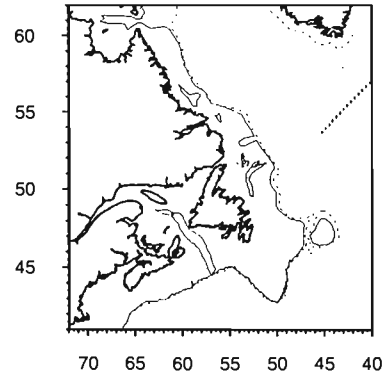
Sep



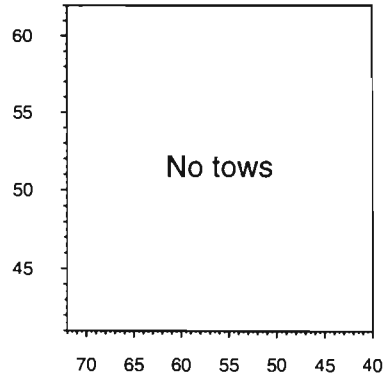
Oct



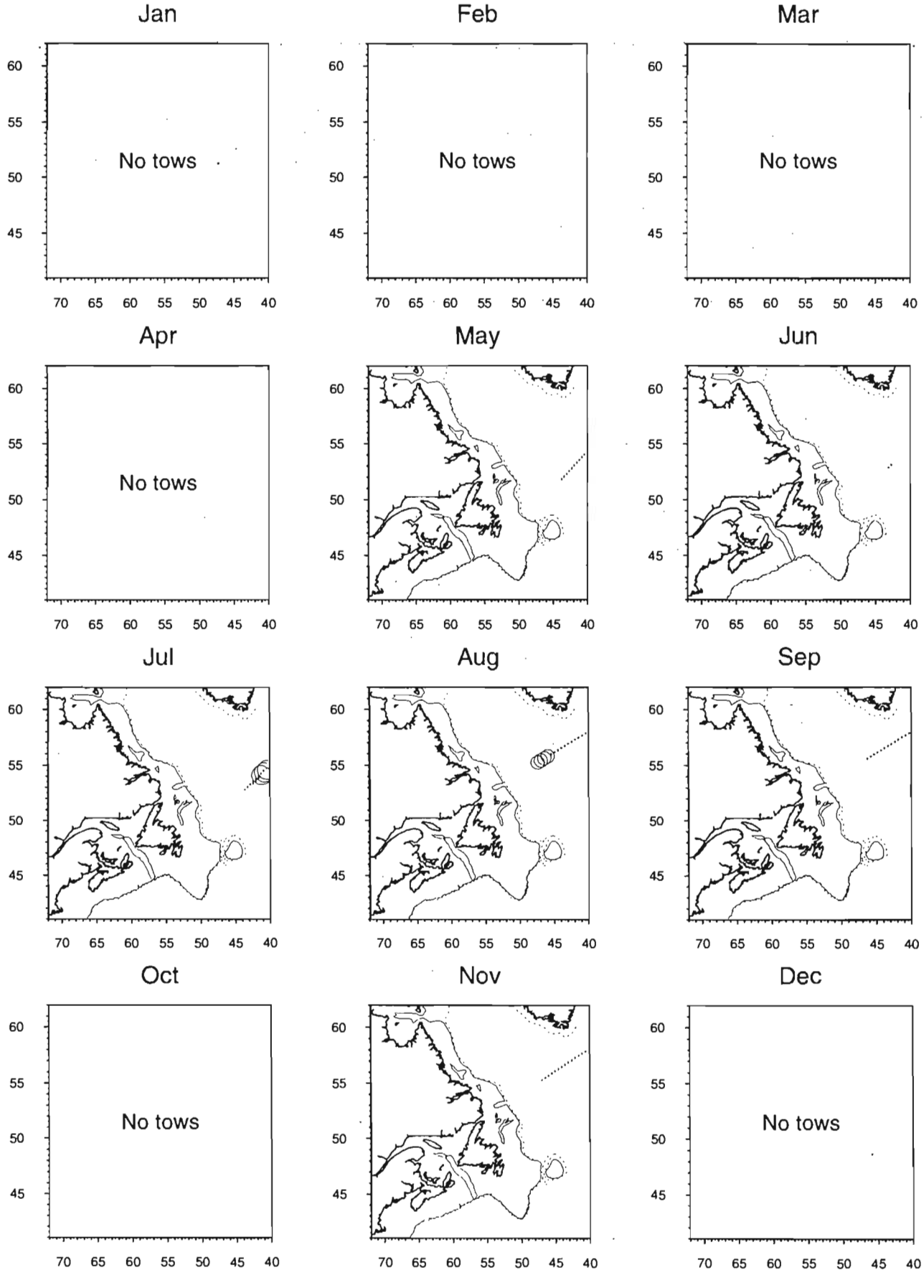
Nov



Dec

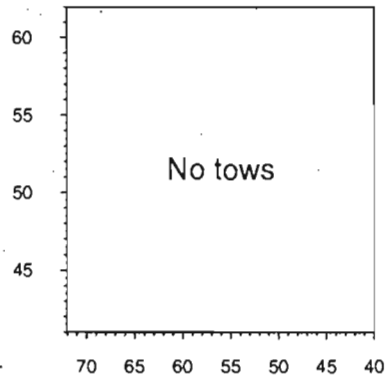


Phytoplankton colour : 1985

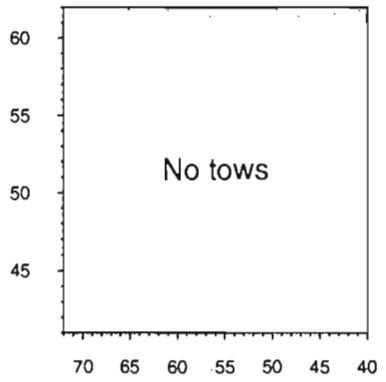


Phytoplankton colour : 1986

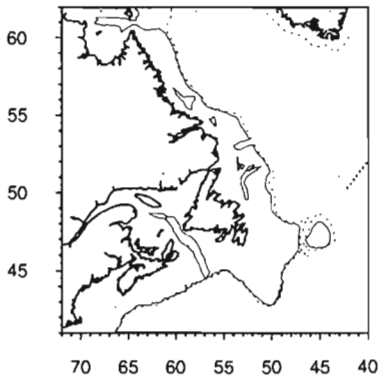
Jan



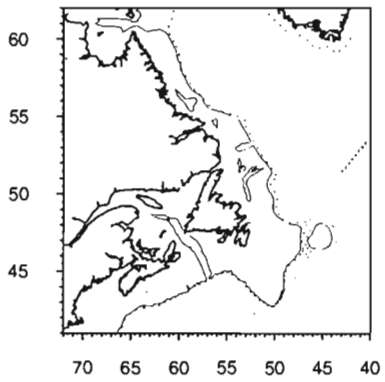
Feb



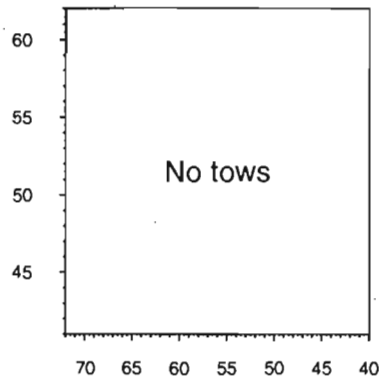
Mar



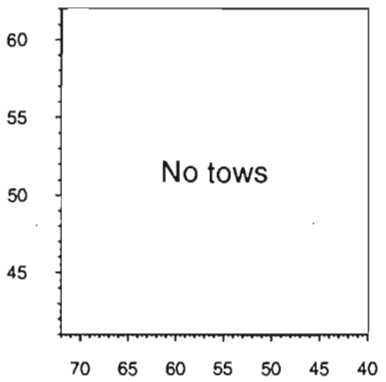
Apr



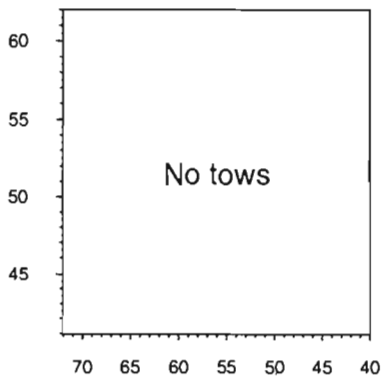
May



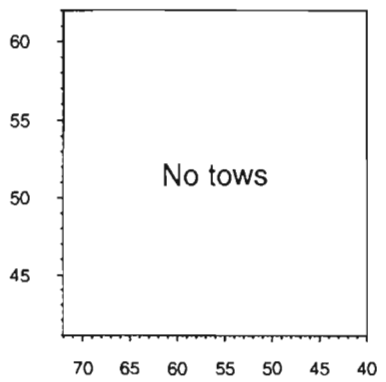
Jun



Jul

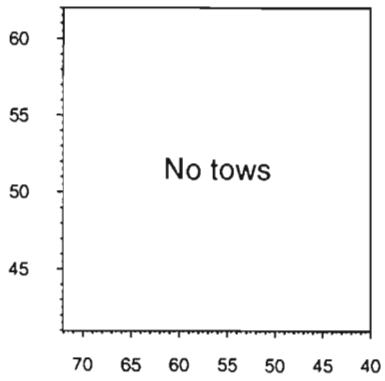


Aug

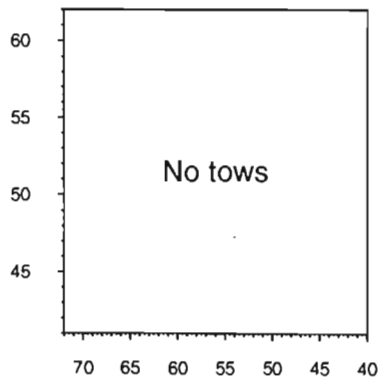


Sep

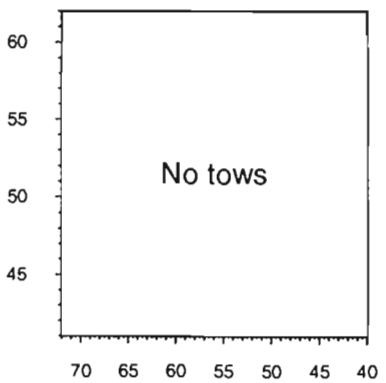
Oct



Nov

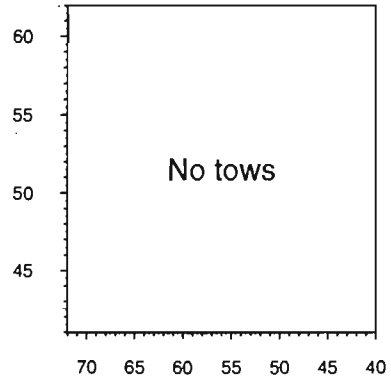


Dec

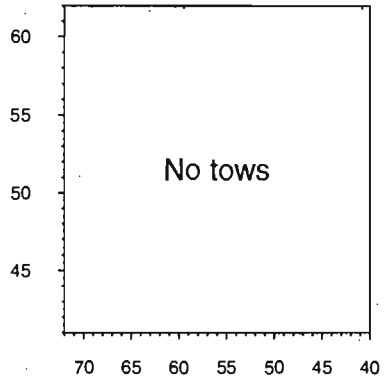


Phytoplankton colour : 1991

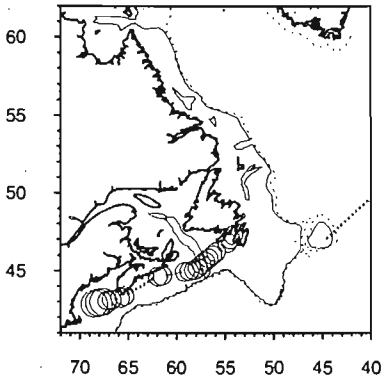
Jan



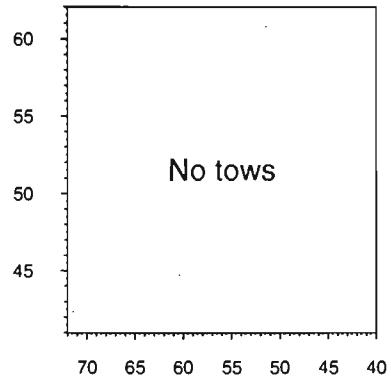
Feb



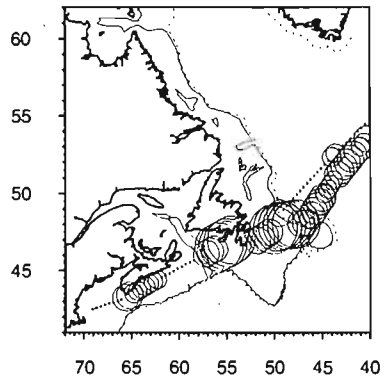
Mar



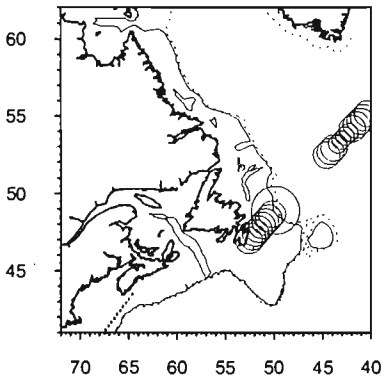
Apr



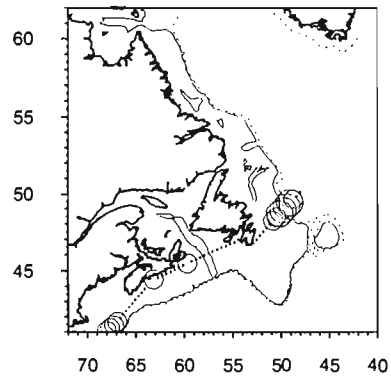
May



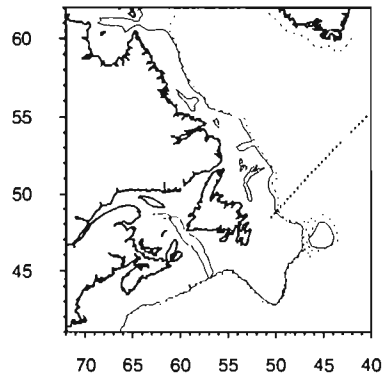
Jun



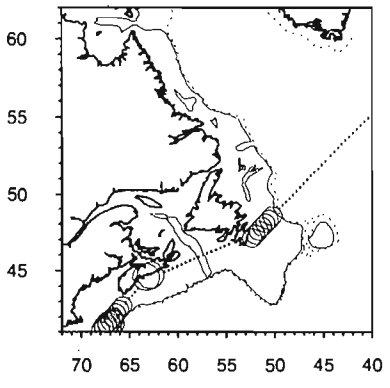
Jul



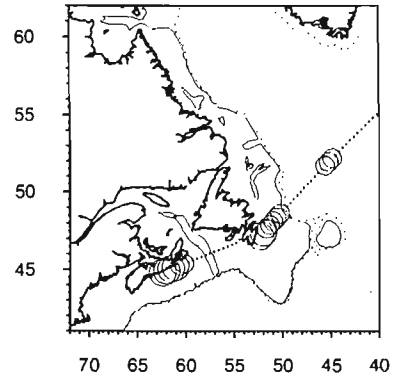
Aug



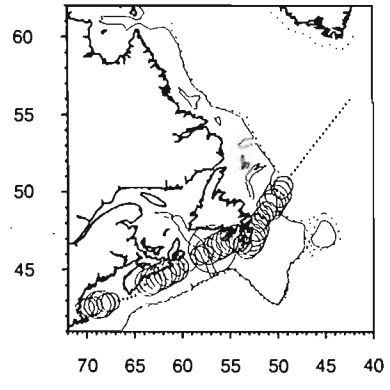
Sep



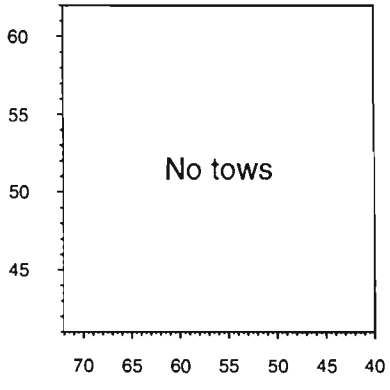
Oct



Nov

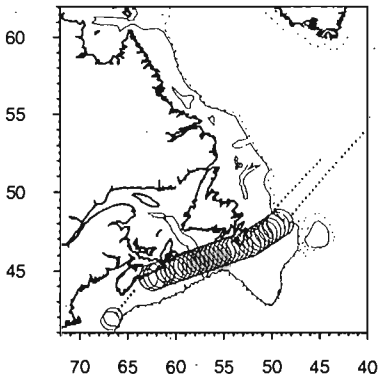


Dec

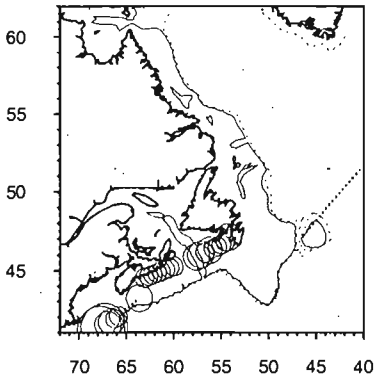


Phytoplankton colour : 1992

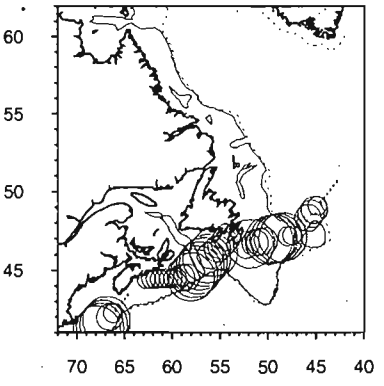
Jan



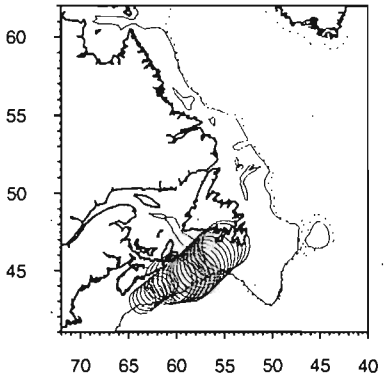
Feb



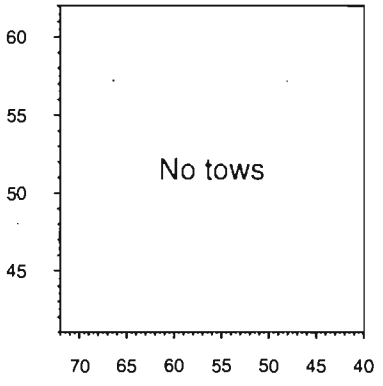
Mar



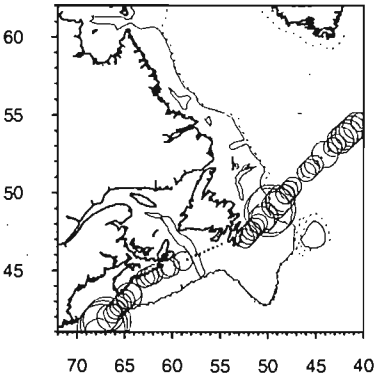
Apr



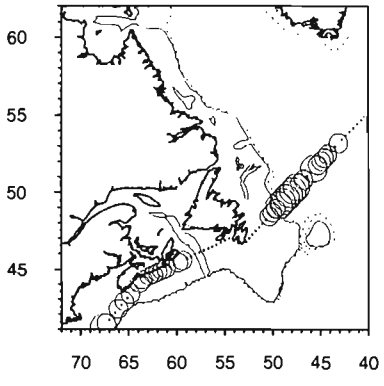
May



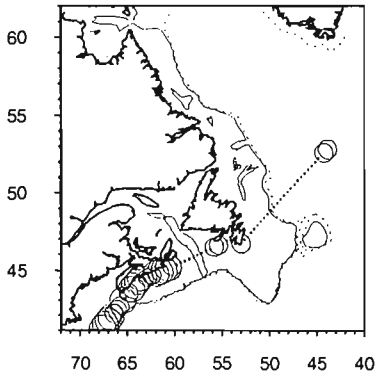
Jun



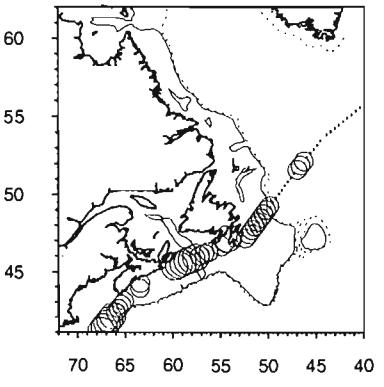
Jul



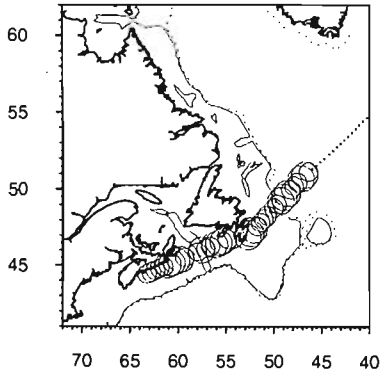
Aug



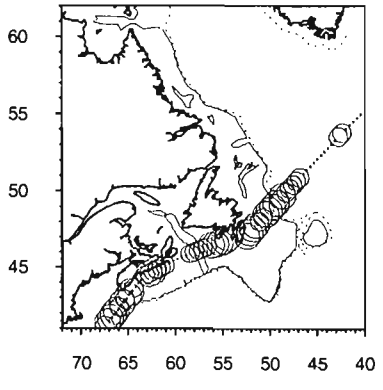
Sep



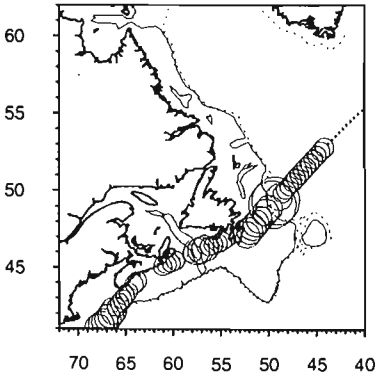
Oct



Nov

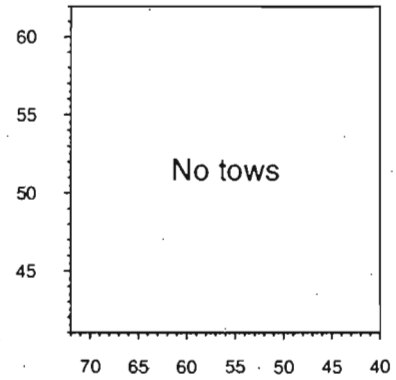


Dec

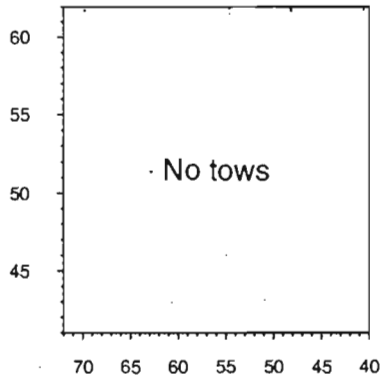


Calanus V-VI Total : 1959

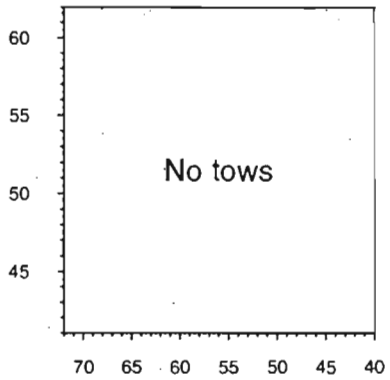
Jan



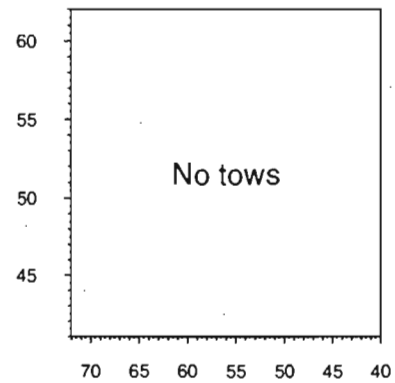
Feb



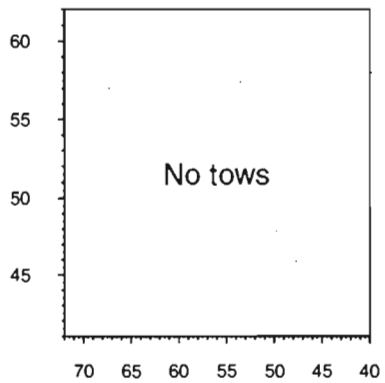
Mar



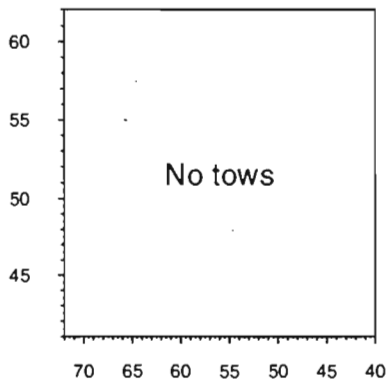
Apr



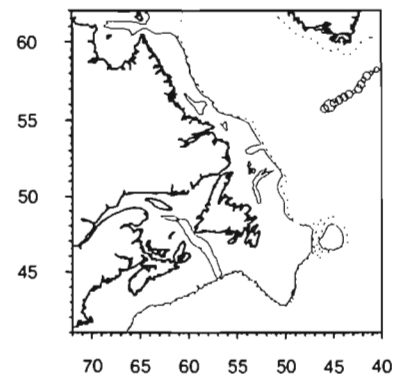
May



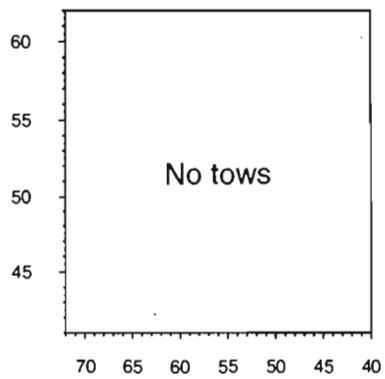
Jun



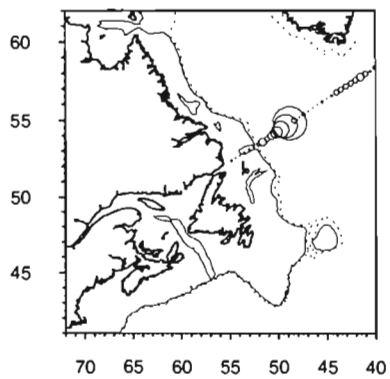
Jul



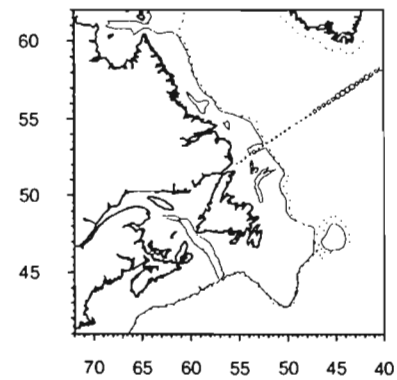
Aug



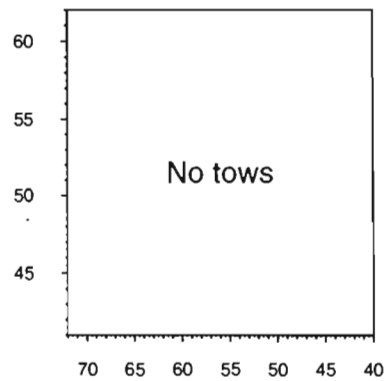
Sep



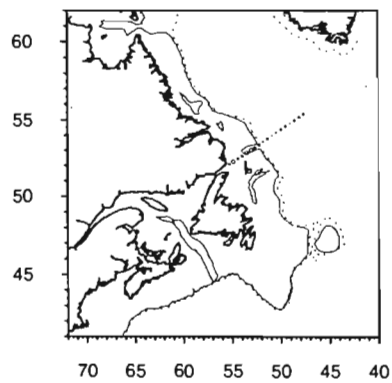
Oct



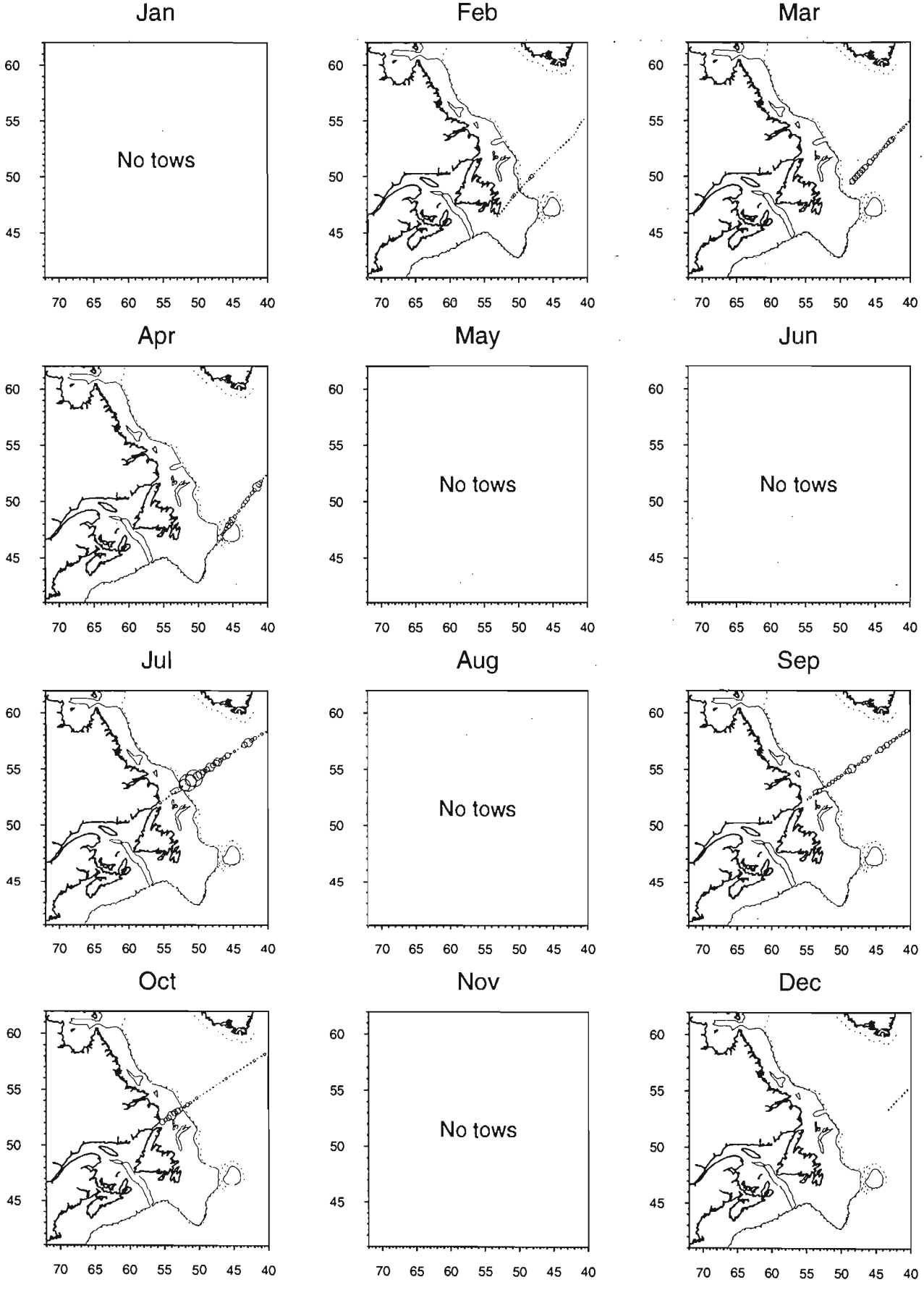
Nov



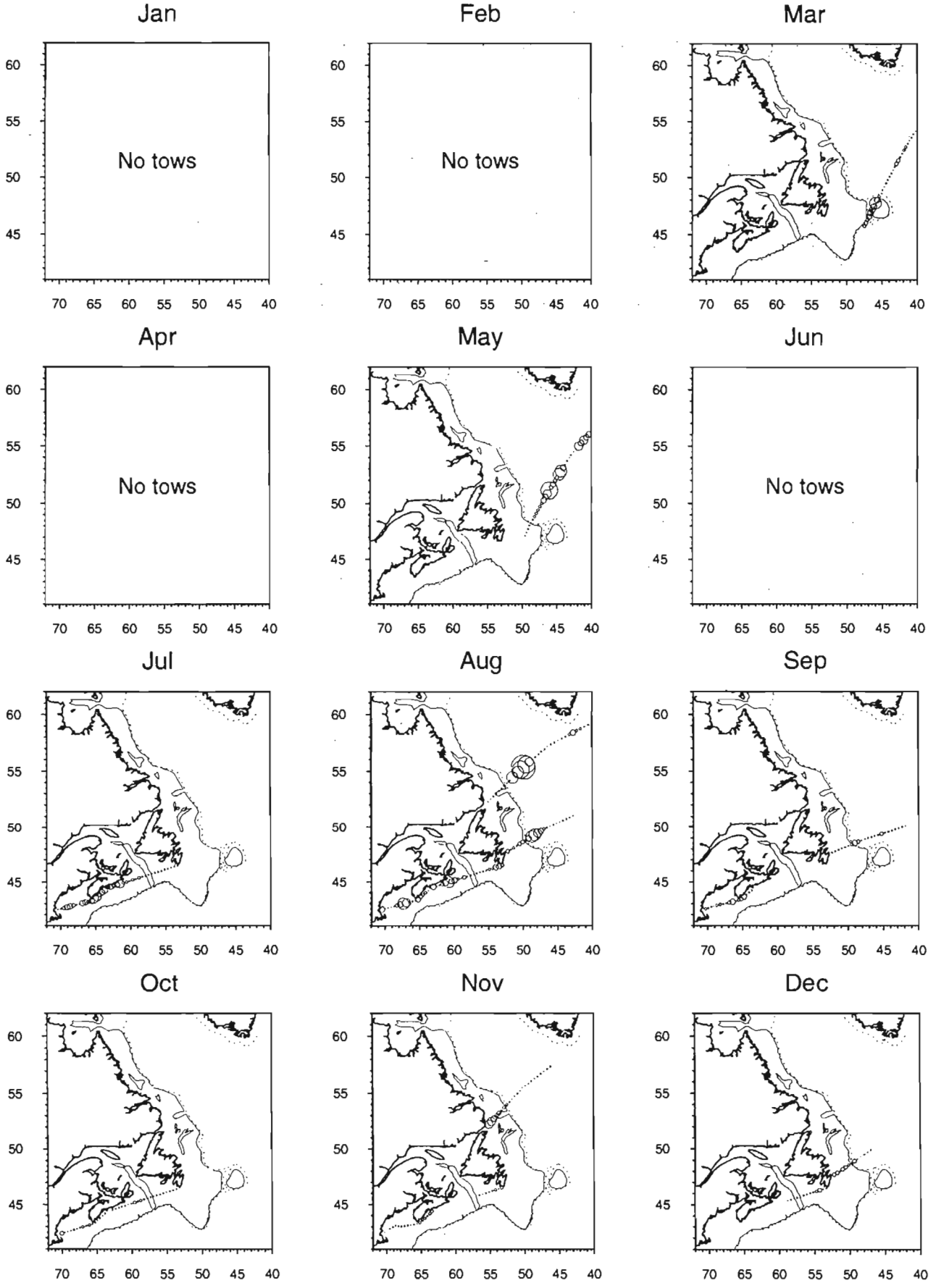
Dec



Calanus V-VI Total : 1960

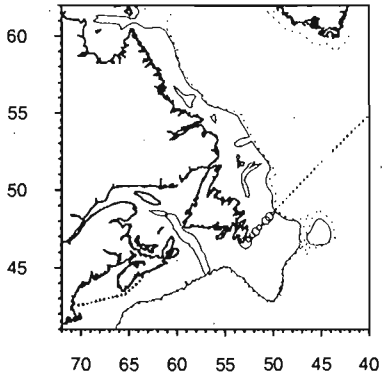


Calanus V-VI Total : 1961

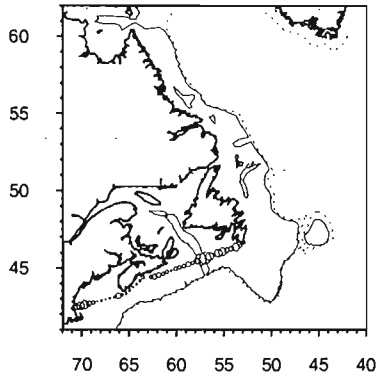


Calanus V-VI Total : 1962

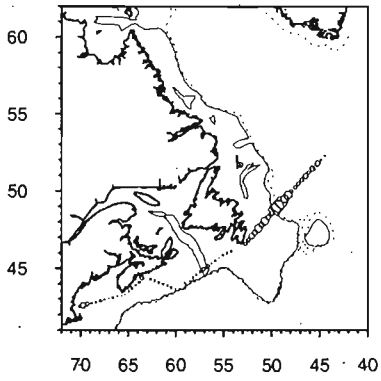
Jan



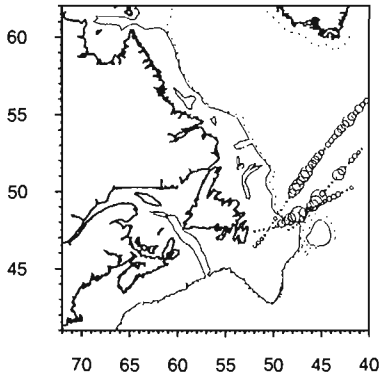
Feb



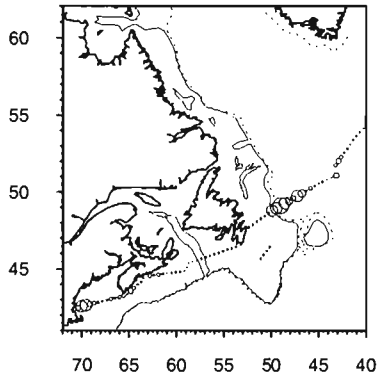
Mar



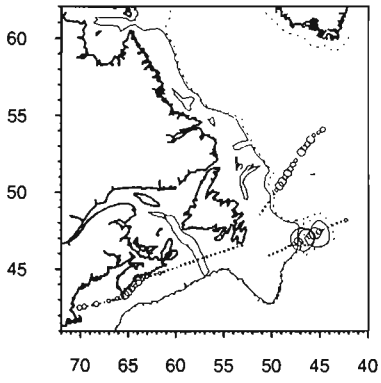
Apr



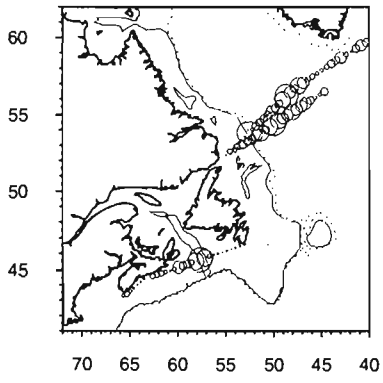
May



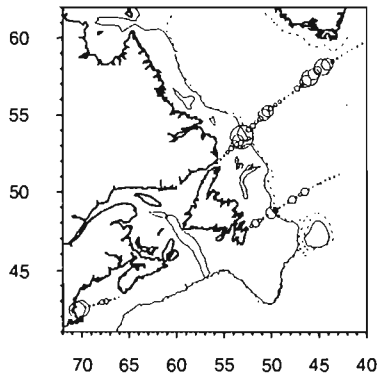
Jun



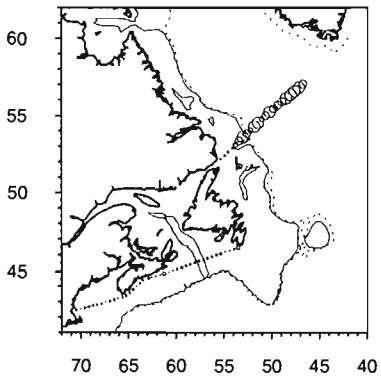
Jul



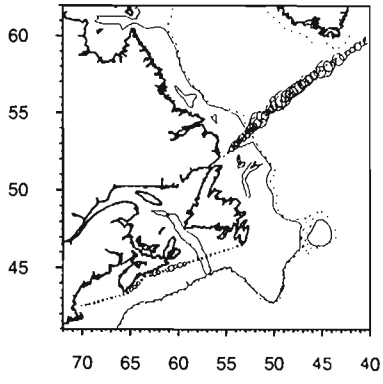
Aug



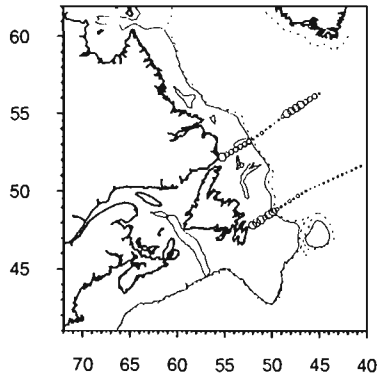
Sep



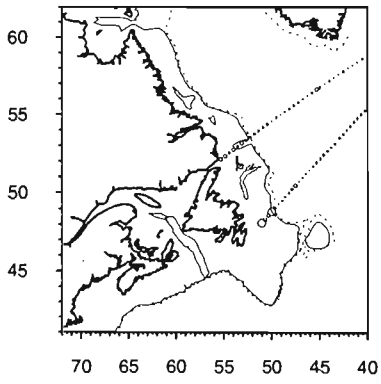
Oct



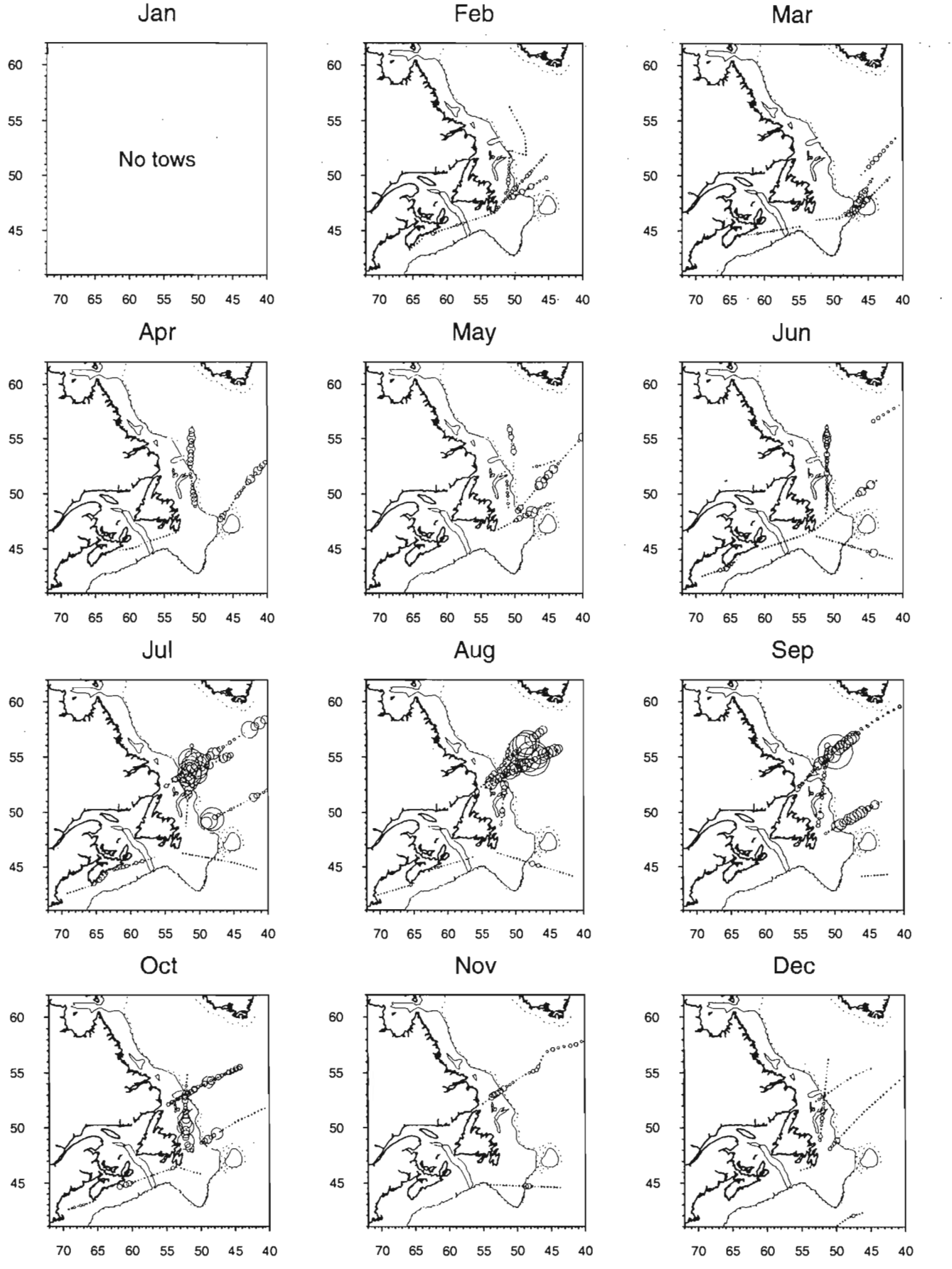
Nov



Dec

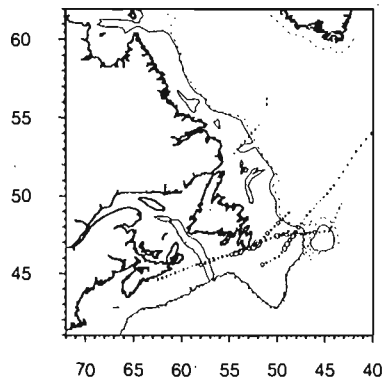


Calanus V-VI Total : 1963

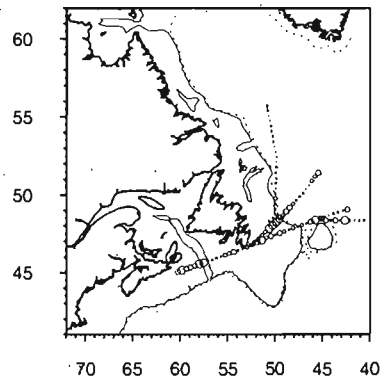


Calanus V-VI Total : 1964

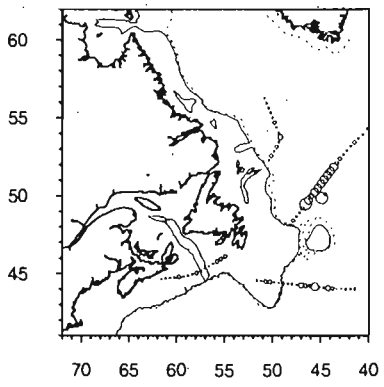
Jan



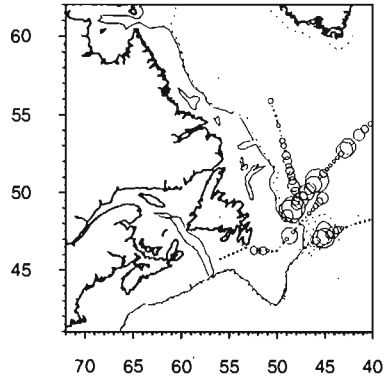
Feb



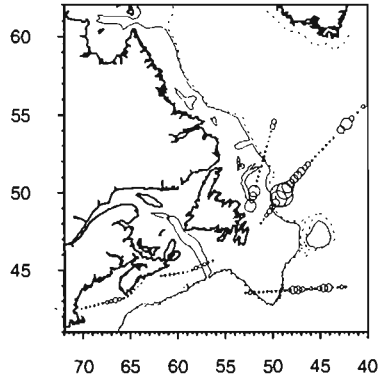
Mar



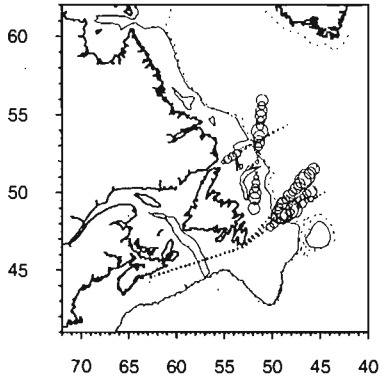
Apr



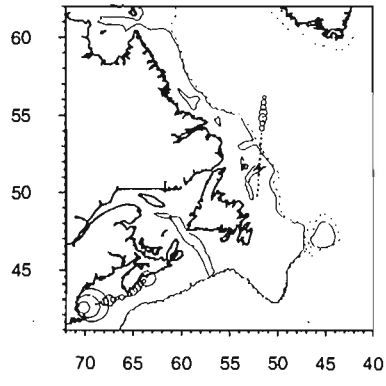
May



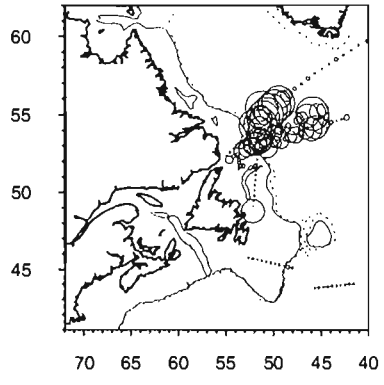
Jun



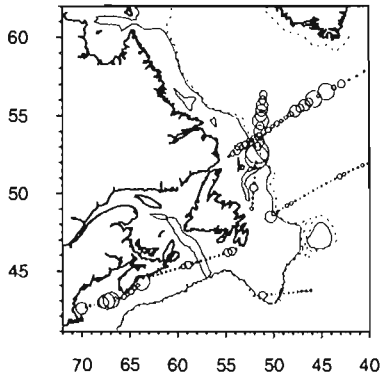
Jul



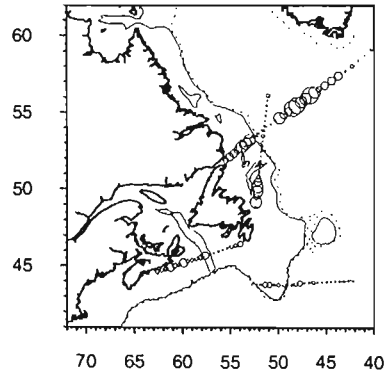
Aug



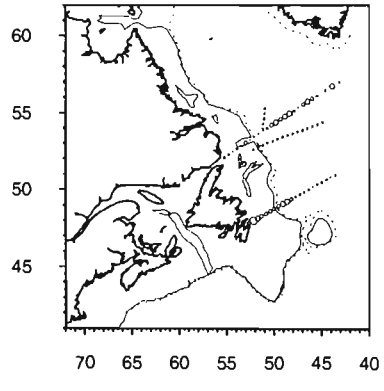
Sep



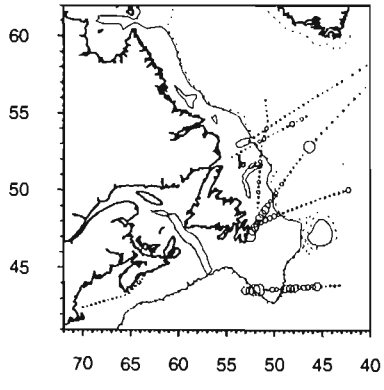
Oct



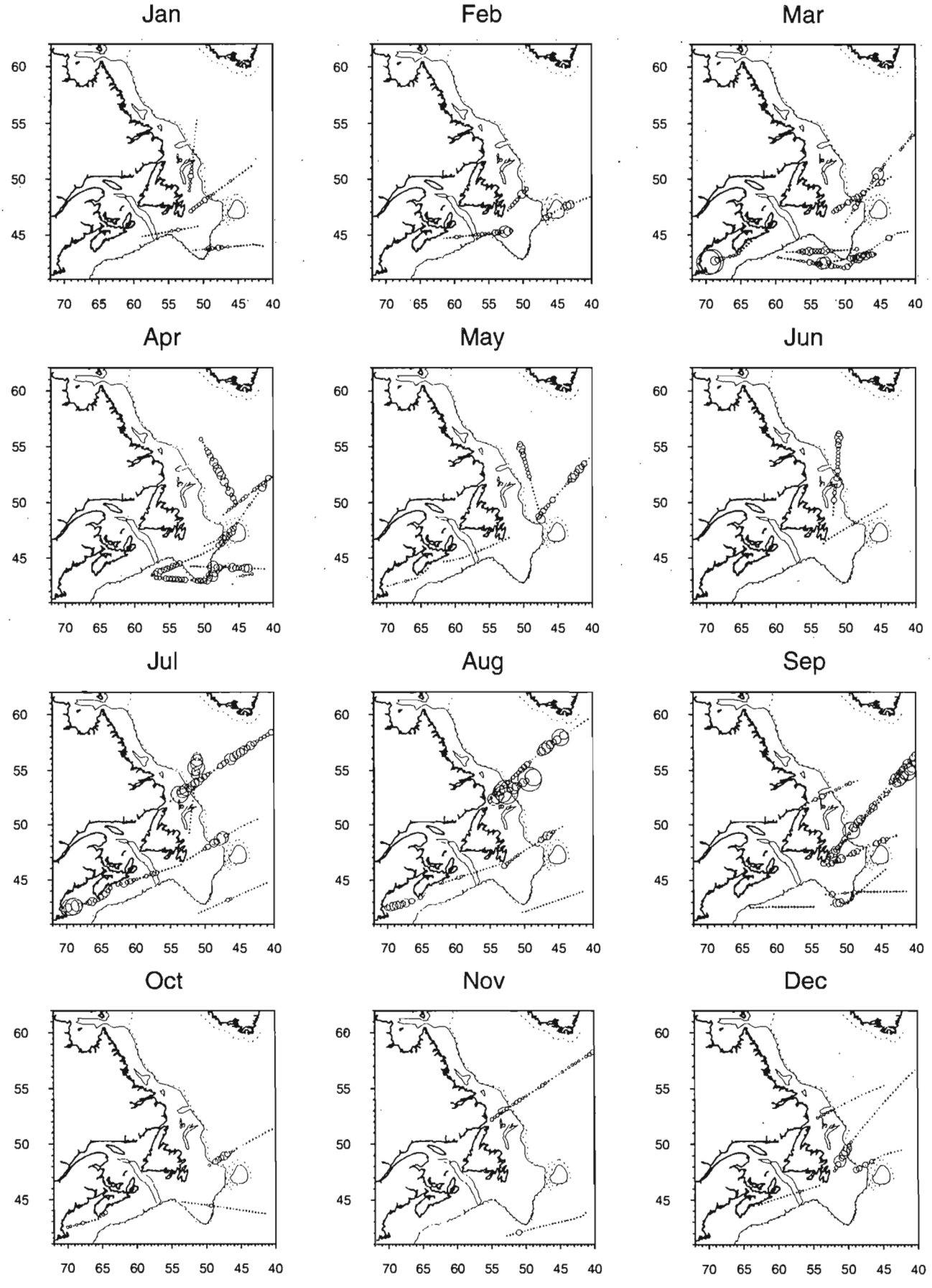
Nov



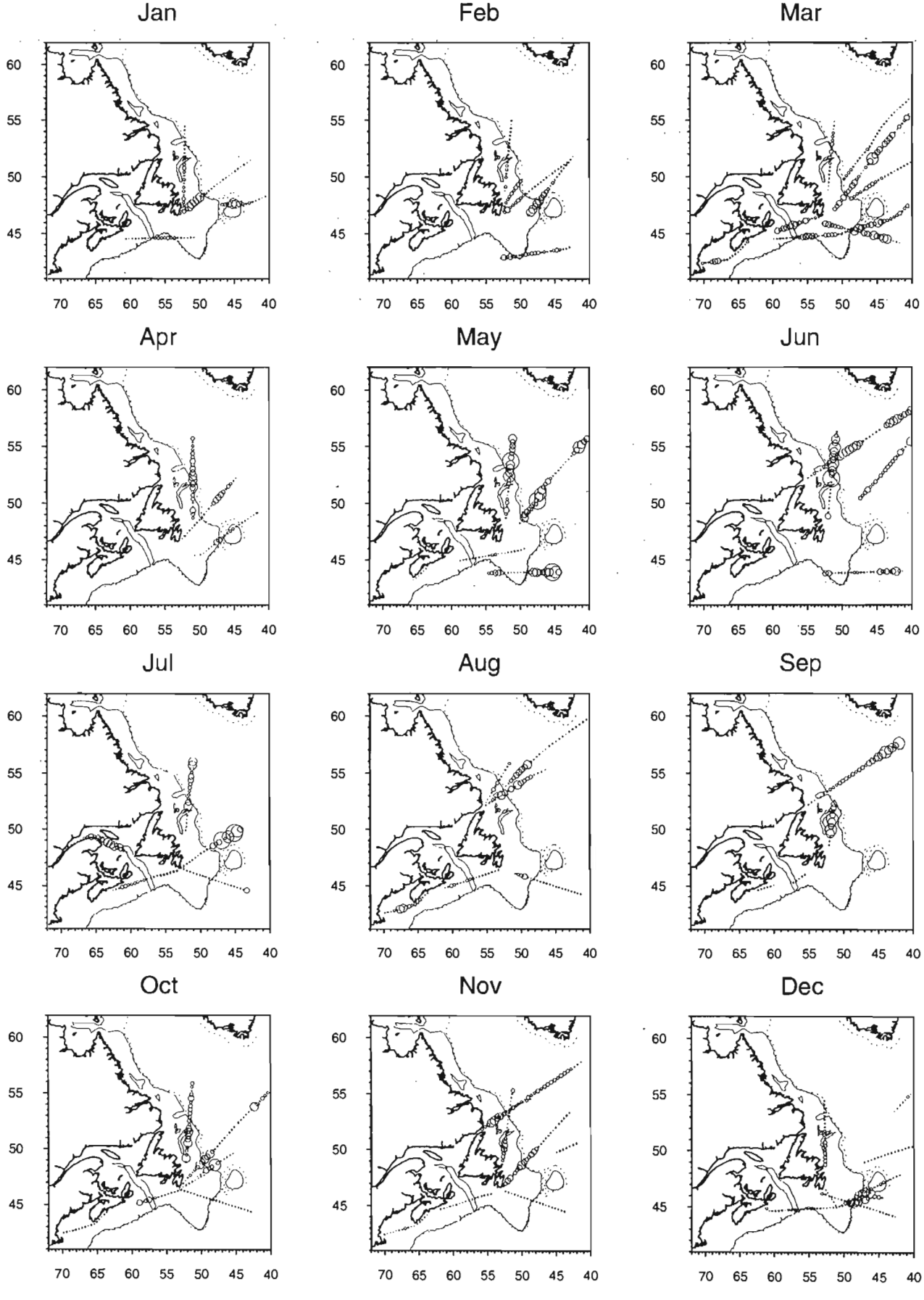
Dec



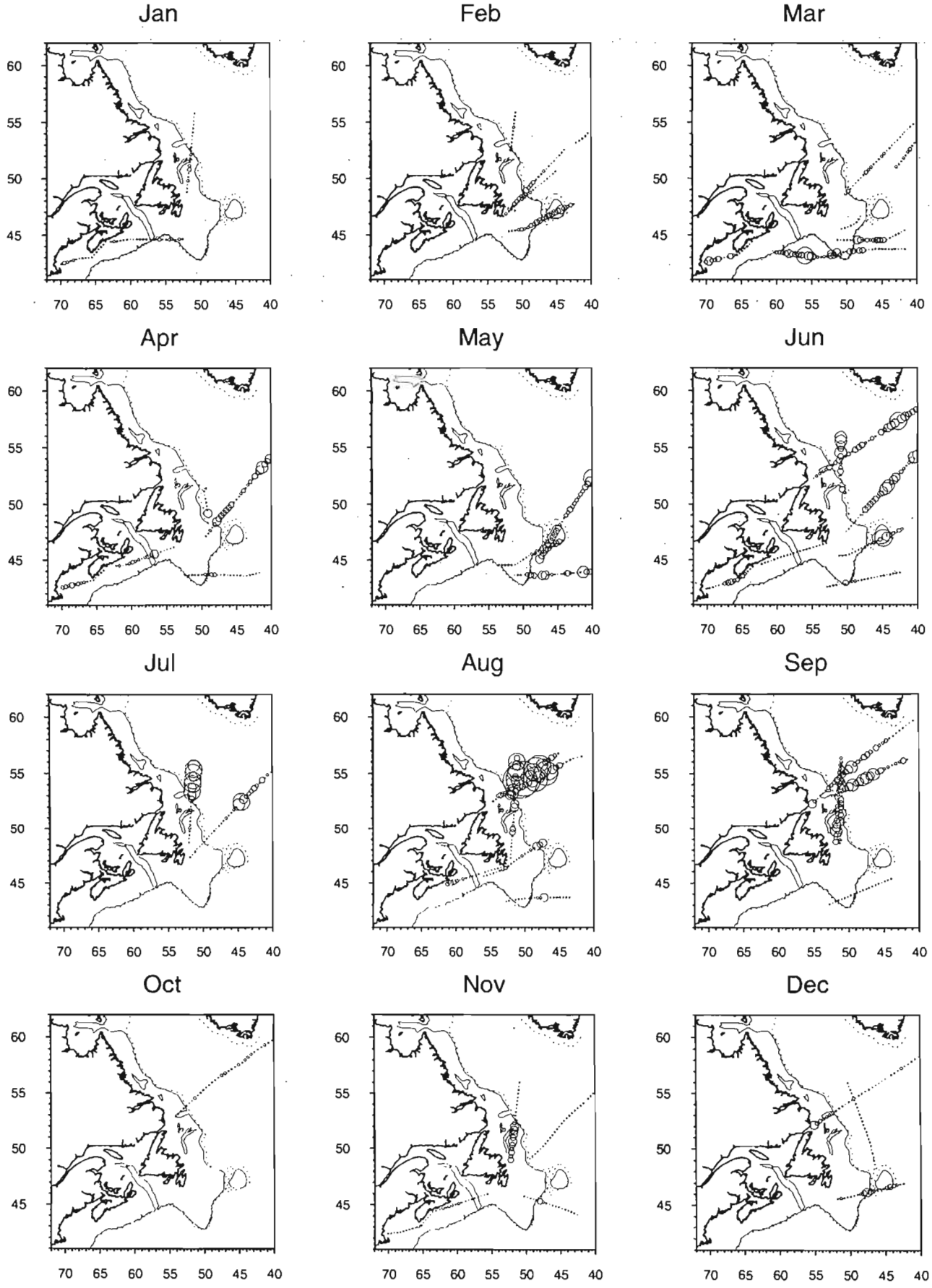
Calanus V-VI Total : 1965



Calanus V-VI Total : 1966

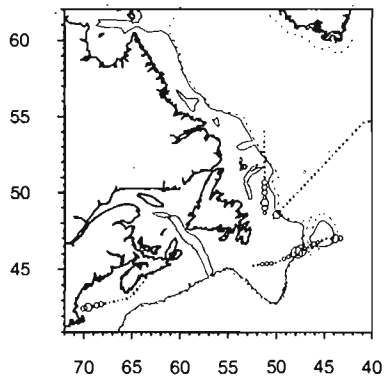


Calanus V-VI Total : 1967

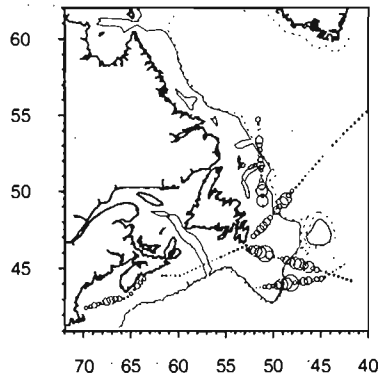


Calanus V-VI Total : 1968

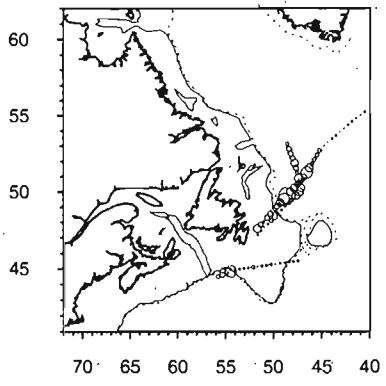
Jan



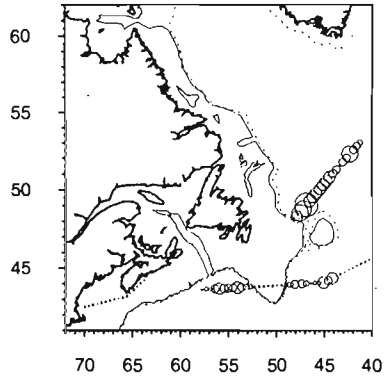
Feb



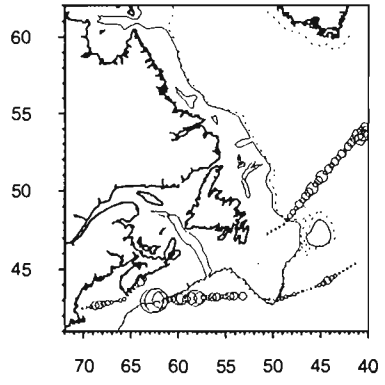
Mar



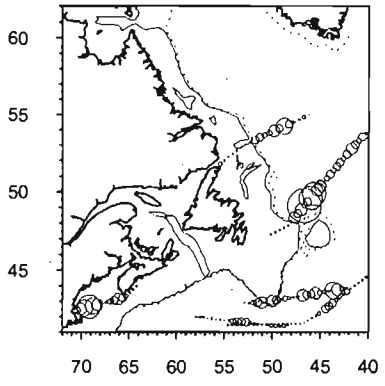
Apr



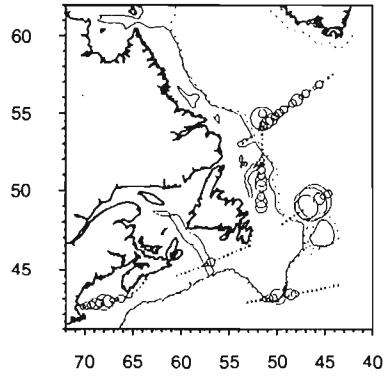
May



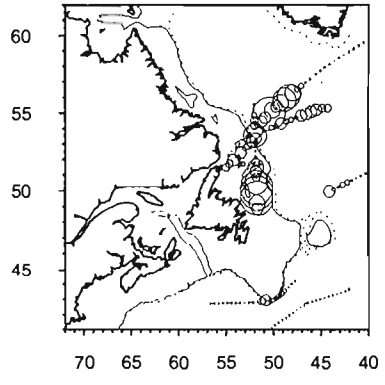
Jun



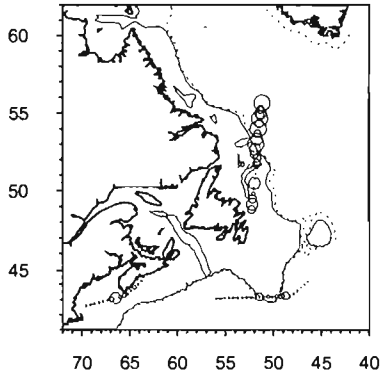
Jul



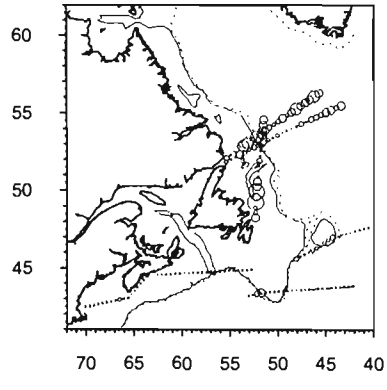
Aug



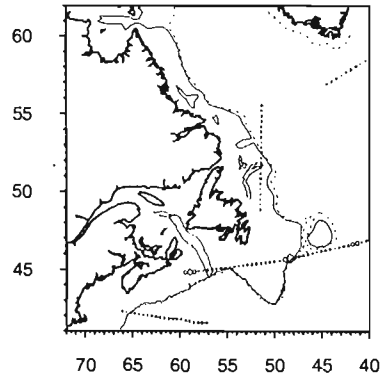
Sep



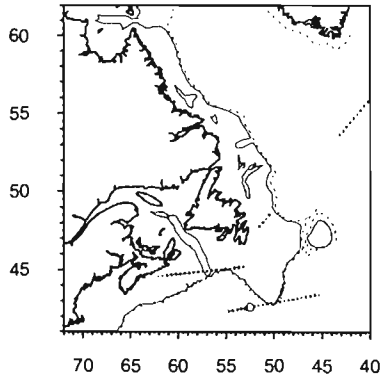
Oct



Nov

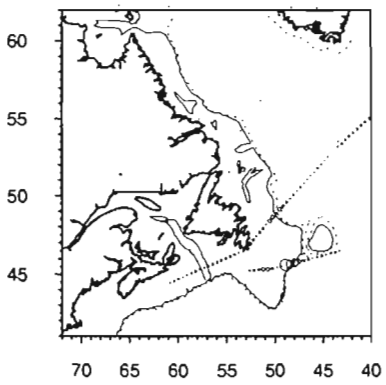


Dec

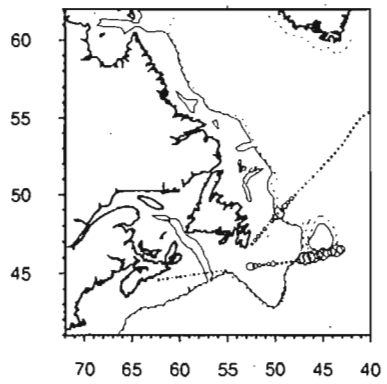


Calanus V-VI Total : 1969

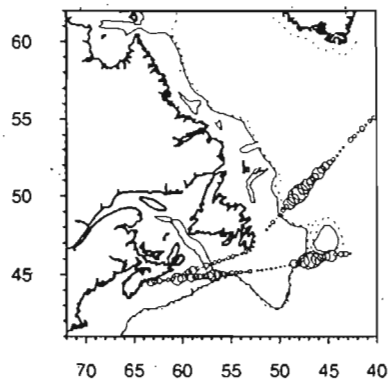
Jan



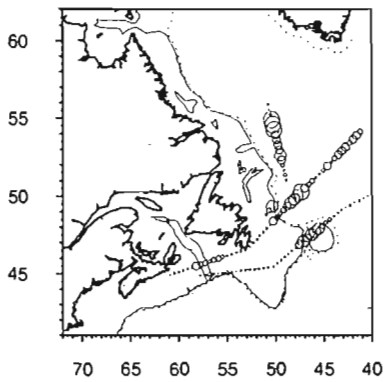
Feb



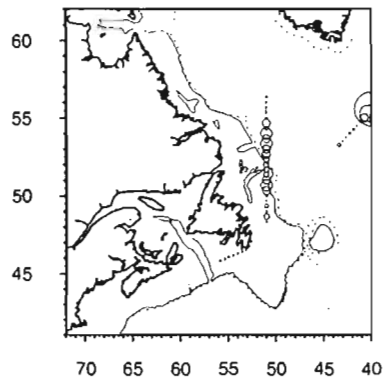
Mar



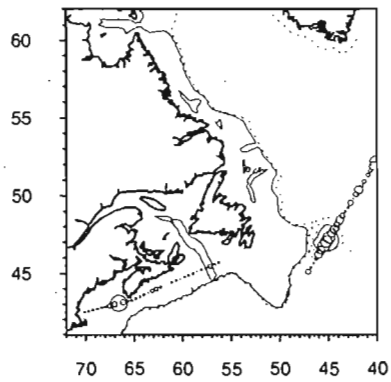
Apr



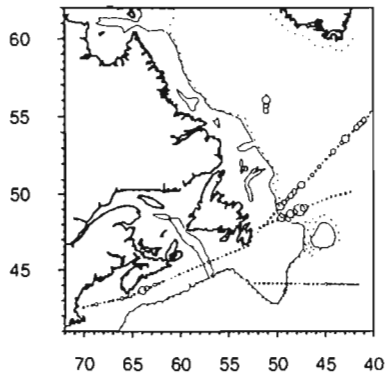
May



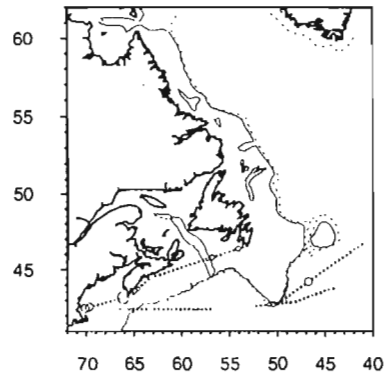
Jun



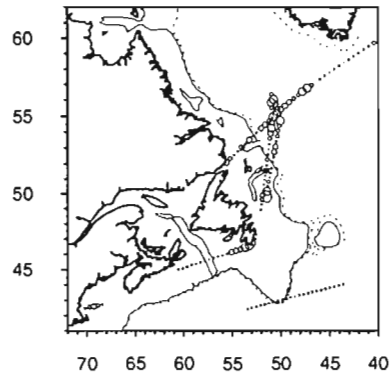
Jul



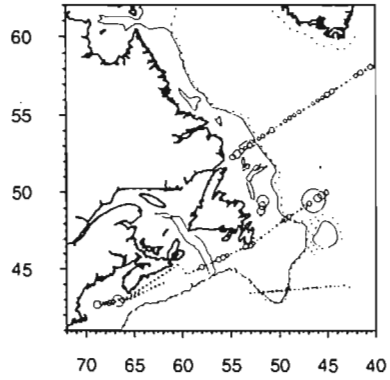
Aug



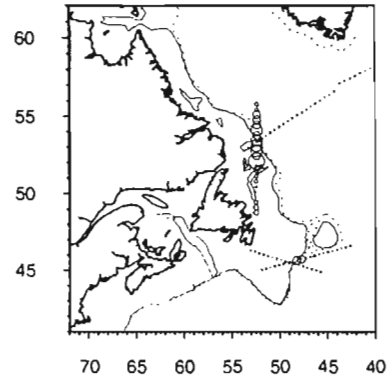
Sep



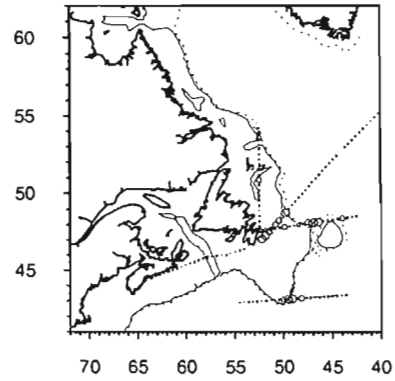
Oct



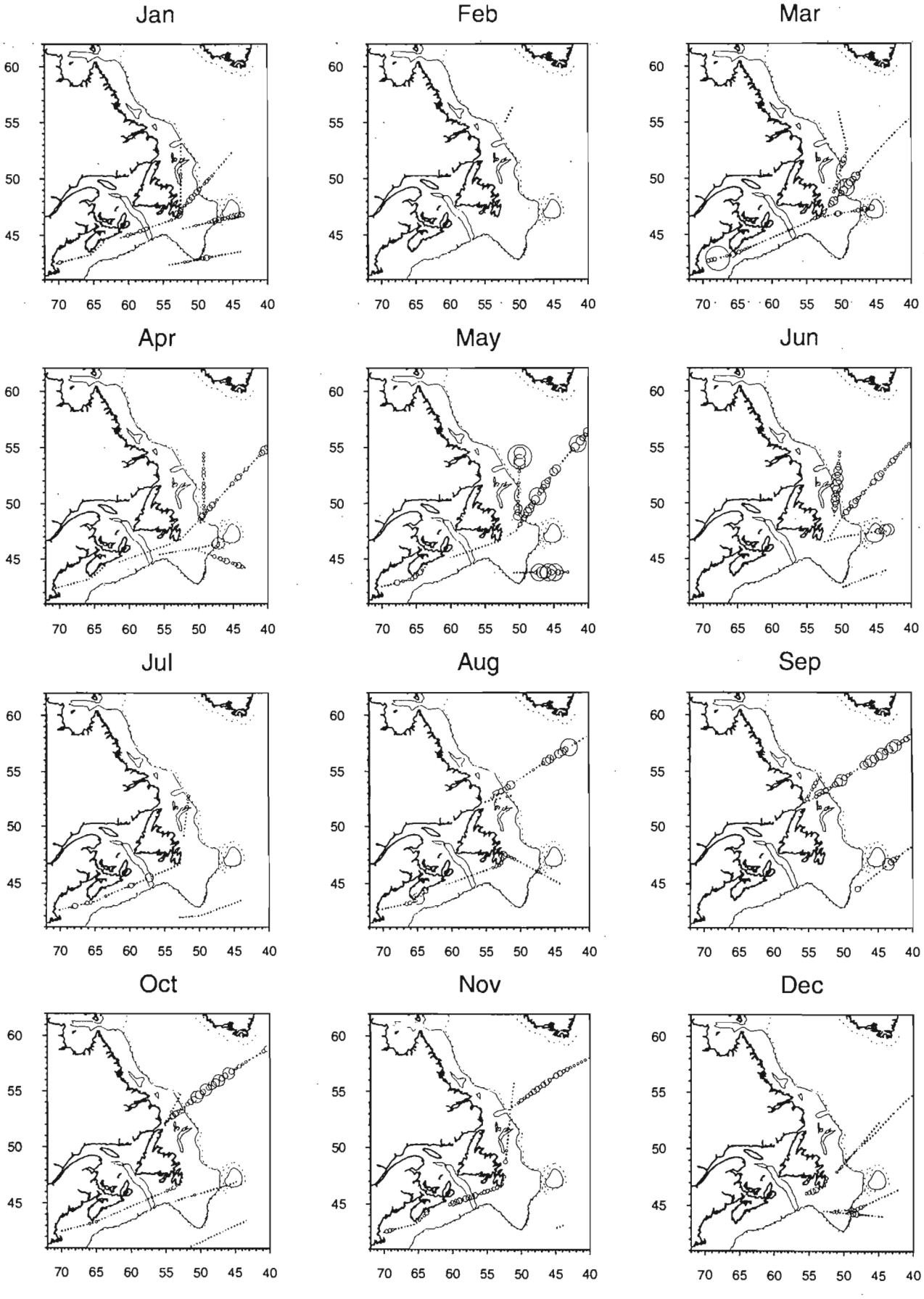
Nov



Dec

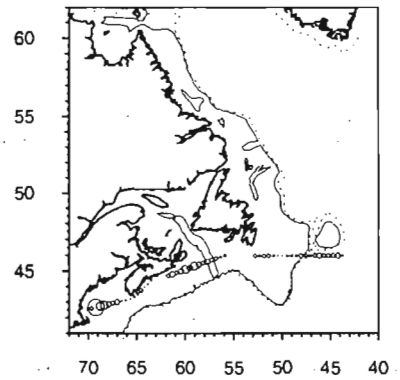


Calanus V-VI Total : 1970

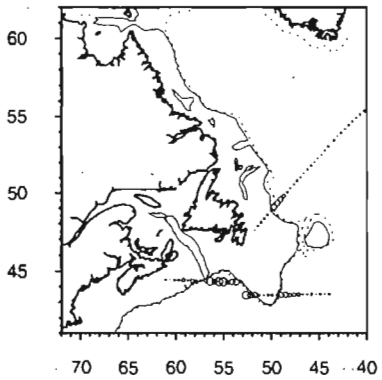


Calanus V-VI Total : 1971

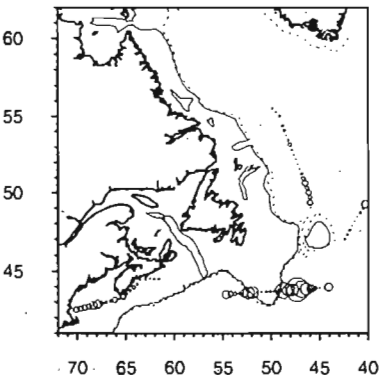
Jan



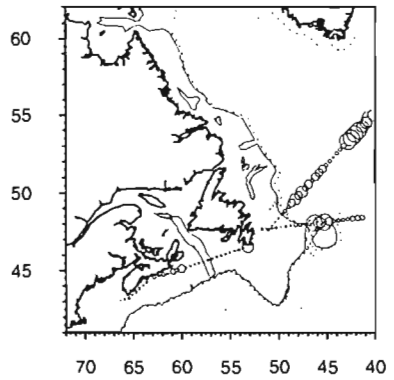
Feb



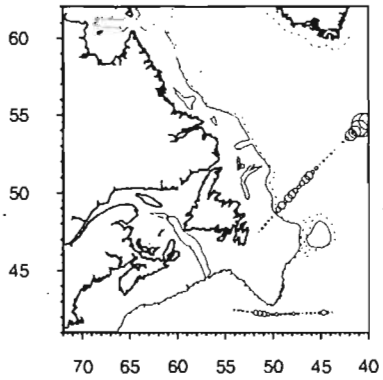
Mar



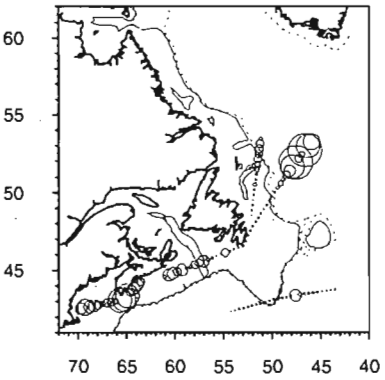
Apr



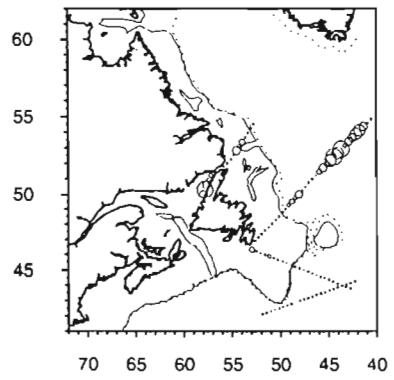
May



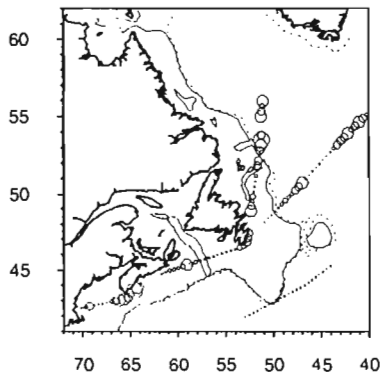
Jun



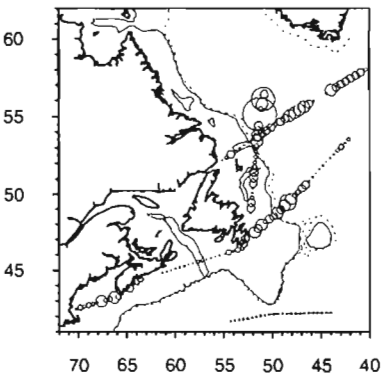
Jul



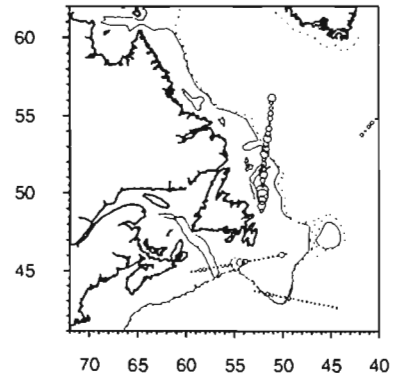
Aug



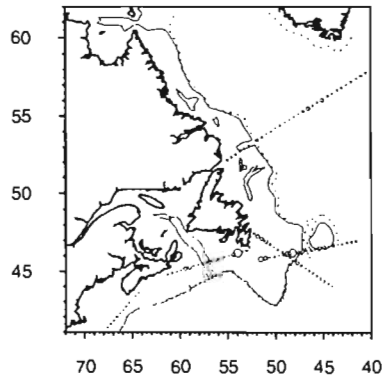
Sep



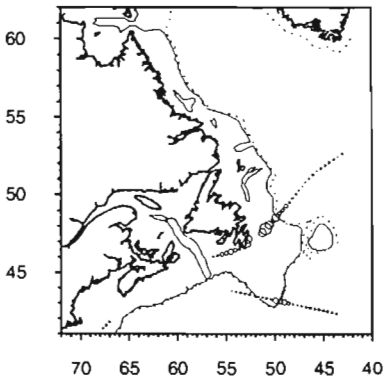
Oct



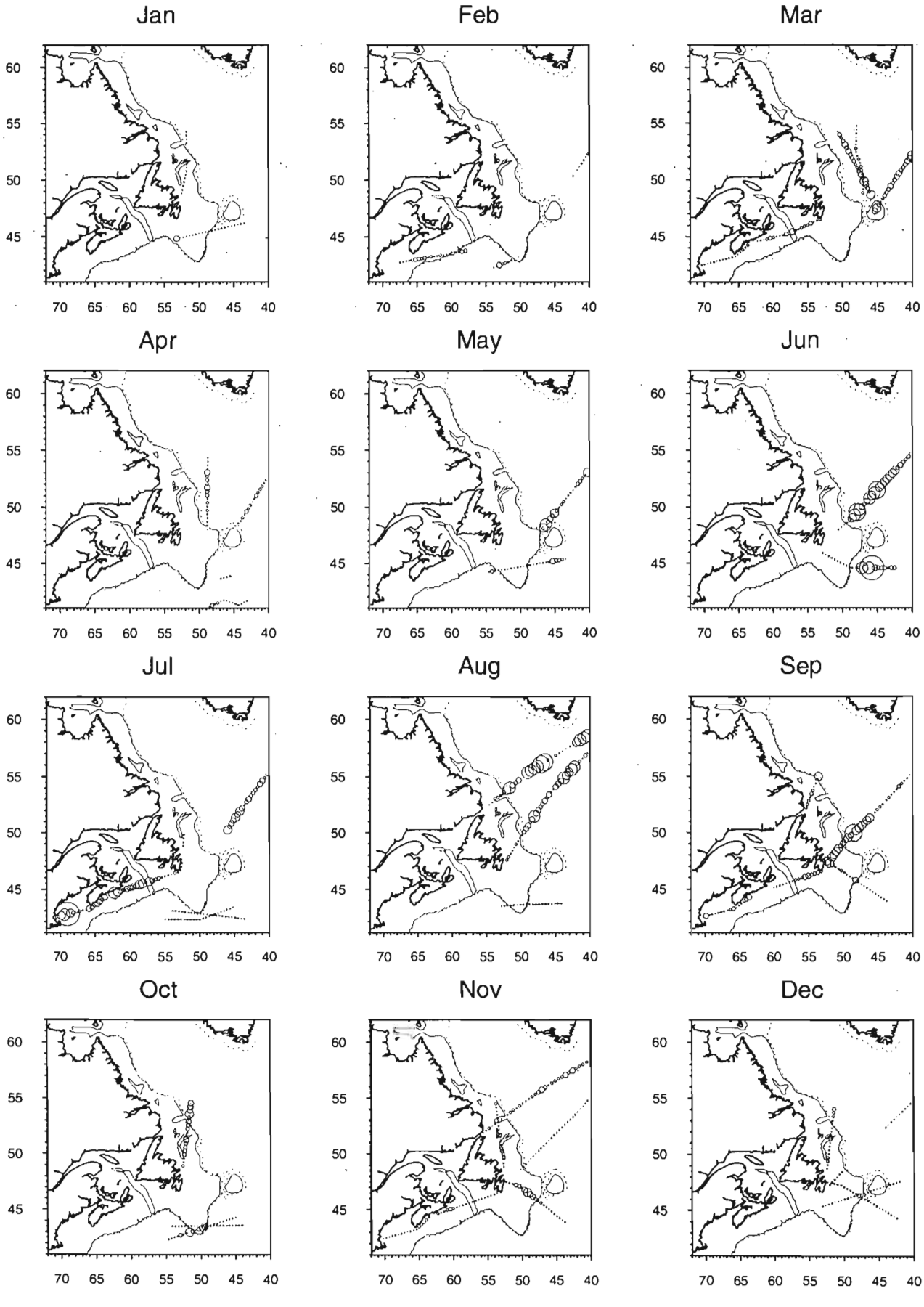
Nov



Dec

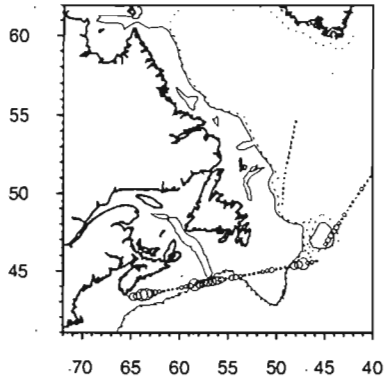


Calanus V-VI Total : 1972

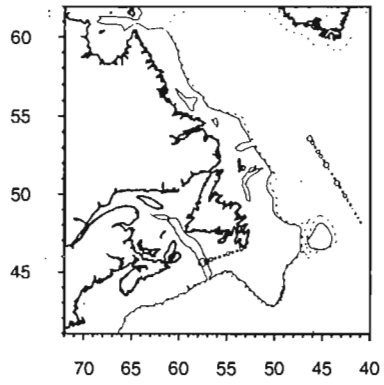


Calanus V-VI Total : 1973

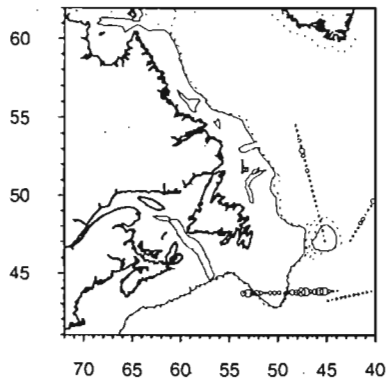
Jan



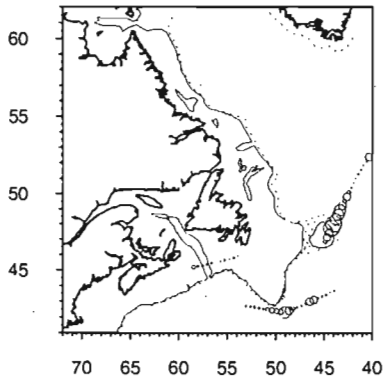
Feb



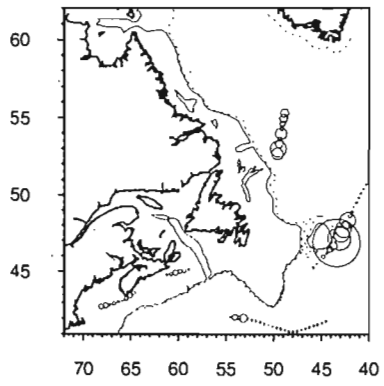
Mar



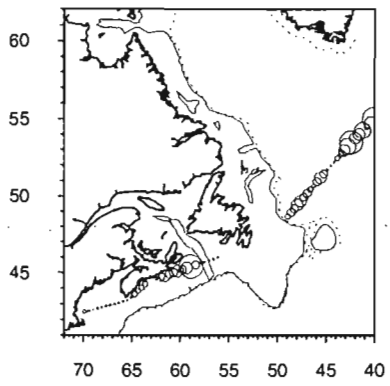
Apr



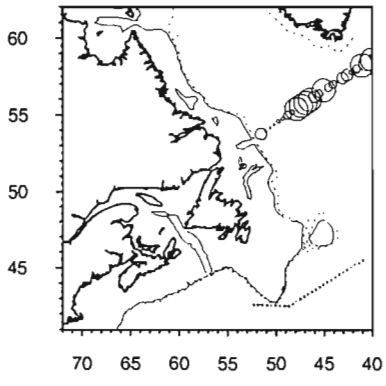
May



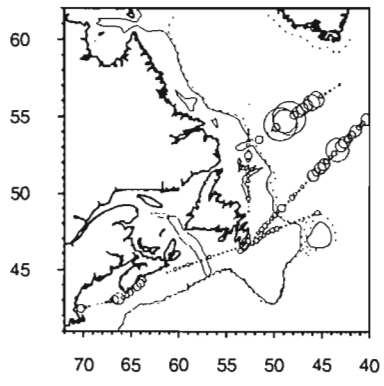
Jun



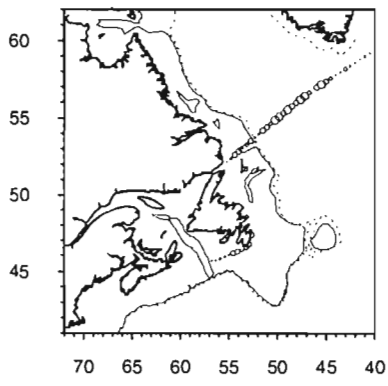
Jul



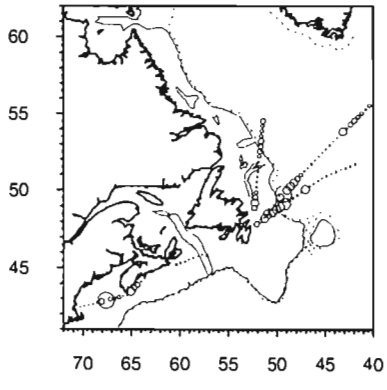
Aug



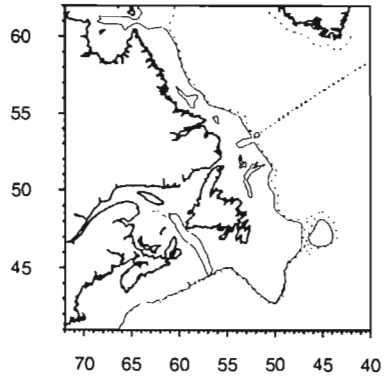
Sep



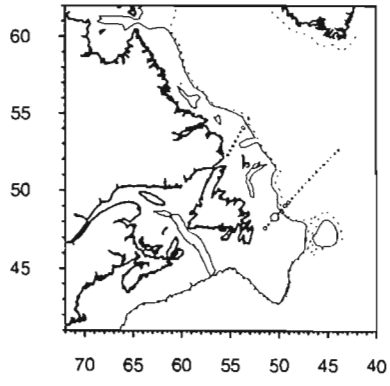
Oct



Nov

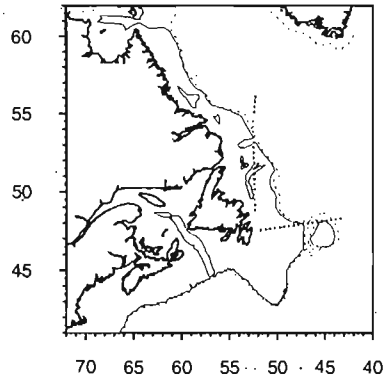


Dec

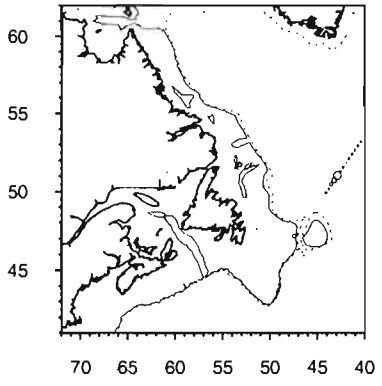


Calanus V-VI Total : 1974

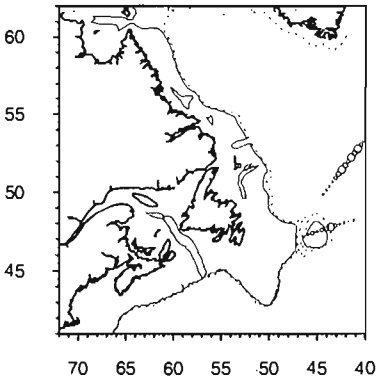
Jan



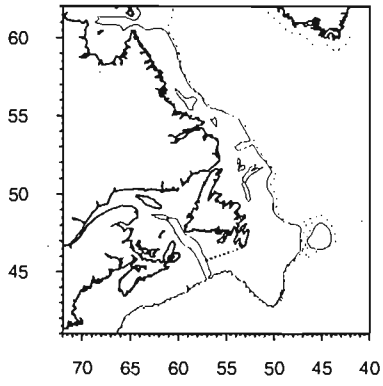
Feb



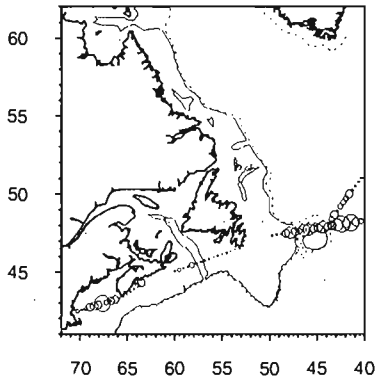
Mar



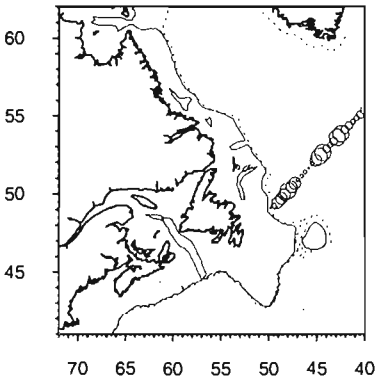
Apr



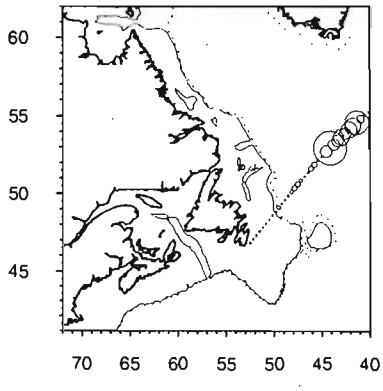
May



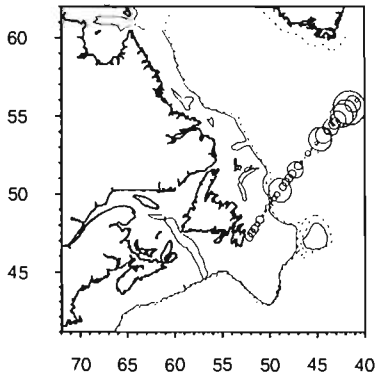
Jun



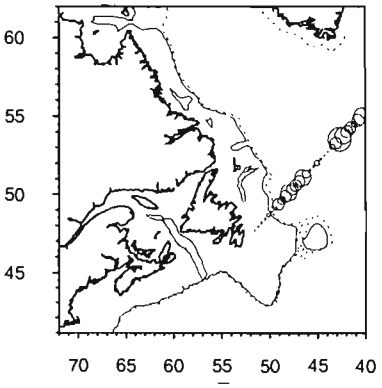
Jul



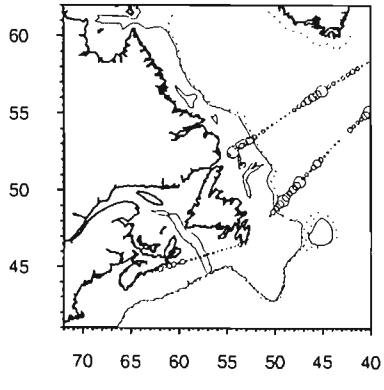
Aug



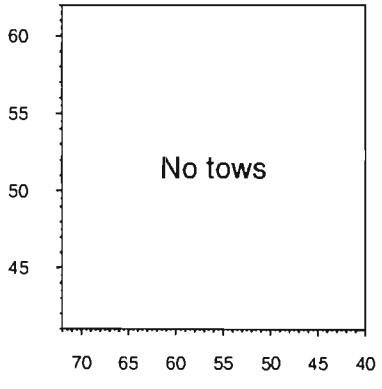
Sep



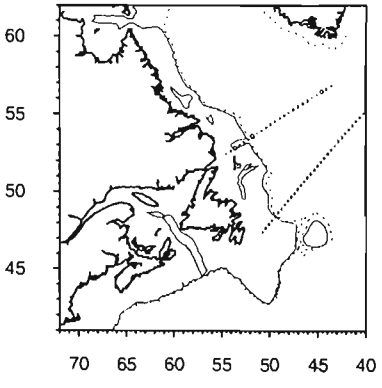
Oct



Nov

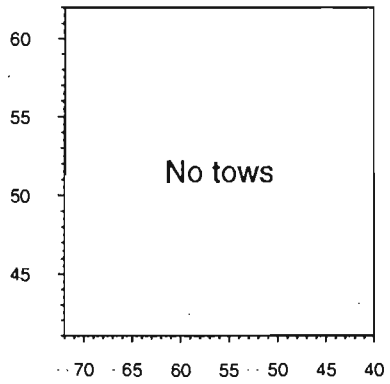


Dec

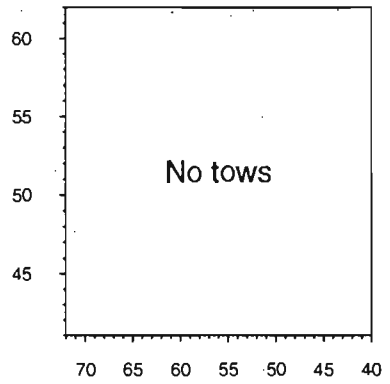


Calanus V-VI Total : 1975

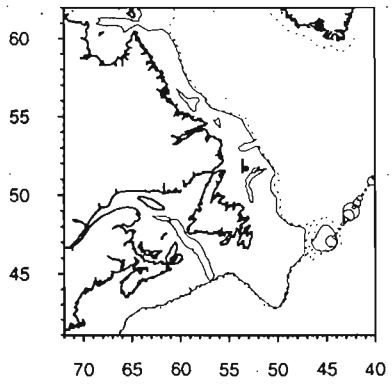
Jan



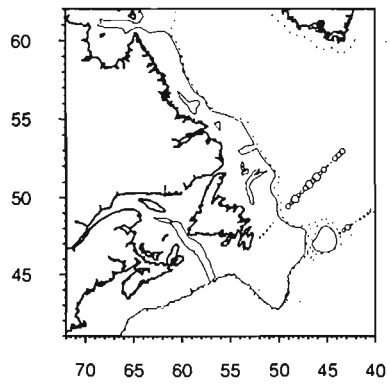
Feb



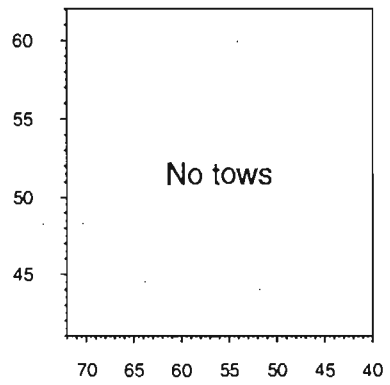
Mar



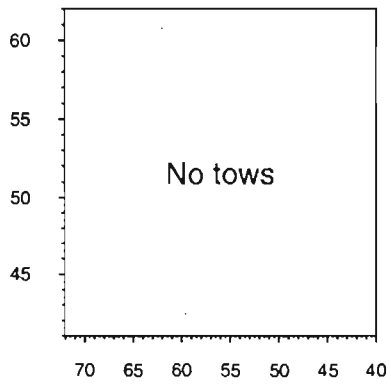
Apr



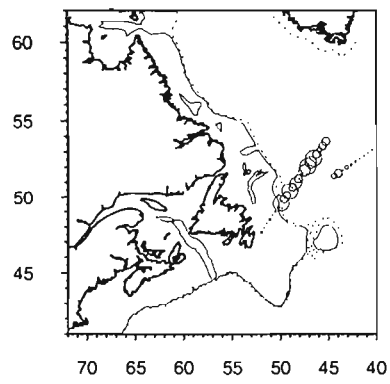
May



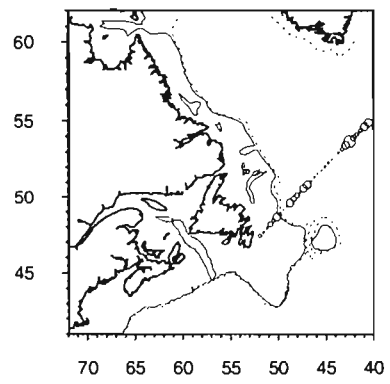
Jun



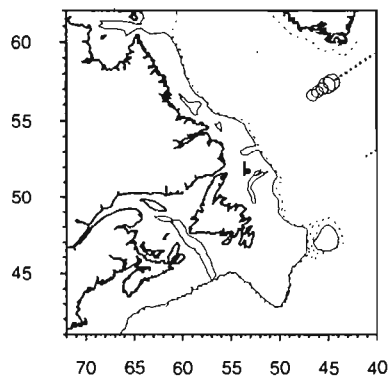
Jul



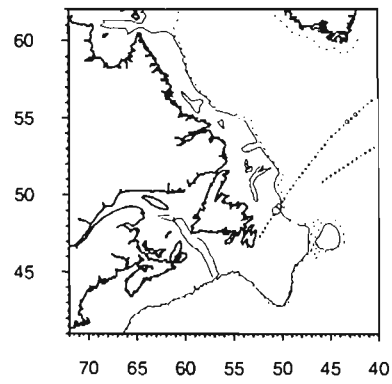
Aug



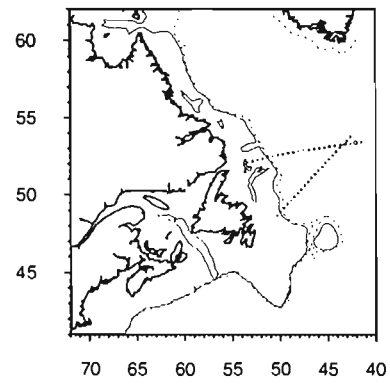
Sep



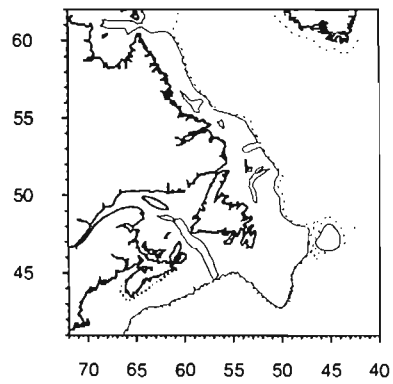
Oct



Nov

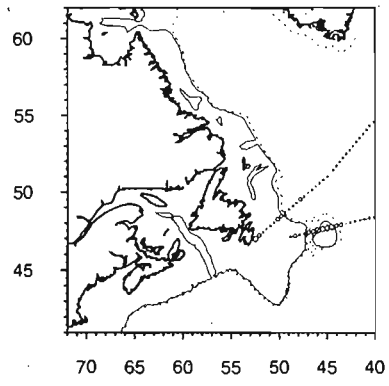


Dec

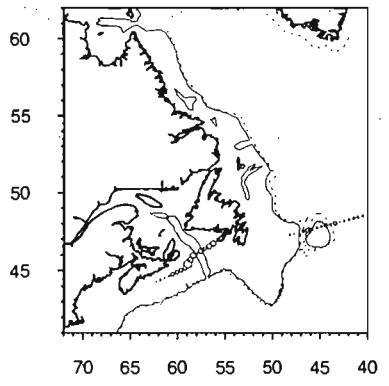


Calanus V-VI Total : 1976

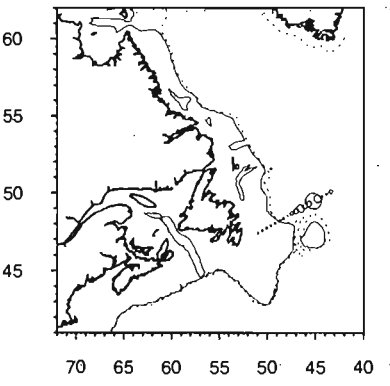
Jan



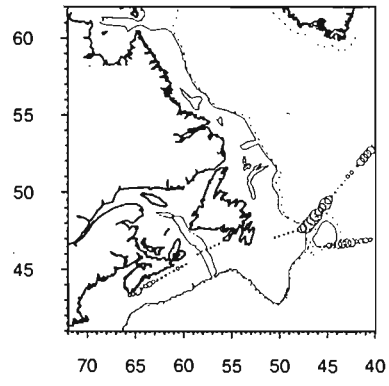
Feb



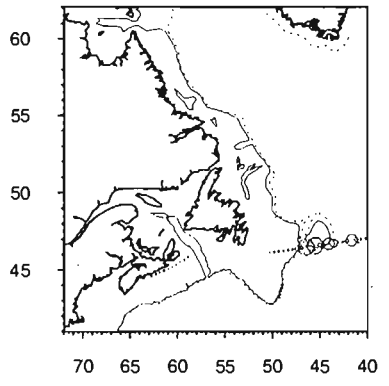
Mar



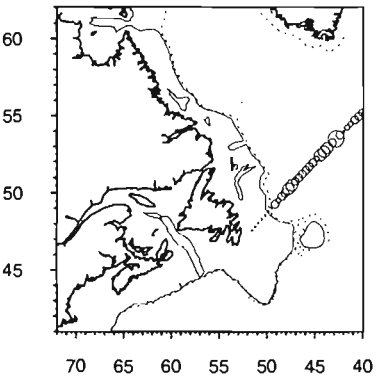
Apr



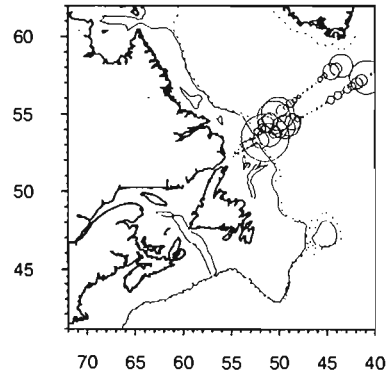
May



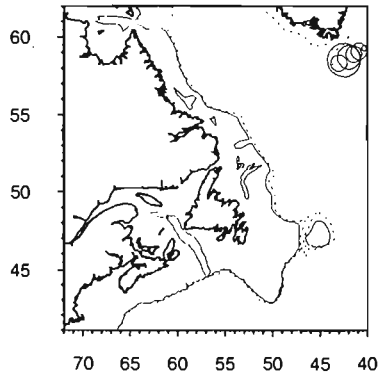
Jun



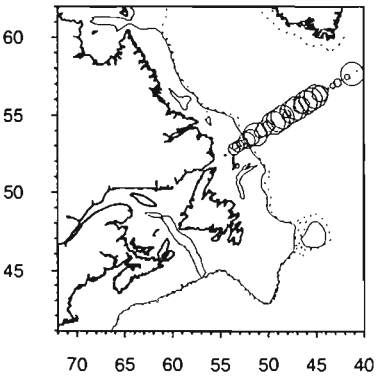
Jul



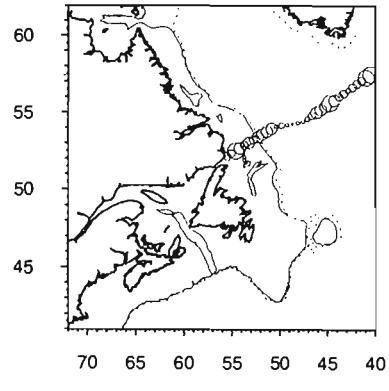
Aug



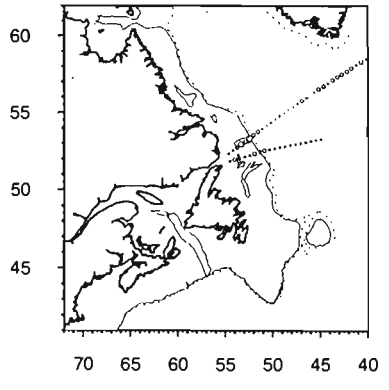
Sep



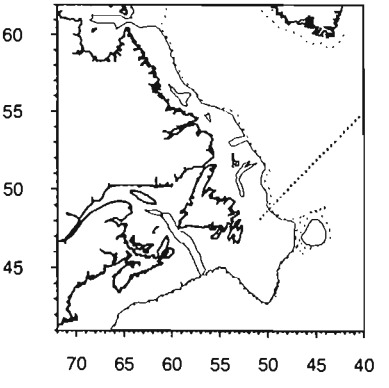
Oct



Nov

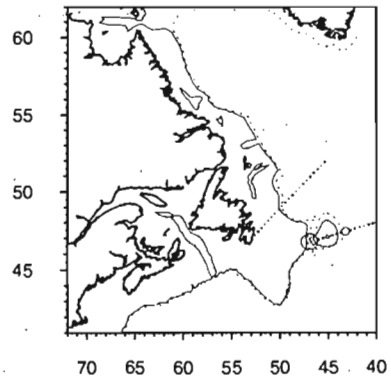


Dec

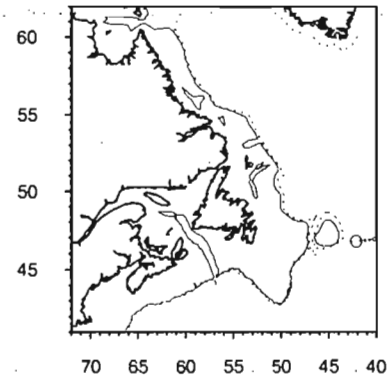


Calanus V-VI Total : 1977

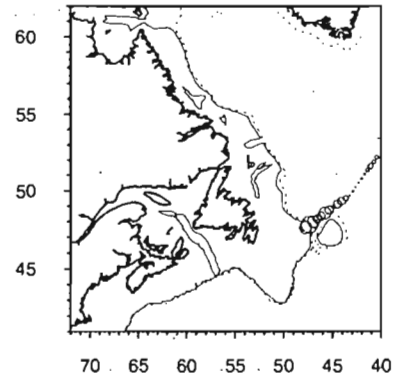
Jan



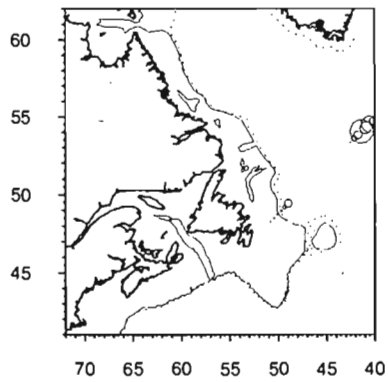
Feb



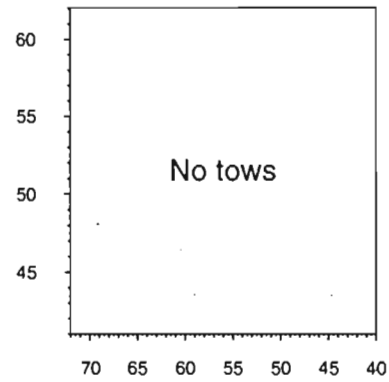
Mar



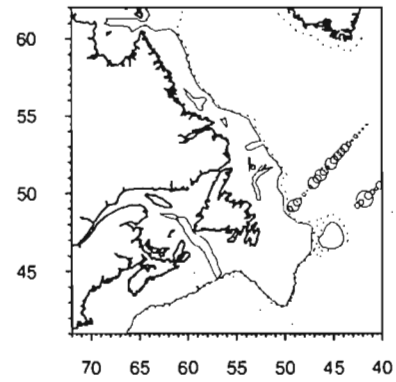
Apr



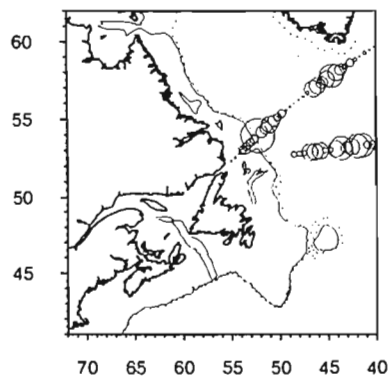
May



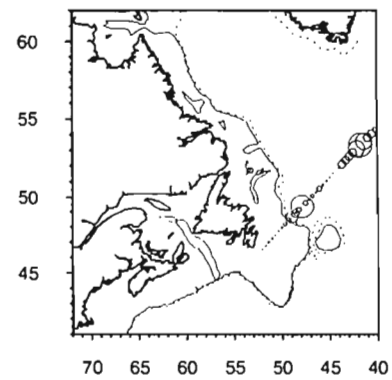
Jun



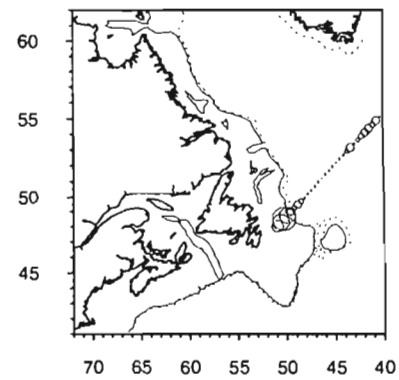
Jul



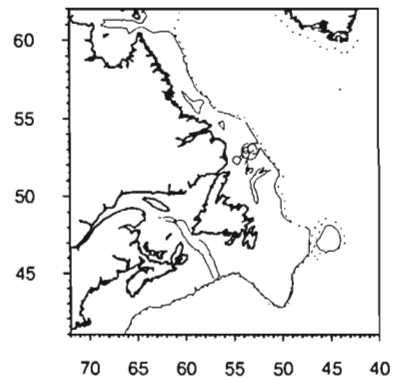
Aug



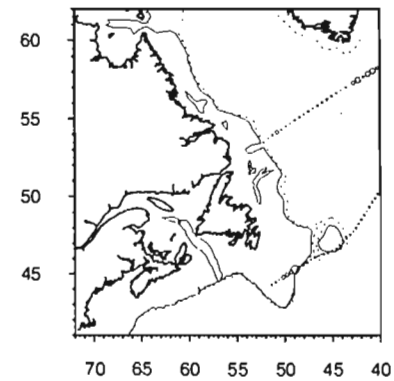
Sep



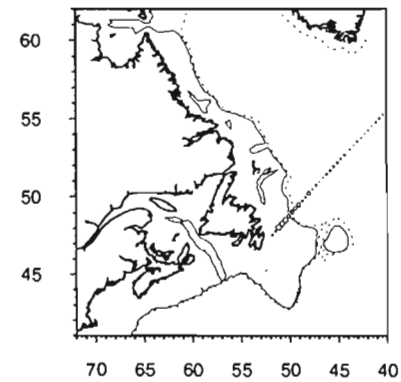
Oct



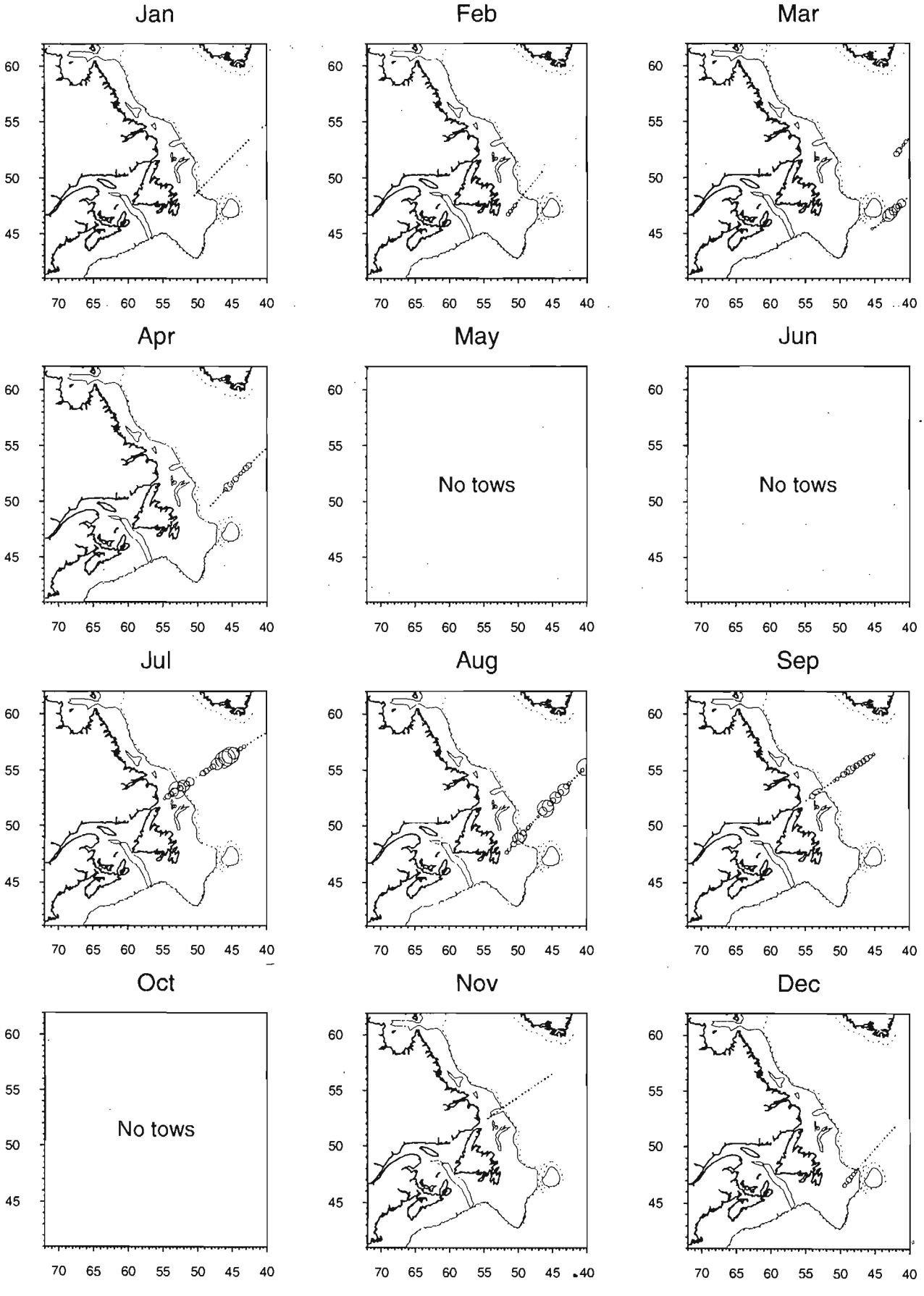
Nov



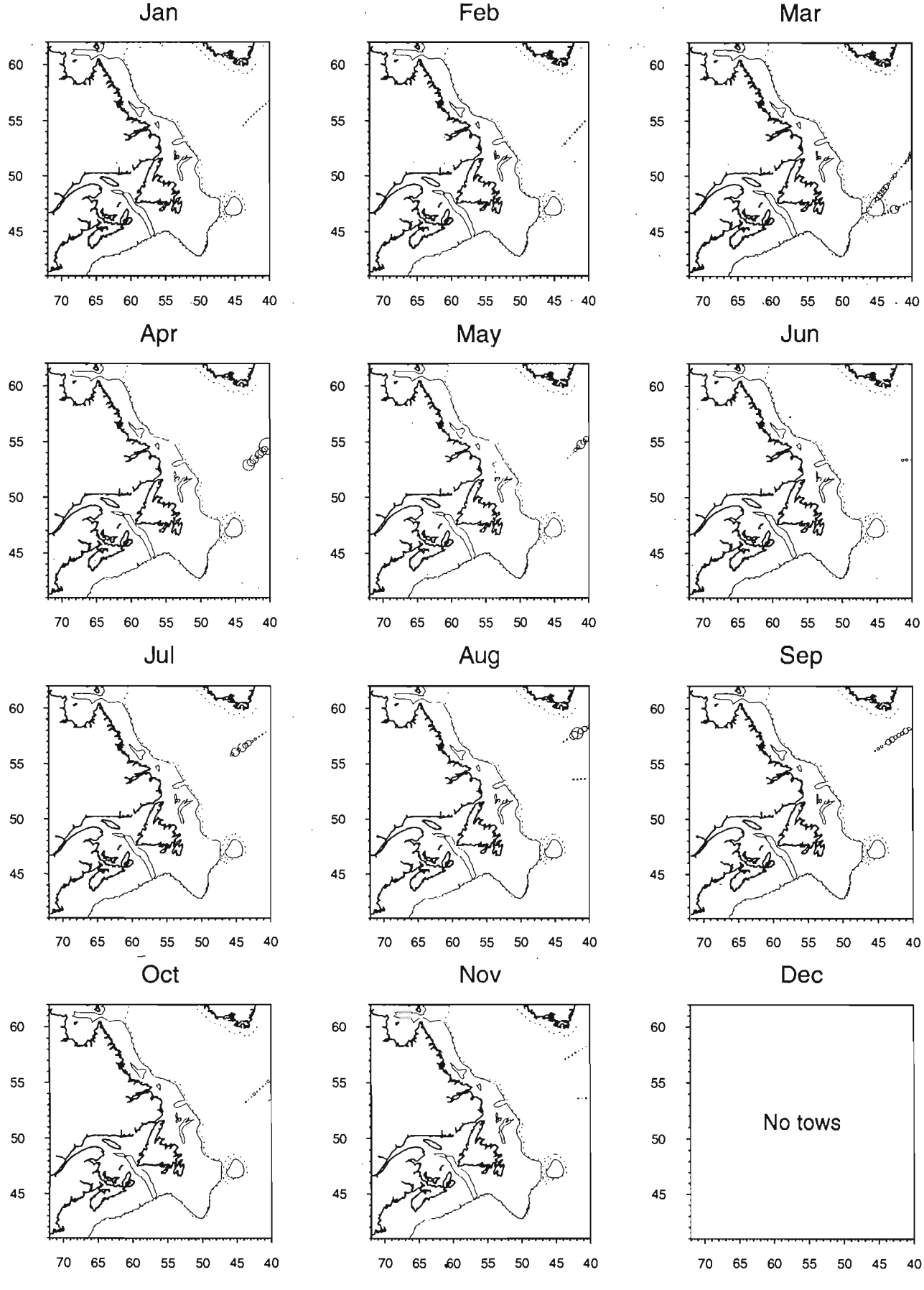
Dec



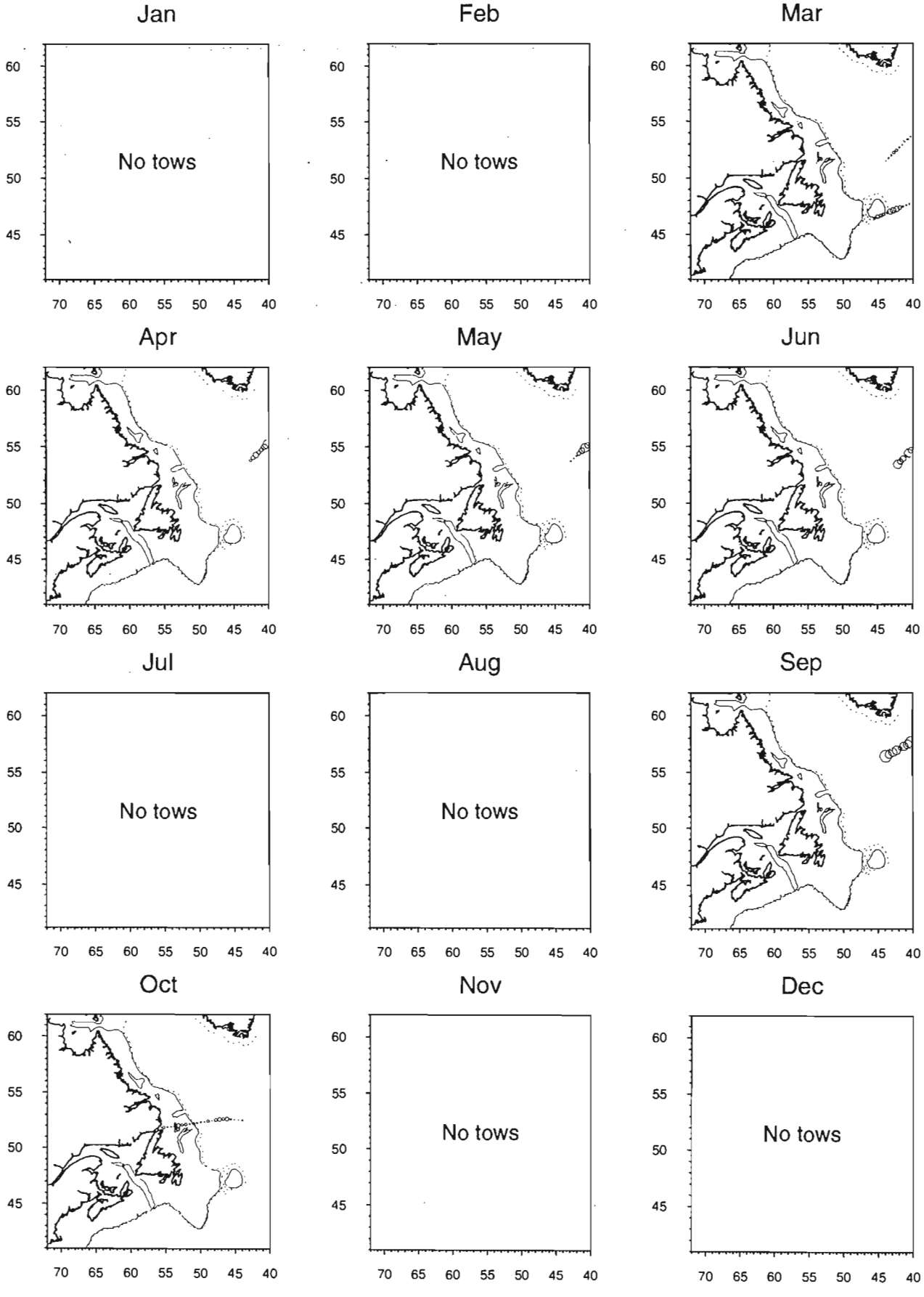
Calanus V-VI Total : 1978



Calanus V-VI Total : 1979

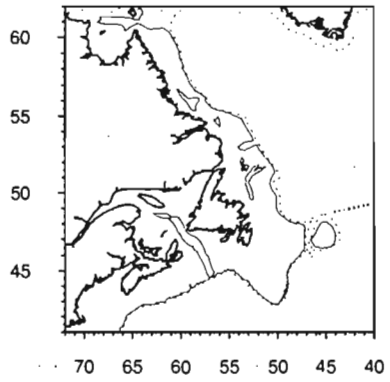


Calanus V-VI Total : 1980

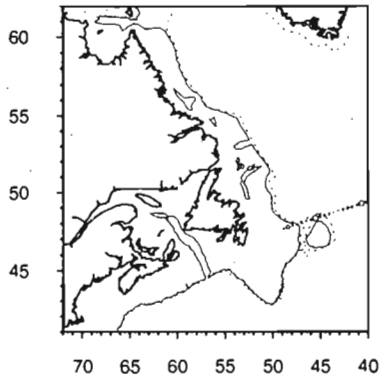


Calanus V-VI Total : 1981

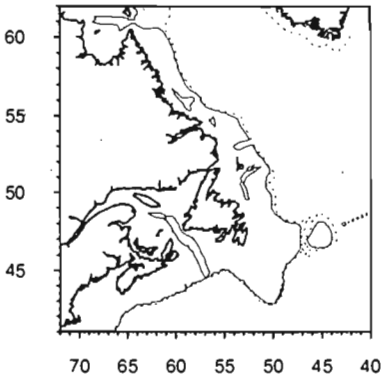
Jan



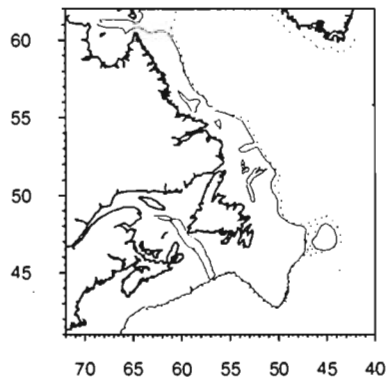
Feb



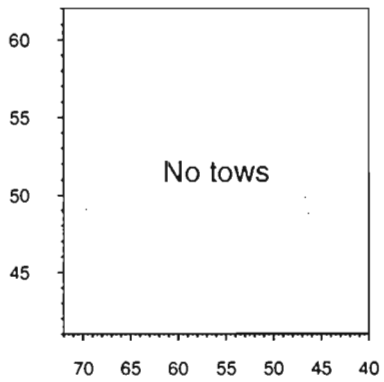
Mar



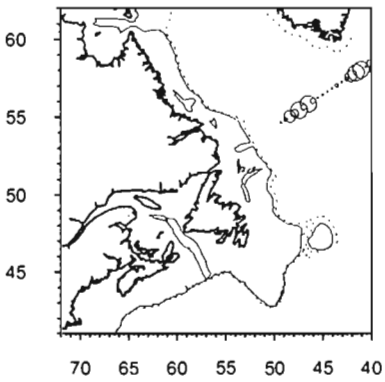
Apr



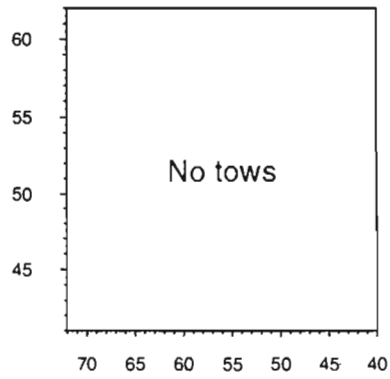
May



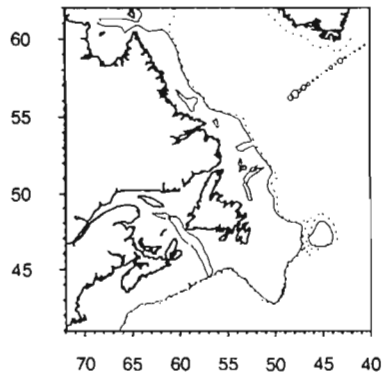
Jun



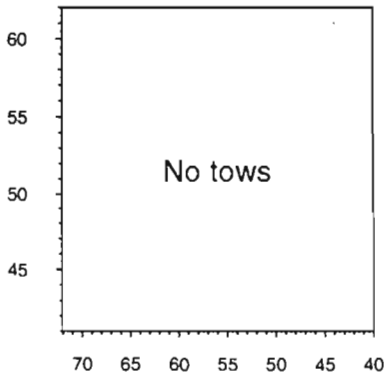
Jul



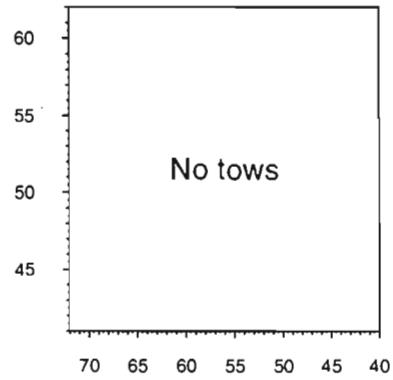
Aug



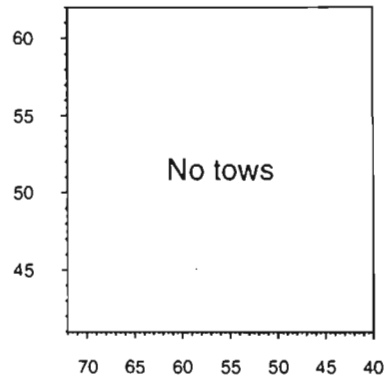
Sep



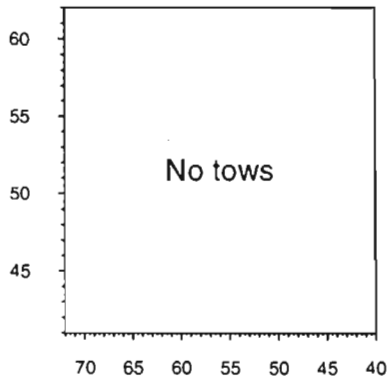
Oct



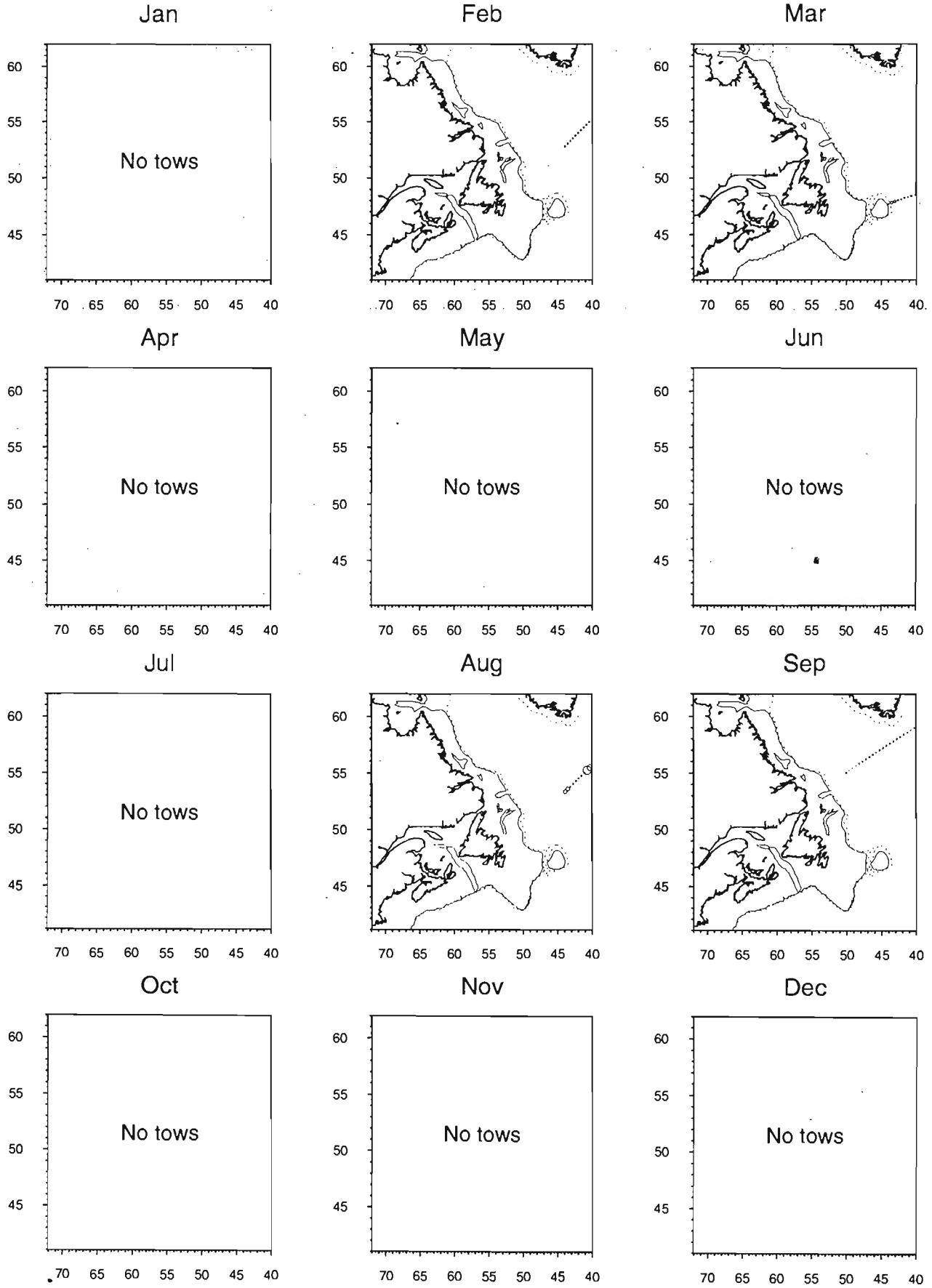
Nov



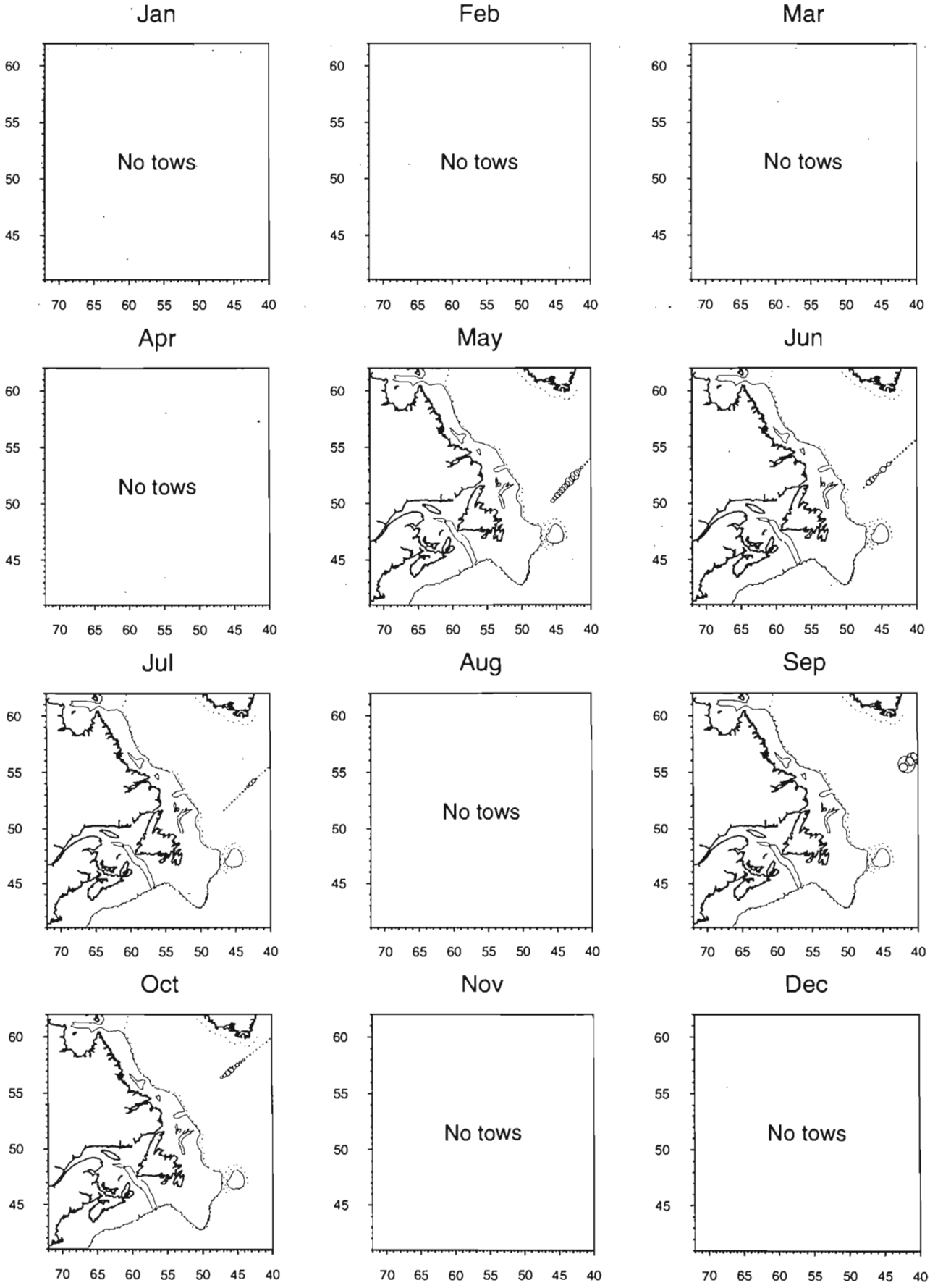
Dec



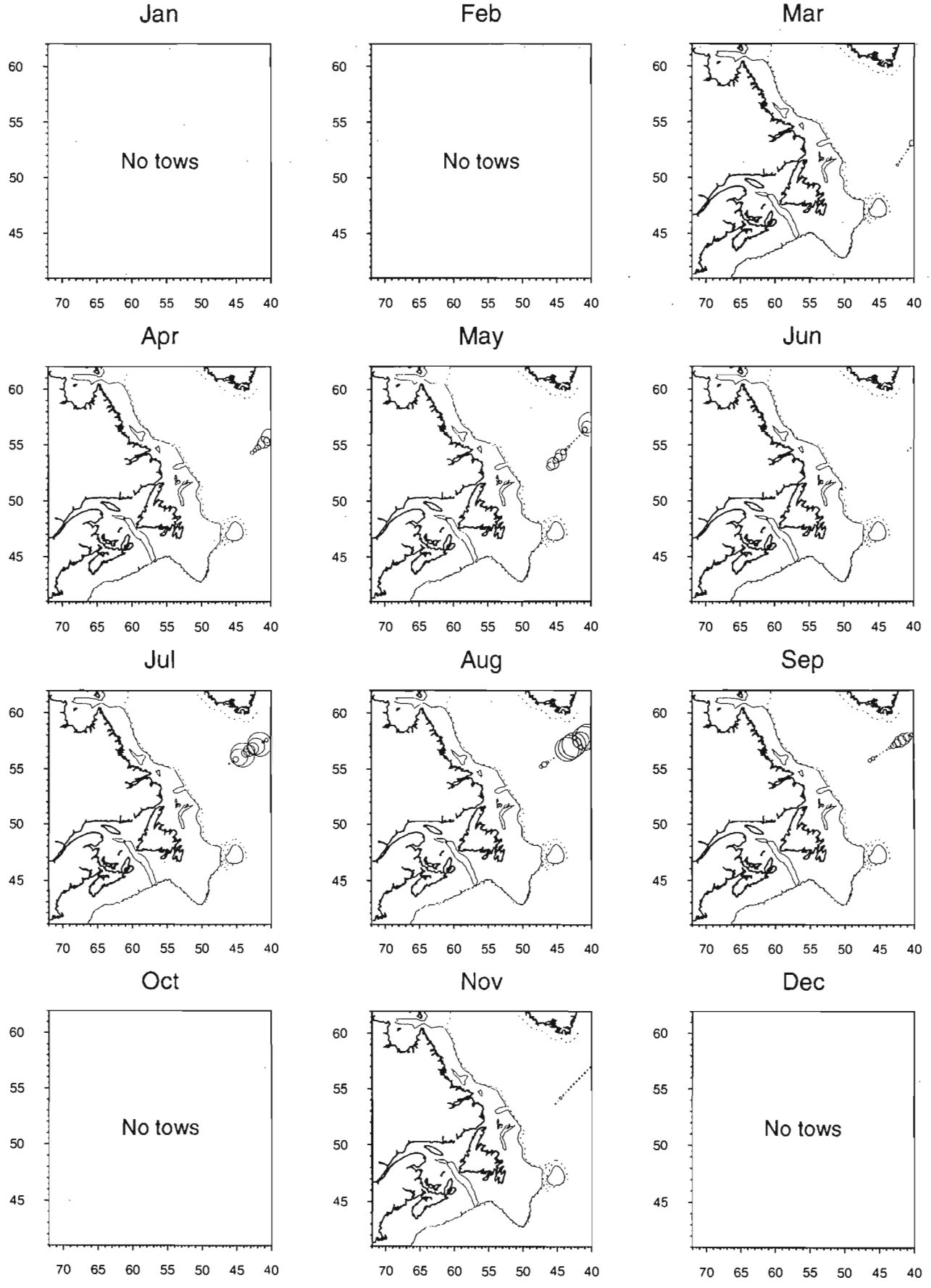
Calanus V-VI Total : 1982



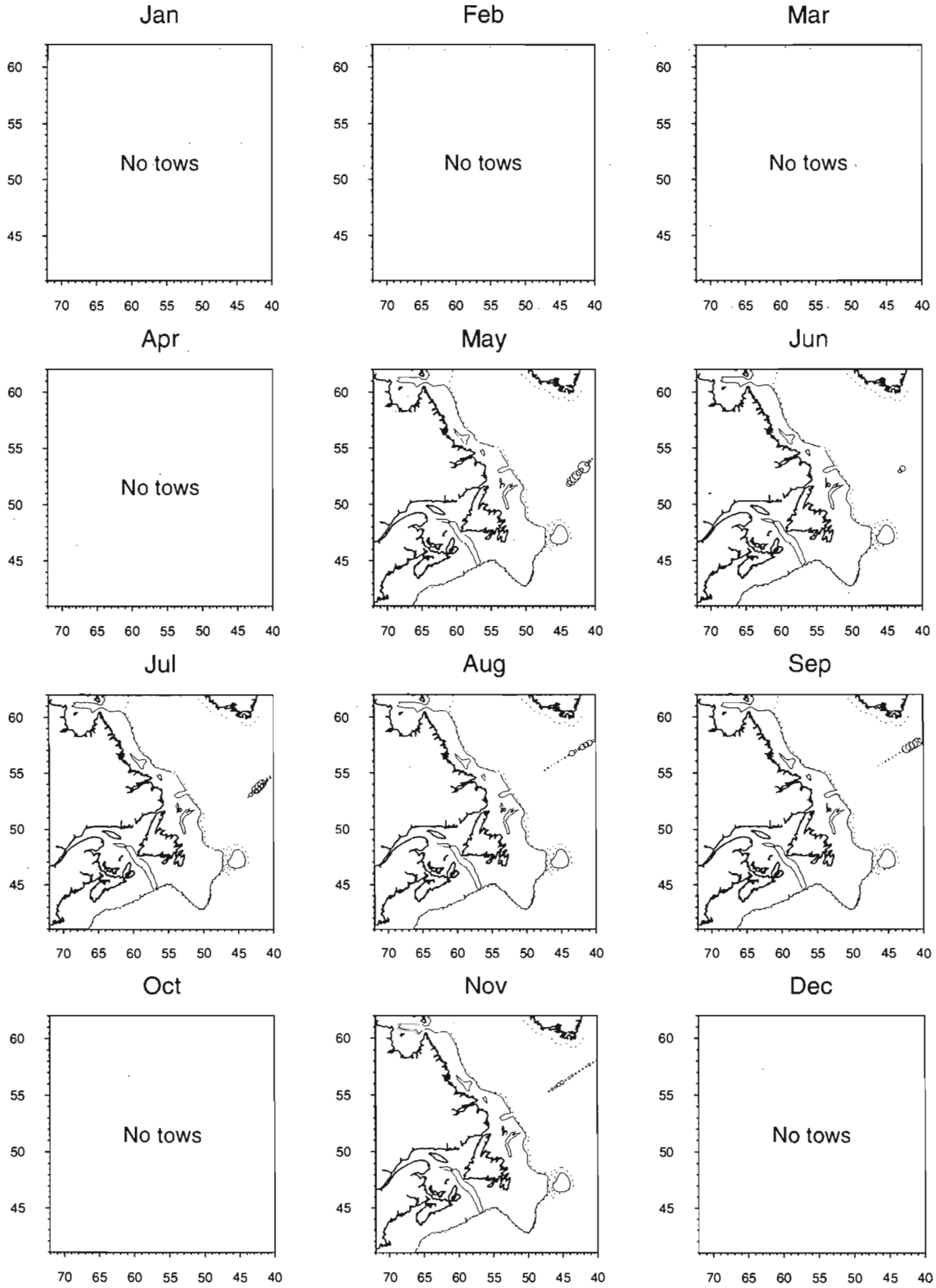
Calanus V-VI Total : 1983



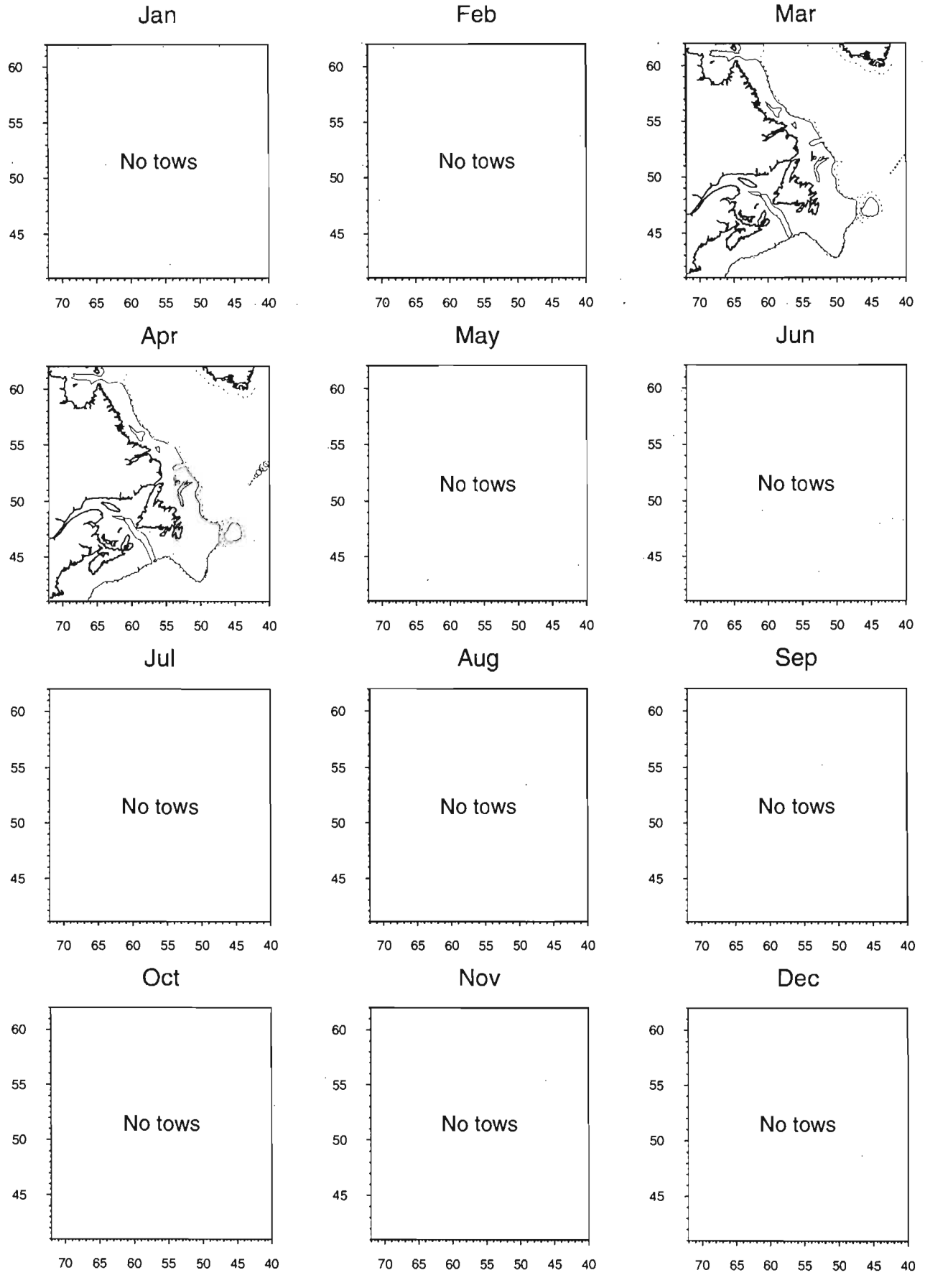
Calanus V-VI Total : 1984



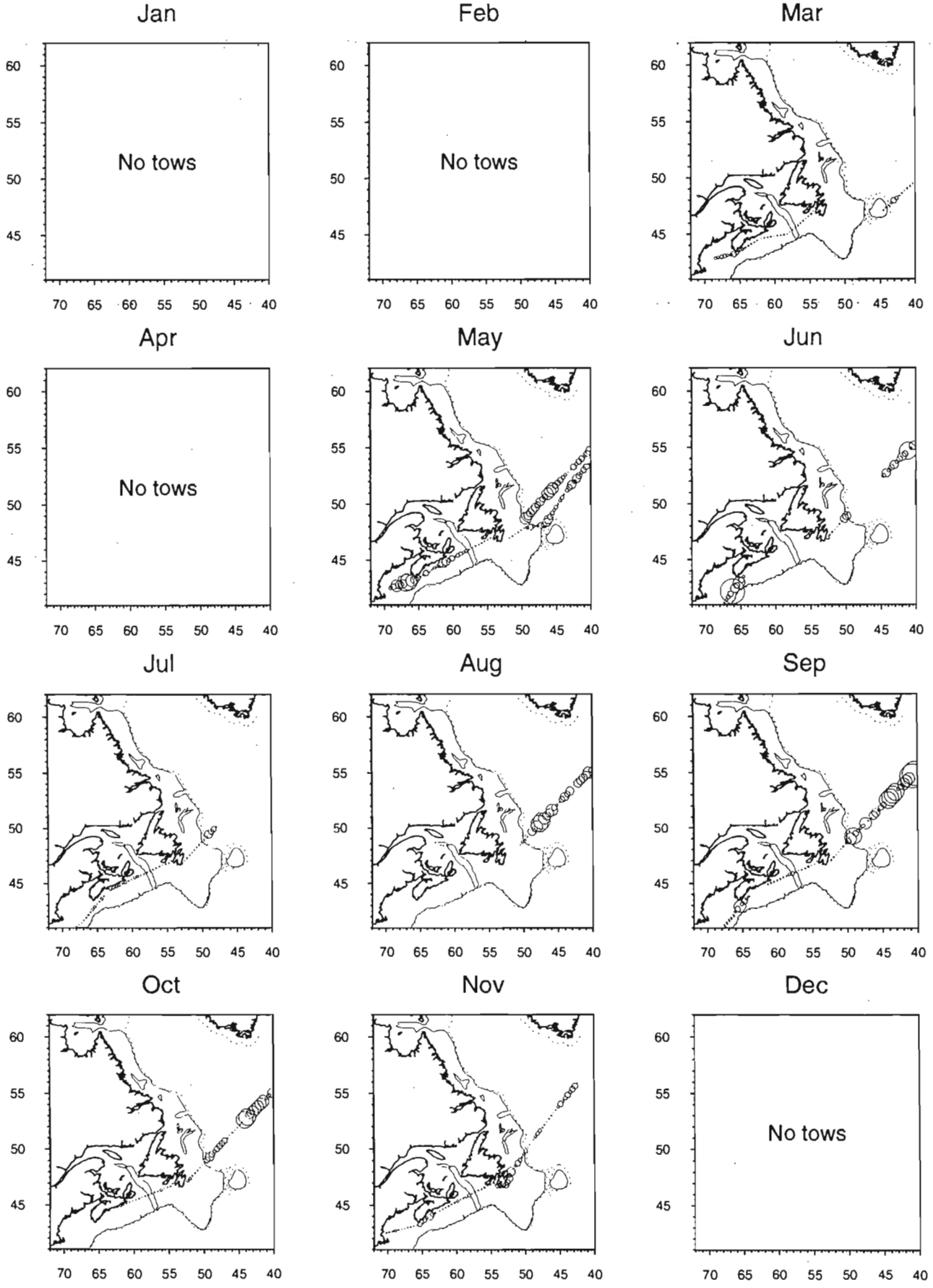
Calanus V-VI Total : 1985



Calanus V-VI Total : 1986

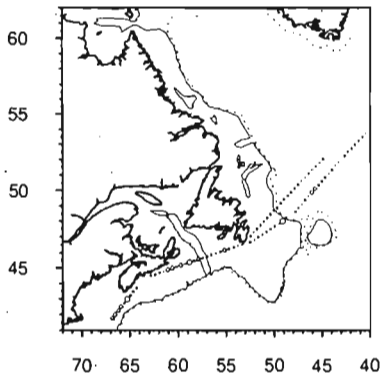


Calanus V-VI Total : 1991

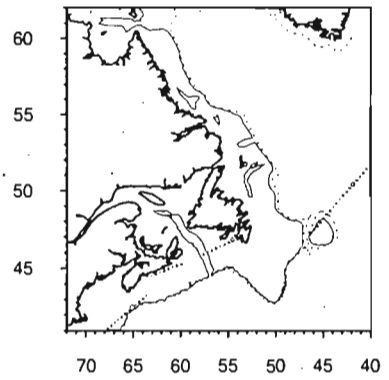


Calanus V-VI Total : 1992

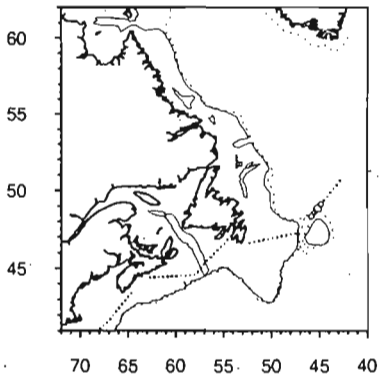
Jan



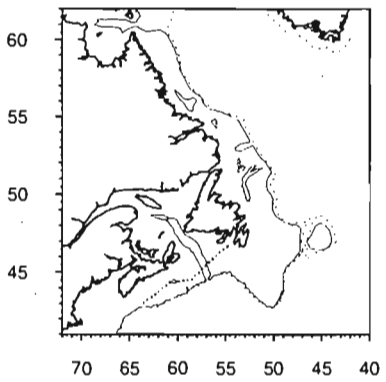
Feb



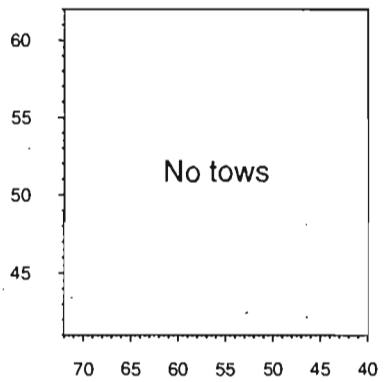
Mar



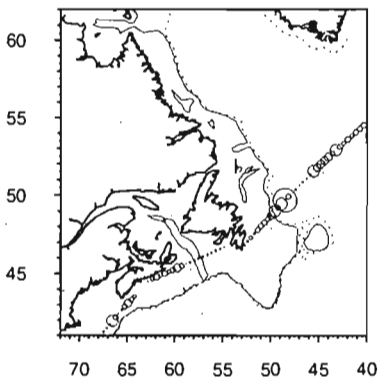
Apr



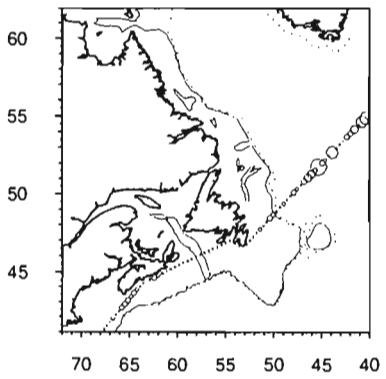
May



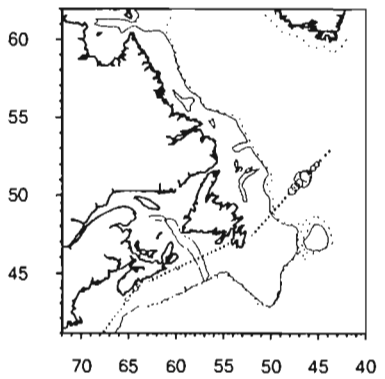
Jun



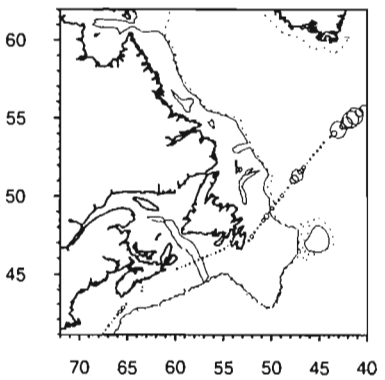
Jul



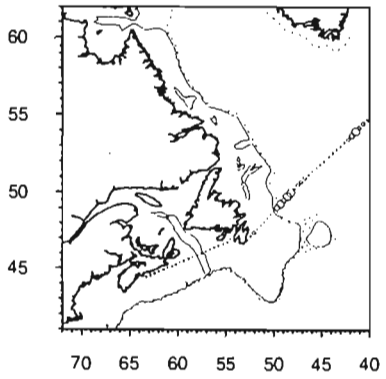
Aug



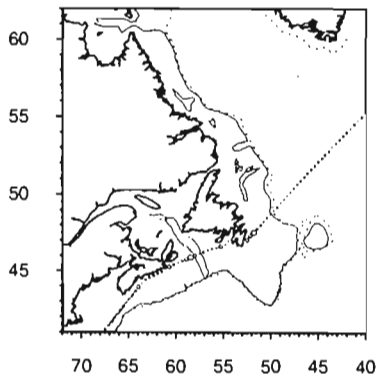
Sep



Oct



Nov



Dec

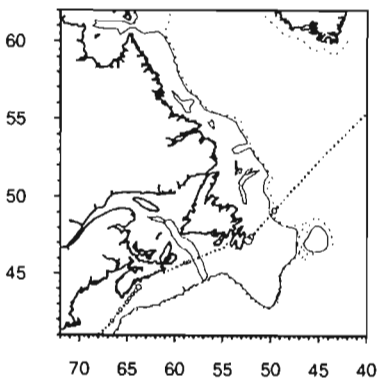
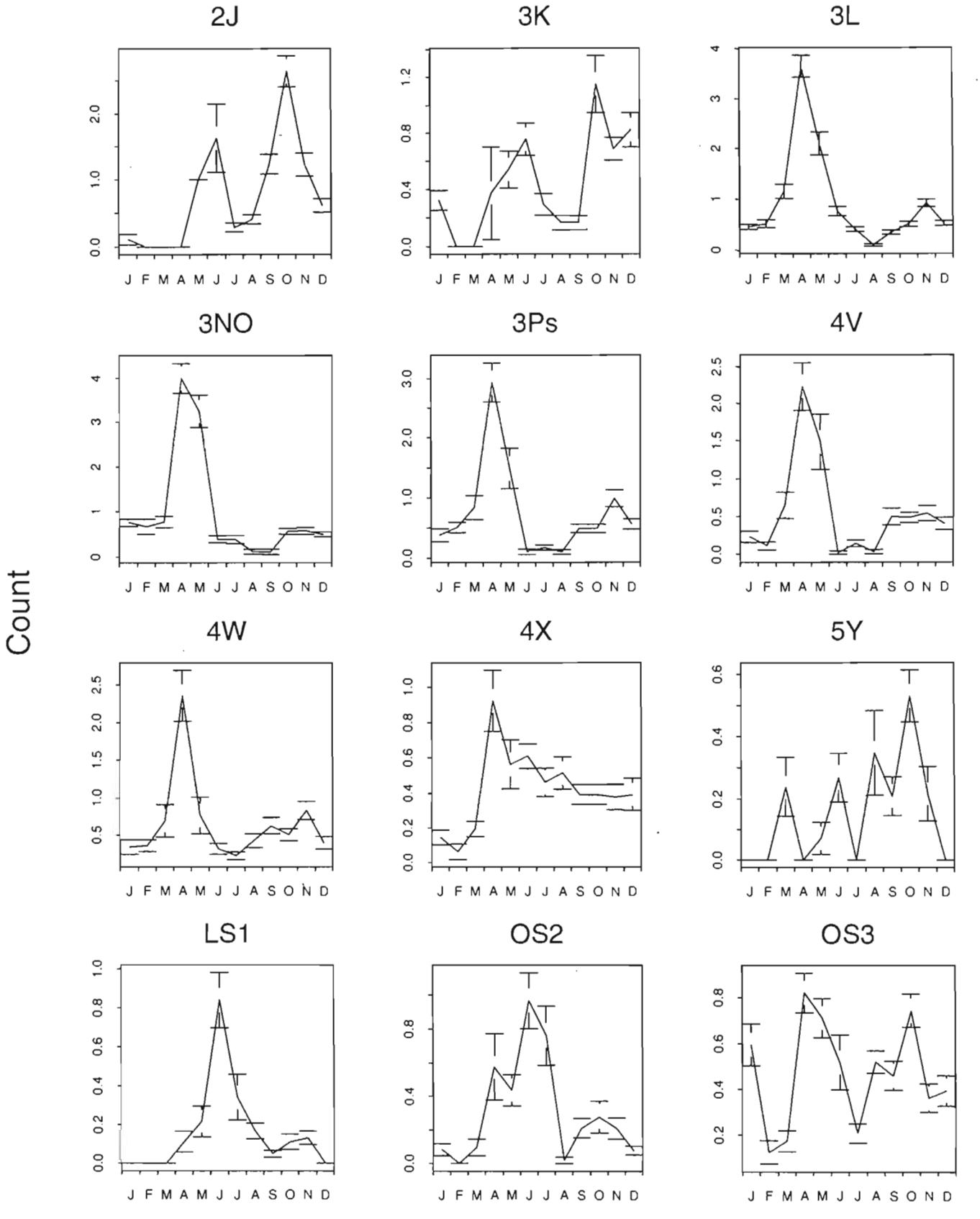
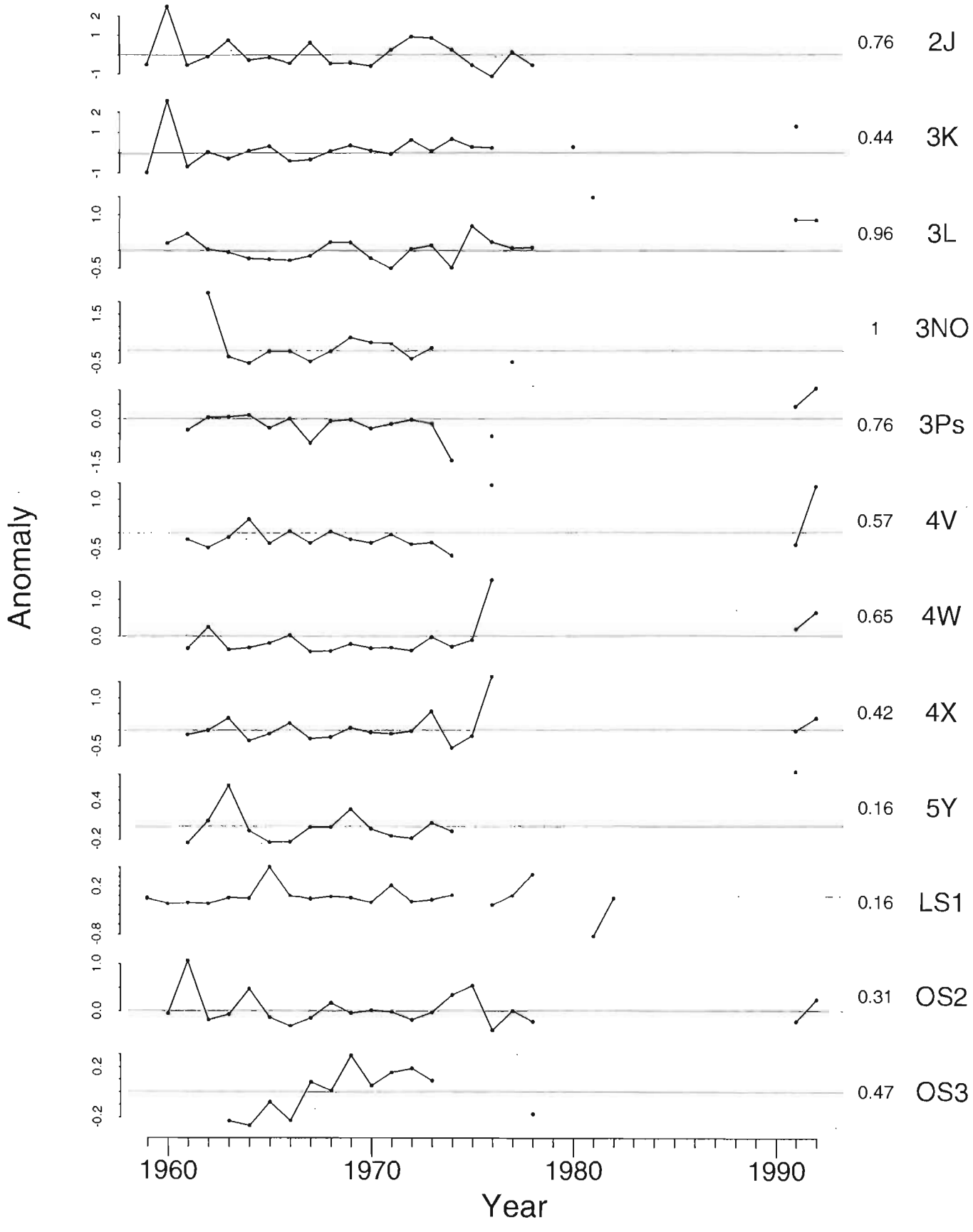


Figure 5. Seasonal cycles (1st page) and yearly anomalies (2nd page) for selected taxa in each sub-region. Each seasonal cycle page consists of 12 panels, each of which represents a sub-region and shows the monthly mean count and associated standard error. Each yearly anomalies page consists of 12 vertically stacked plots, each showing annual departures from the seasonal cycle in each region. On the right hand side of each plot is the mean of the seasonal cycle and the name of the sub-region. Note that all of these plots have self-scaled ordinates.

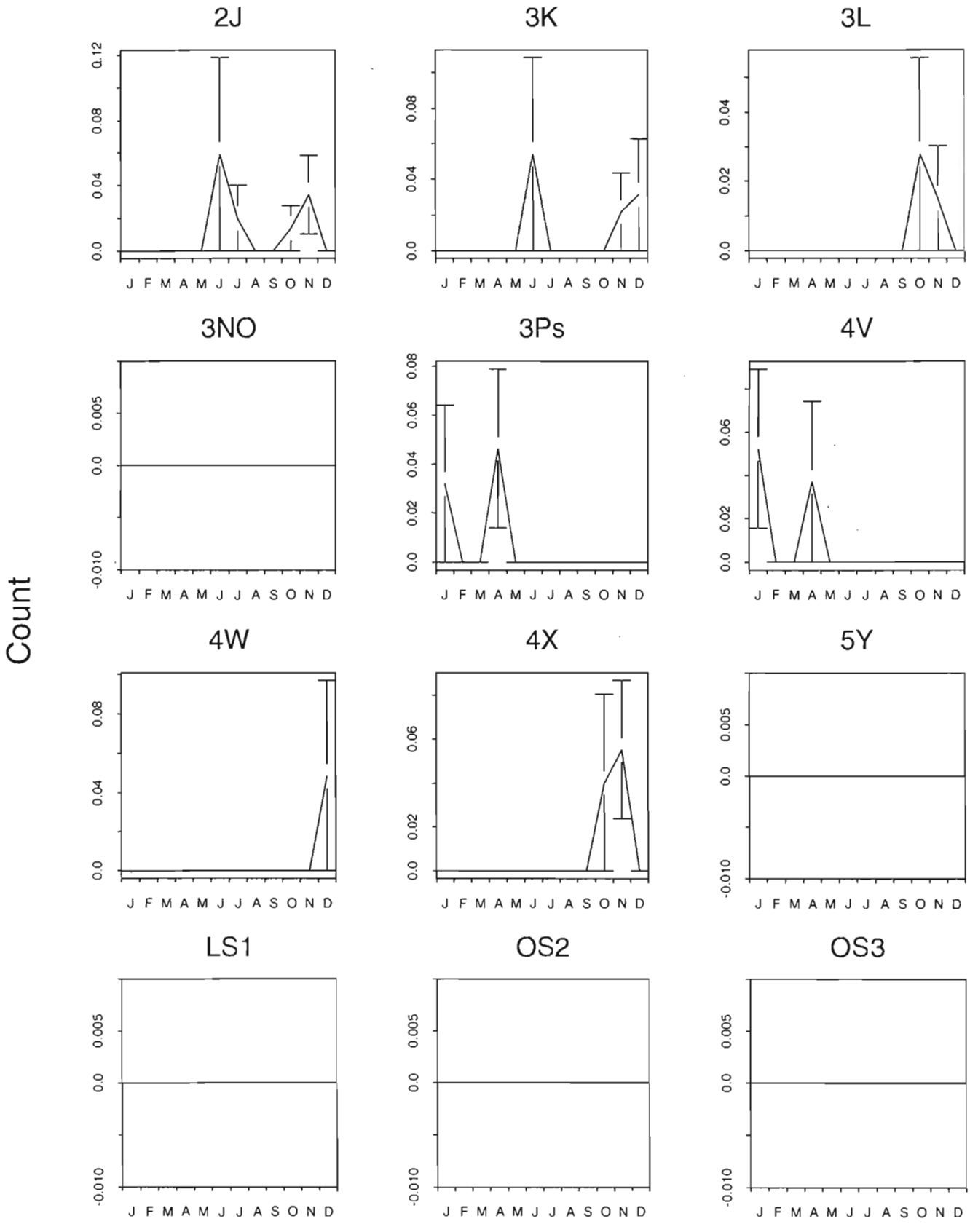
Phytoplankton colour



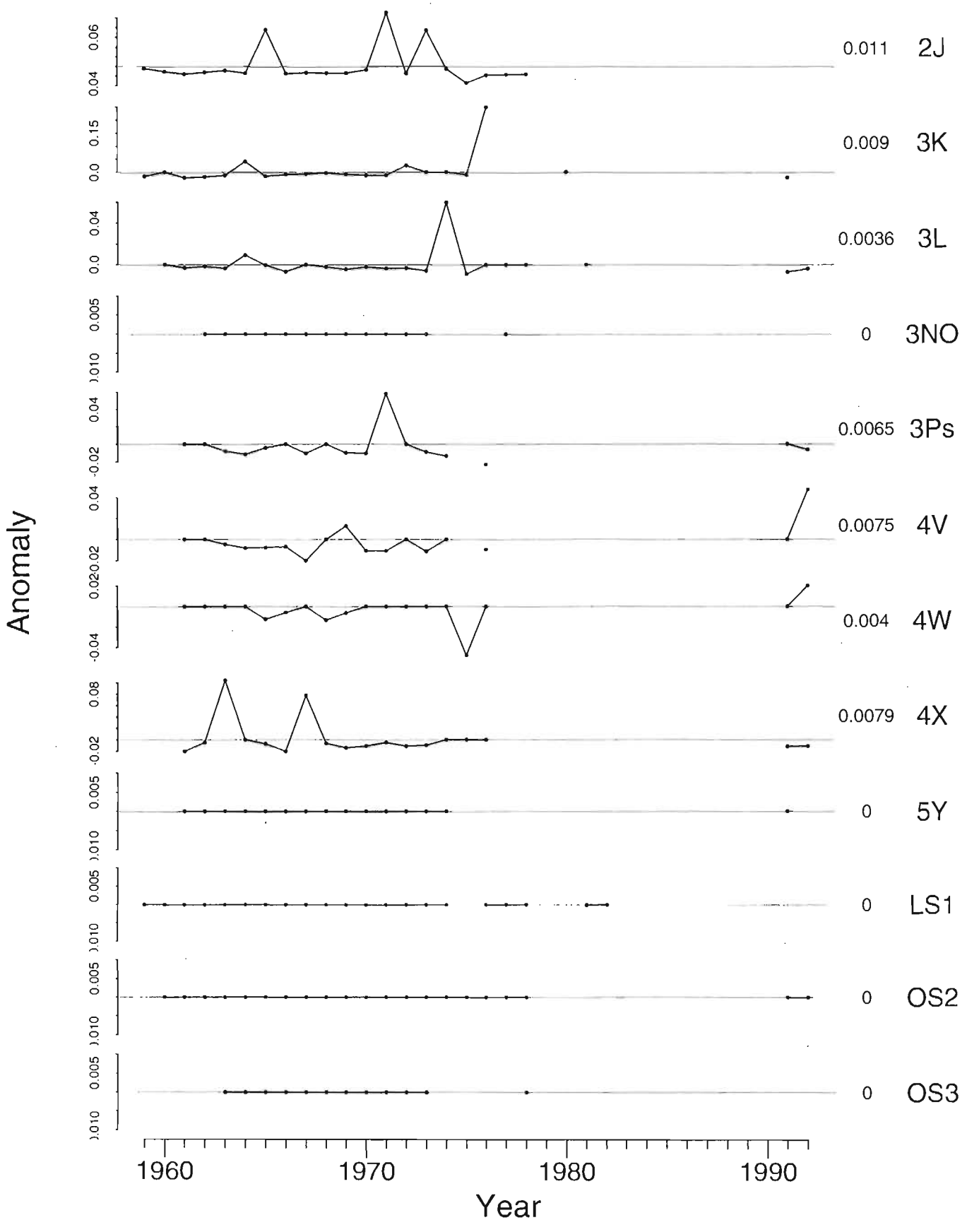
Phytoplankton colour



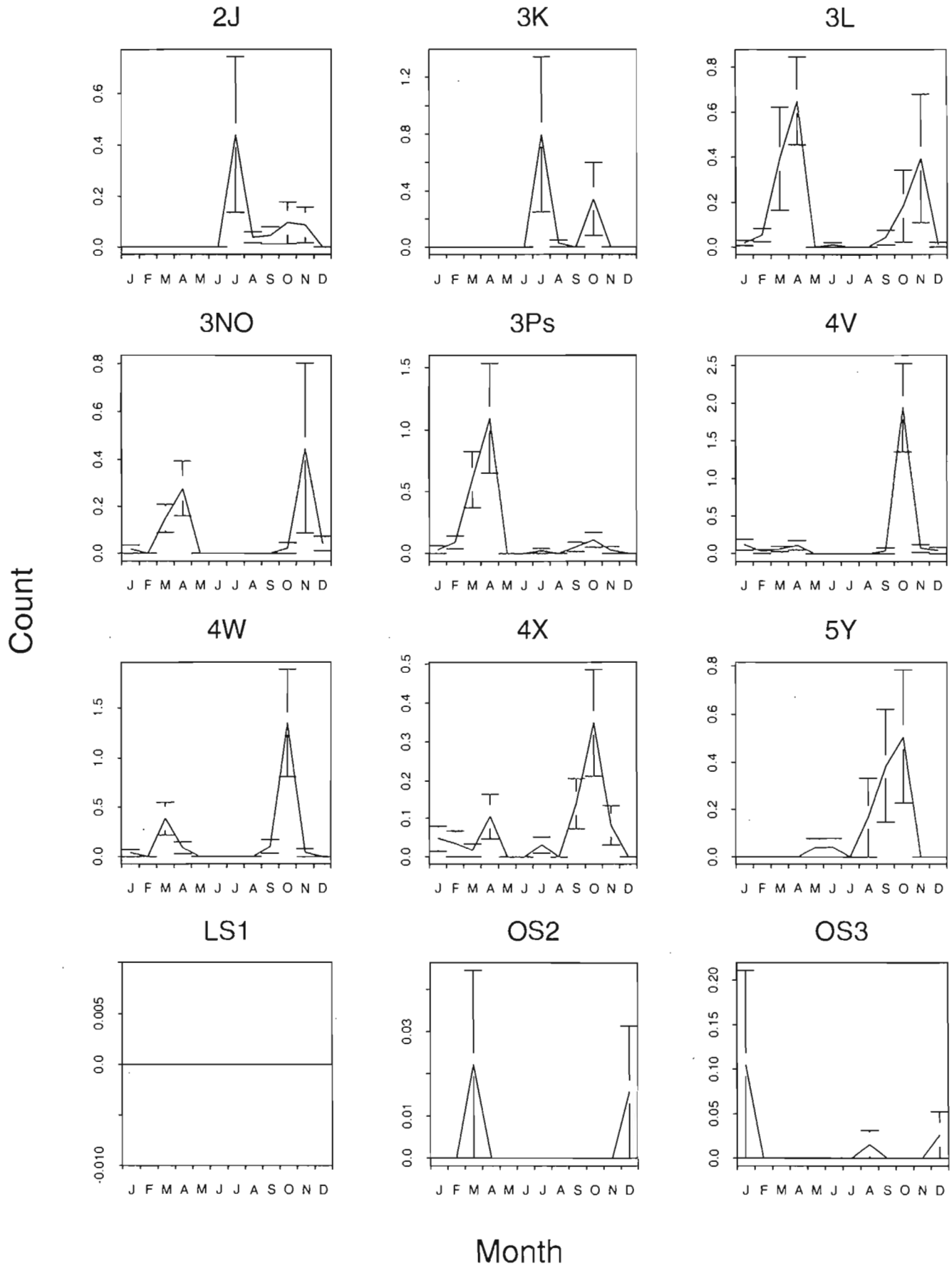
Paralia sulcata



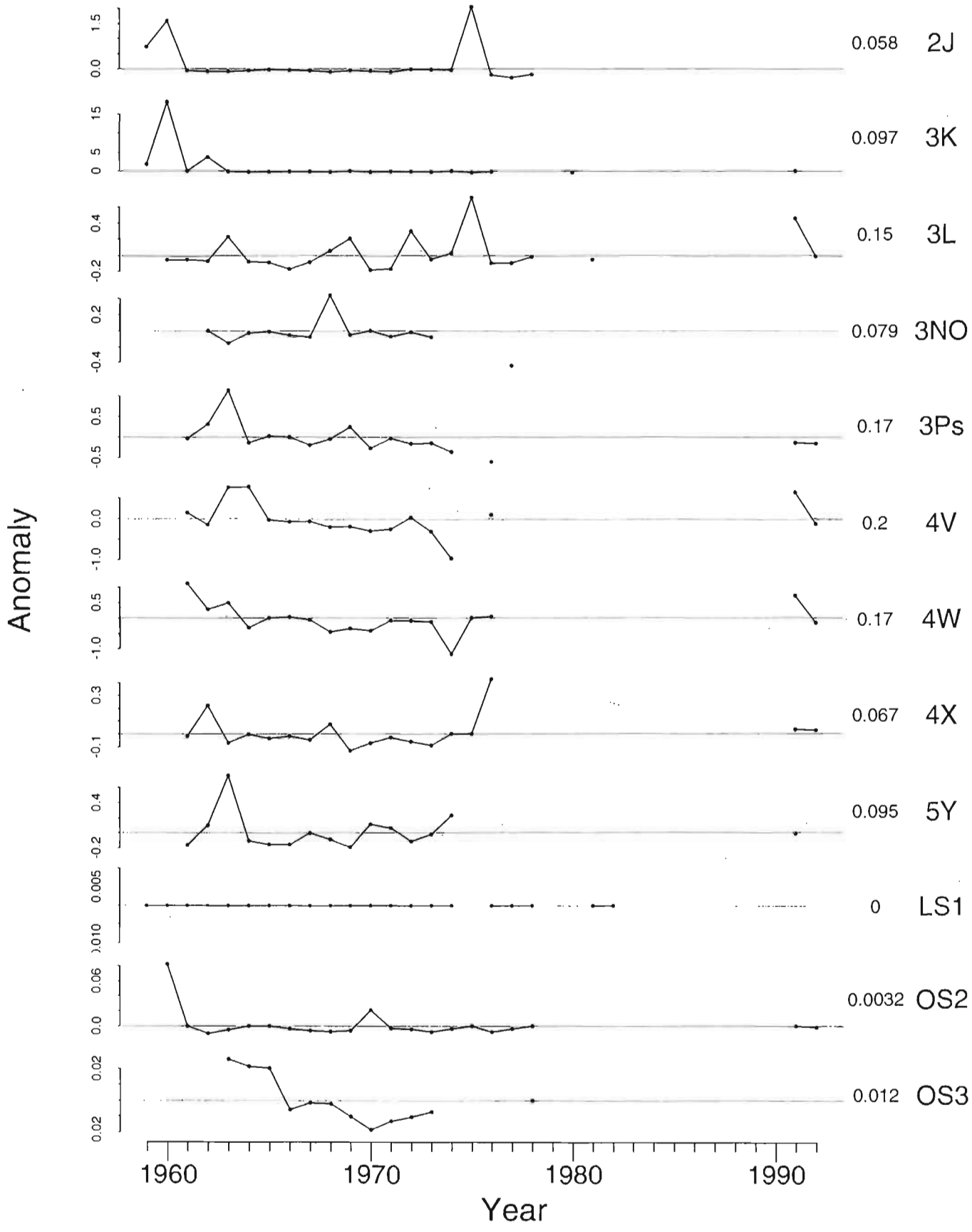
Paralia sulcata



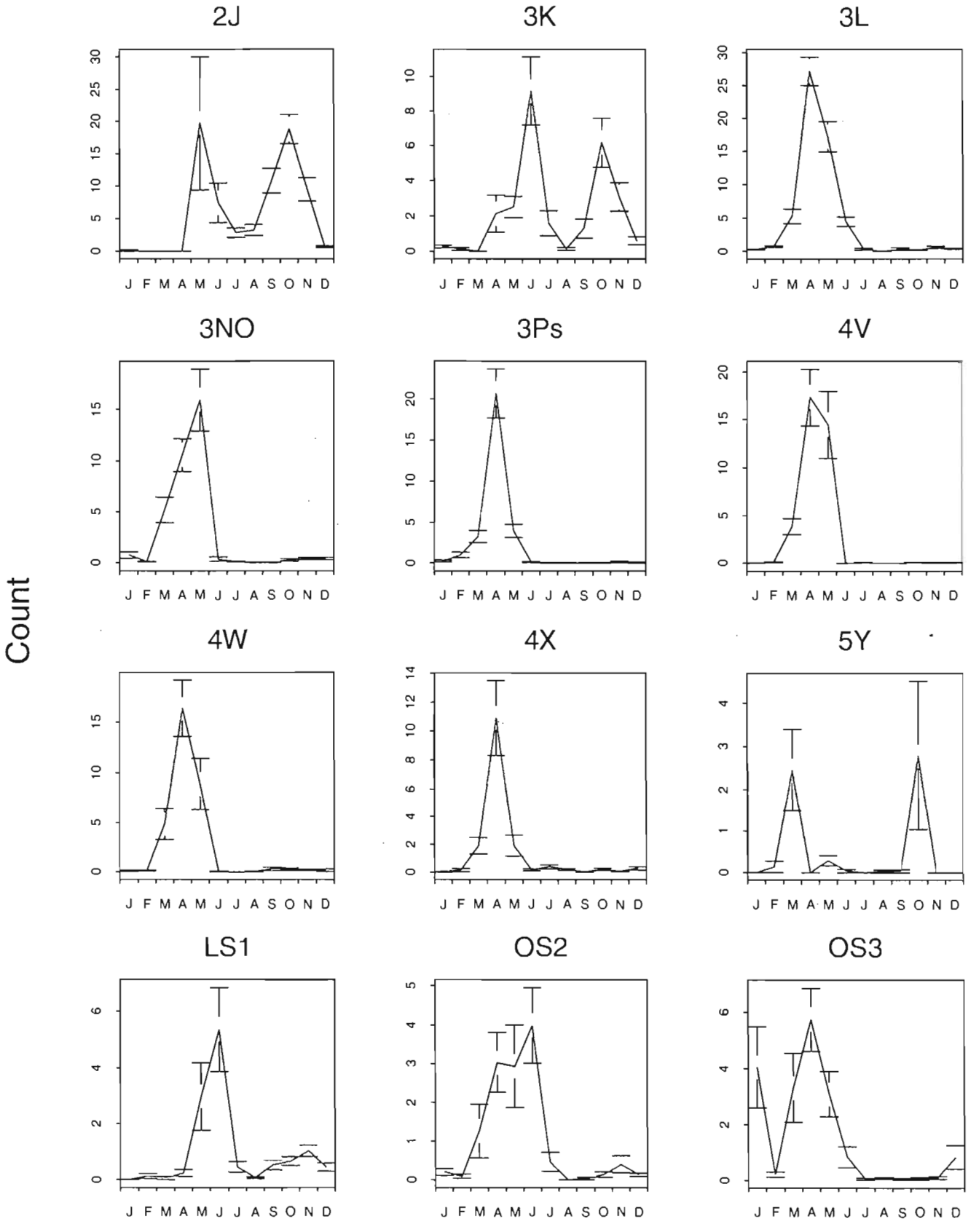
Skeletonema costatum



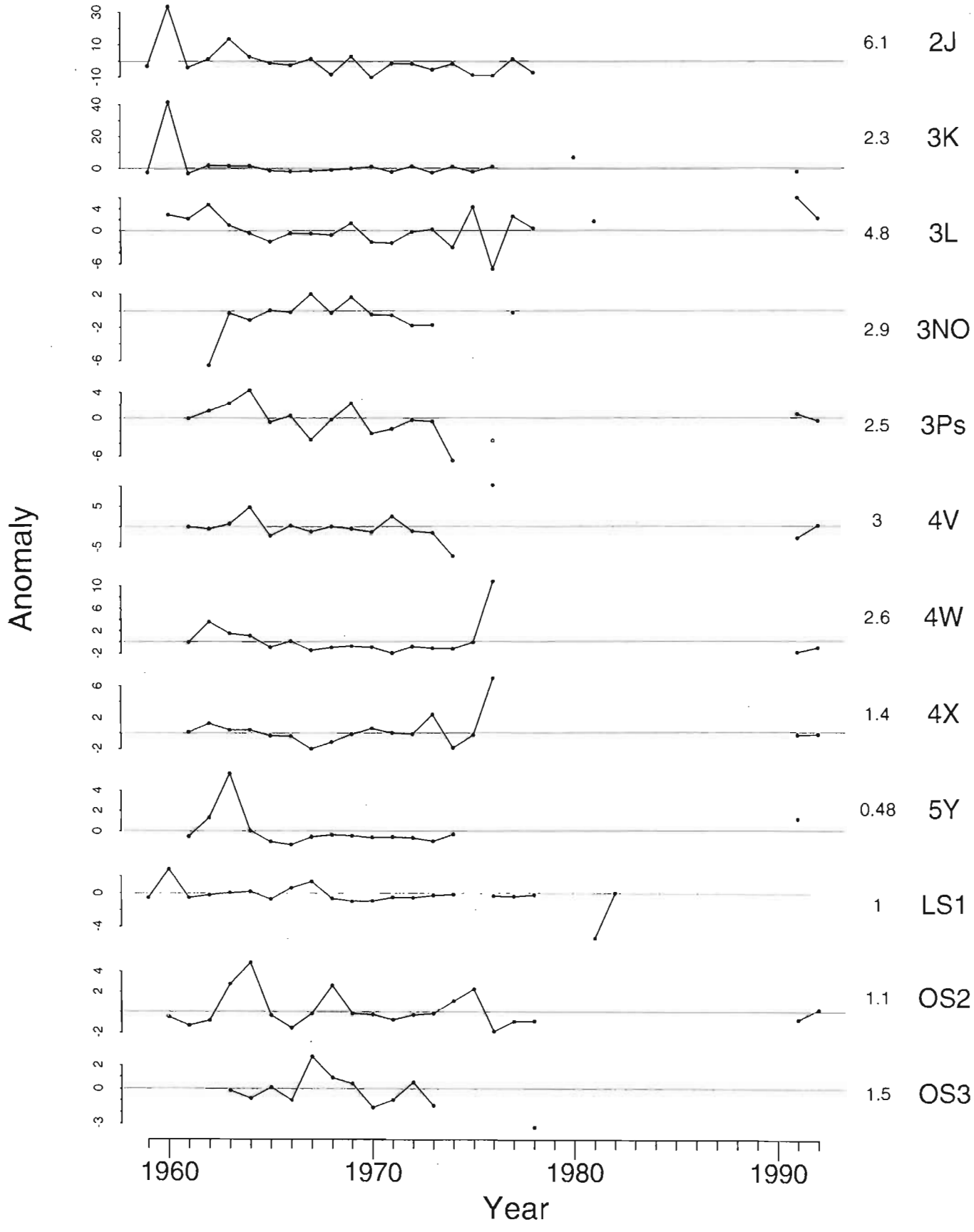
Skeletonema costatum



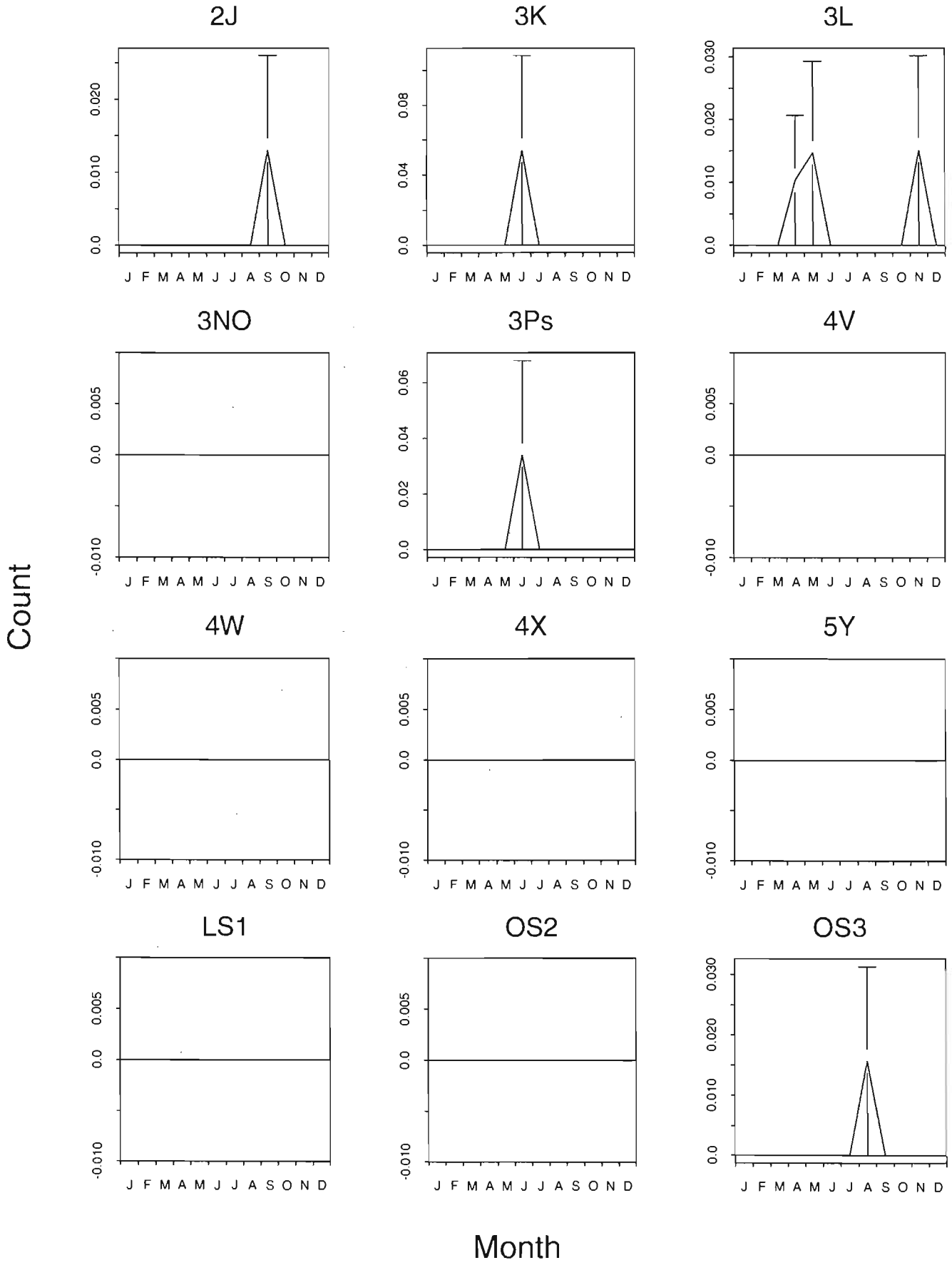
Thalassiosira spp.



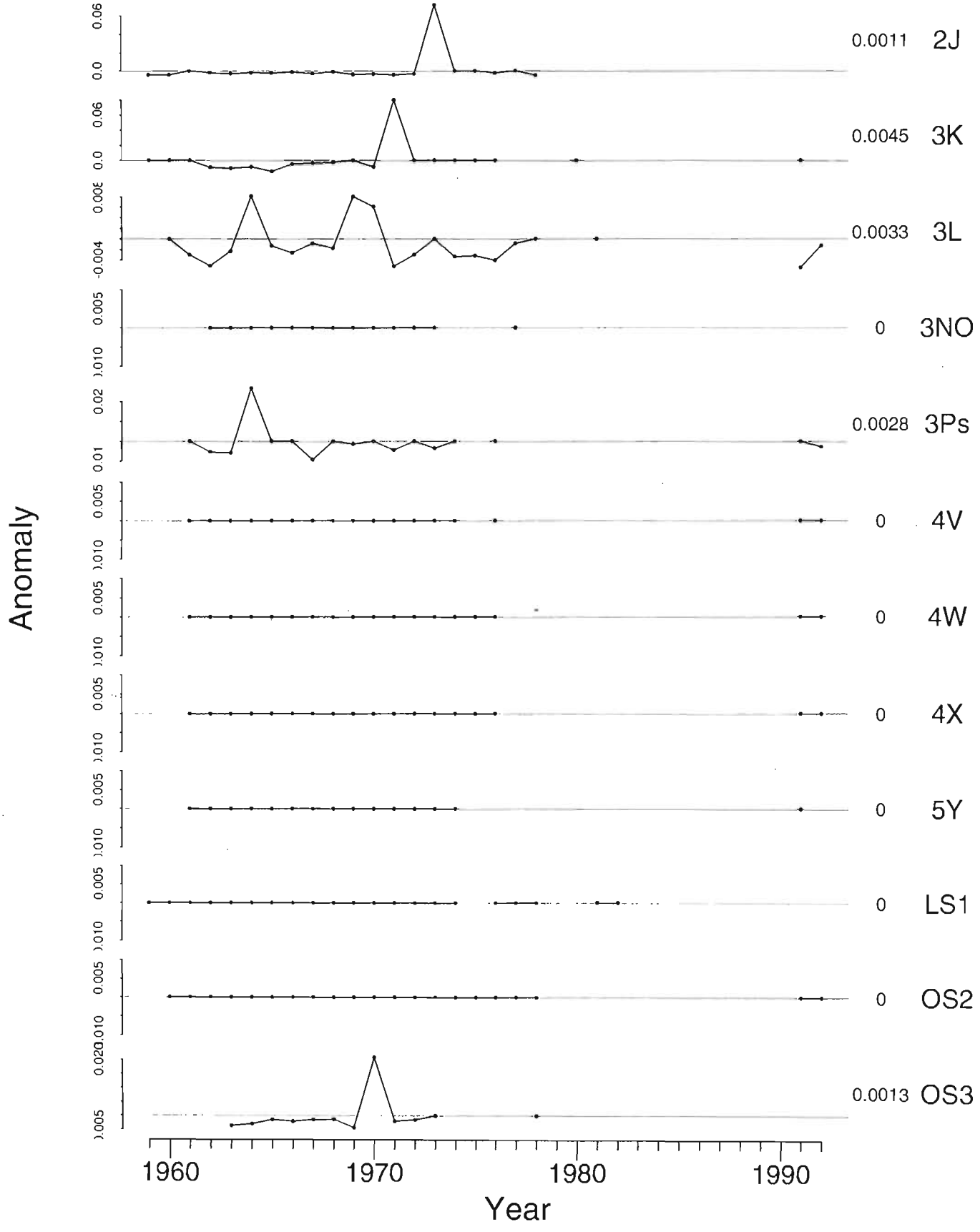
Thalassiosira spp.



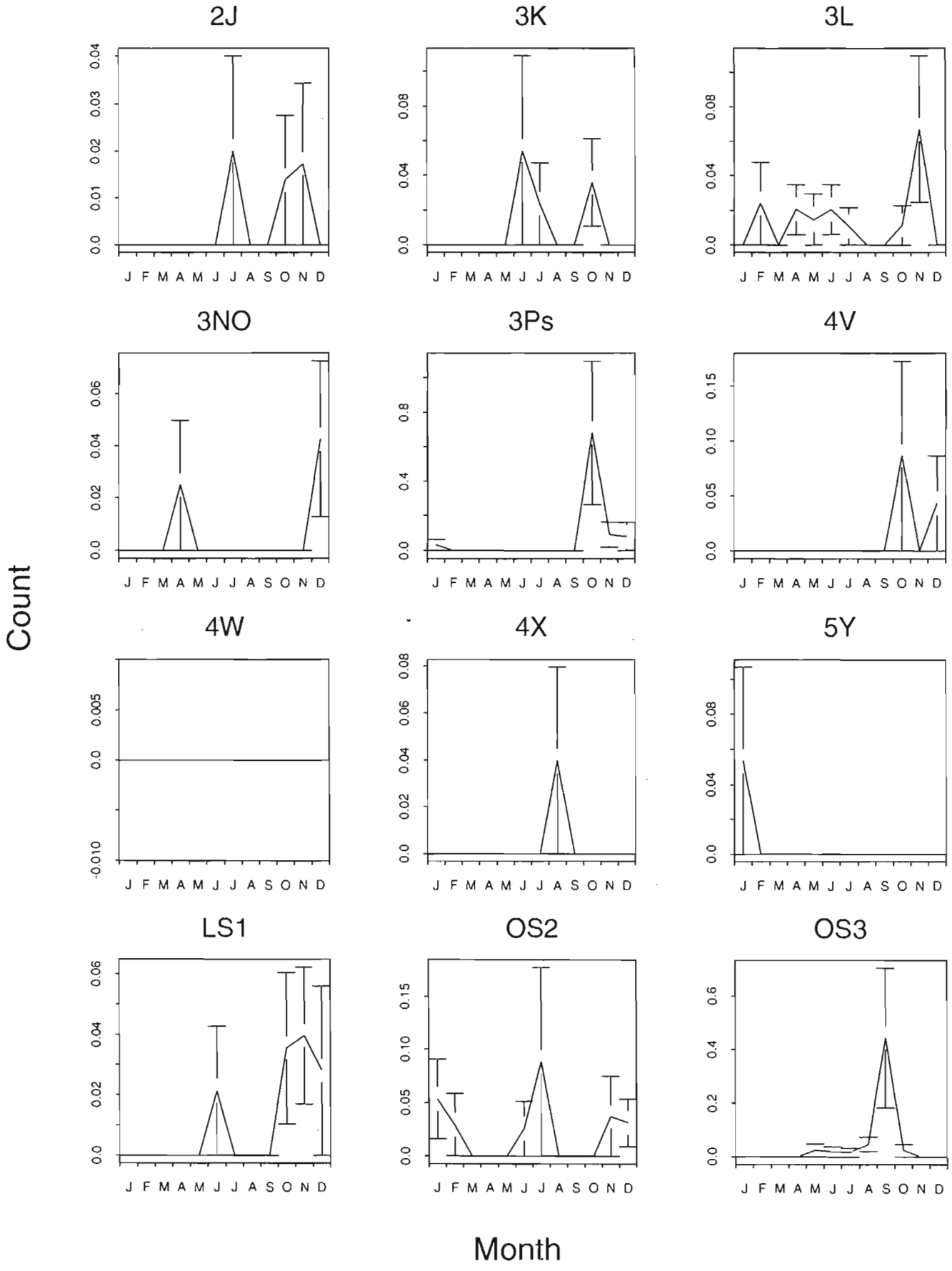
Dactyliosolen antarcticus



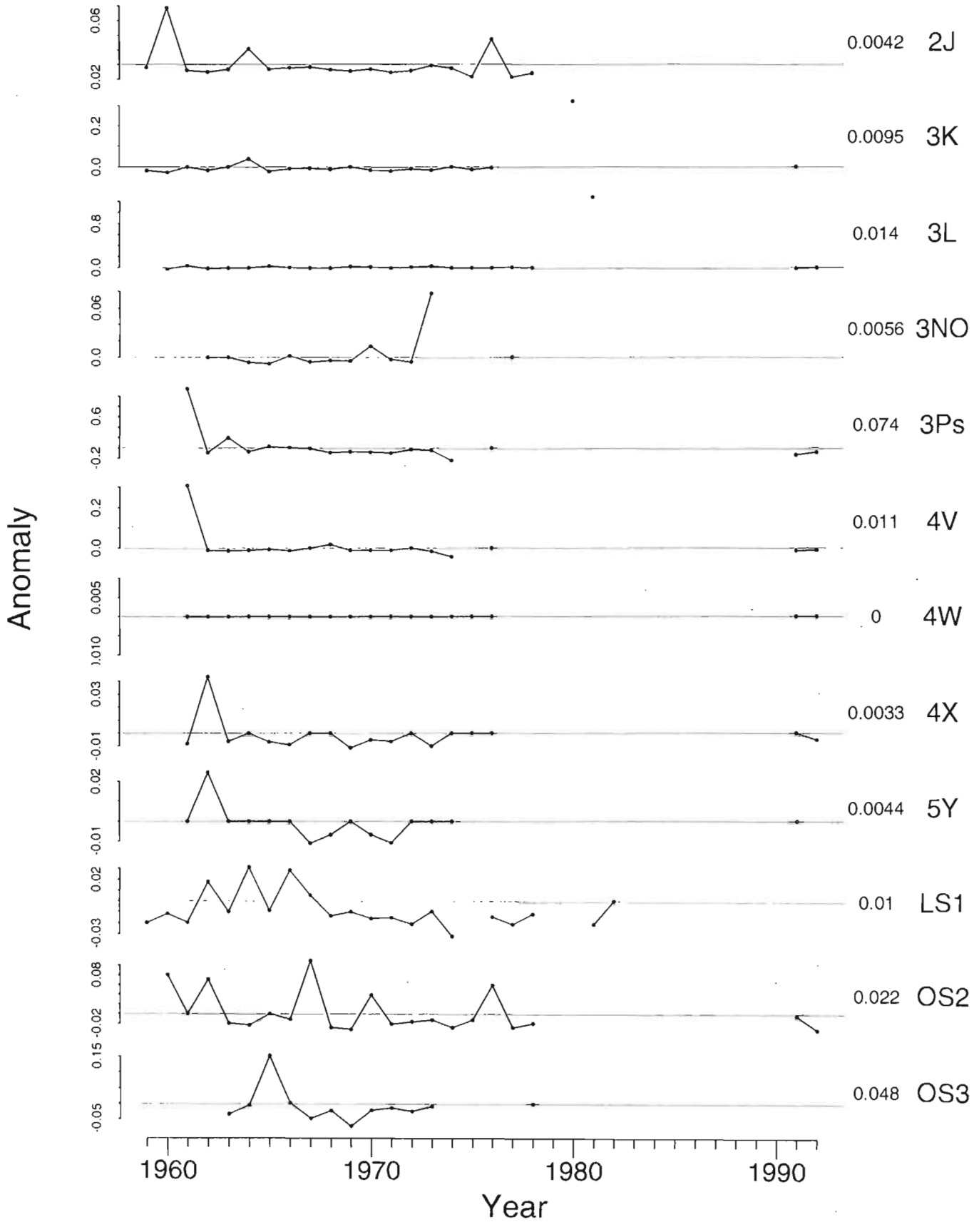
Dactyliosolen antarcticus



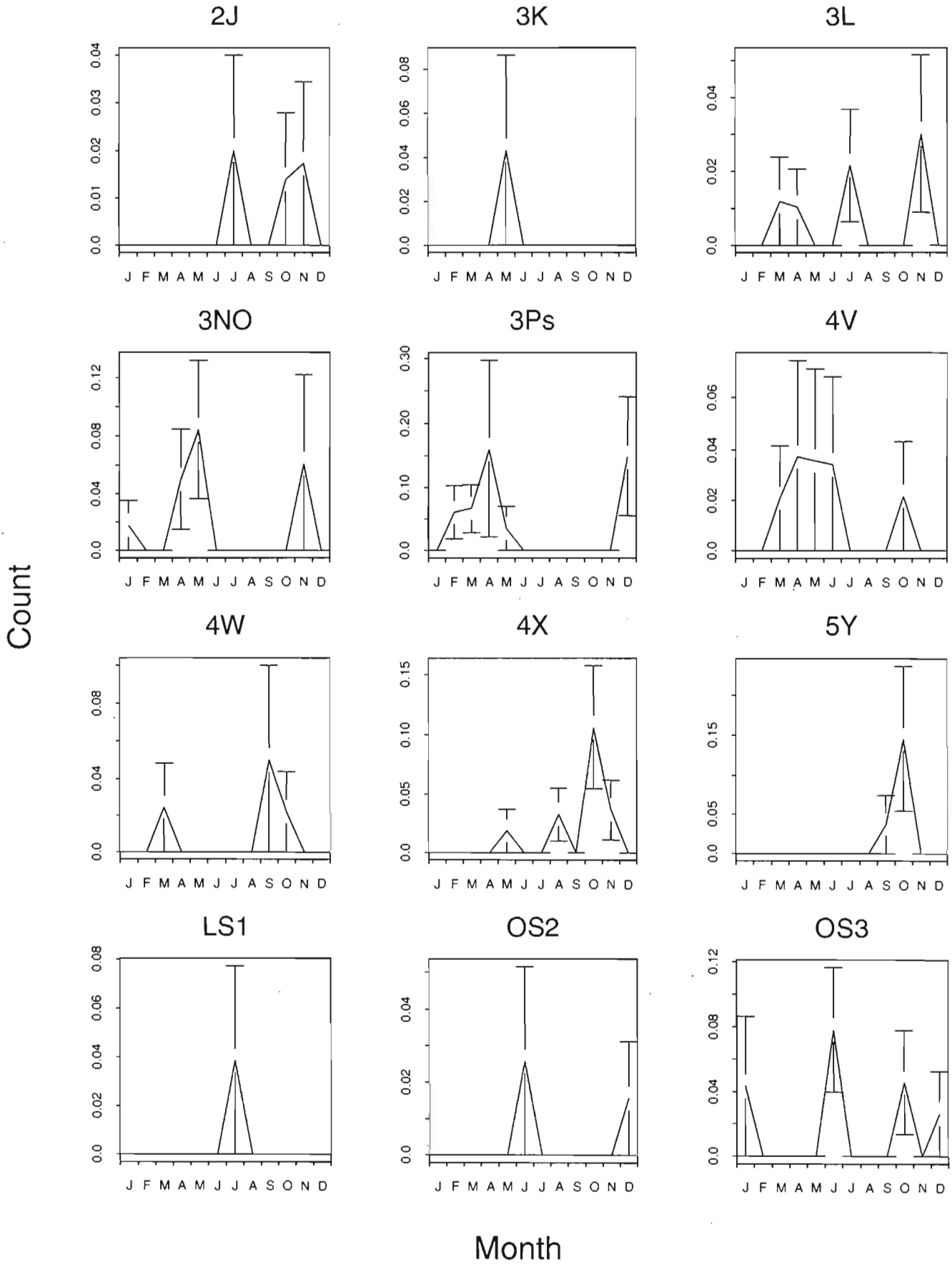
Dactyliosolen mediterraneus



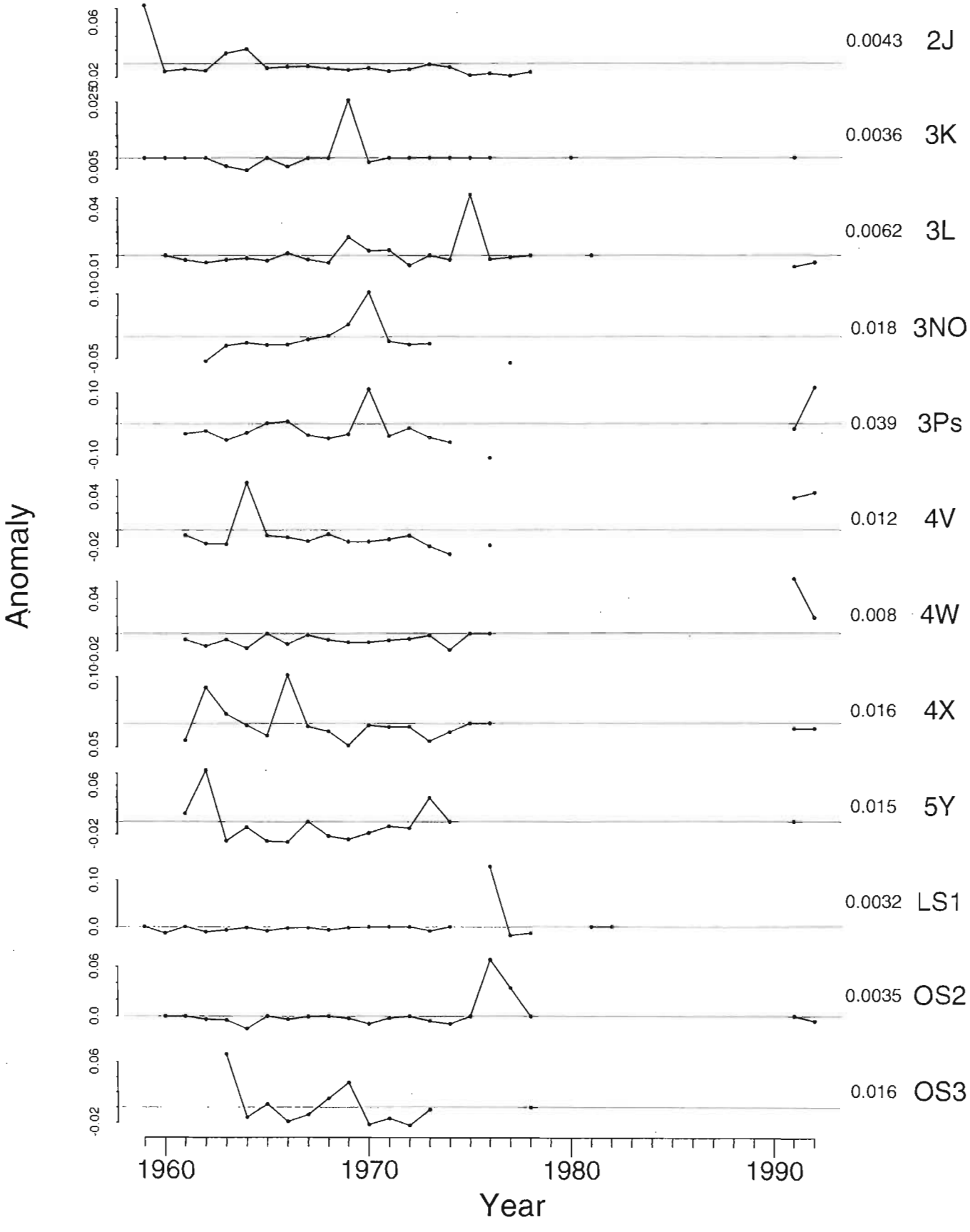
Dactyliosolen mediterraneus



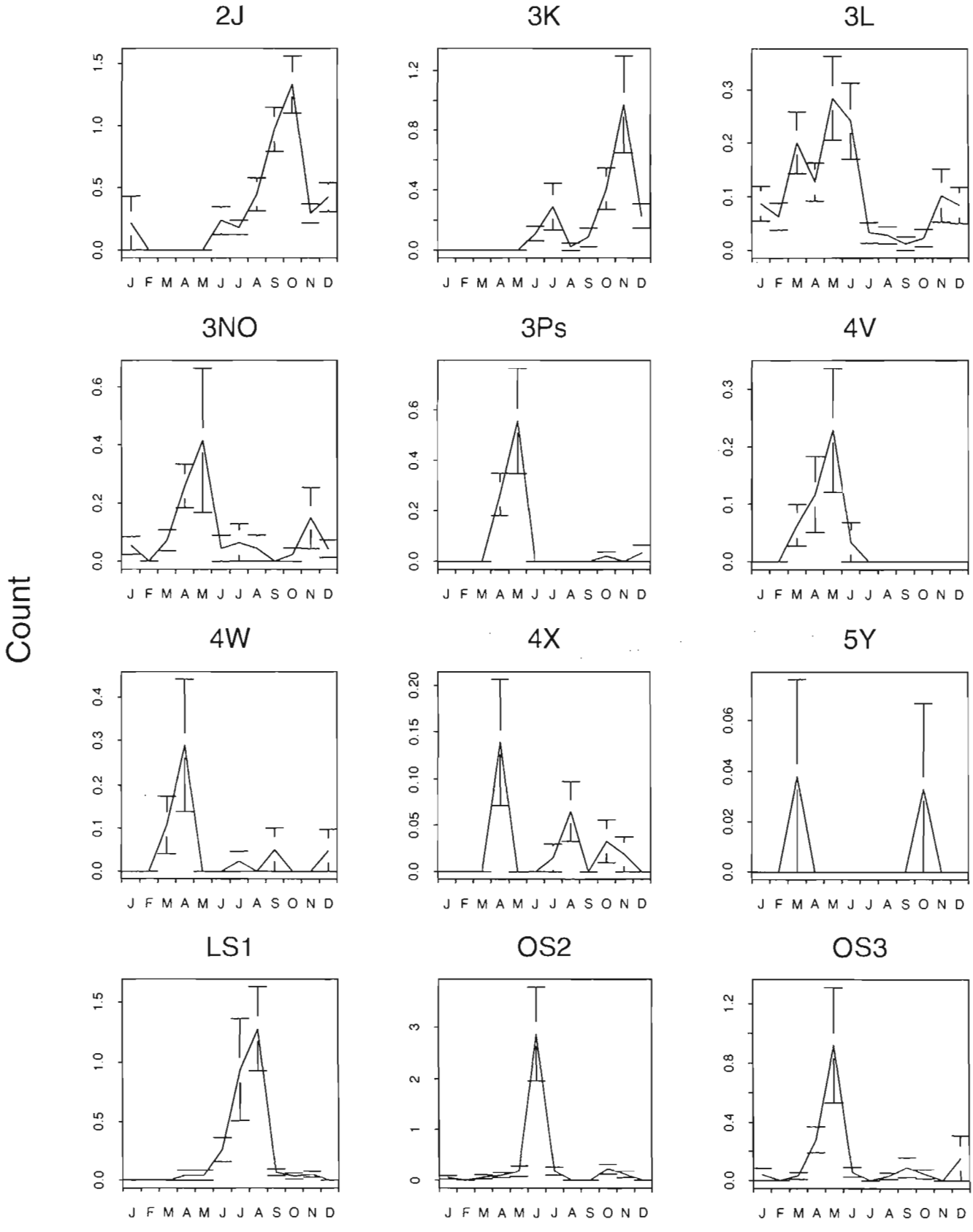
Rhizosolenia imbrica. shrubsolei



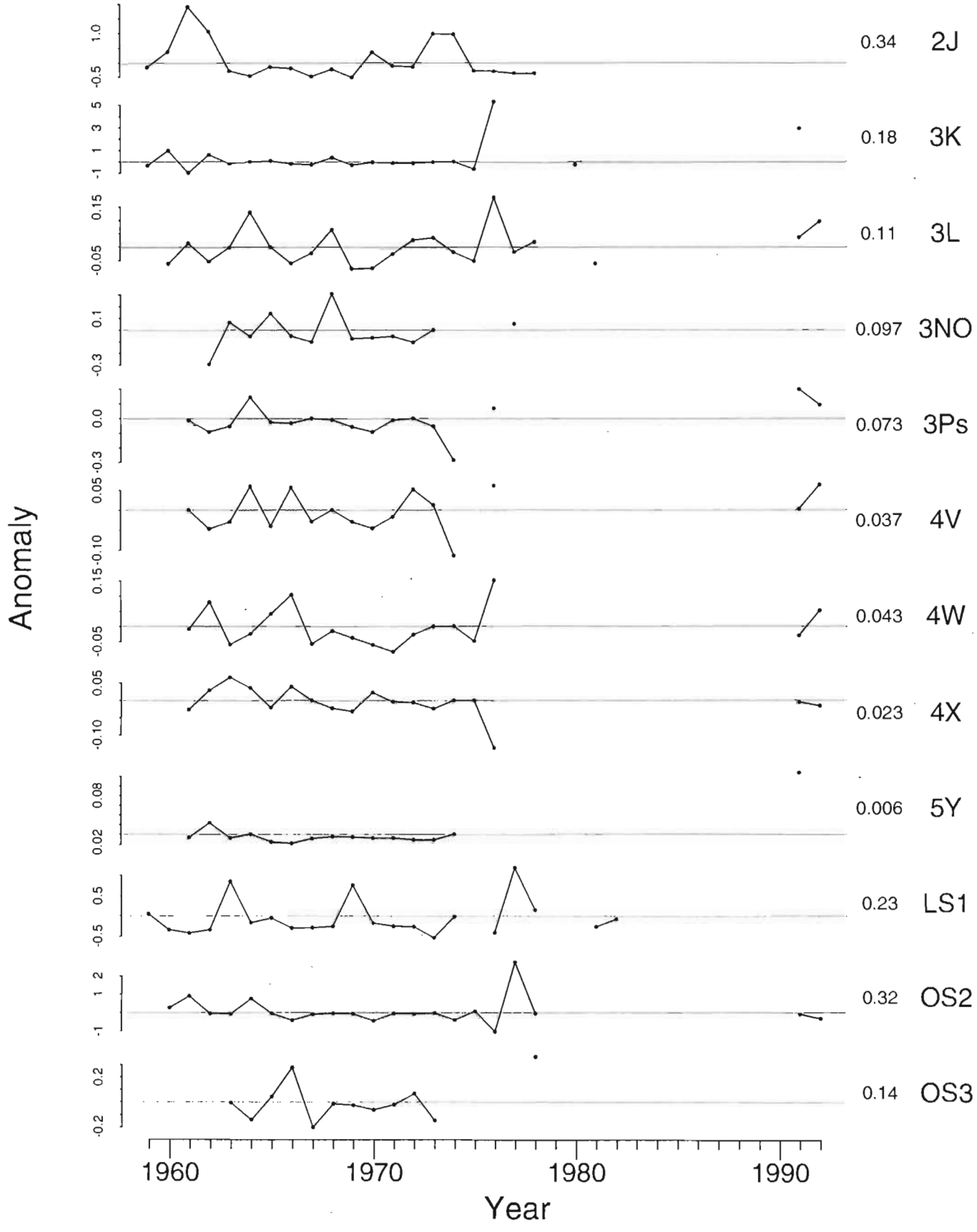
Rhizosolenia imbrica. shrubsolei



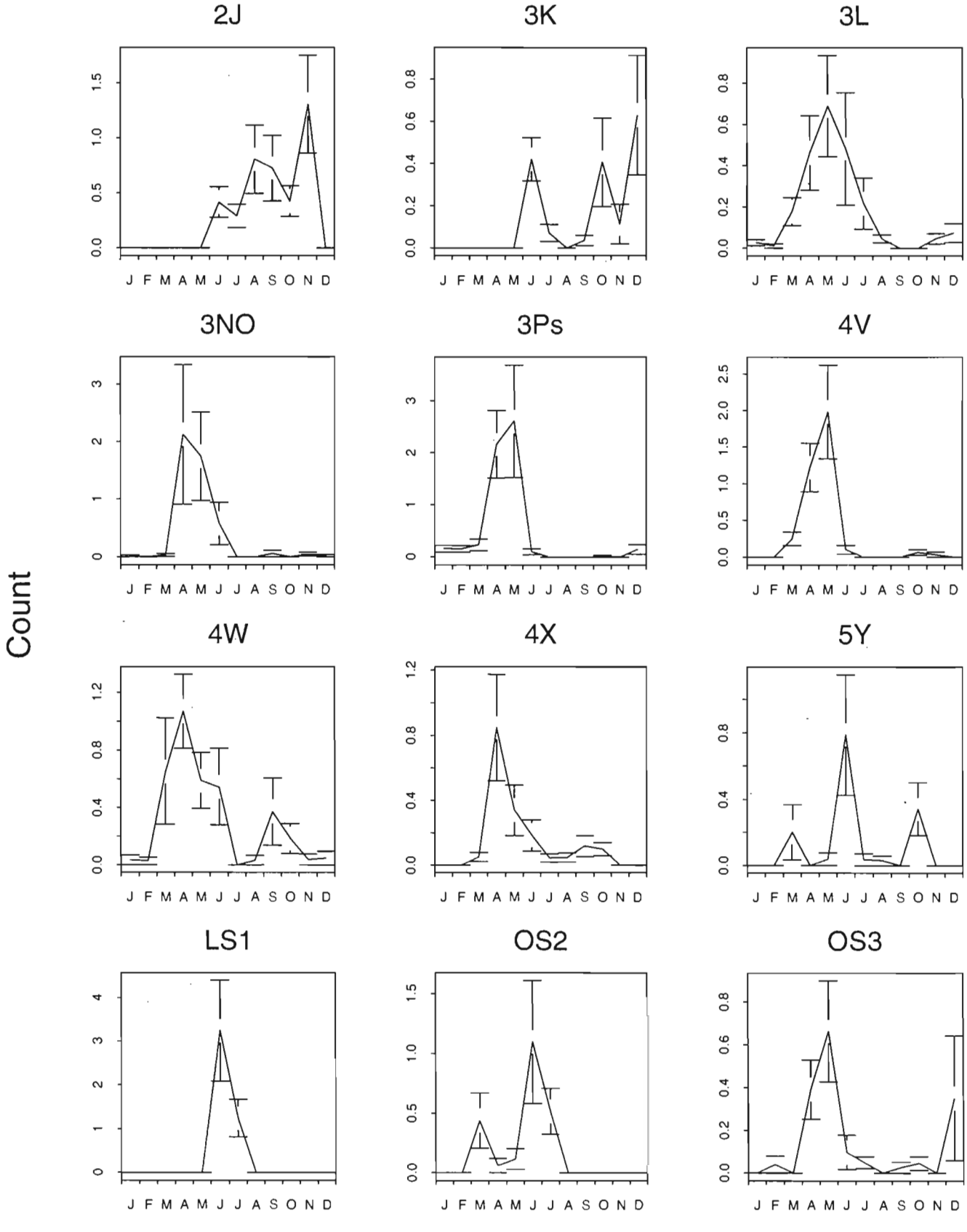
Rhizosolenia styliformis



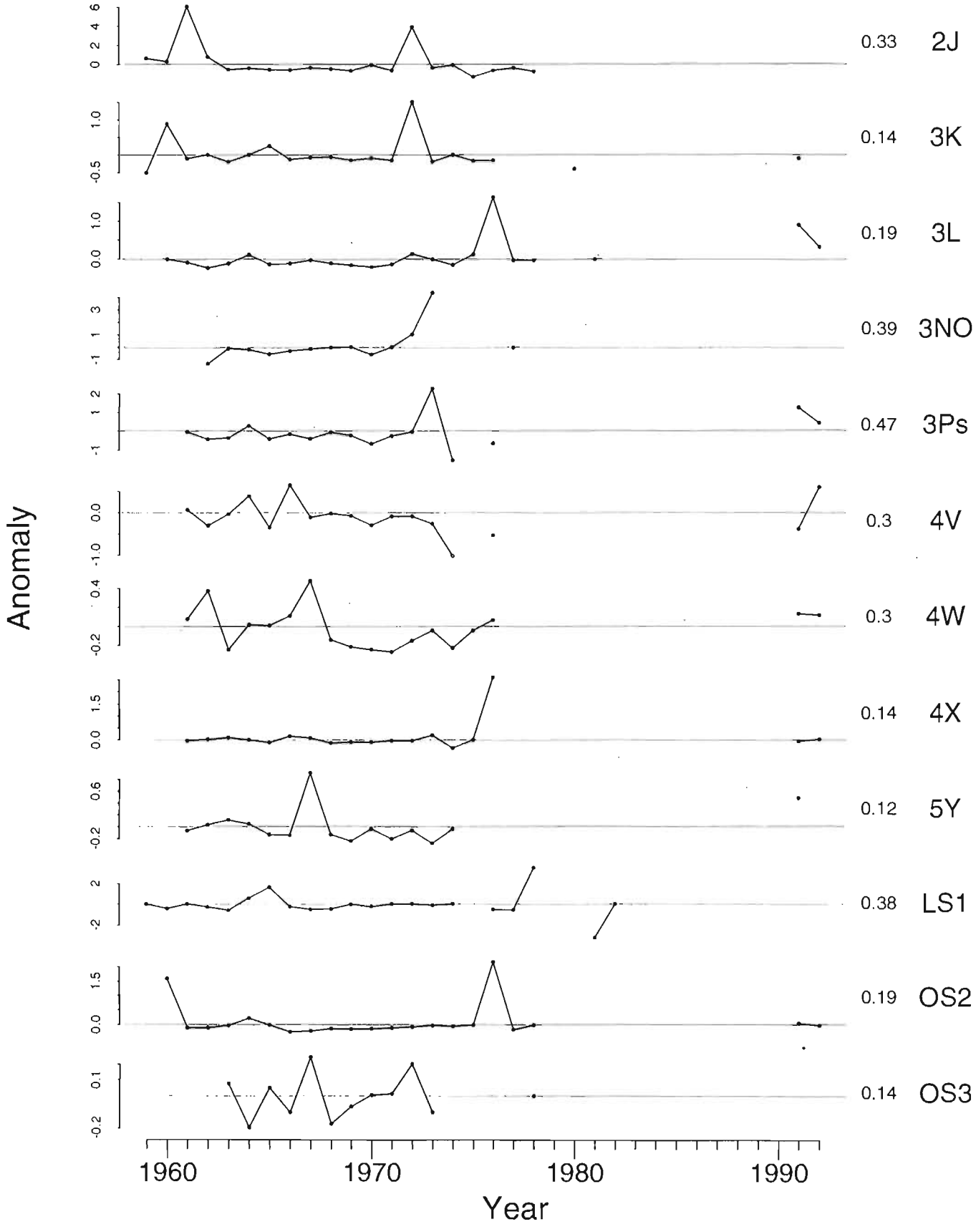
Rhizosolenia styliformis



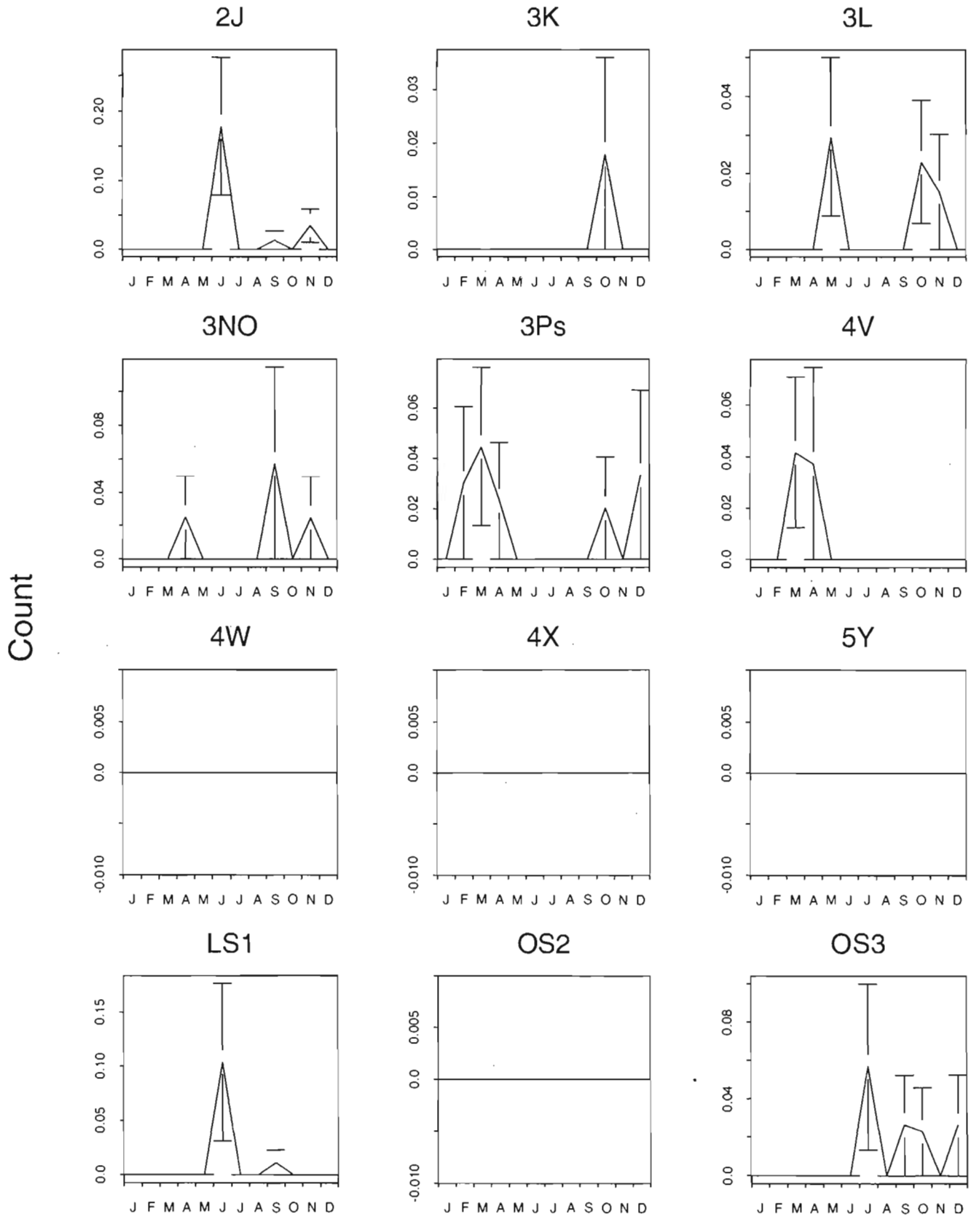
Rhizosolenia hebetata semispina



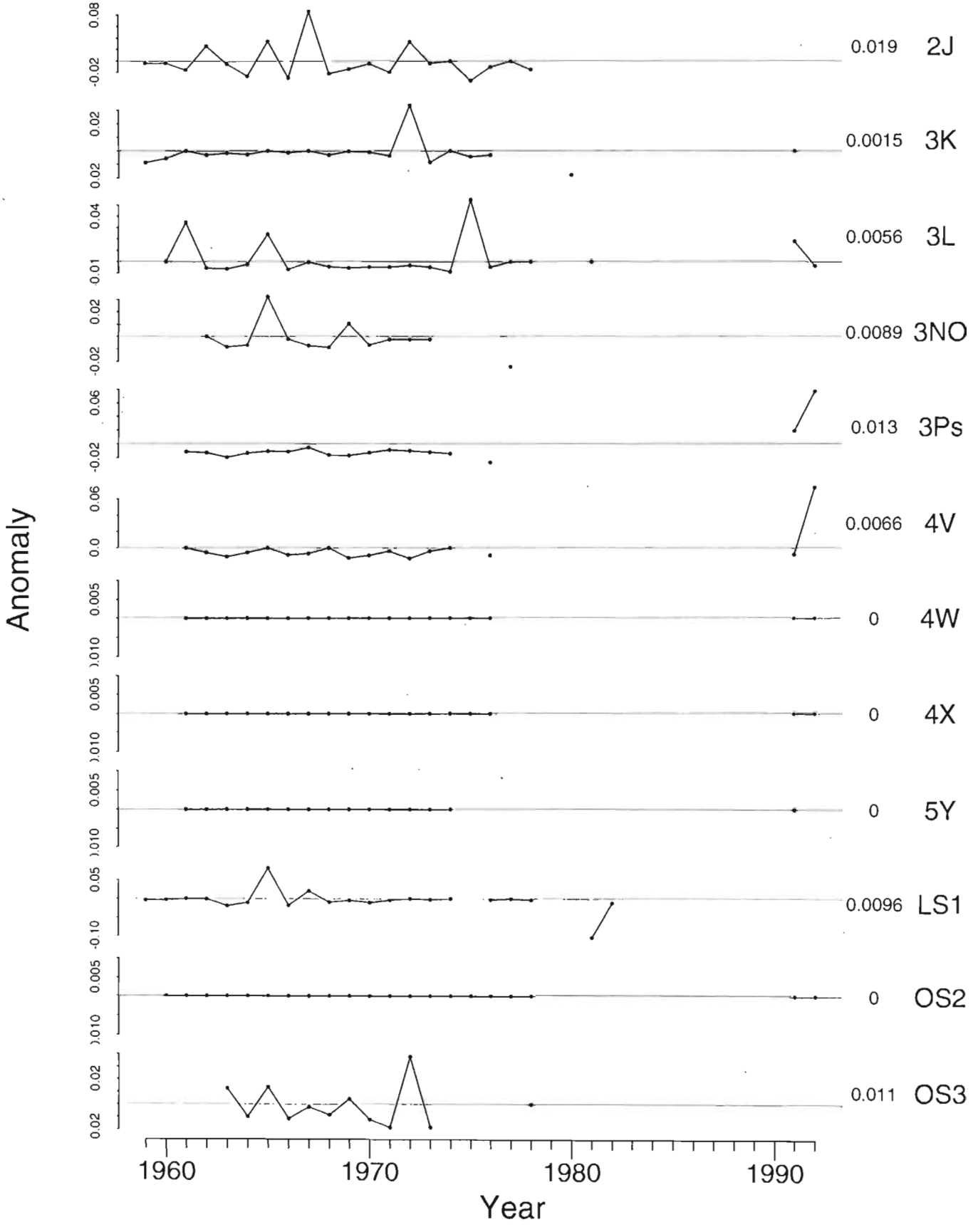
Rhizosolenia hebetata semispina



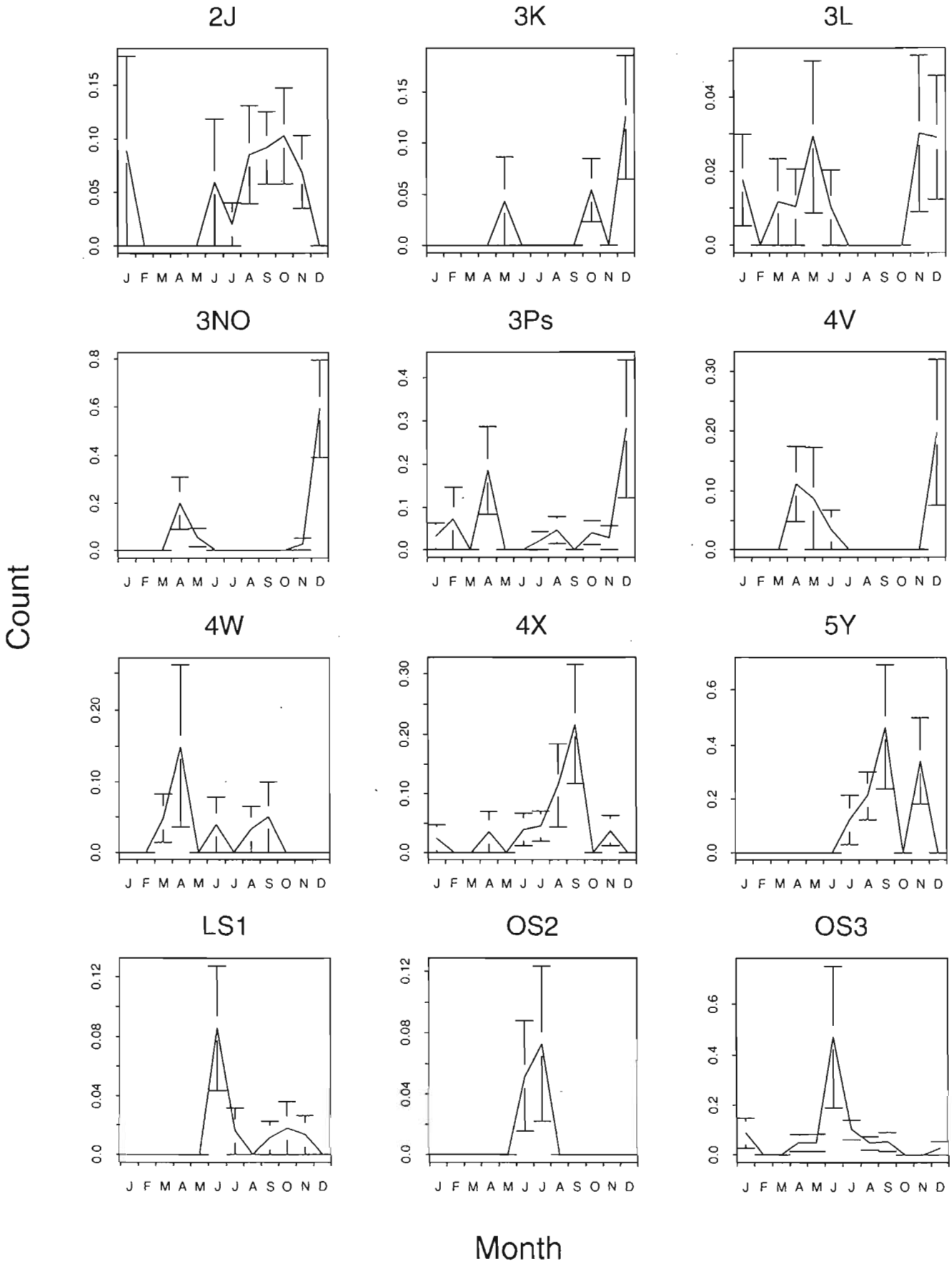
Rhizosolenia alata indica



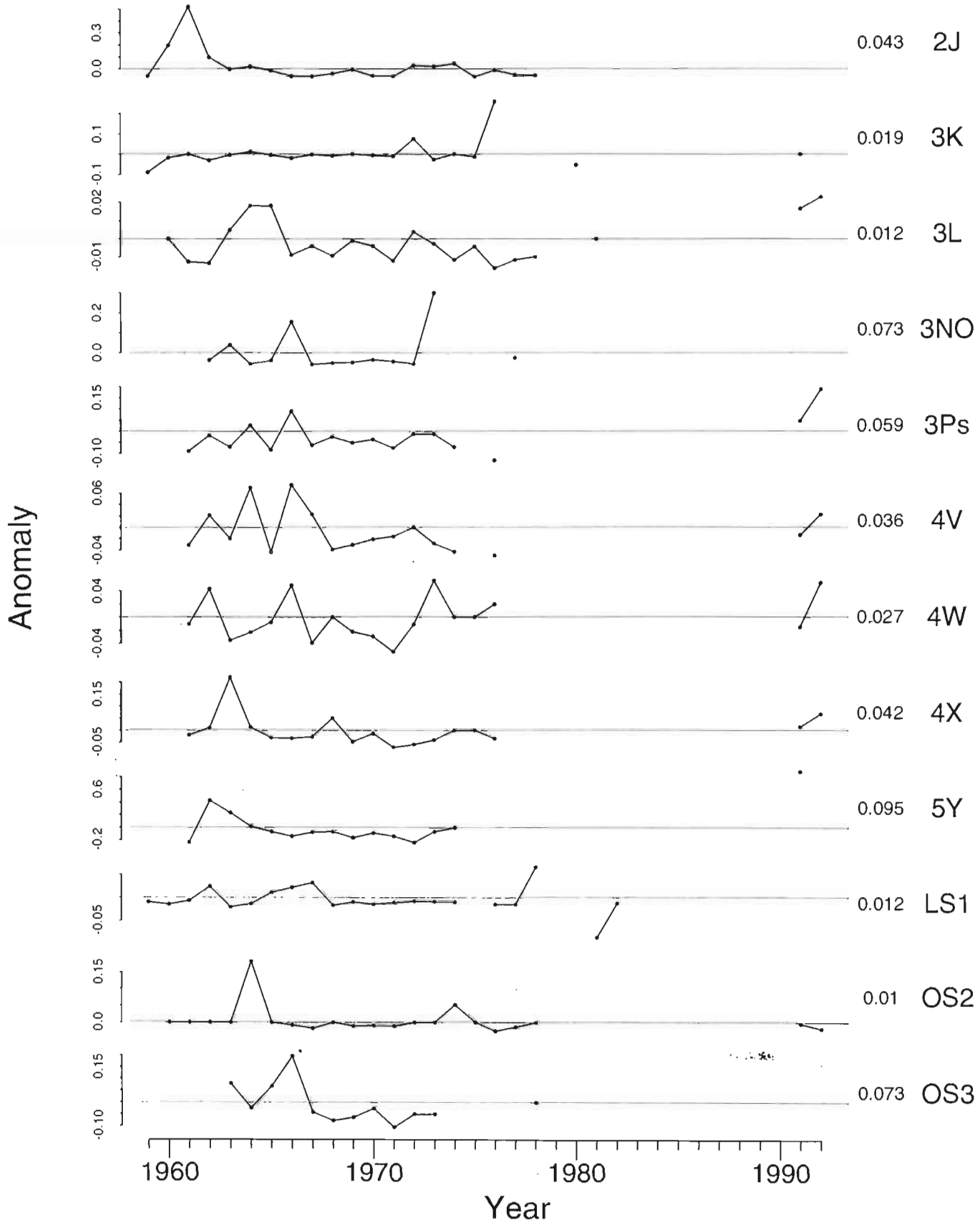
Rhizosolenia alata indica



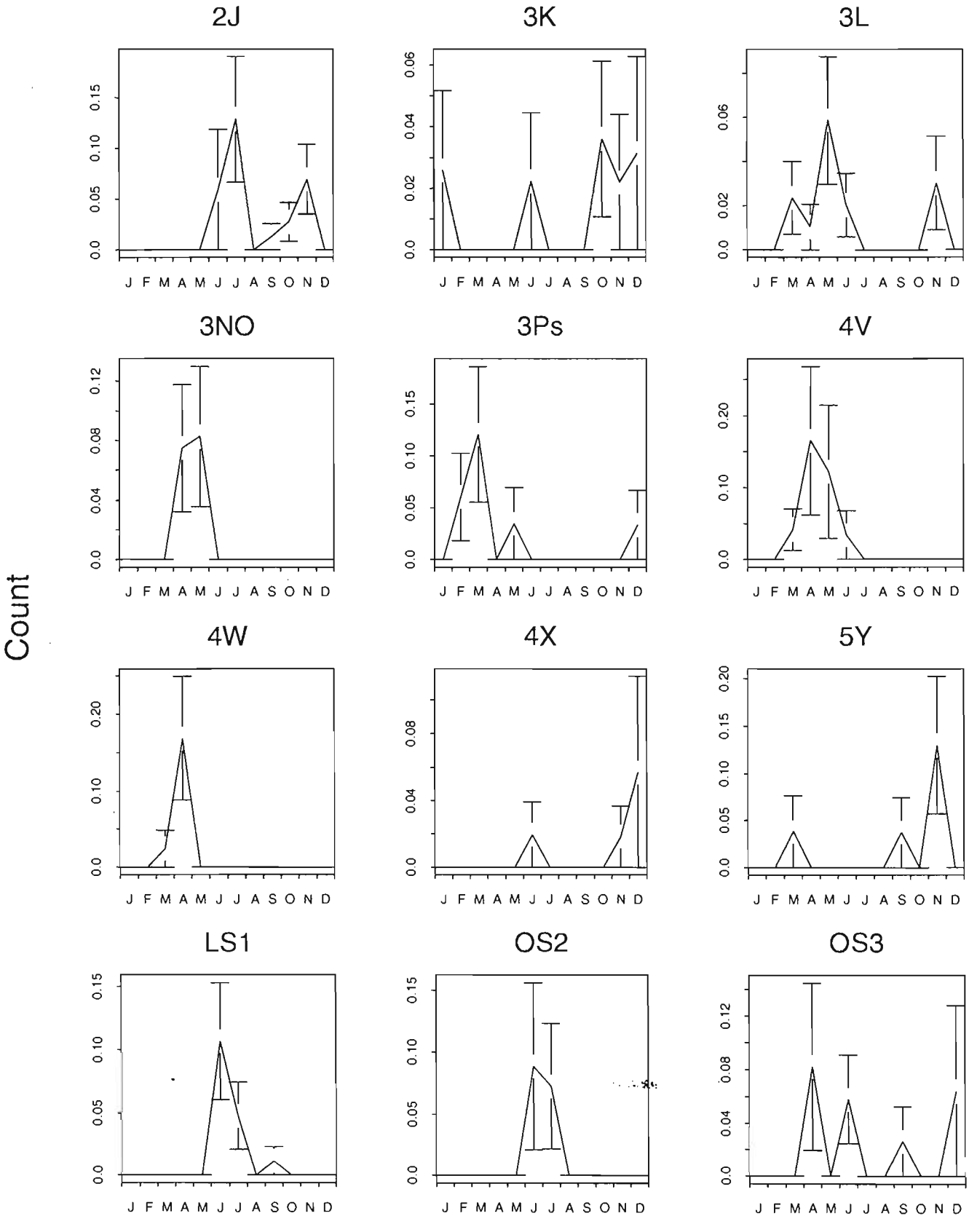
Rhizosolenia alata alata



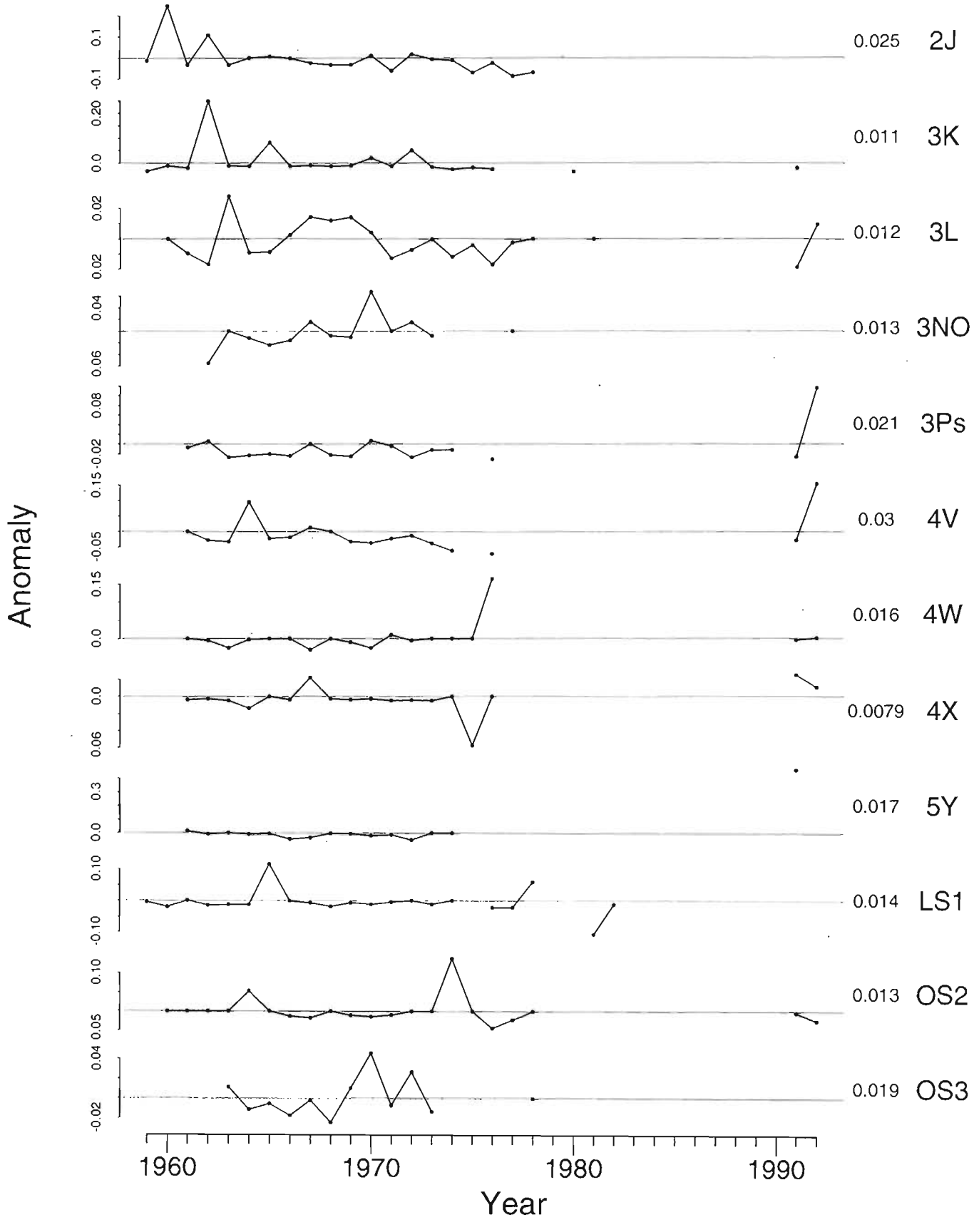
Rhizosolenia alata alata



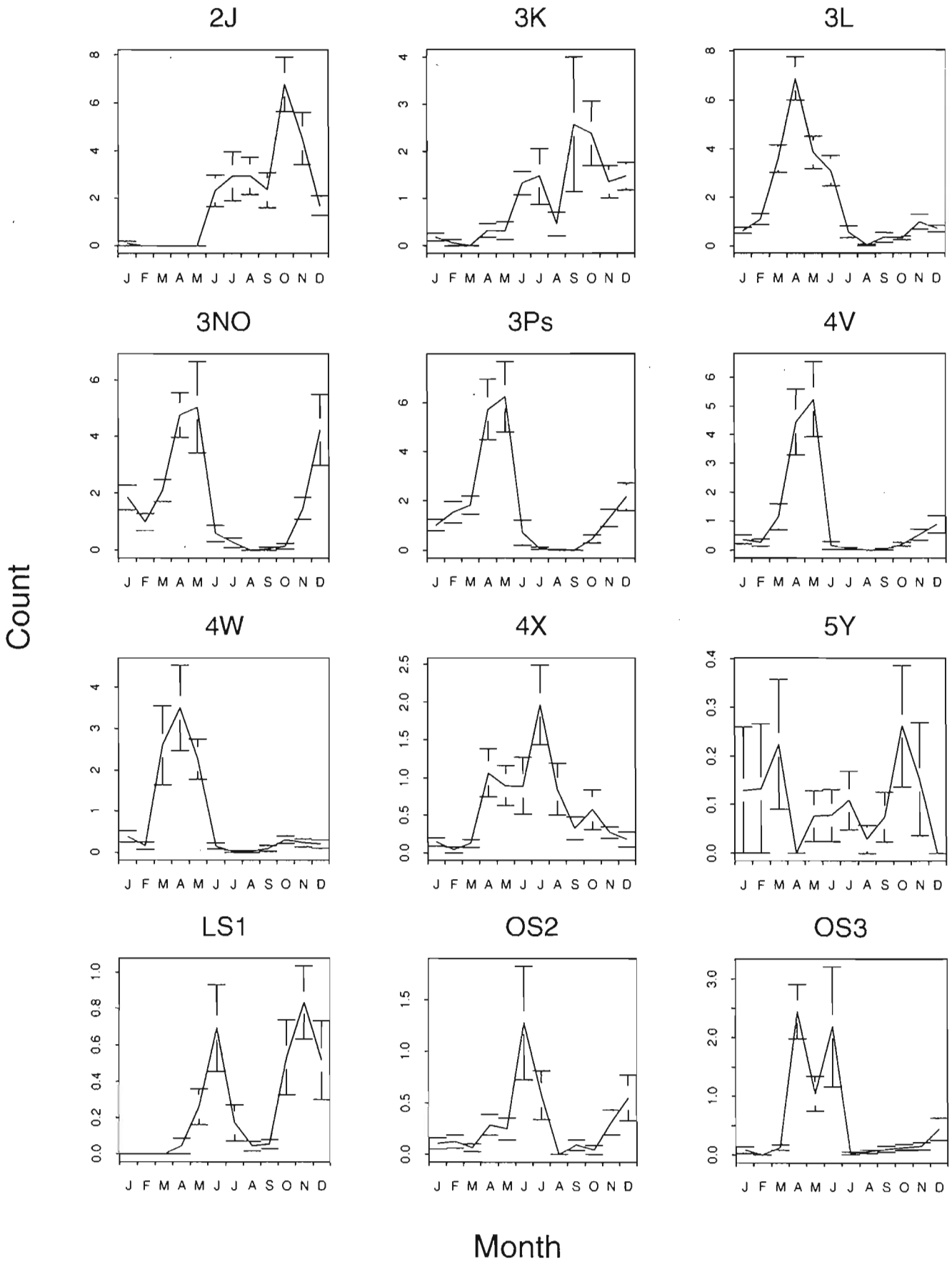
Rhizosolenia alata inermis



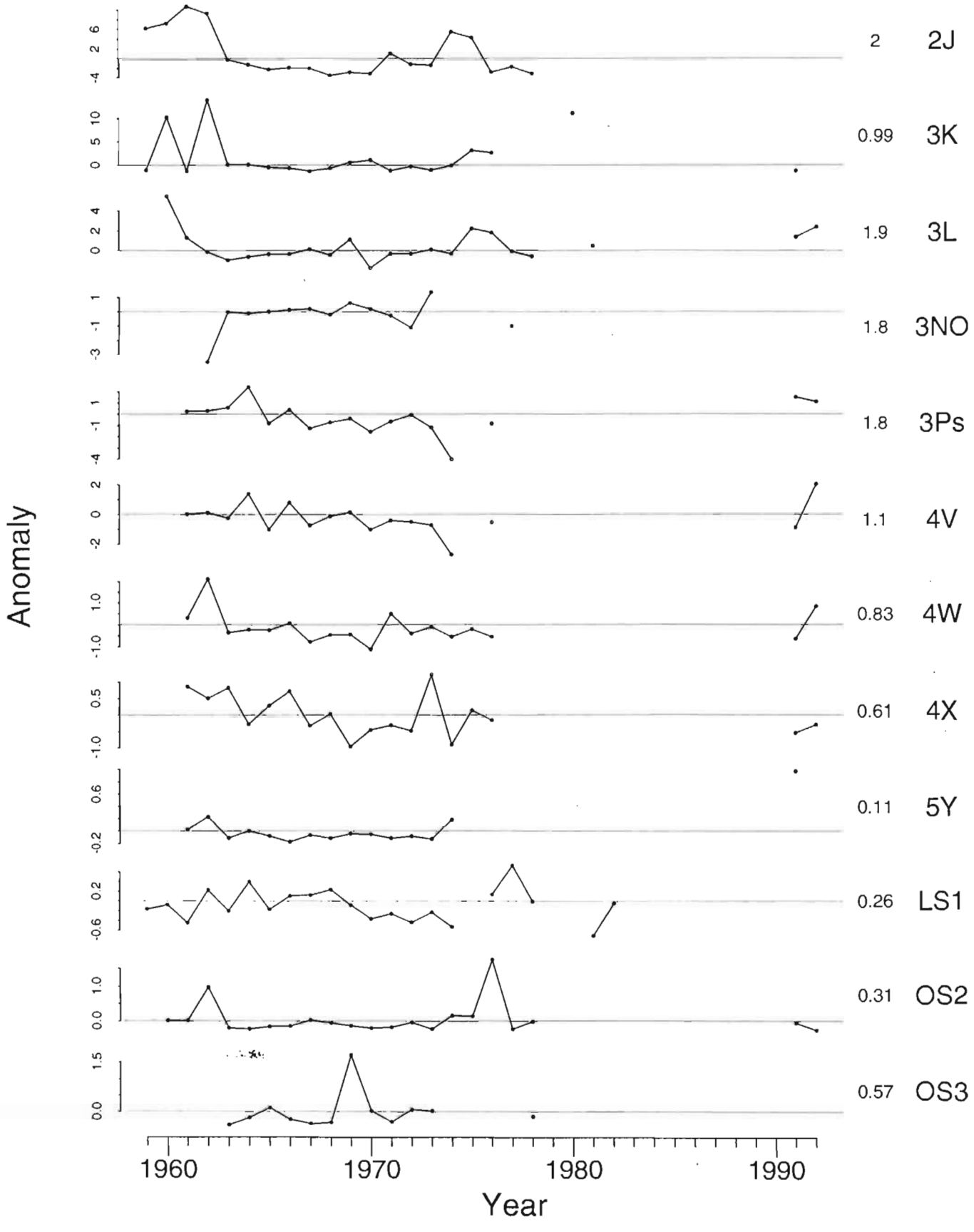
Rhizosolenia alata inermis



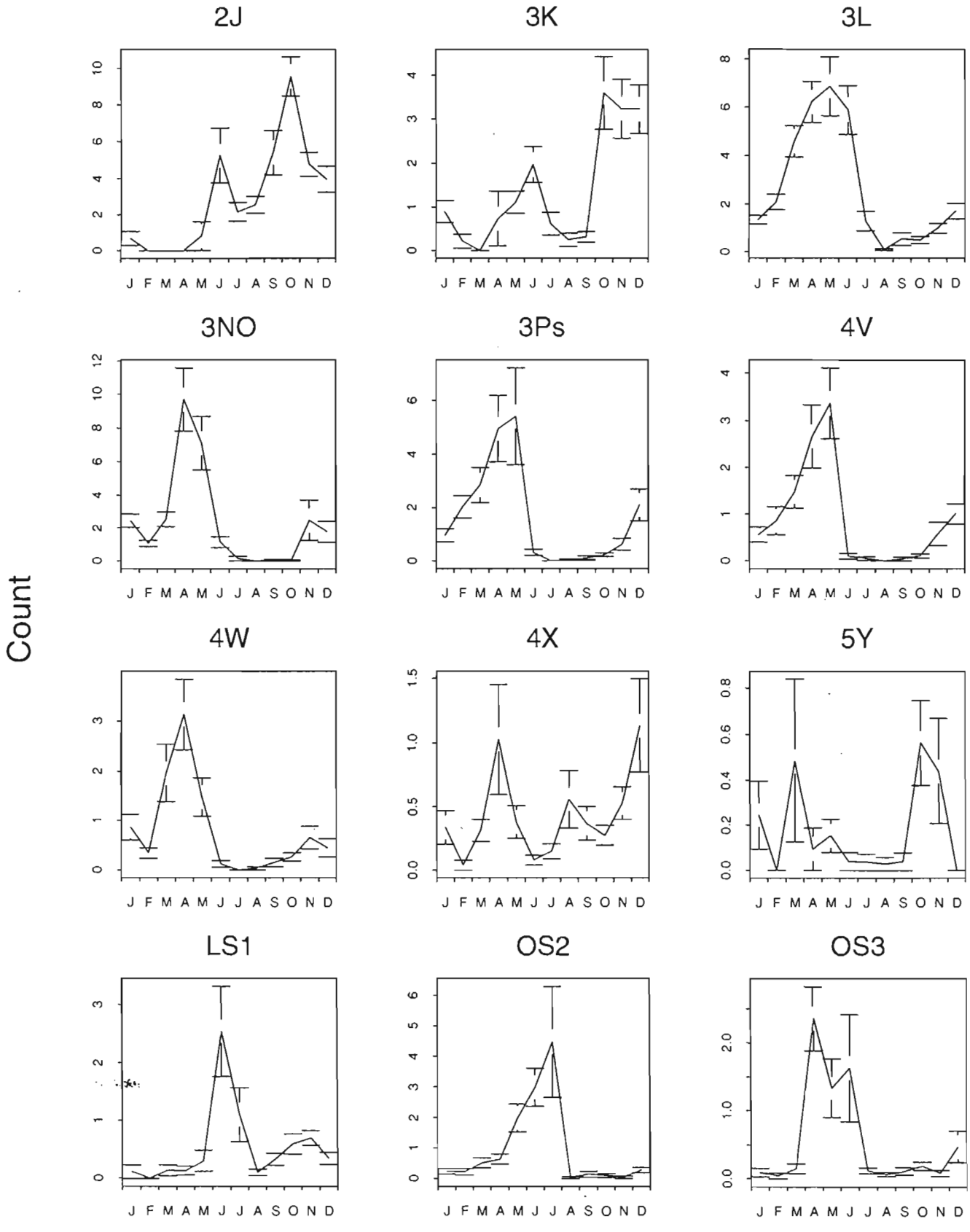
Chaetoceros(Hyalochaete) spp.



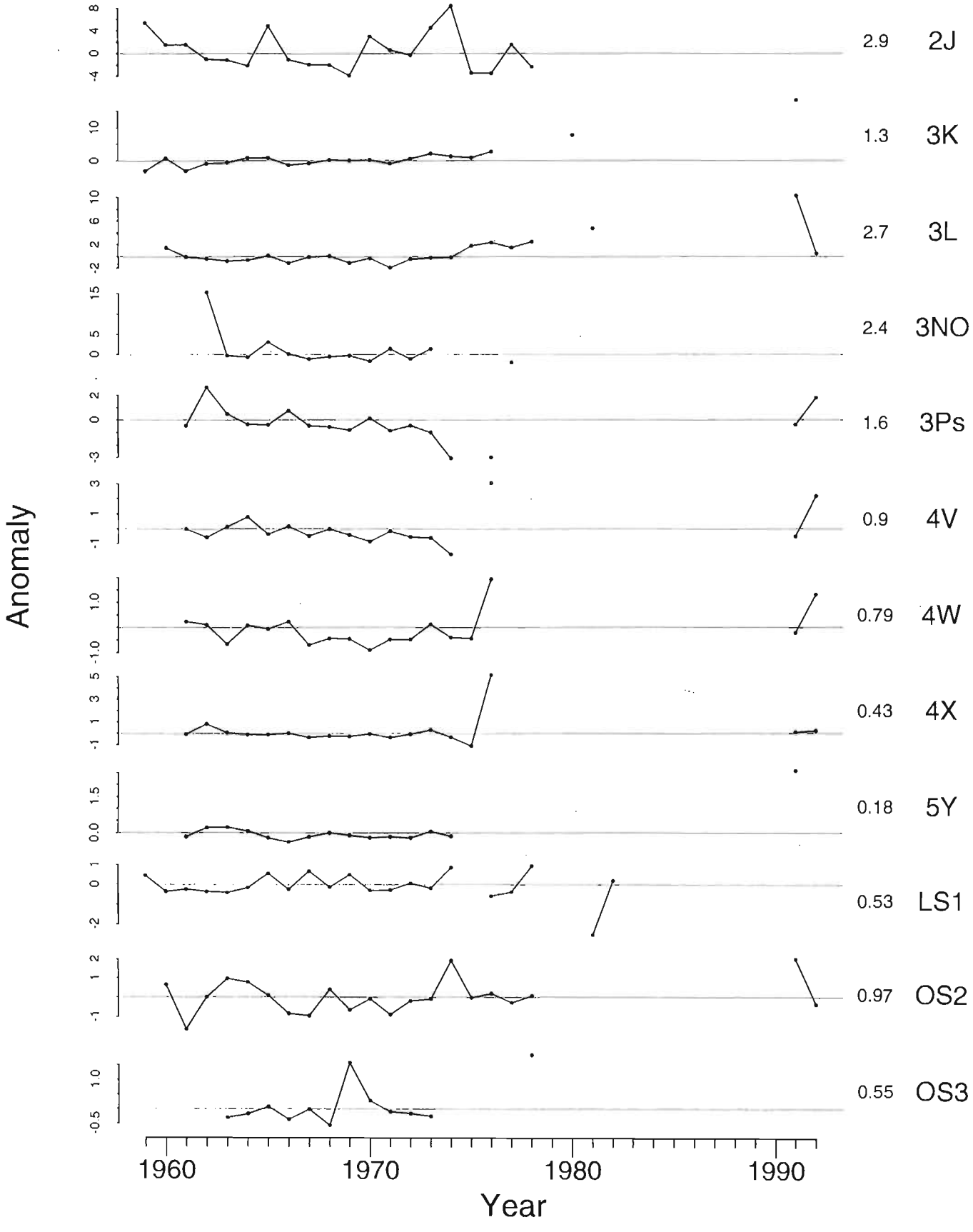
Chaetoceros(Hyalochaete) spp.



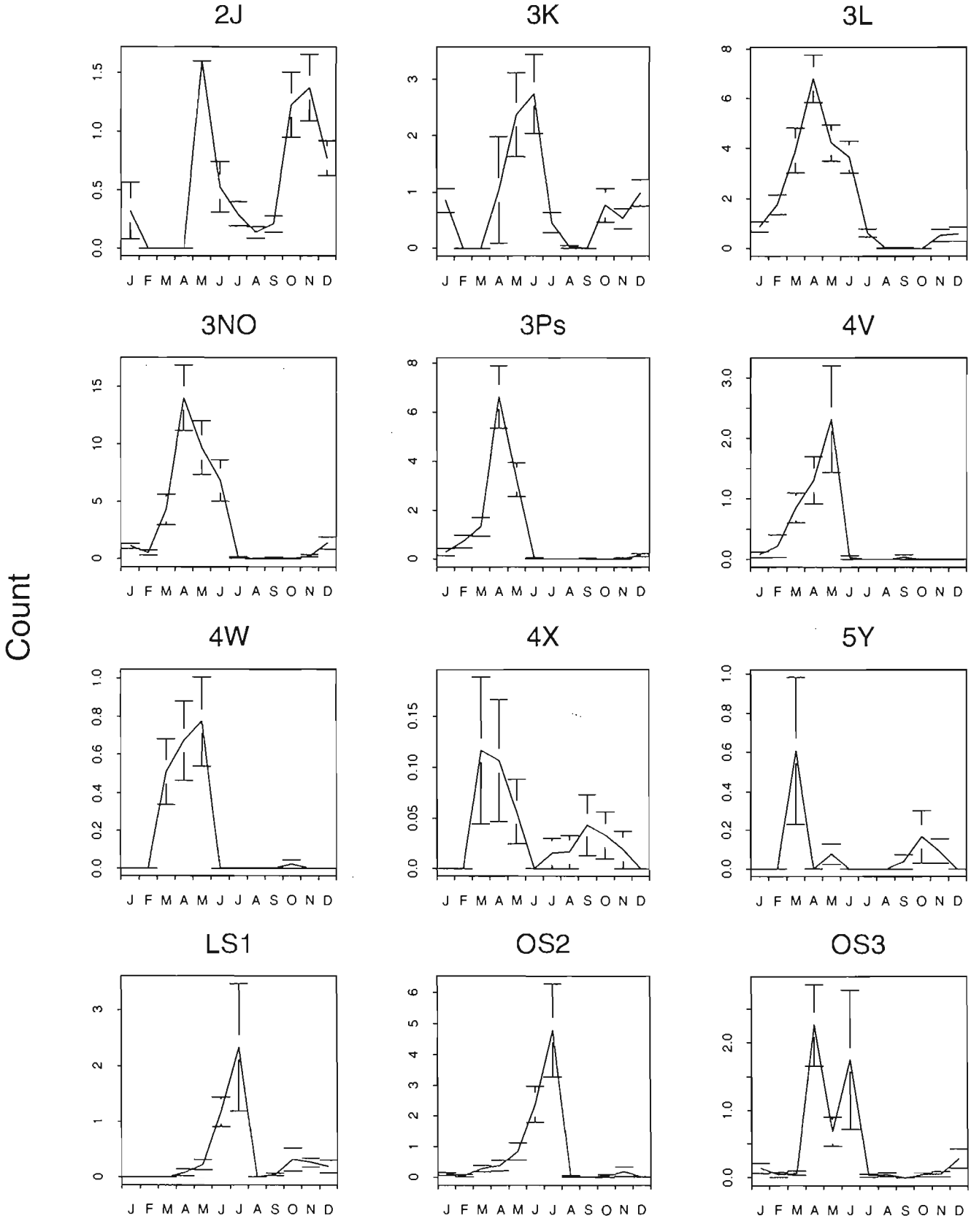
Chaetoceros(Phaeoceros) spp.



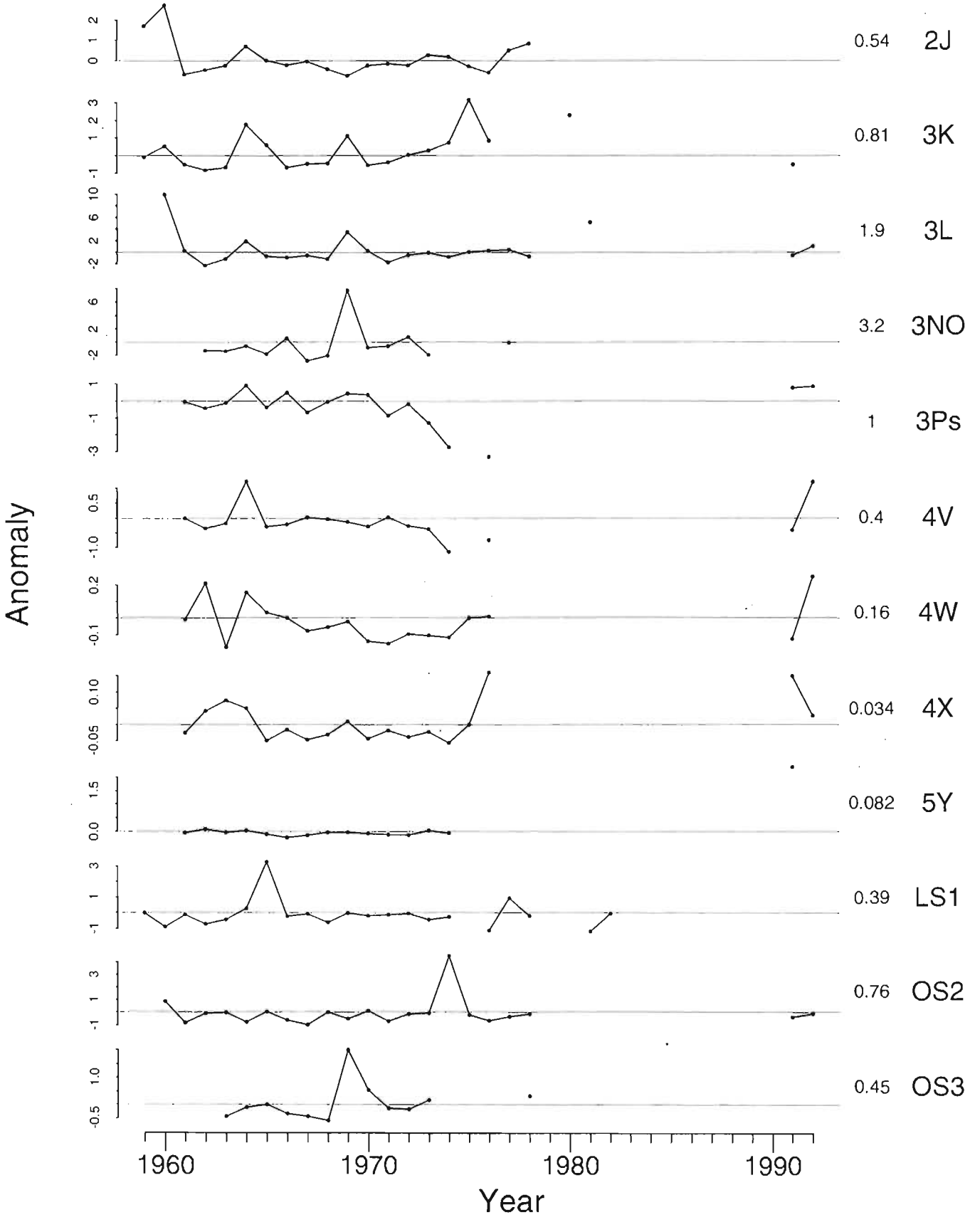
Chaetoceros(Phaeoceros) spp.



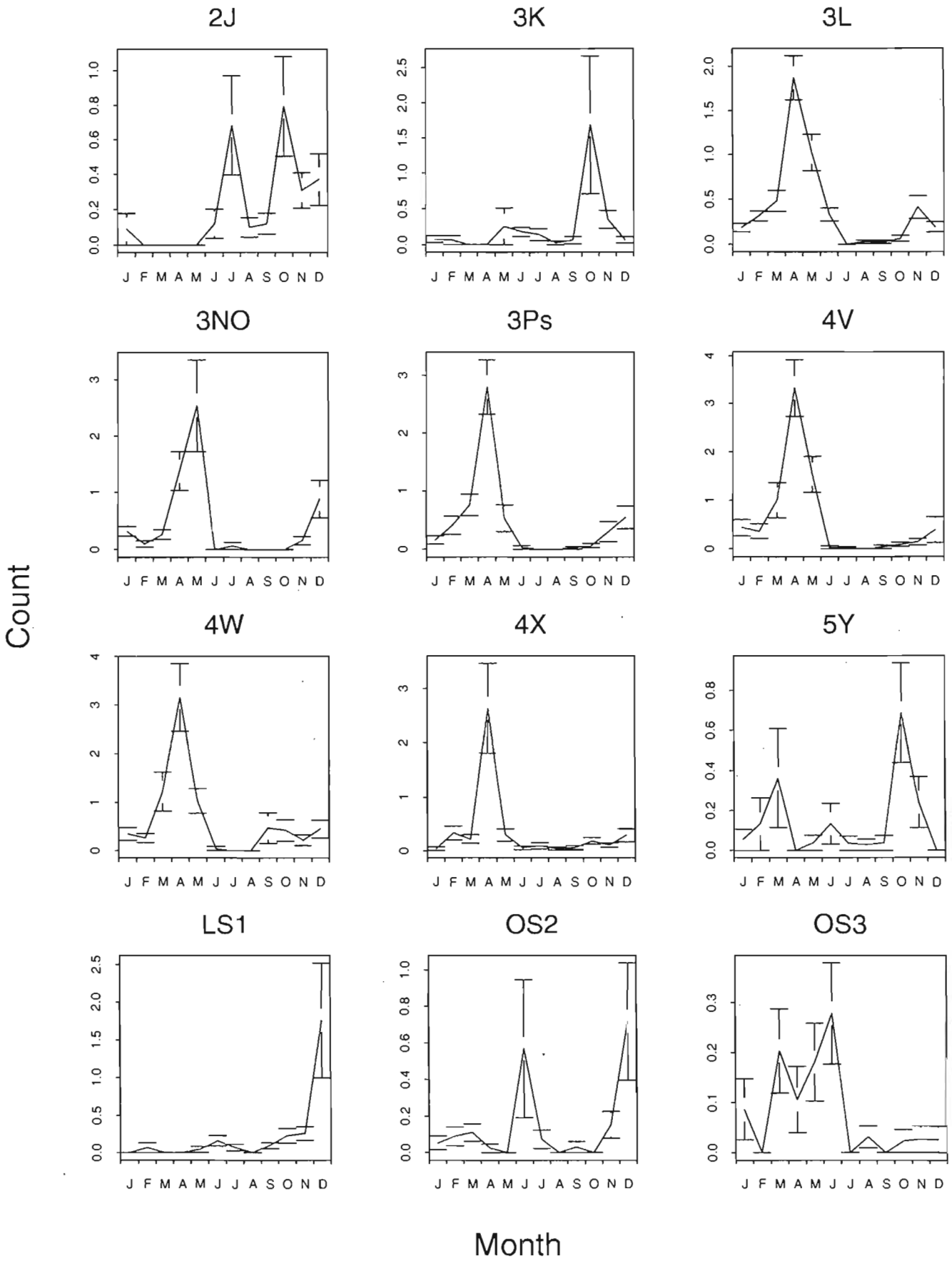
Thalassiothrix longissima



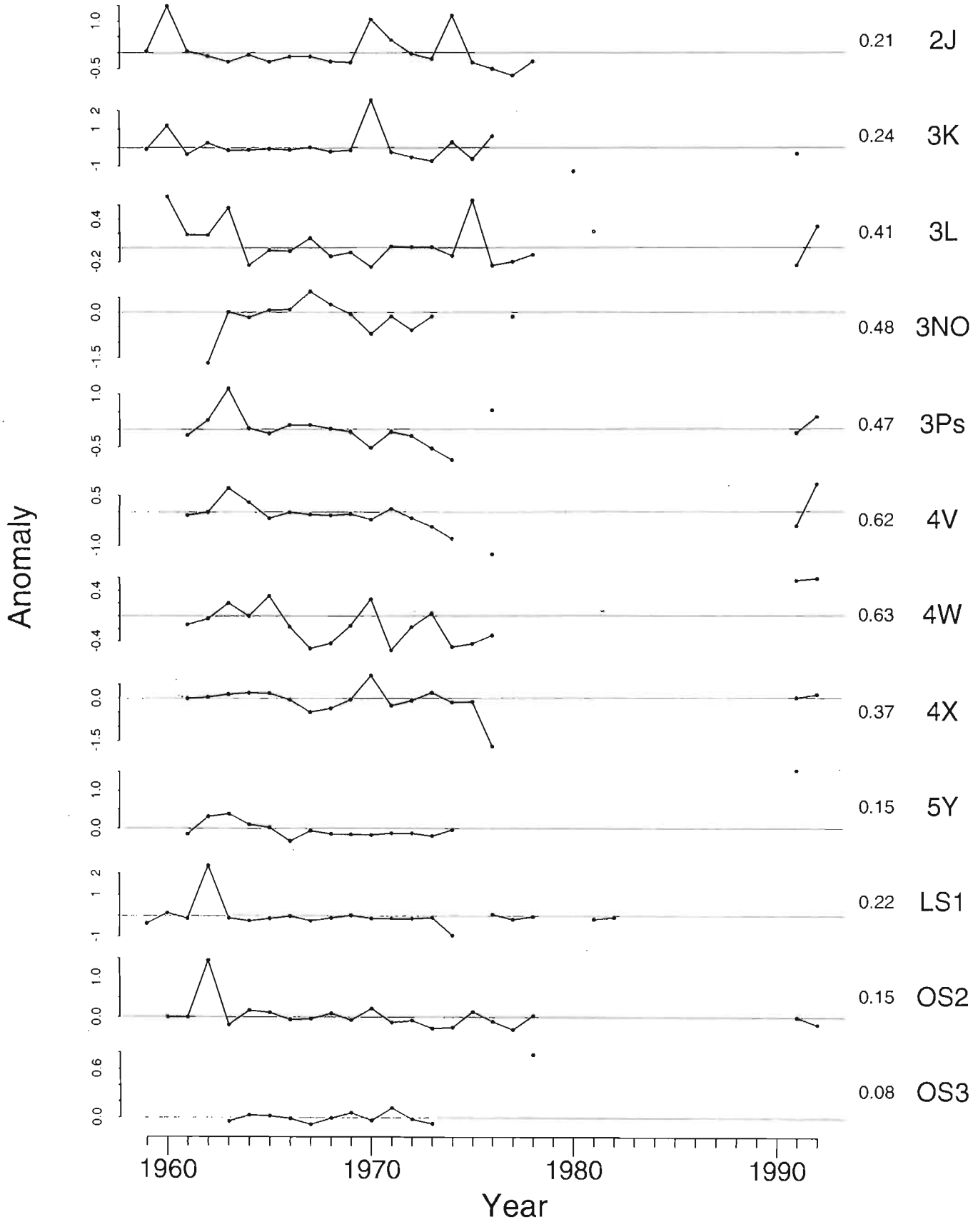
Thalassiothrix longissima



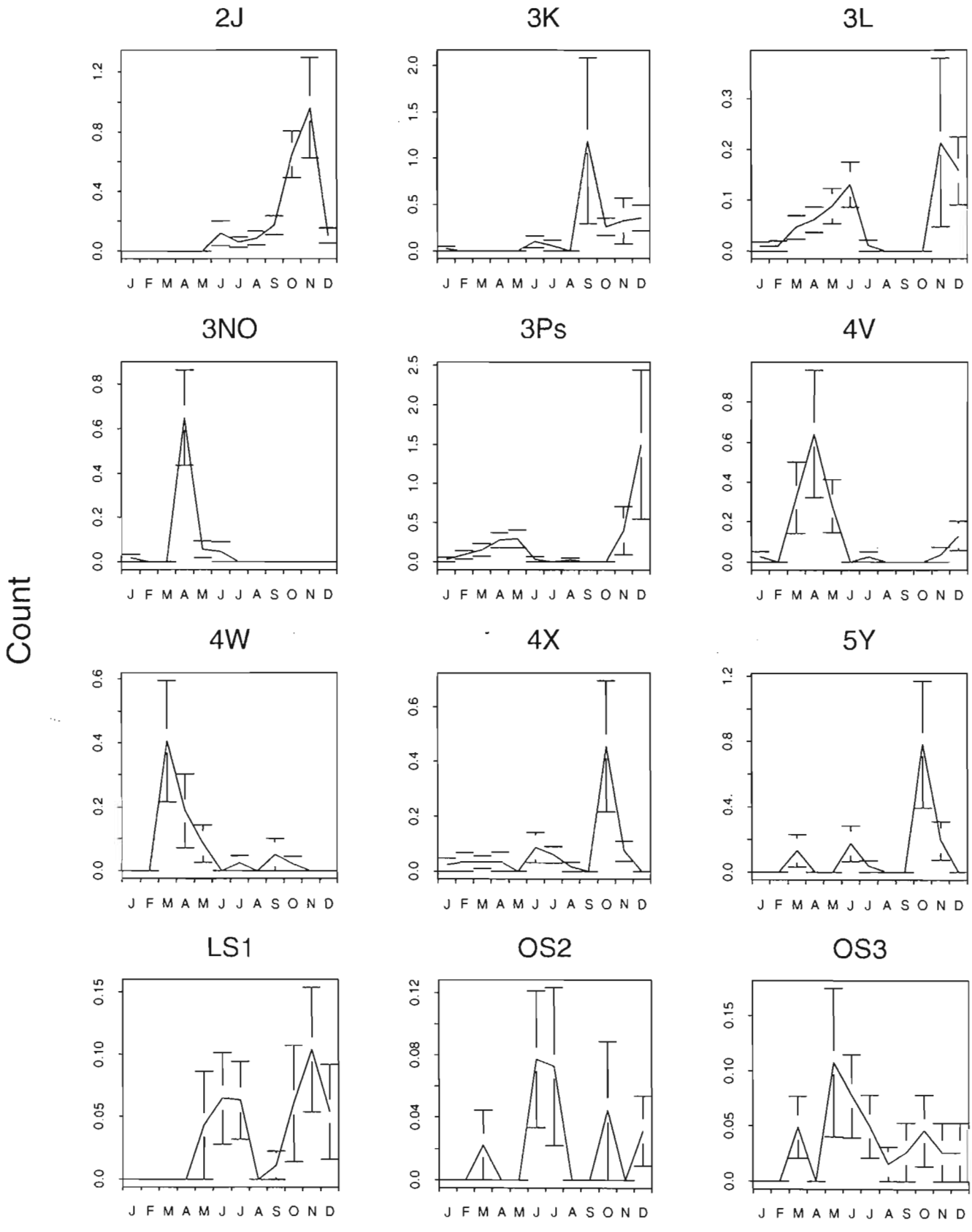
Thalassionema nitzschioides



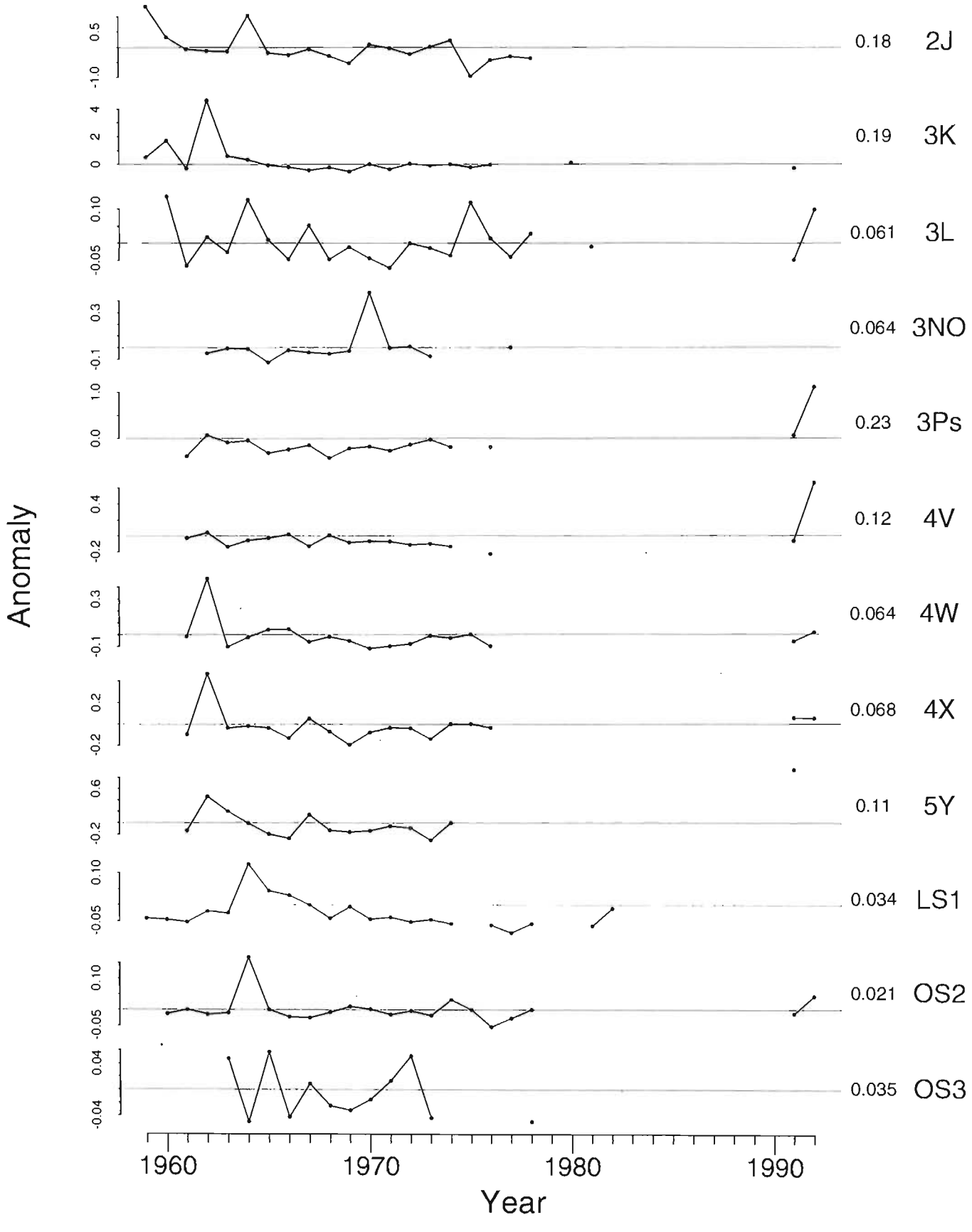
Thalassionema nitzschioides



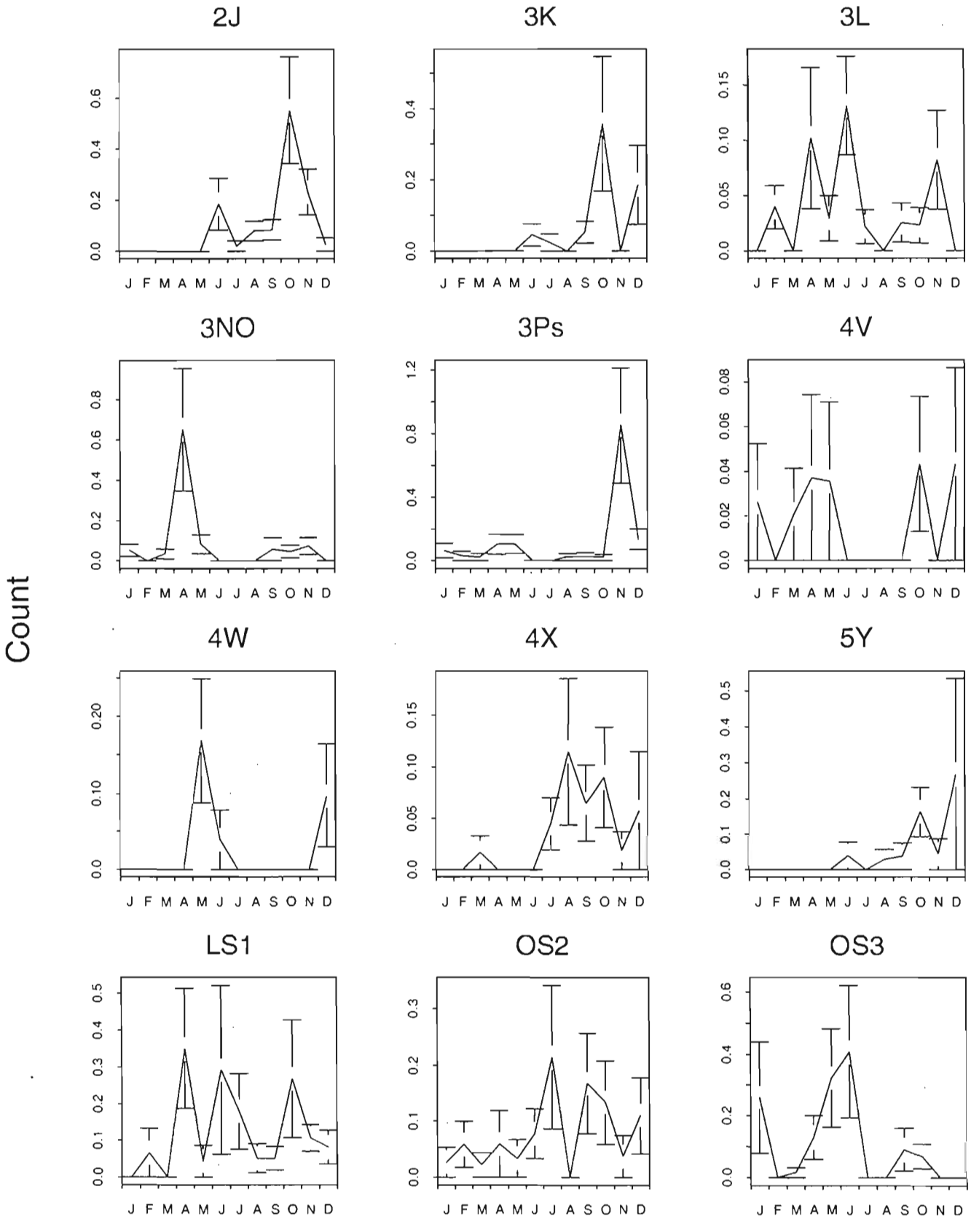
Nitzschia seriata



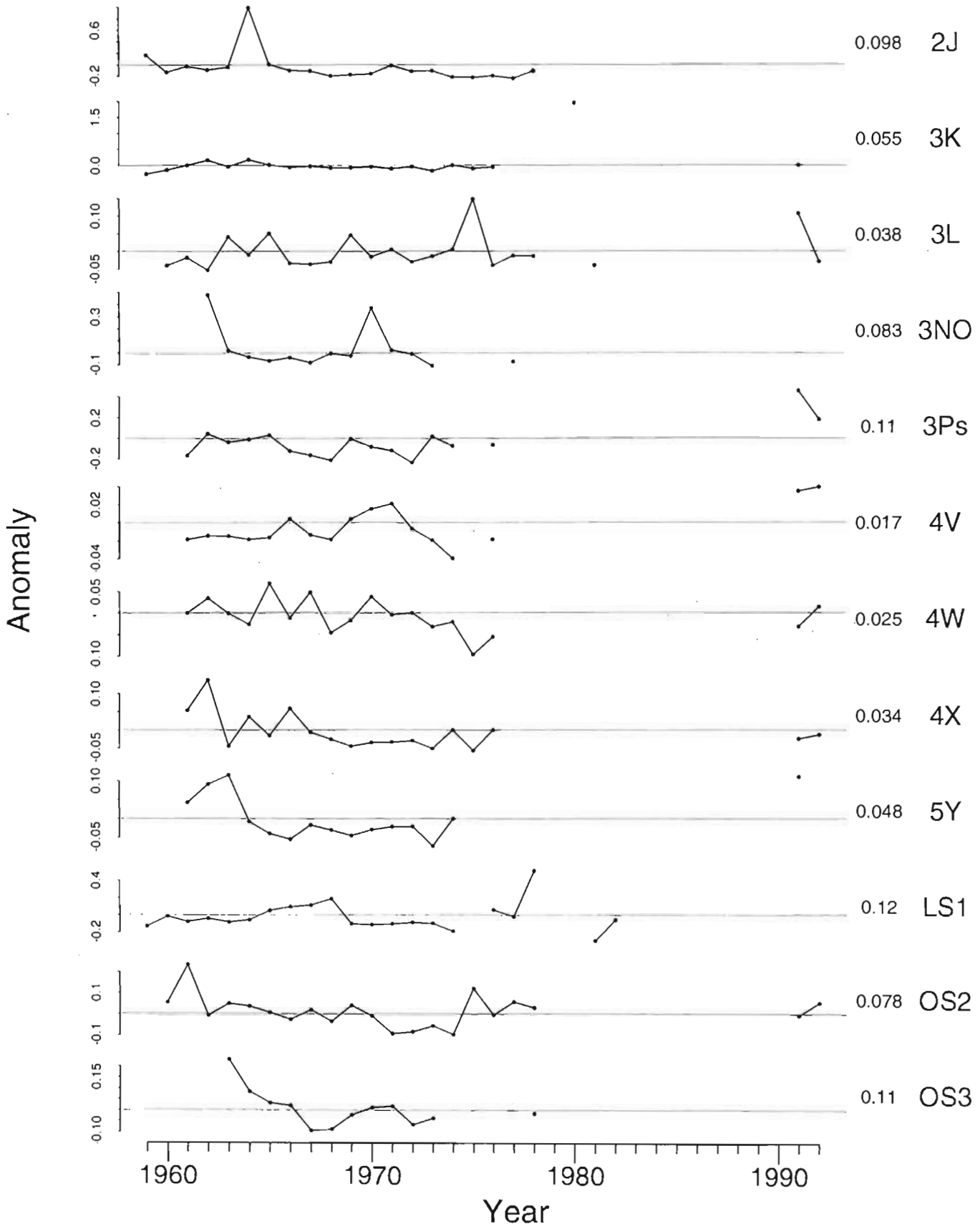
Nitzschia seriata



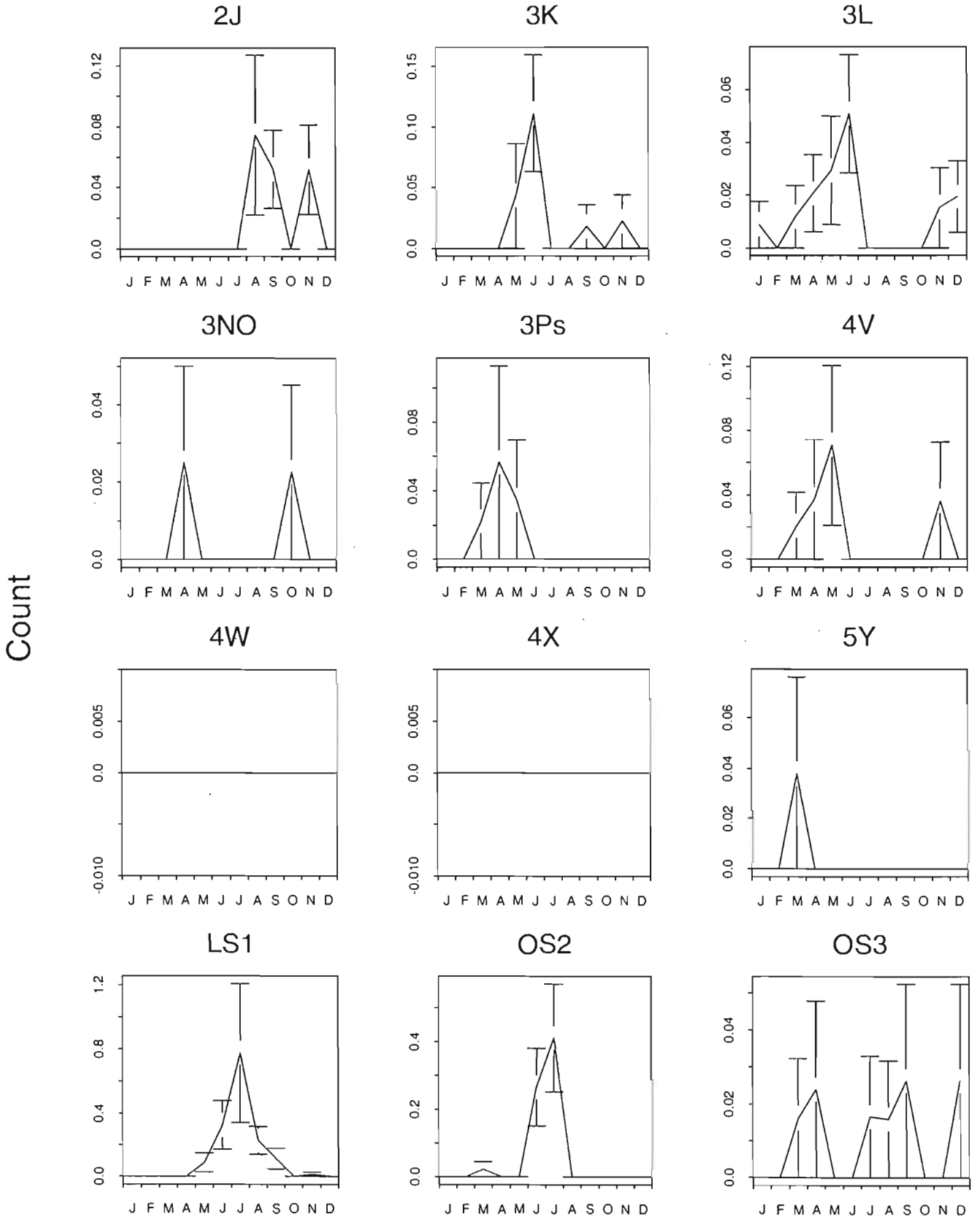
Nitzschia delicatissima



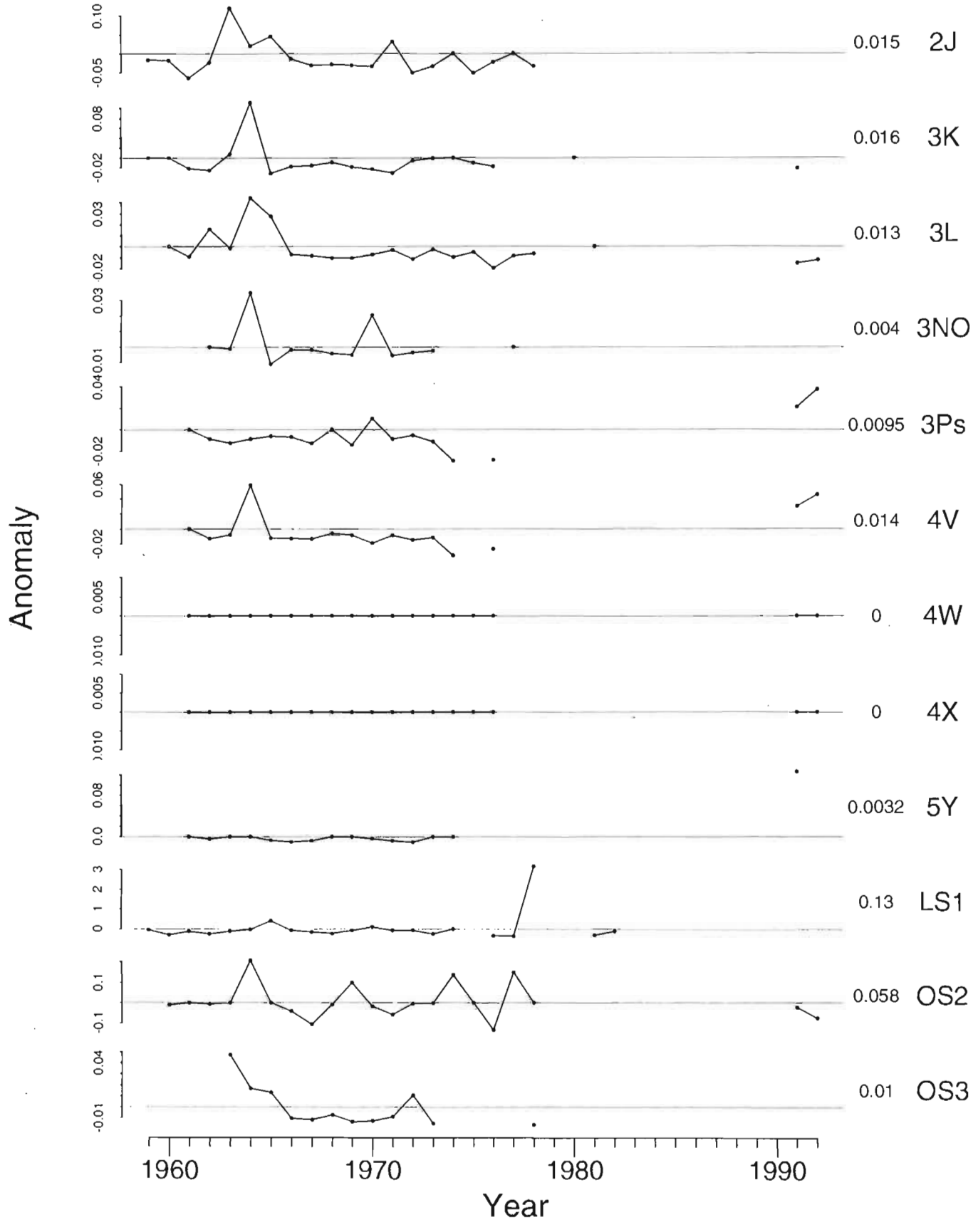
Nitzschia delicatissima



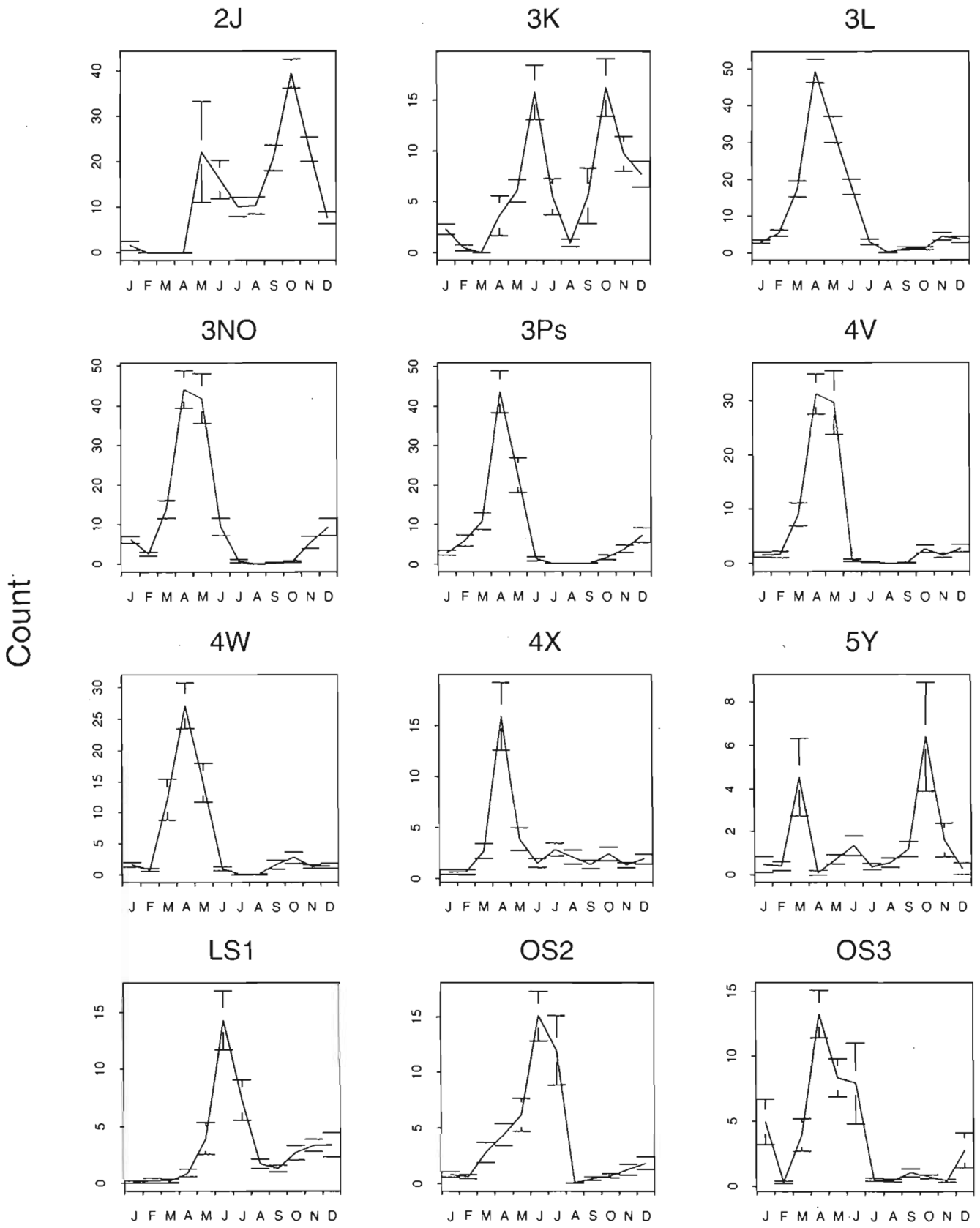
Navicula planamembranacea



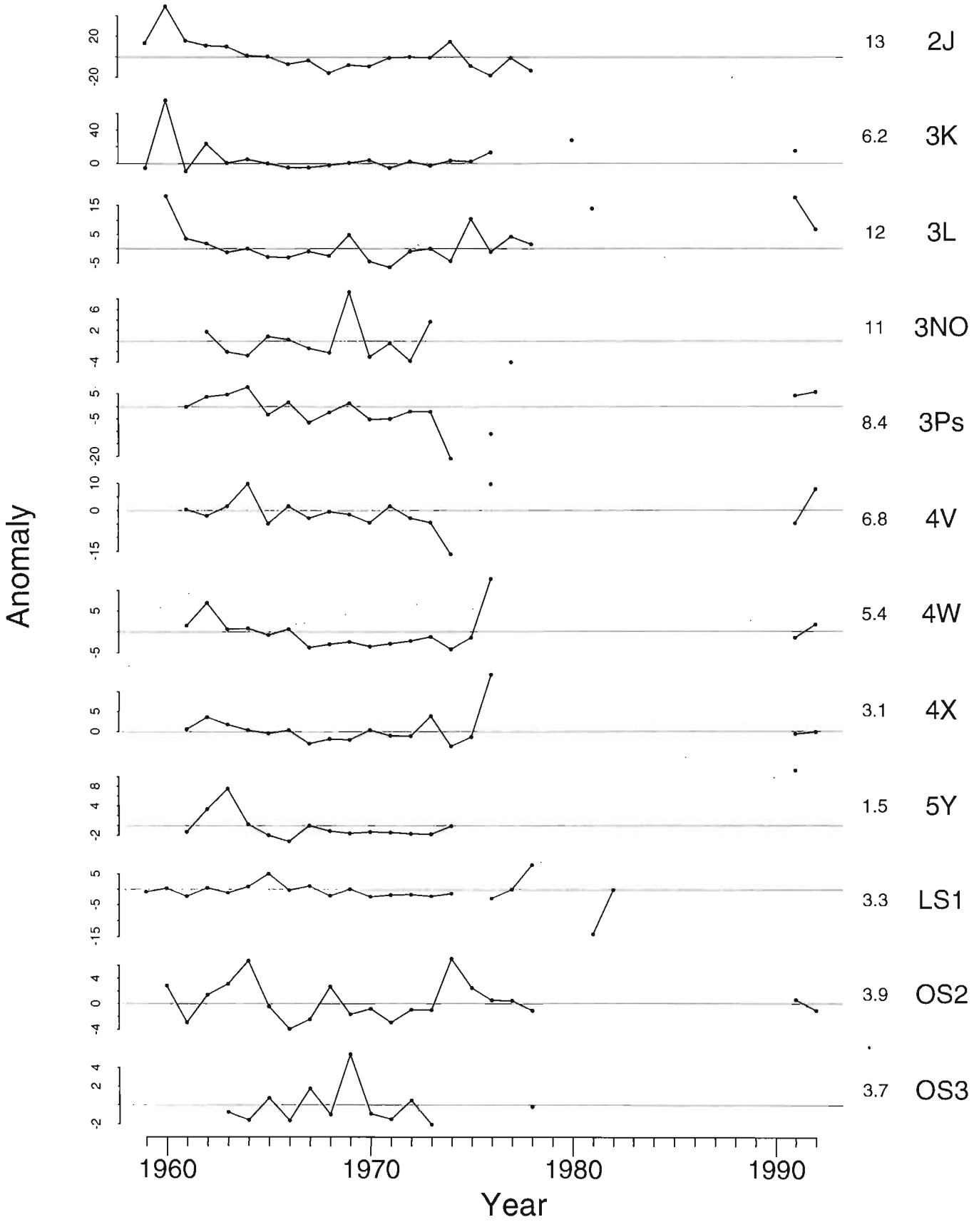
Navicula planamembranacea



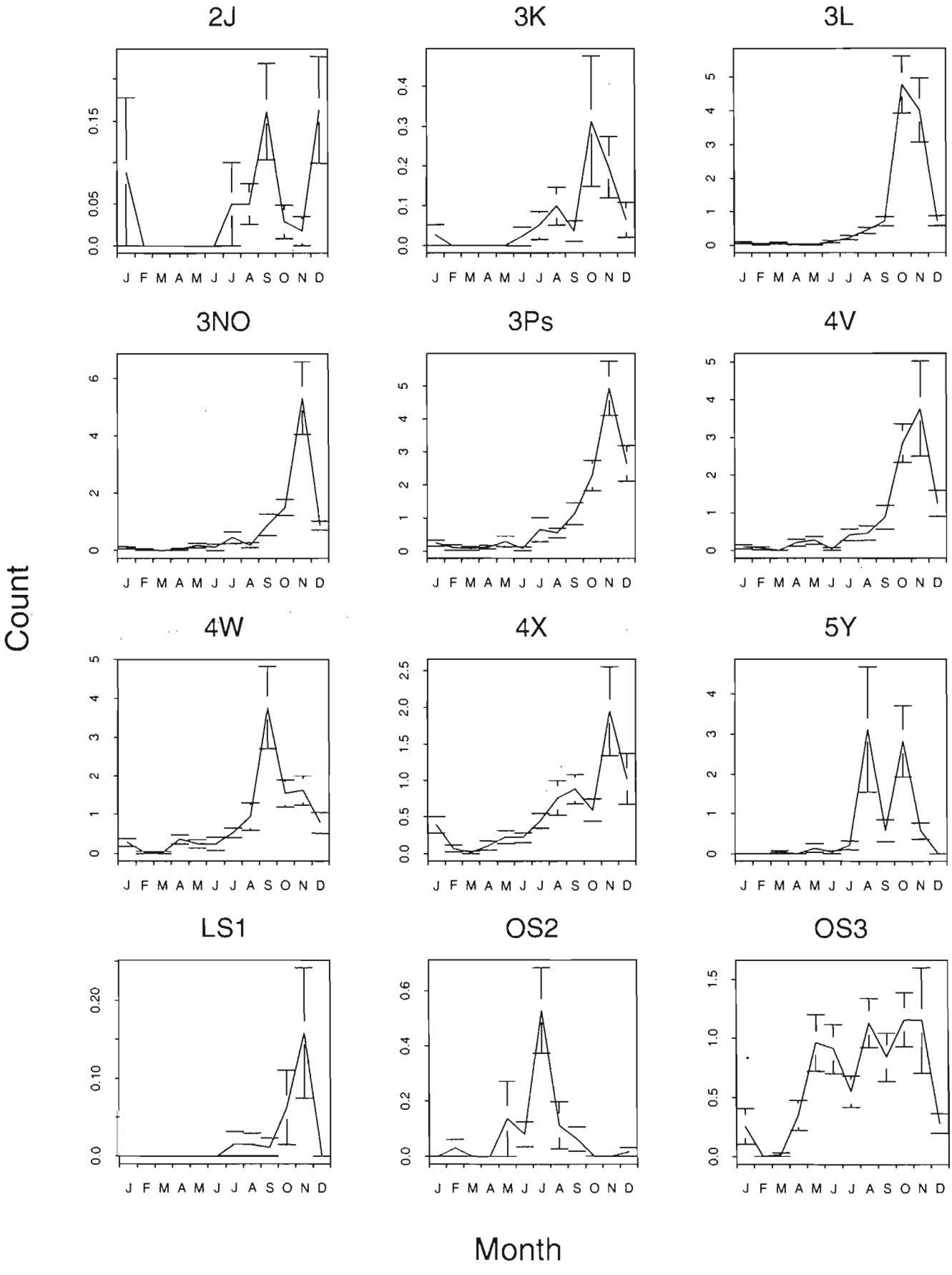
Diatoms


2J
3K
3L
3NO
3Ps
4V
4W
4X
5Y
LS1
OS2
OS3
J F M A M J J A S O N D
Count
Month

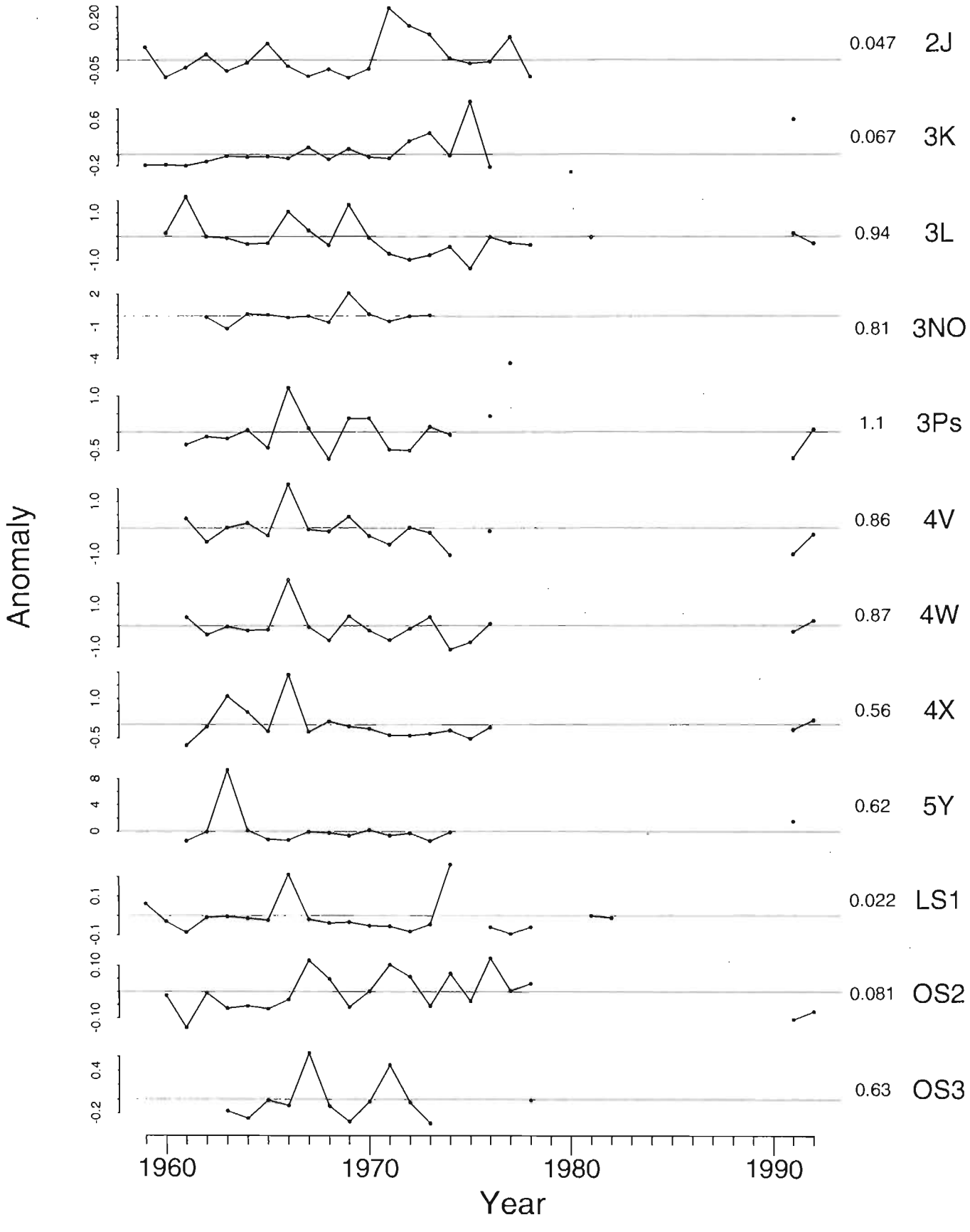
Diatoms


Anomaly
-20 20
0 40
-5 5 15
-4 2 6
-5 5 -20
-15 0 10
-5 5
0 5
-2 4 8
-15 -5 5
-4 0 4
-2 2 4
13 2J
6.2 3K
12 3L
11 3NO
8.4 3Ps
6.8 4V
5.4 4W
3.1 4X
1.5 5Y
3.3 LS1
3.9 OS2
3.7 OS3
1960
1970
1980
1990
Year

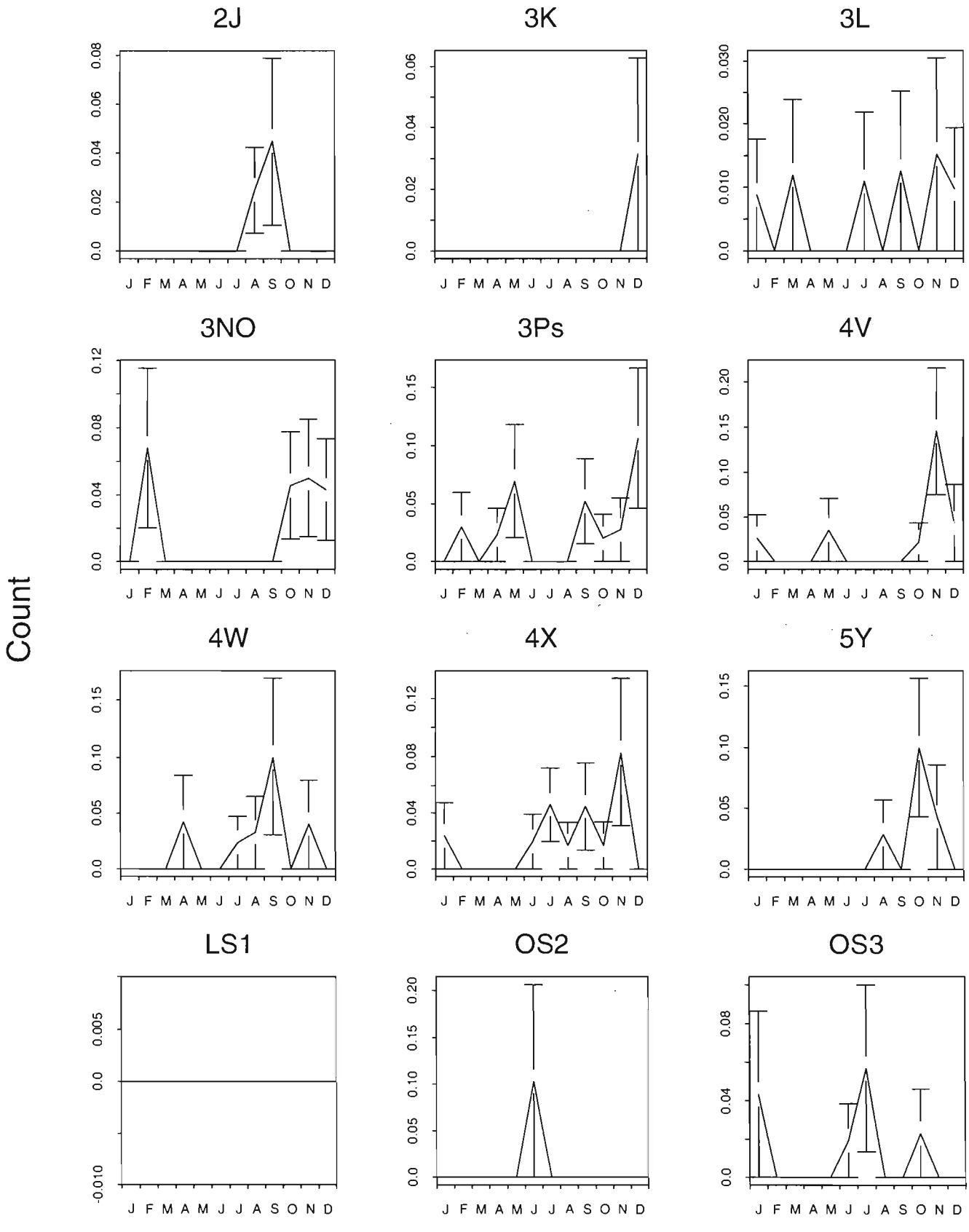
Ceratium fusus



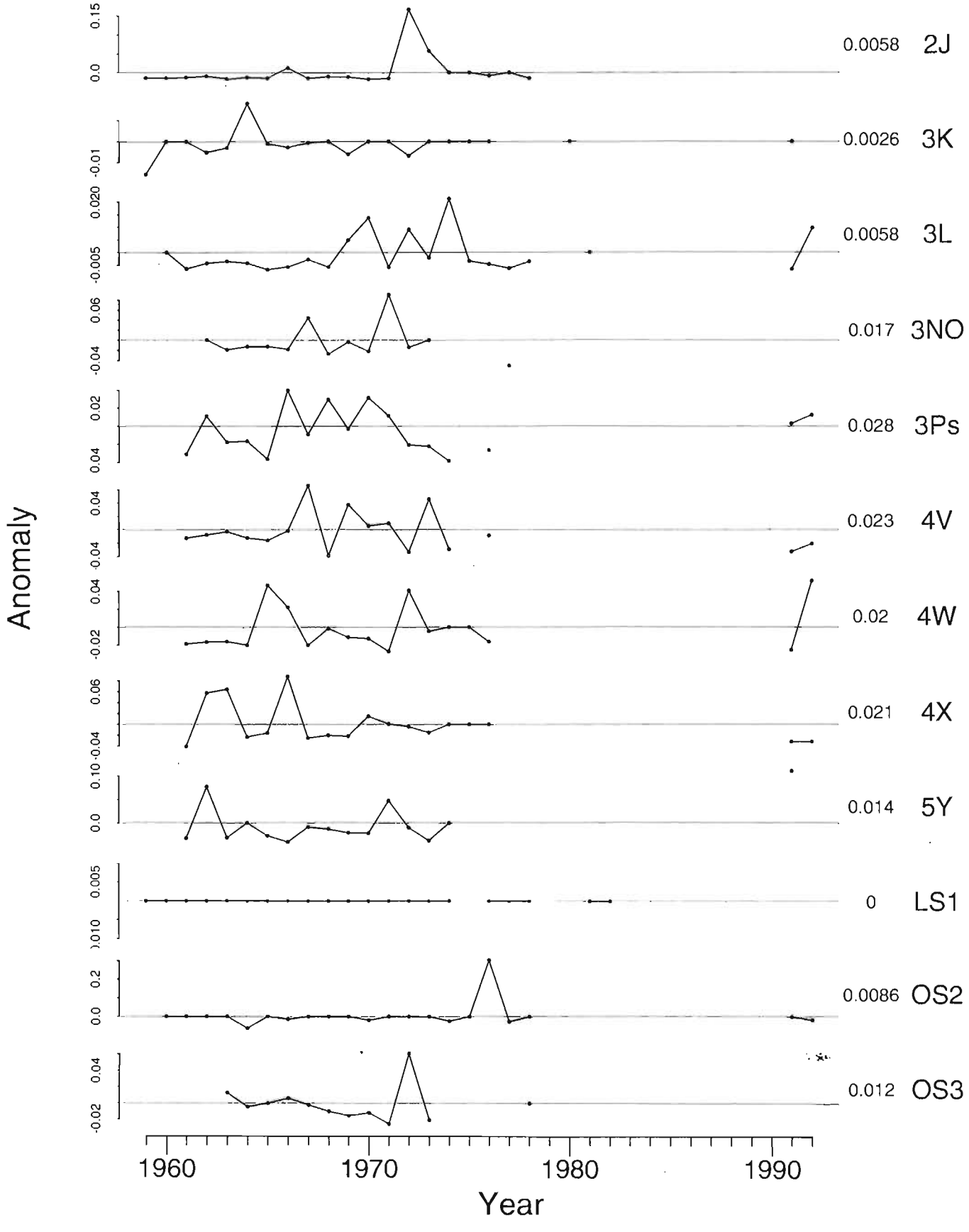
Ceratium fusus



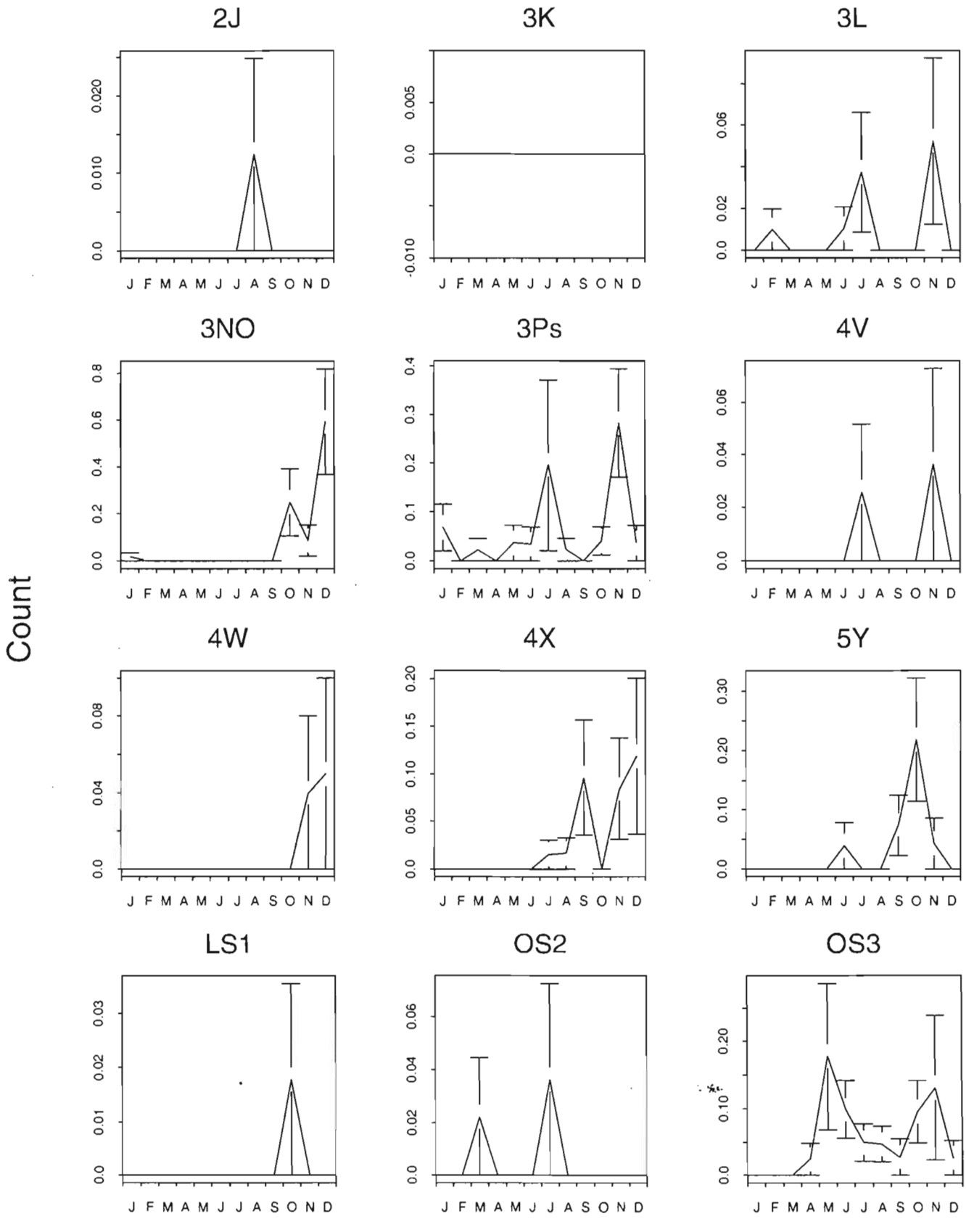
Ceratium furca



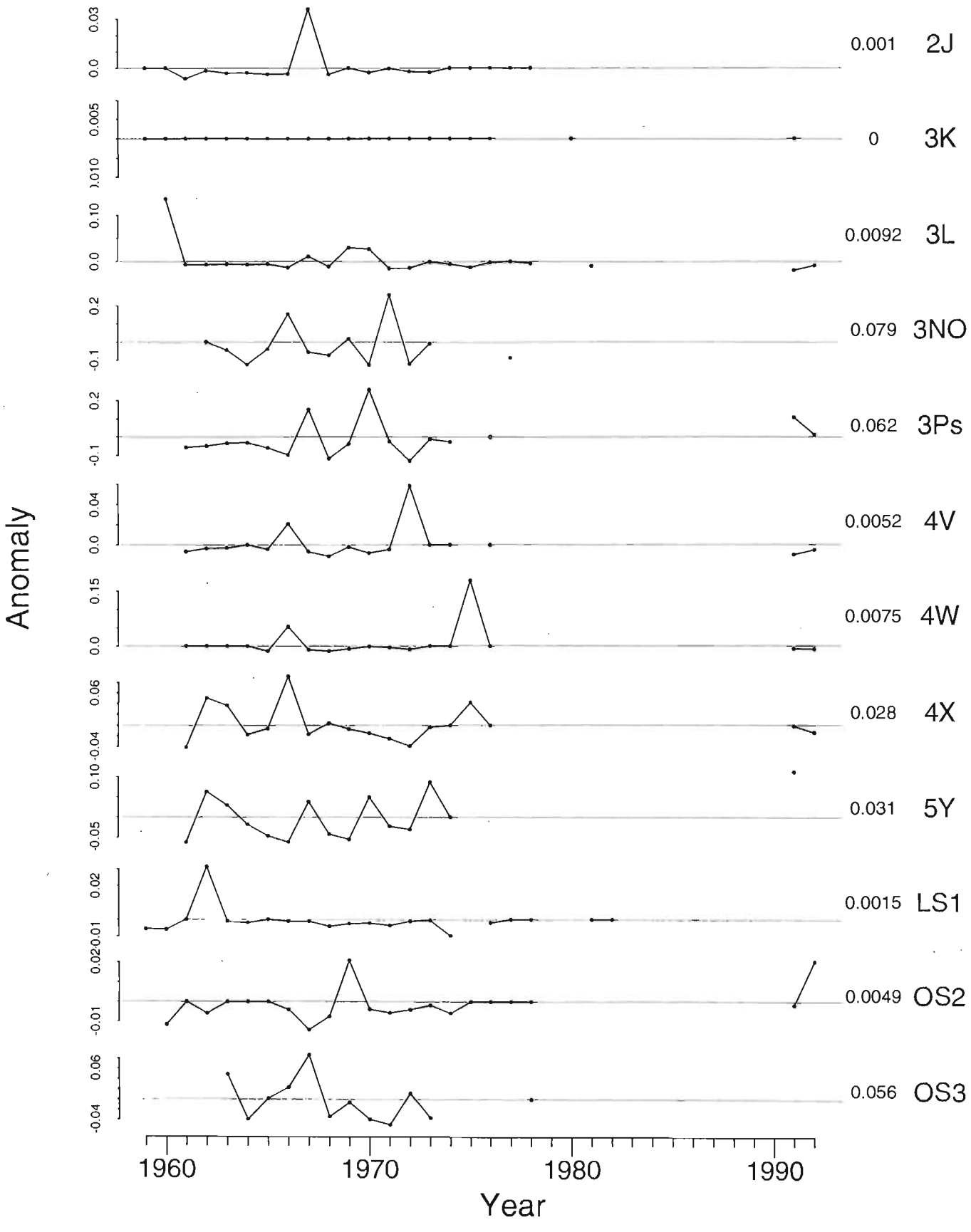
Ceratium furca



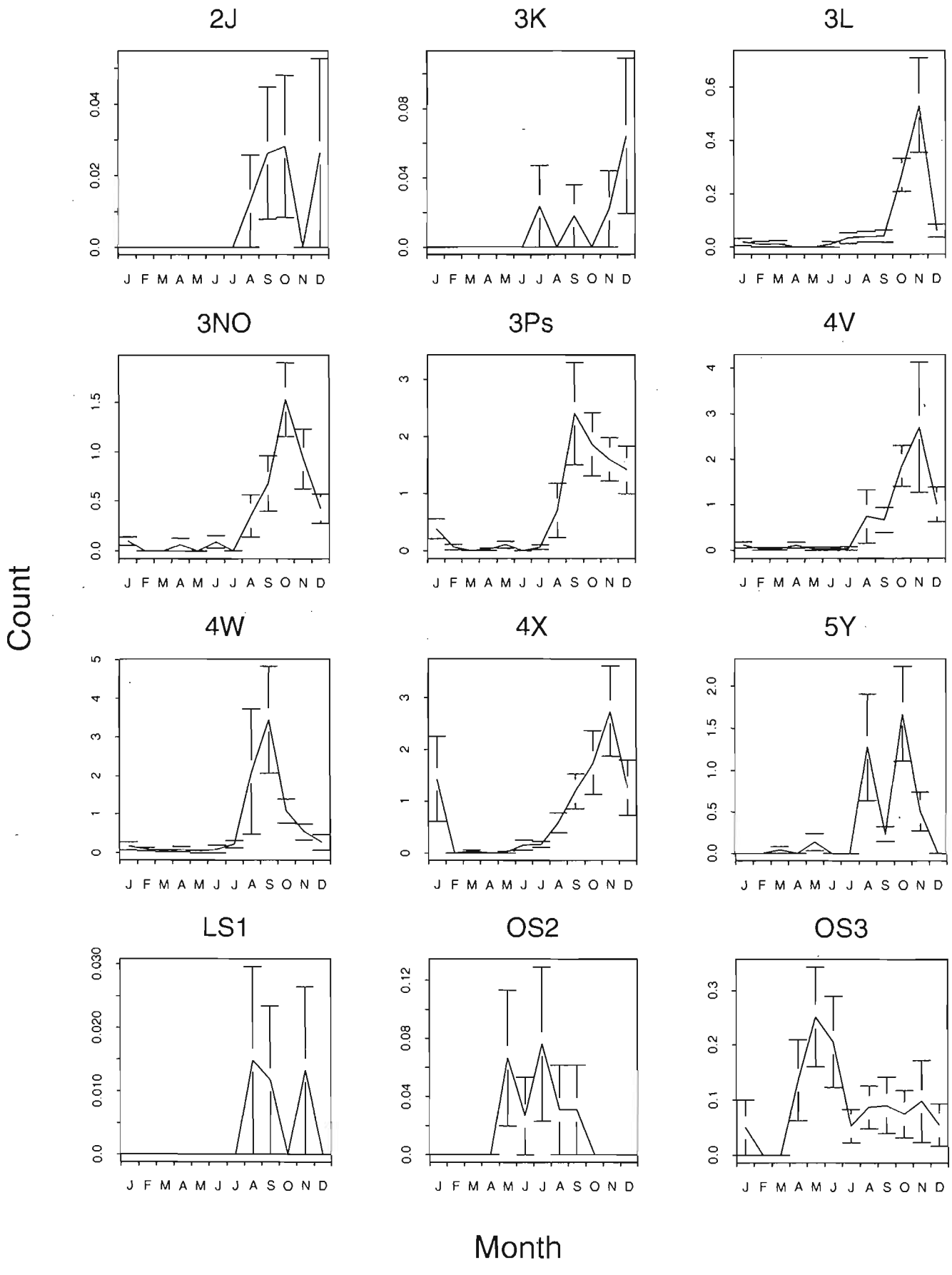
Ceratium lineatum



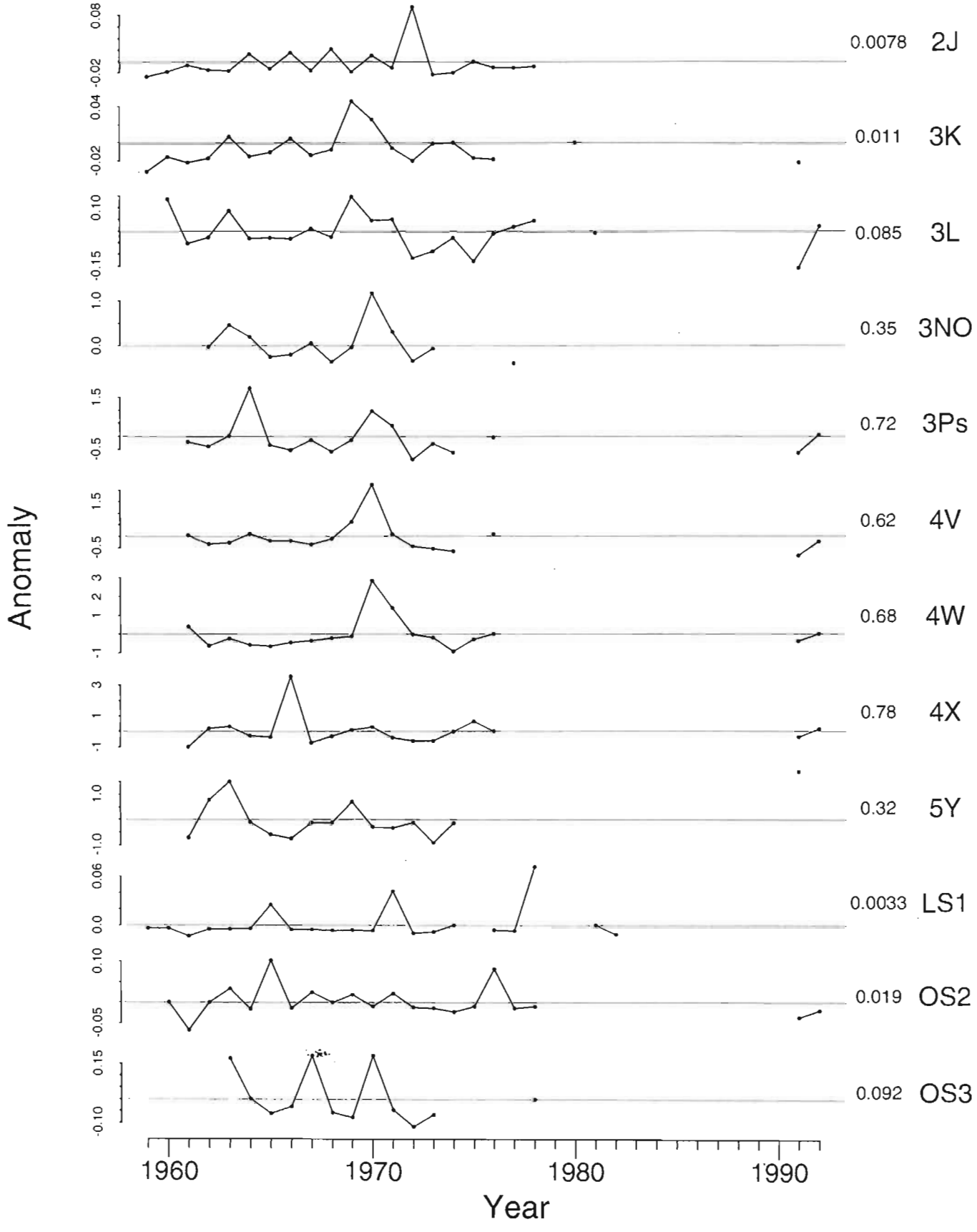
Ceratium lineatum



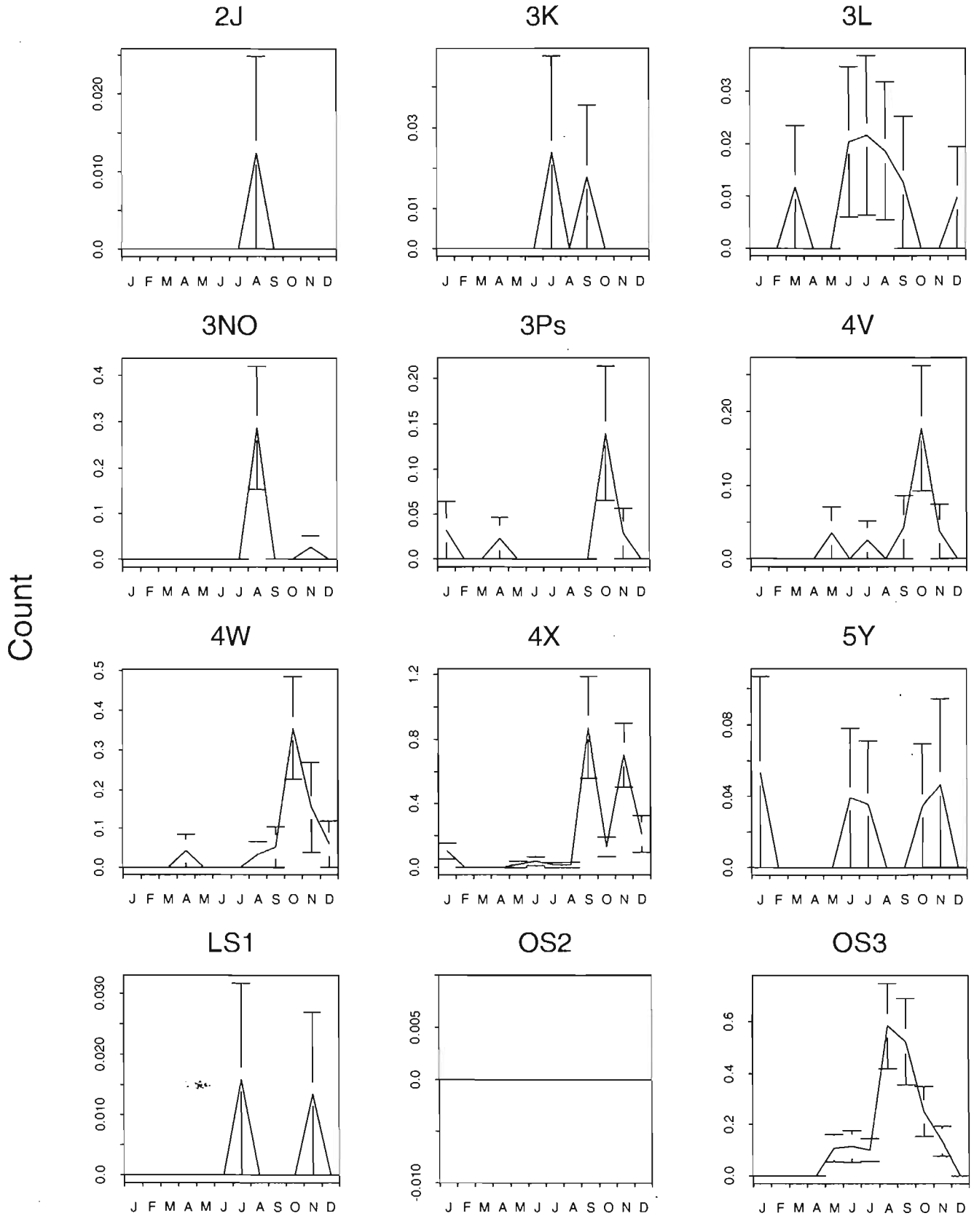
Ceratium tripos



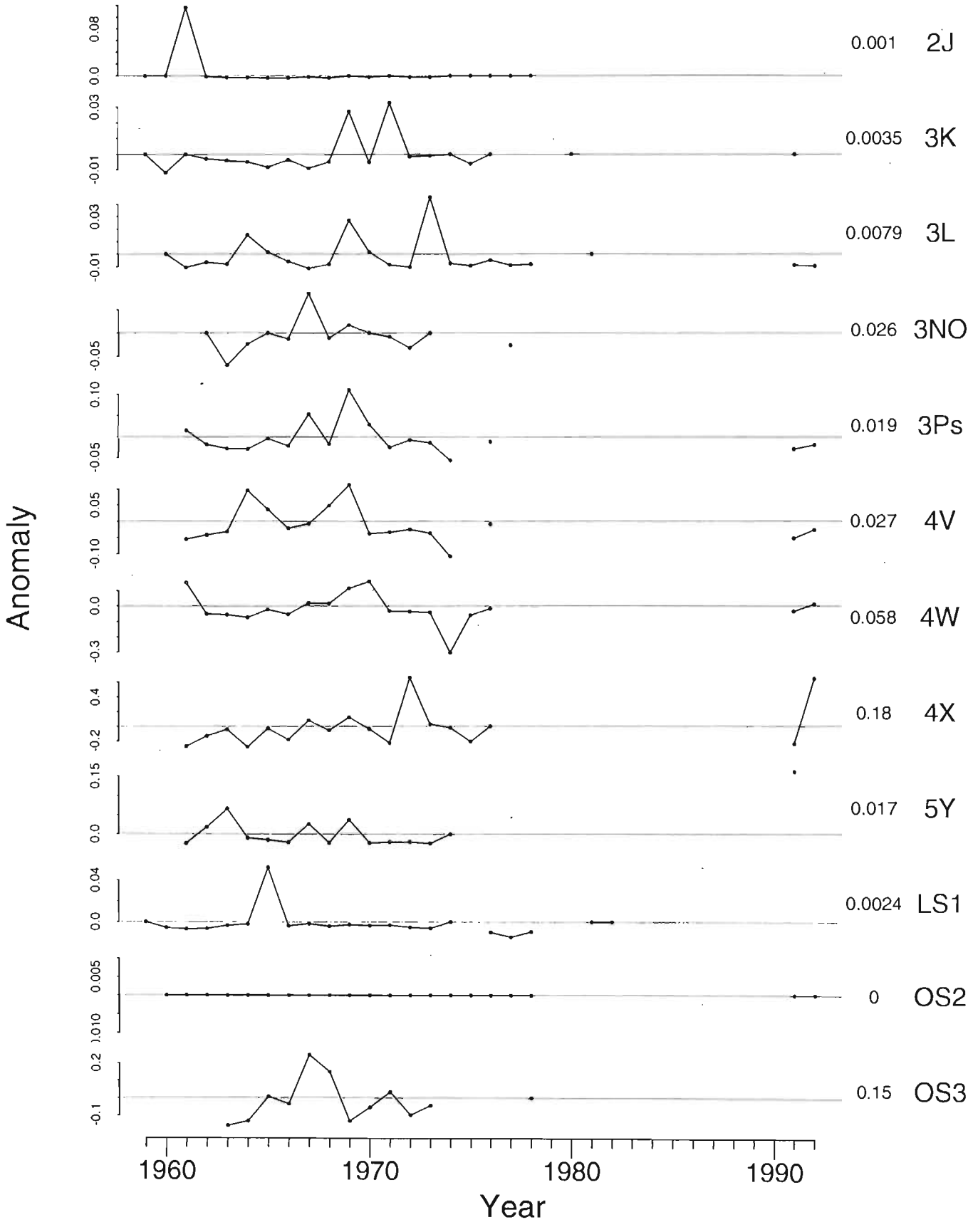
Ceratium tripos



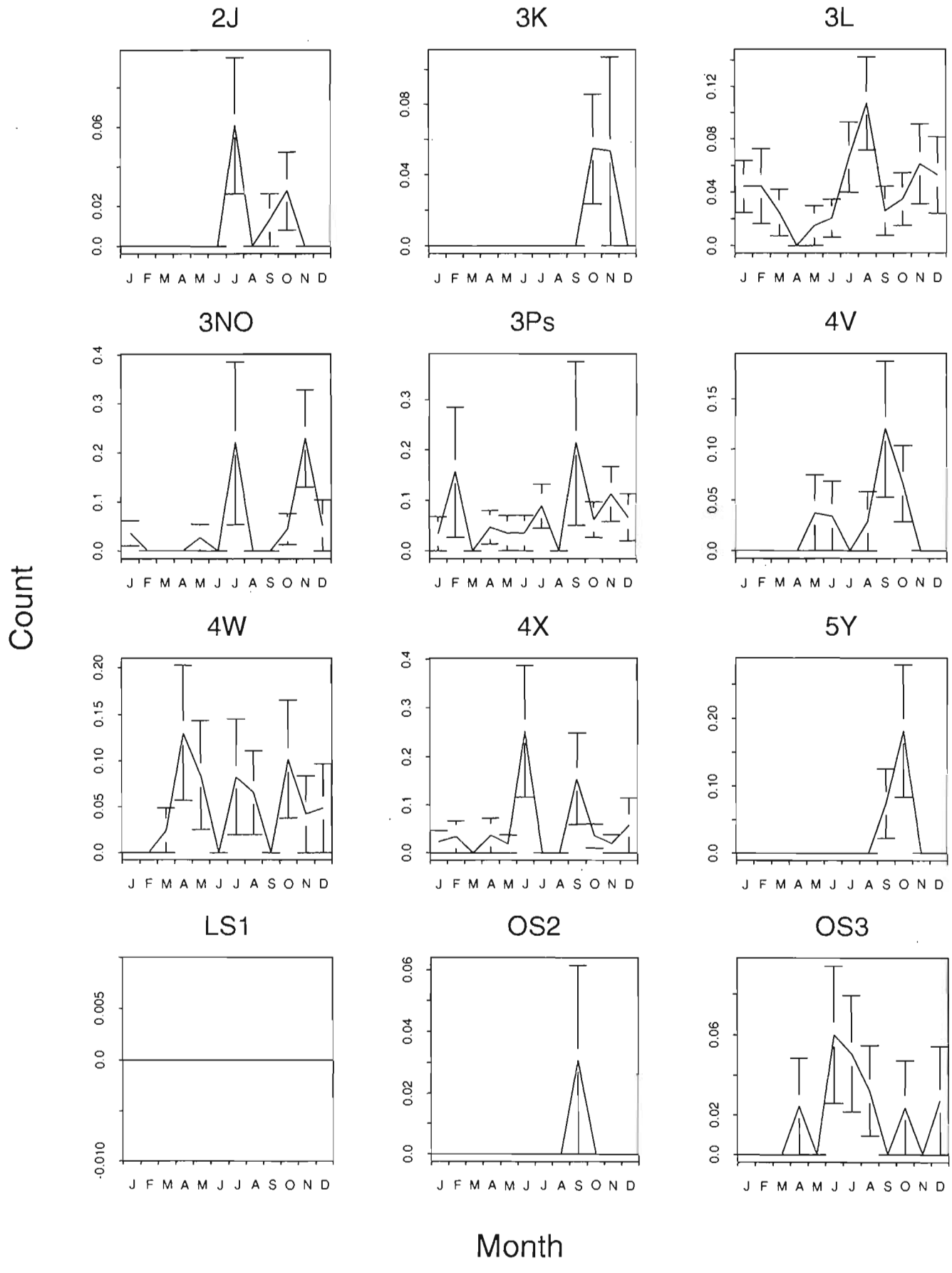
Ceratium macroceros



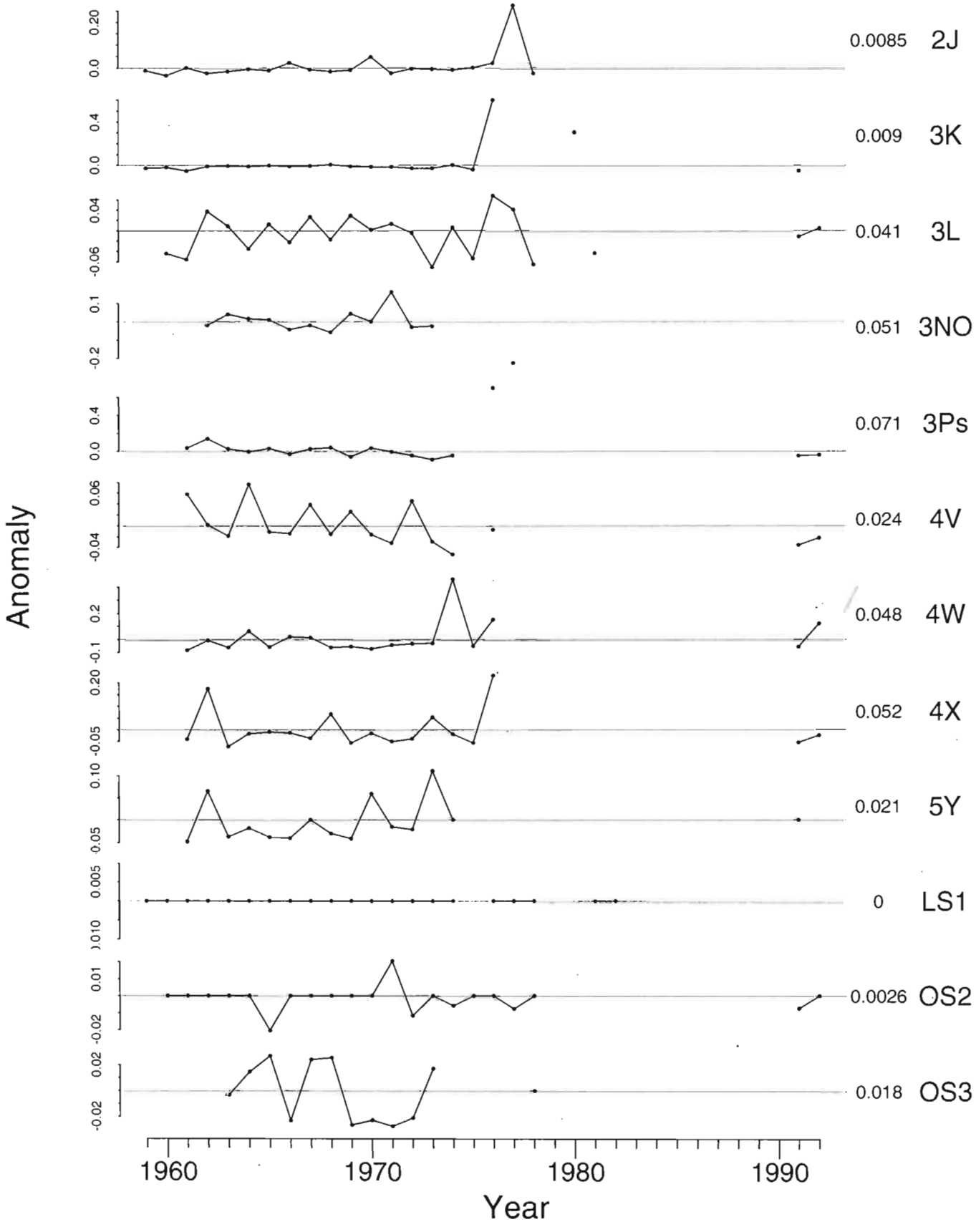
Ceratium macroceros



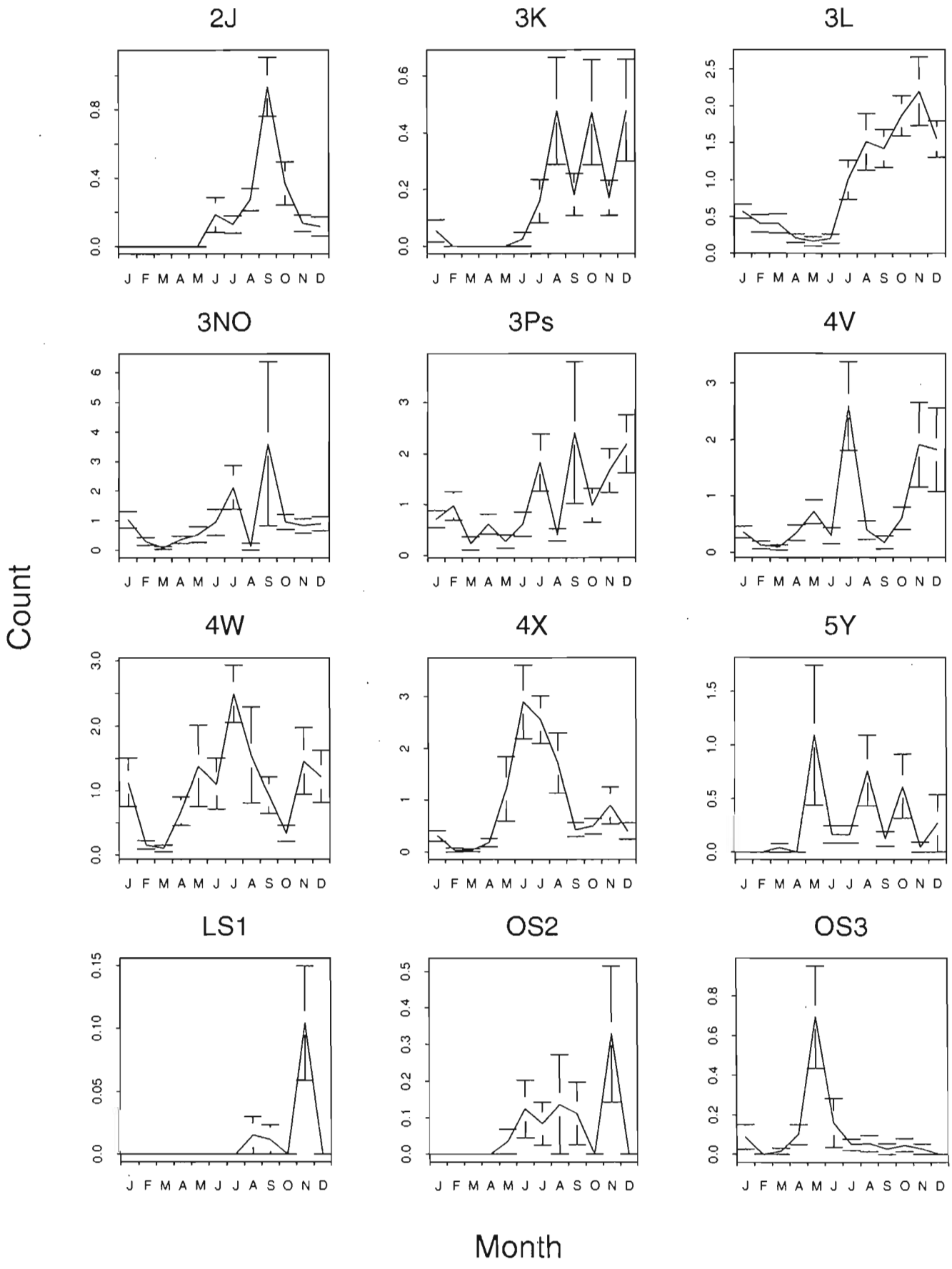
Ceratium horridum



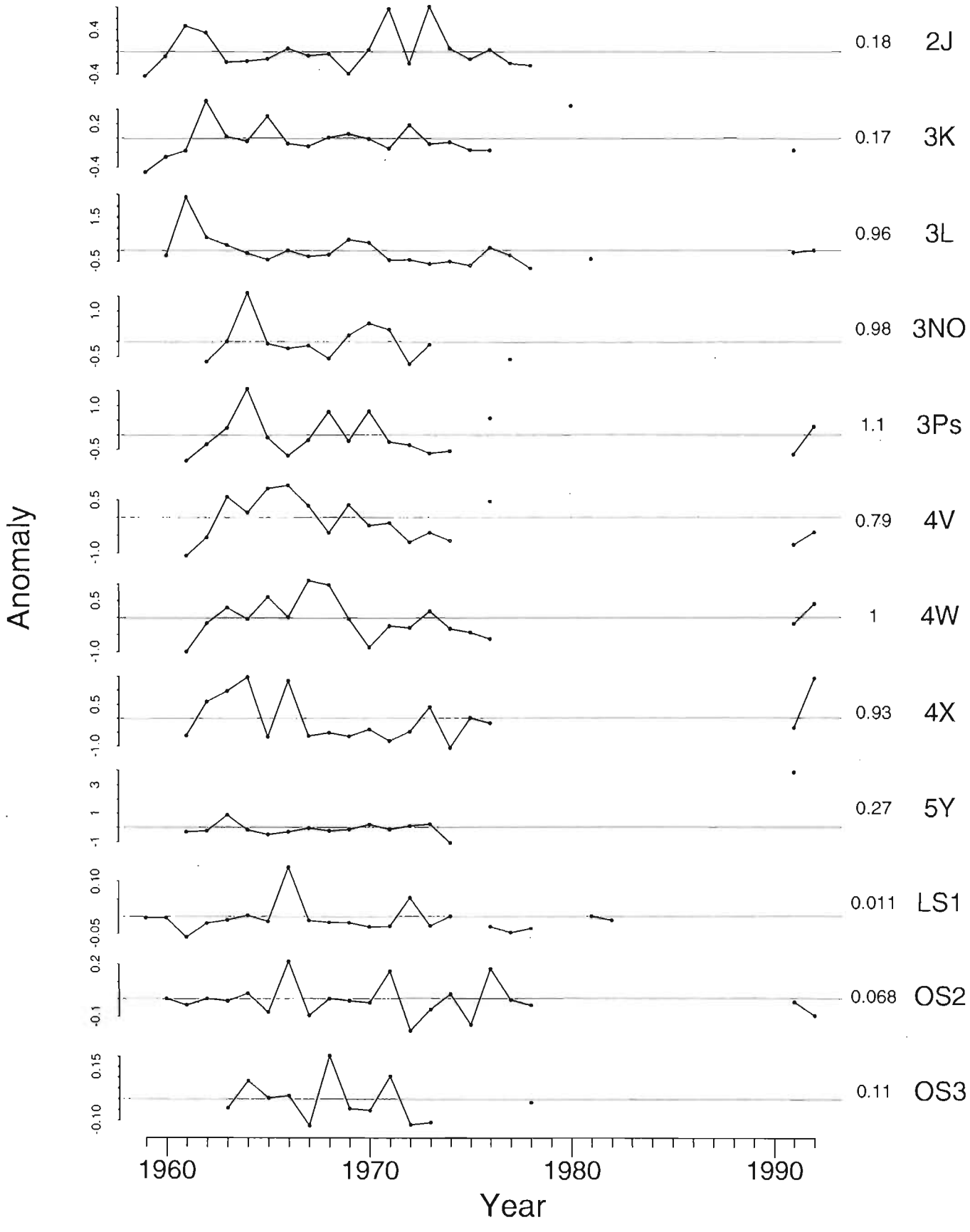
Ceratium horridum



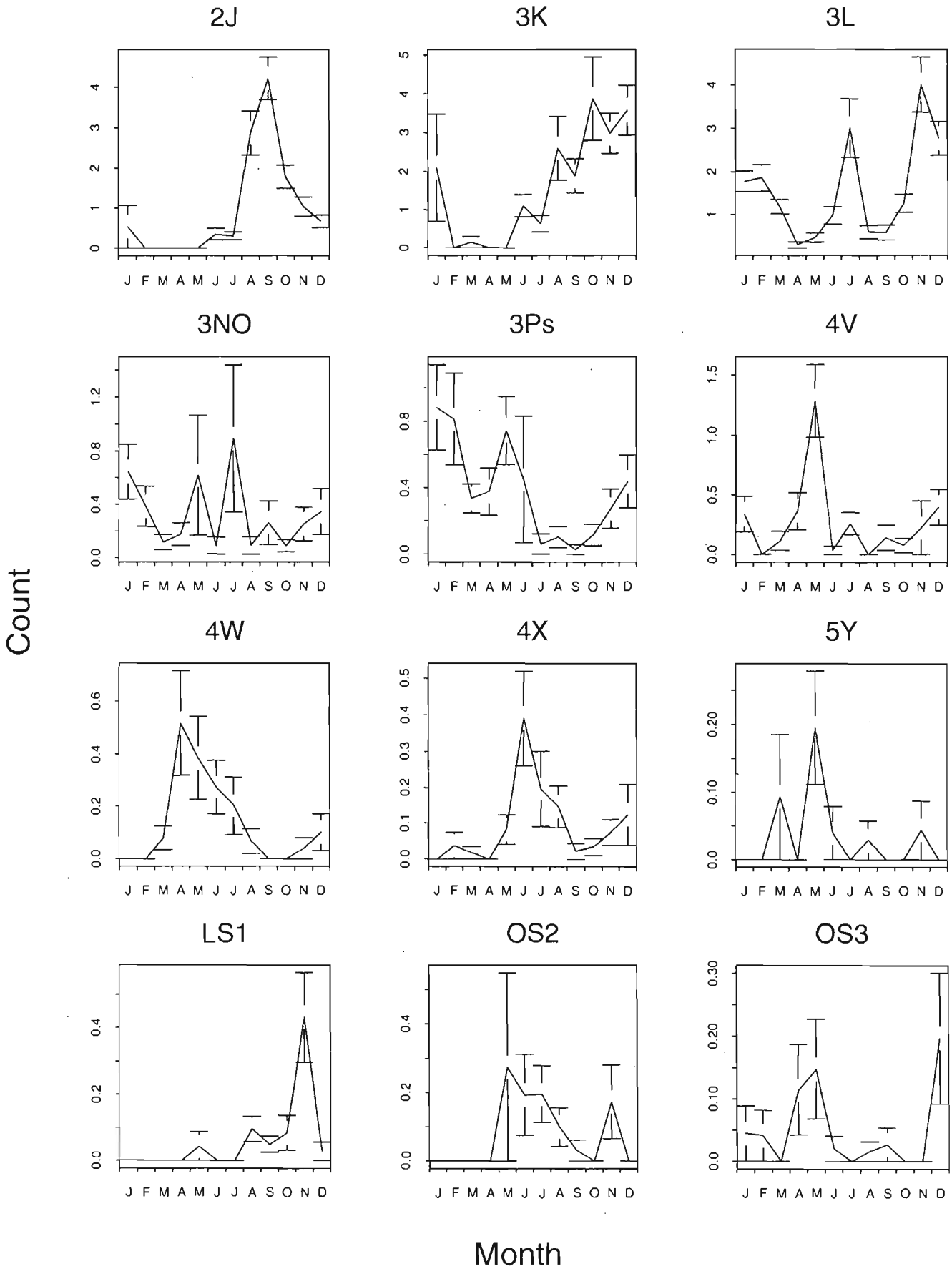
Ceratium longipes



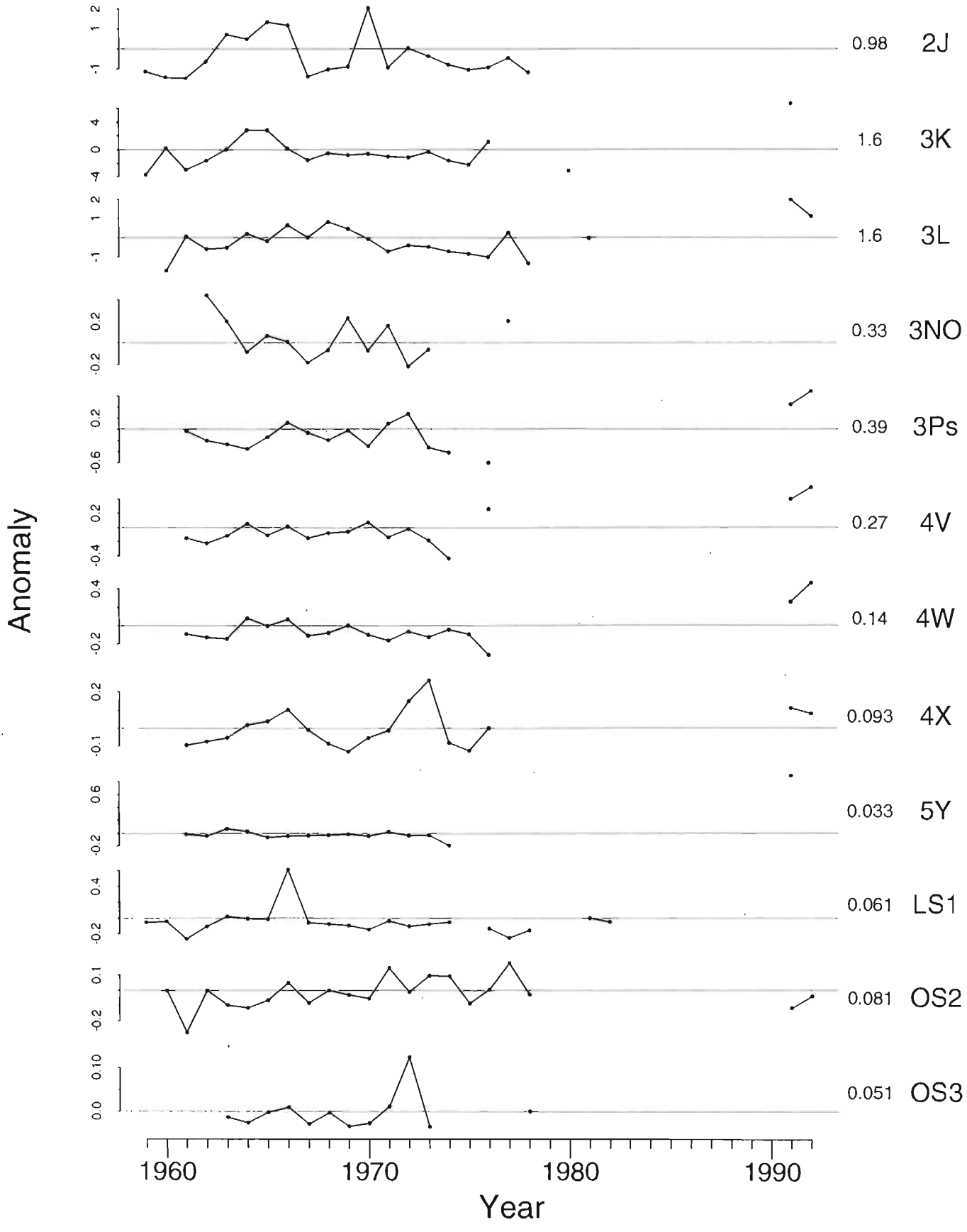
Ceratium longipes



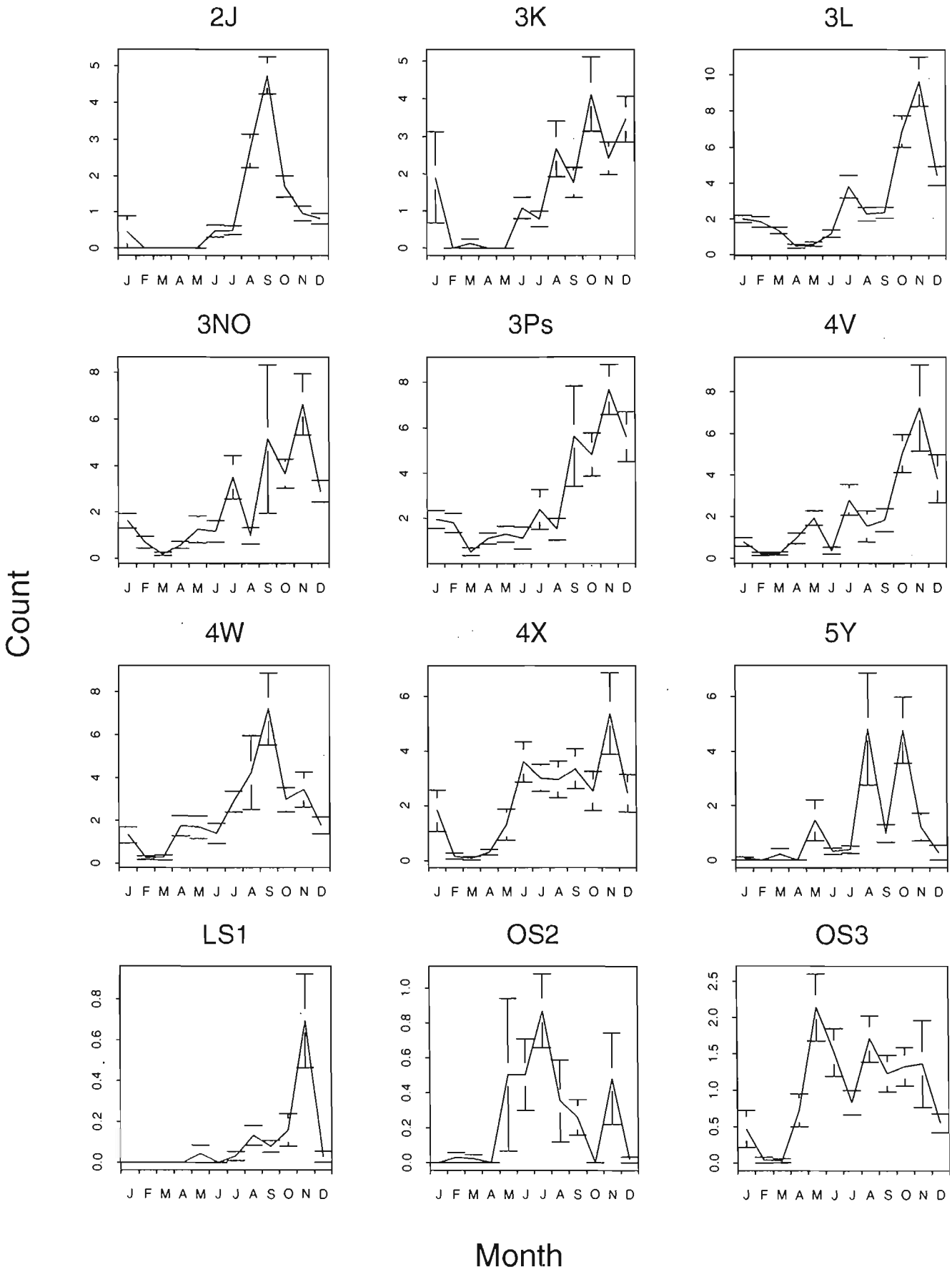
Ceratium arcticum



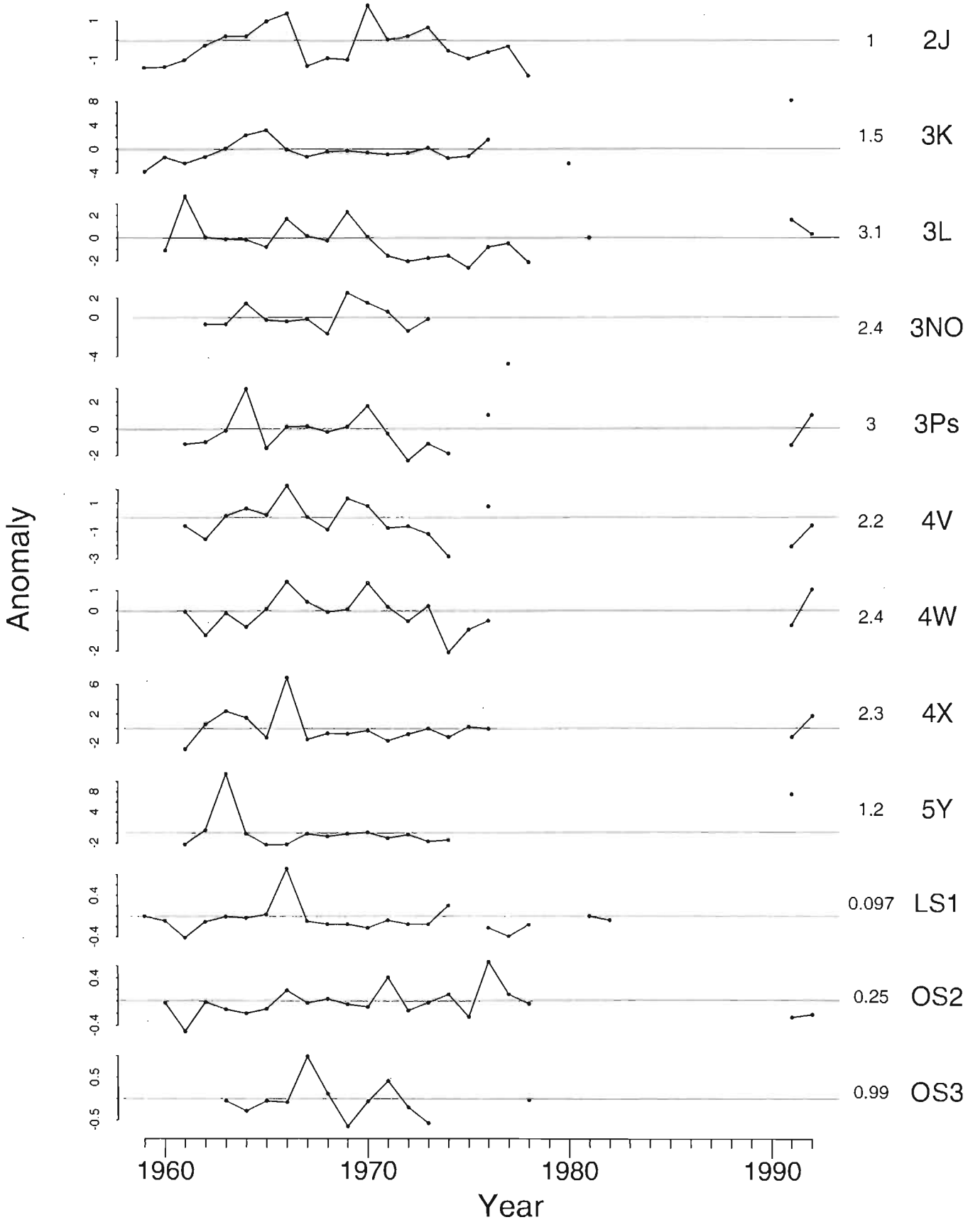
Ceratium arcticum



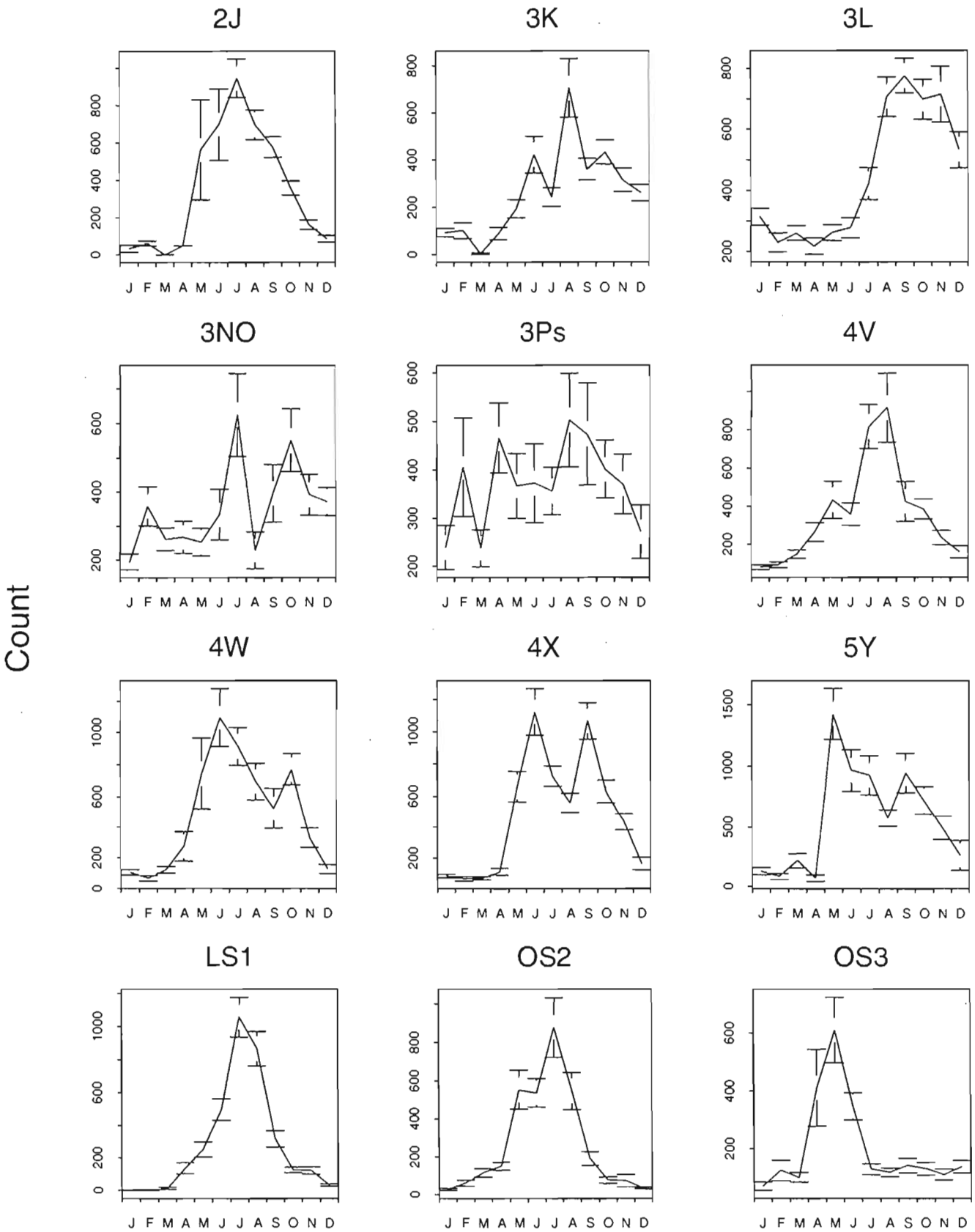
Ceratia


2J
3K
3L
3NO
3Ps
4V
4W
4X
5Y
LS1
OS2
OS3
J F M A M J J A S O N D
Count
Month

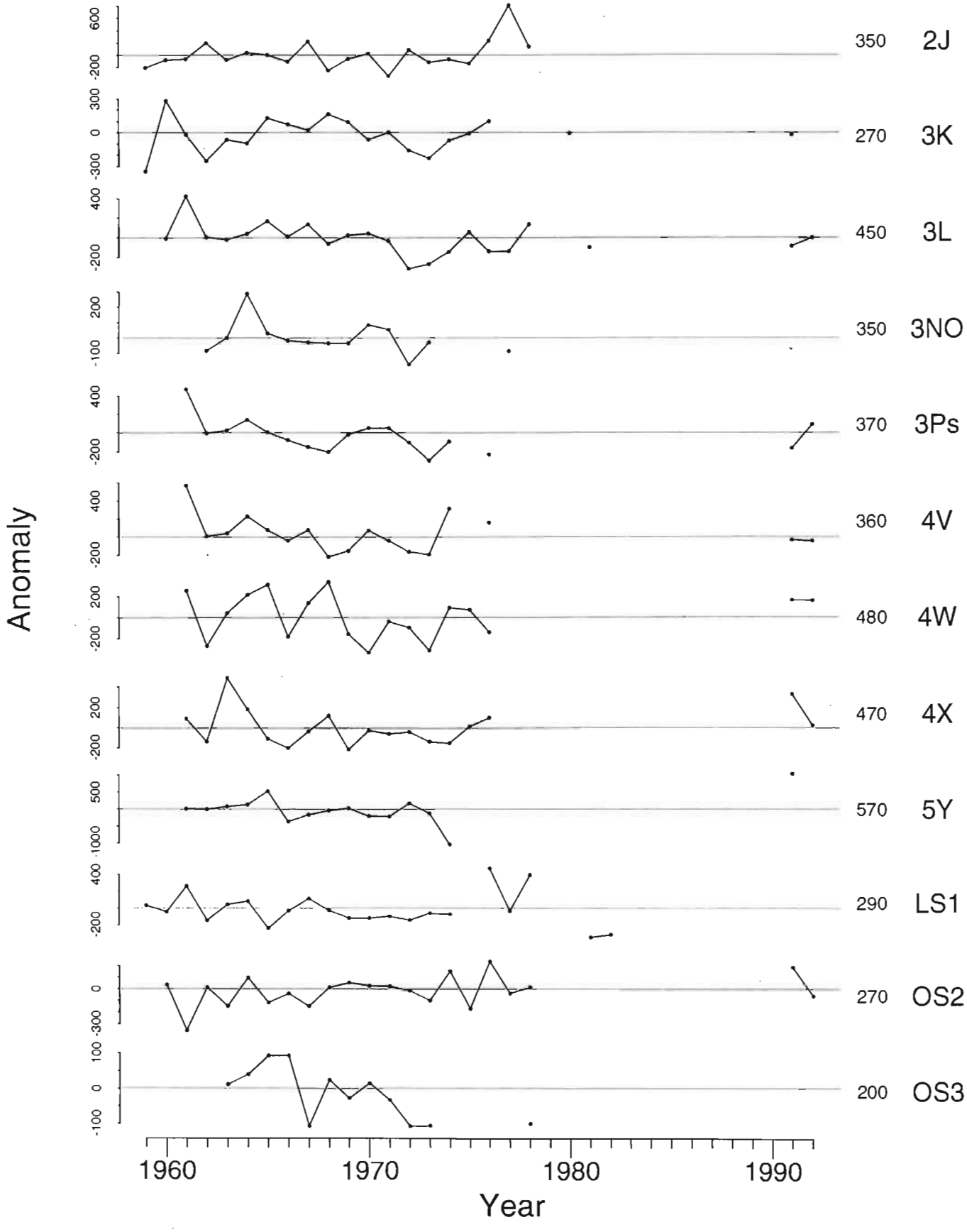
Ceratia


Anomaly
1
1.5
3.1
2.4
3
2.2
2.4
2.3
1.2
0.097
0.25
0.99
2J
3K
3L
3NO
3Ps
4V
4W
4X
5Y
LS1
OS2
OS3
1960
1970
1980
1990
Year

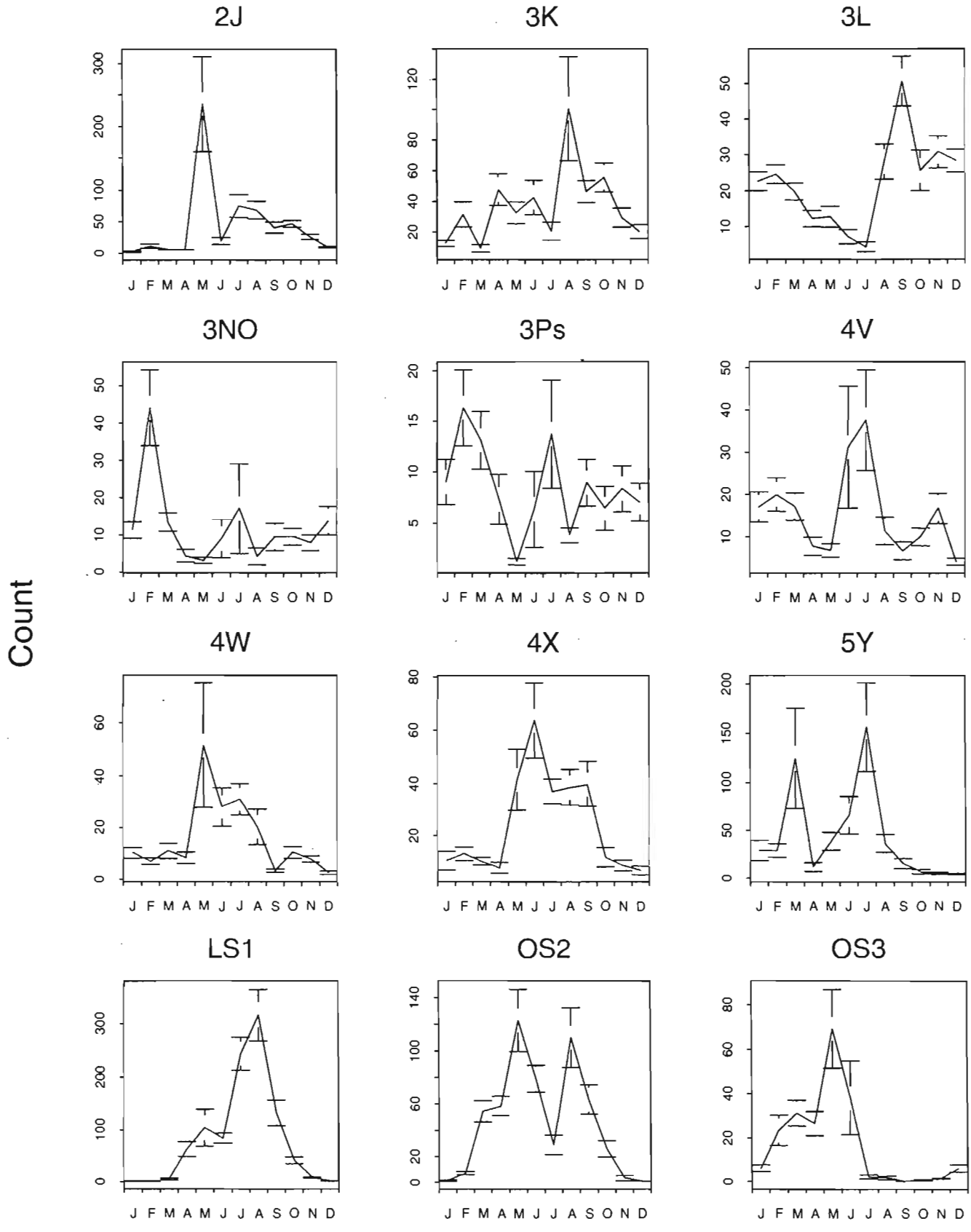
Total Copepods



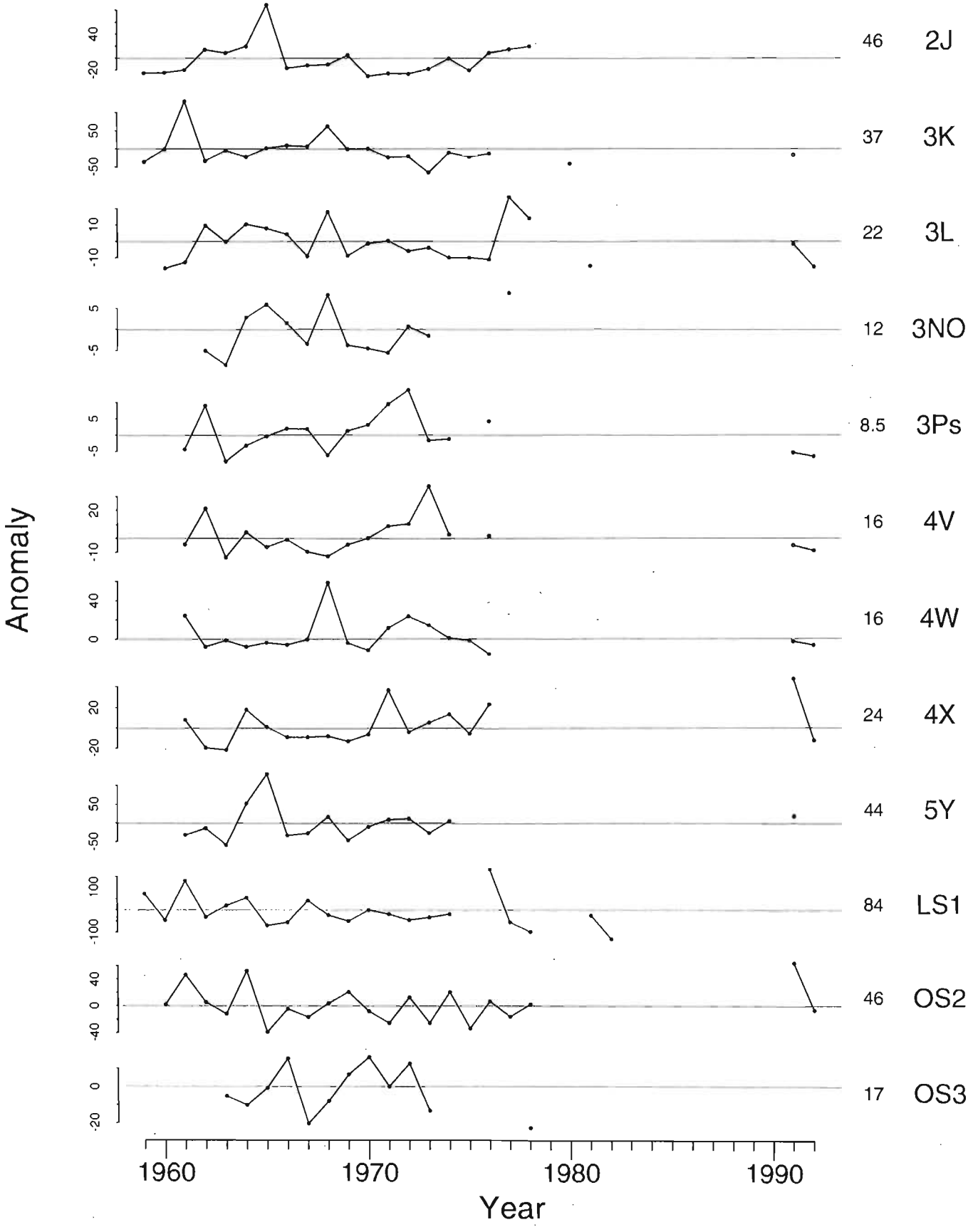
Total Copepods



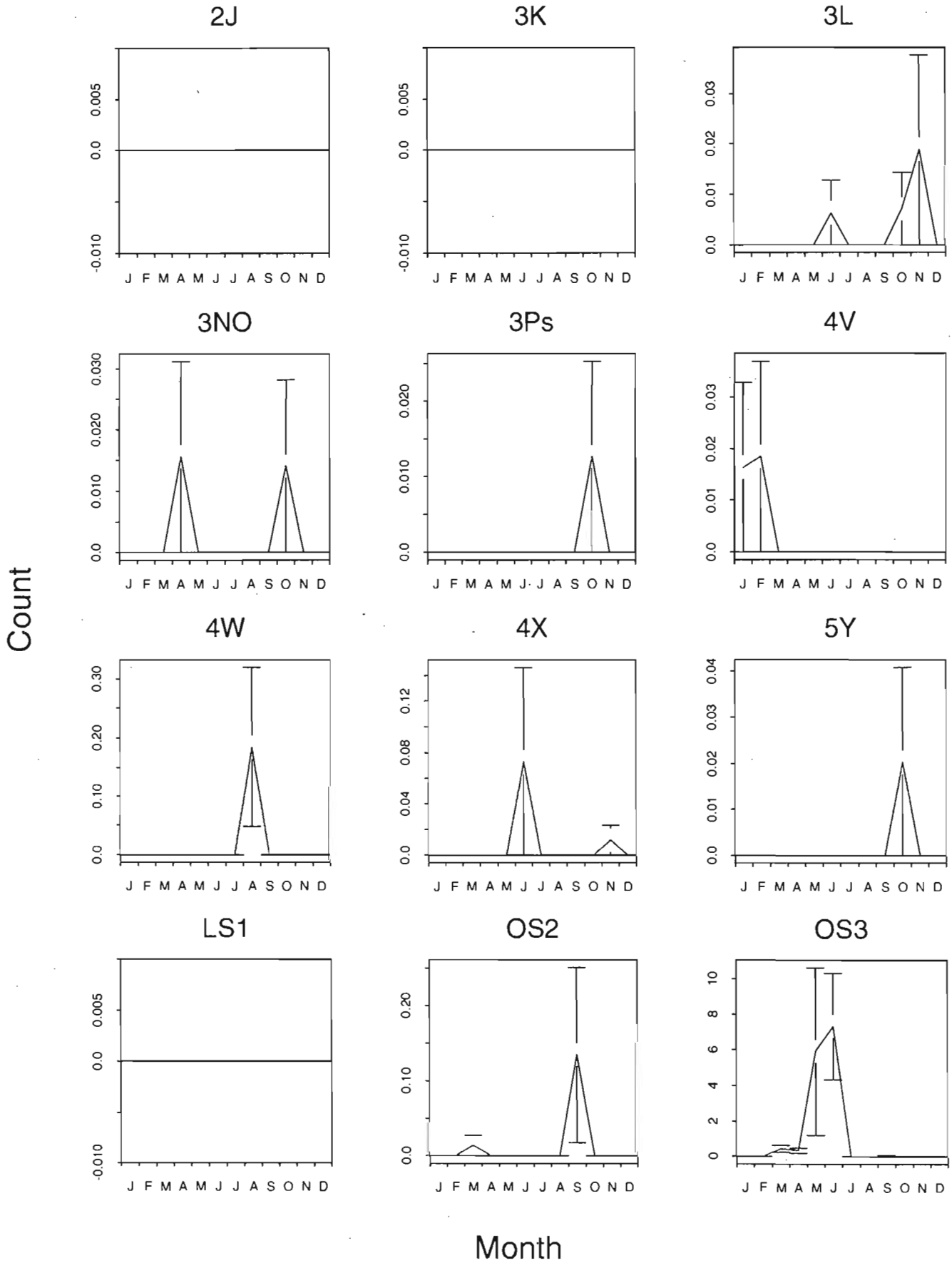
Calanus fin. finmarchicus



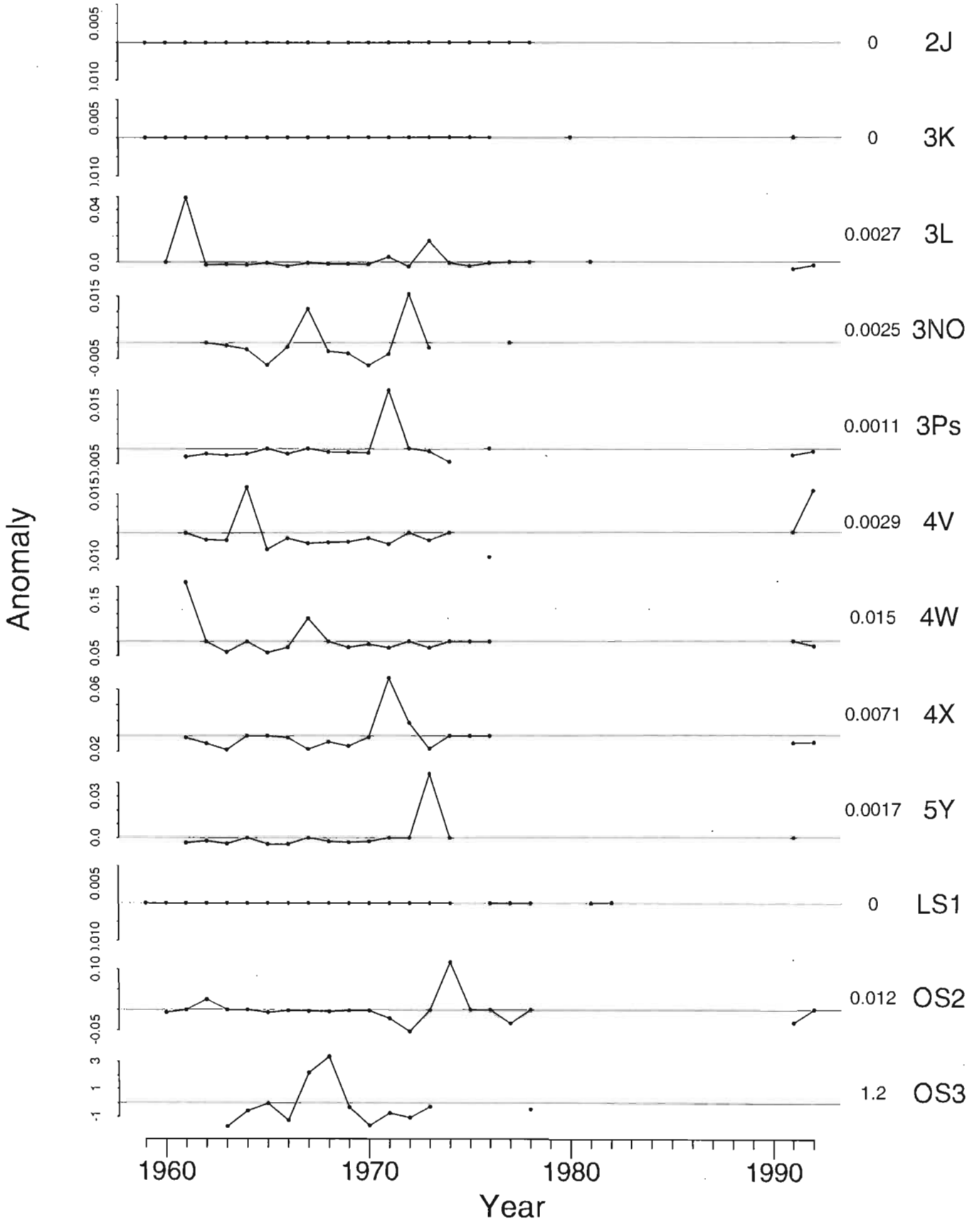
Calanus fin. finmarchicus



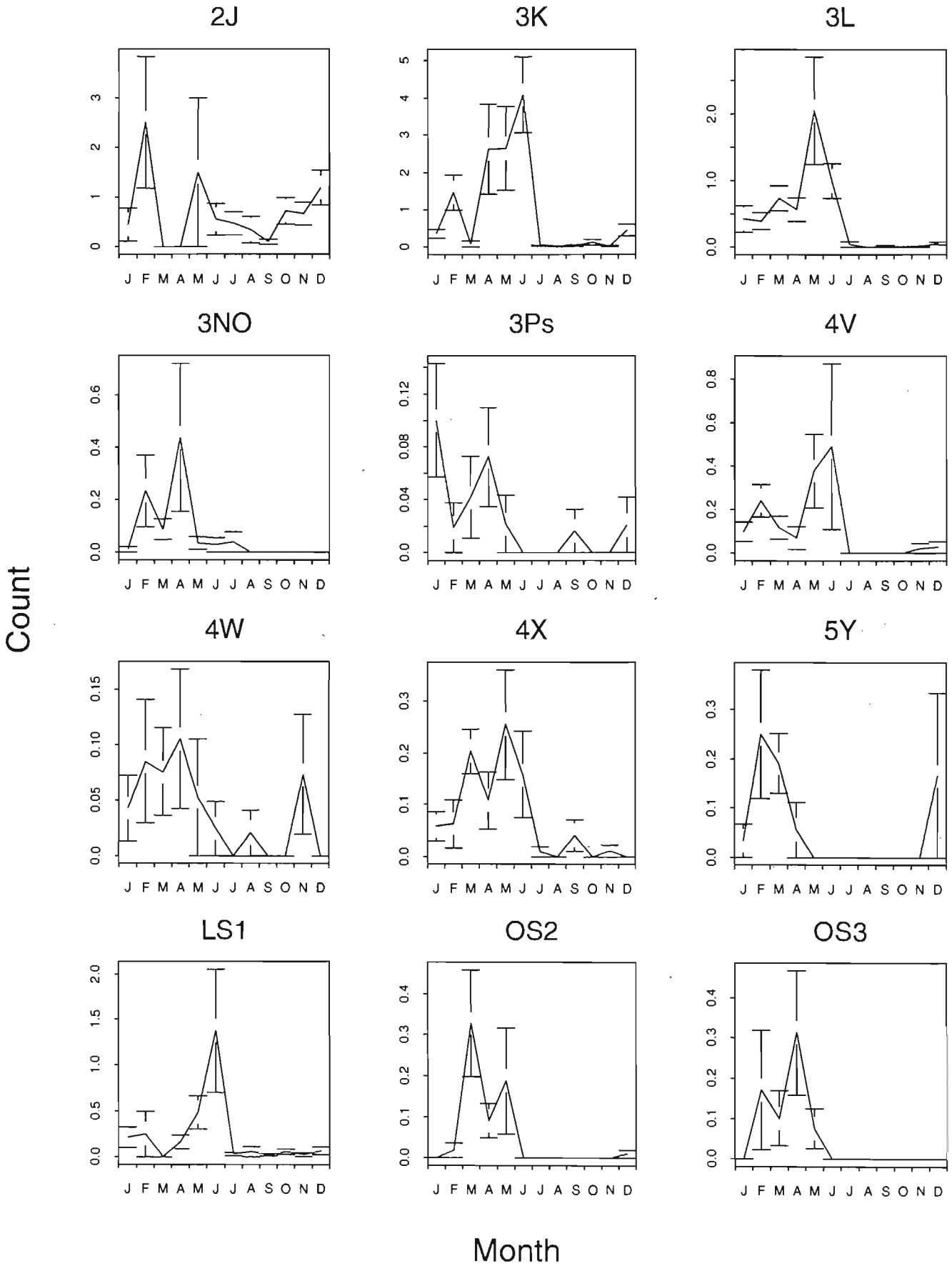
Calanus helgolandicus



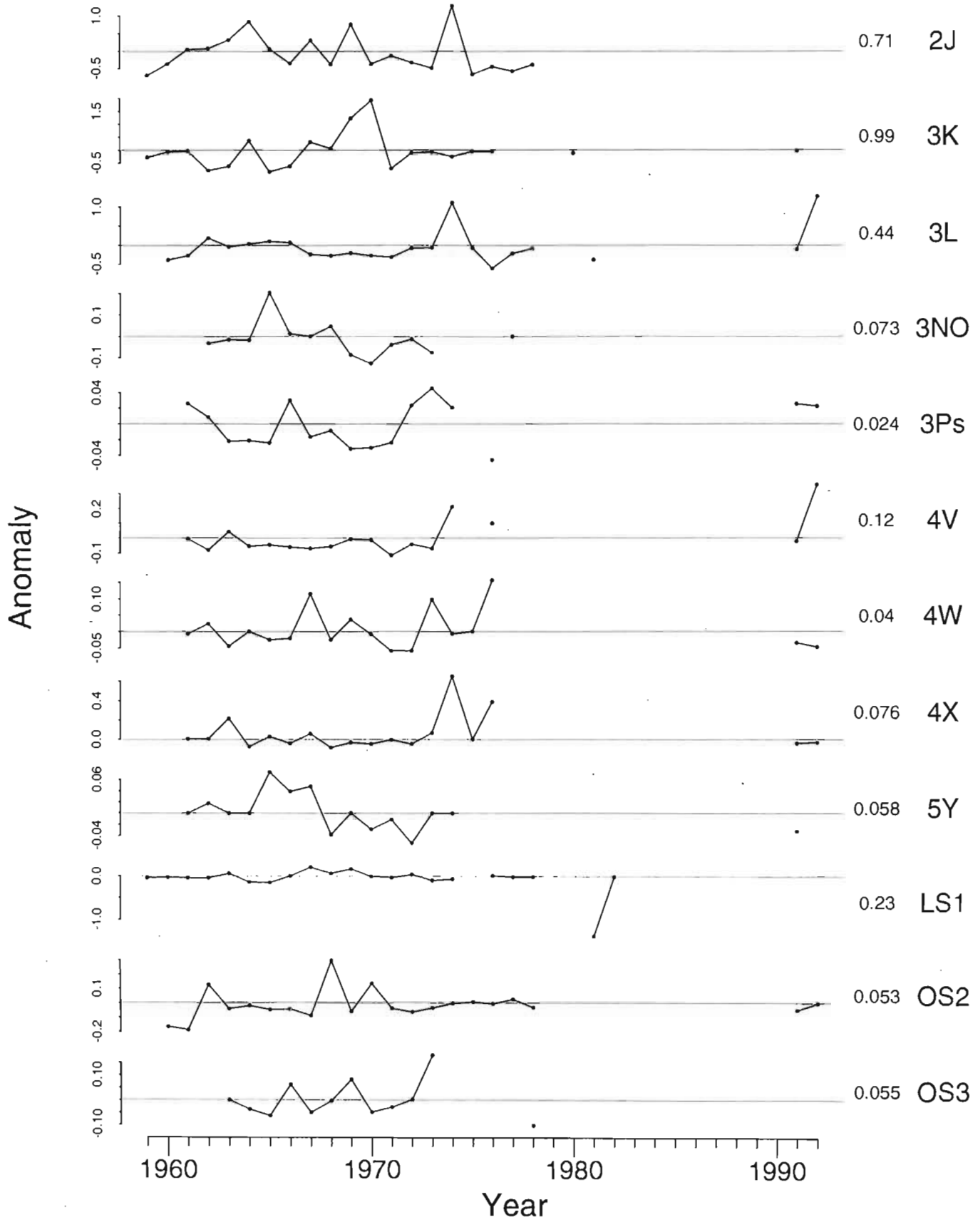
Calanus helgolandicus



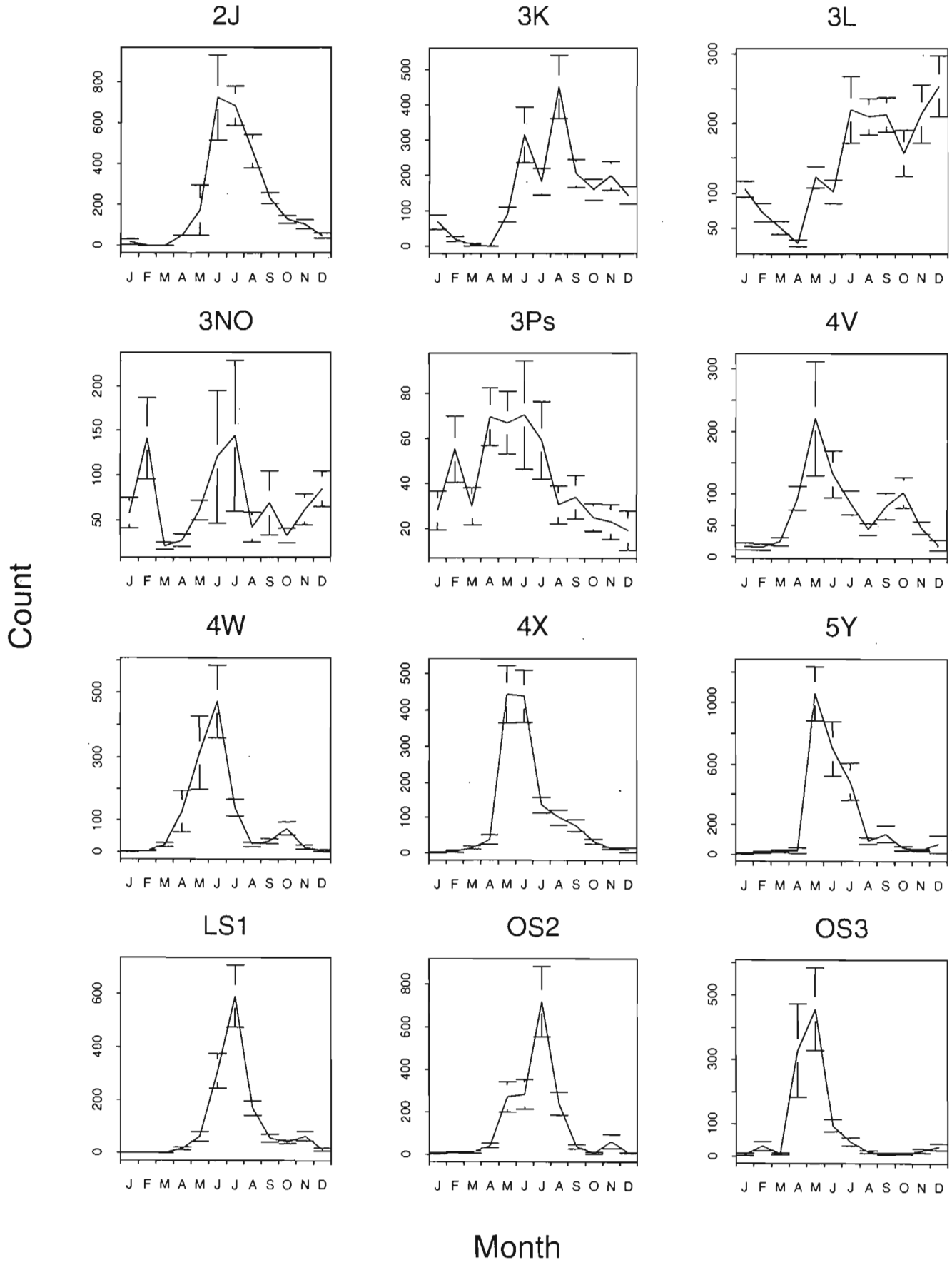
Calanus fin. glacialis



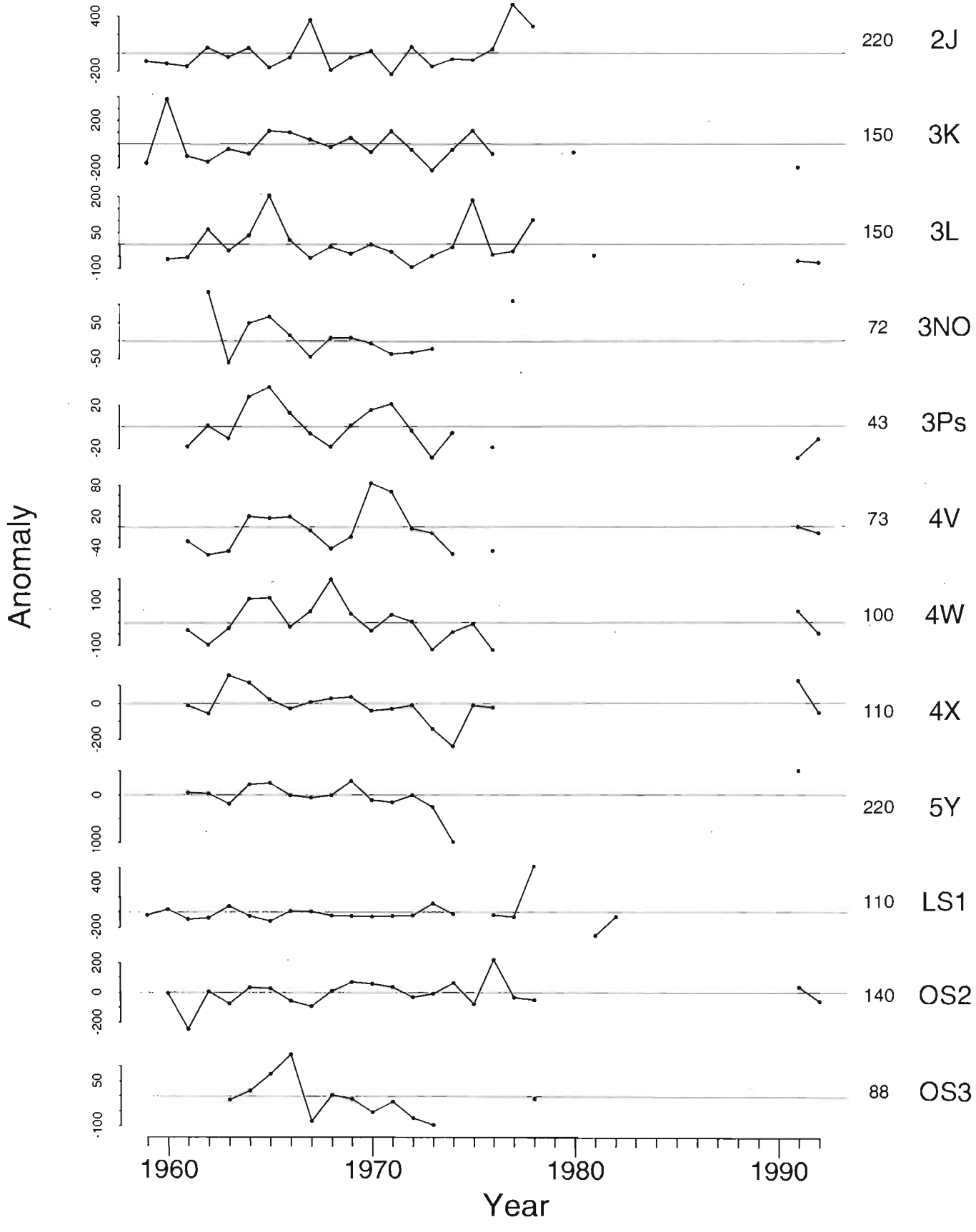
Calanus fin. glacialis



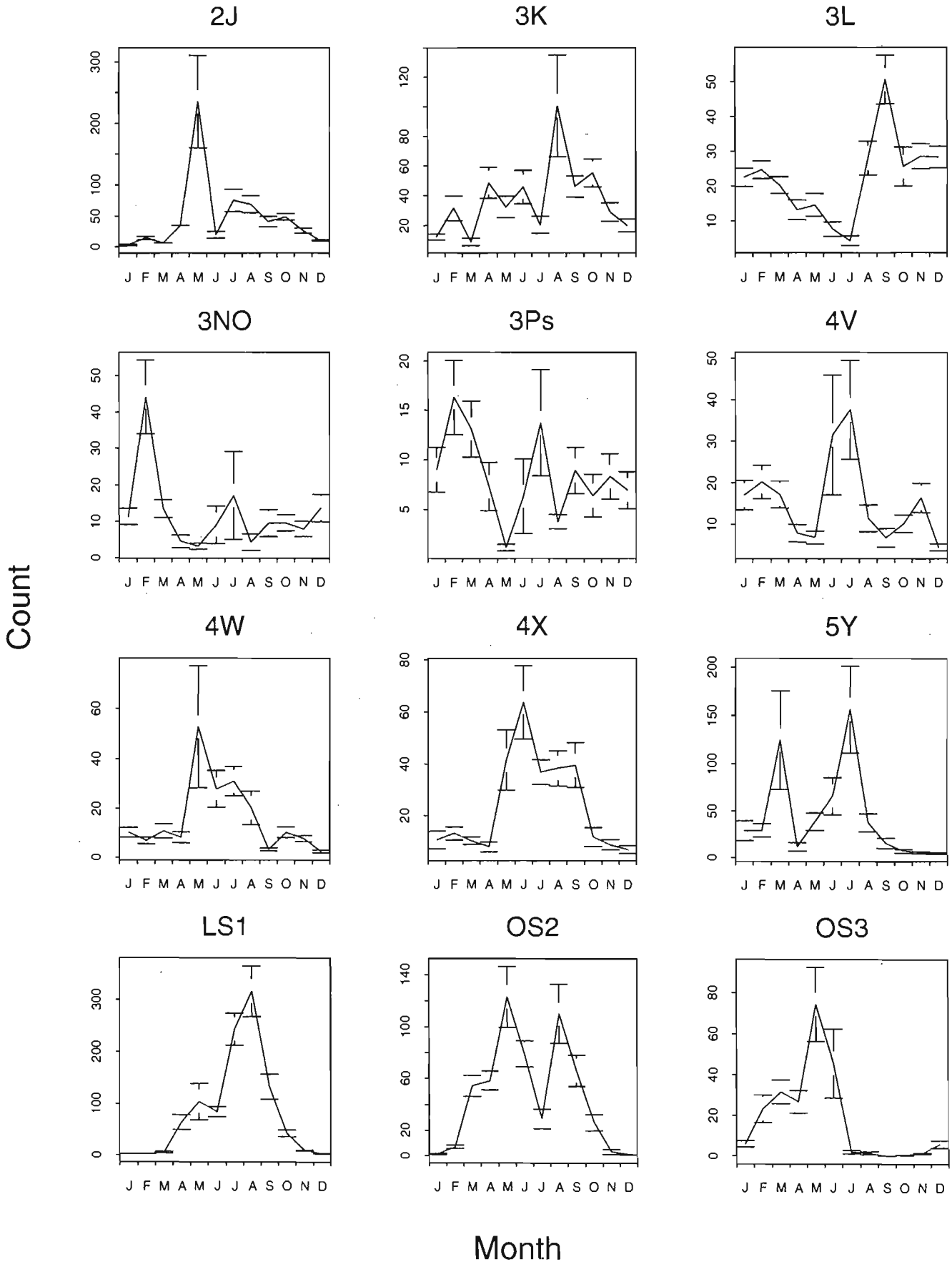
Calanus I-IV


2J
3K
3L
3NO
3Ps
4V
4W
4X
5Y
LS1
OS2
OS3
J F M A M J J A S O N D
Count
Month

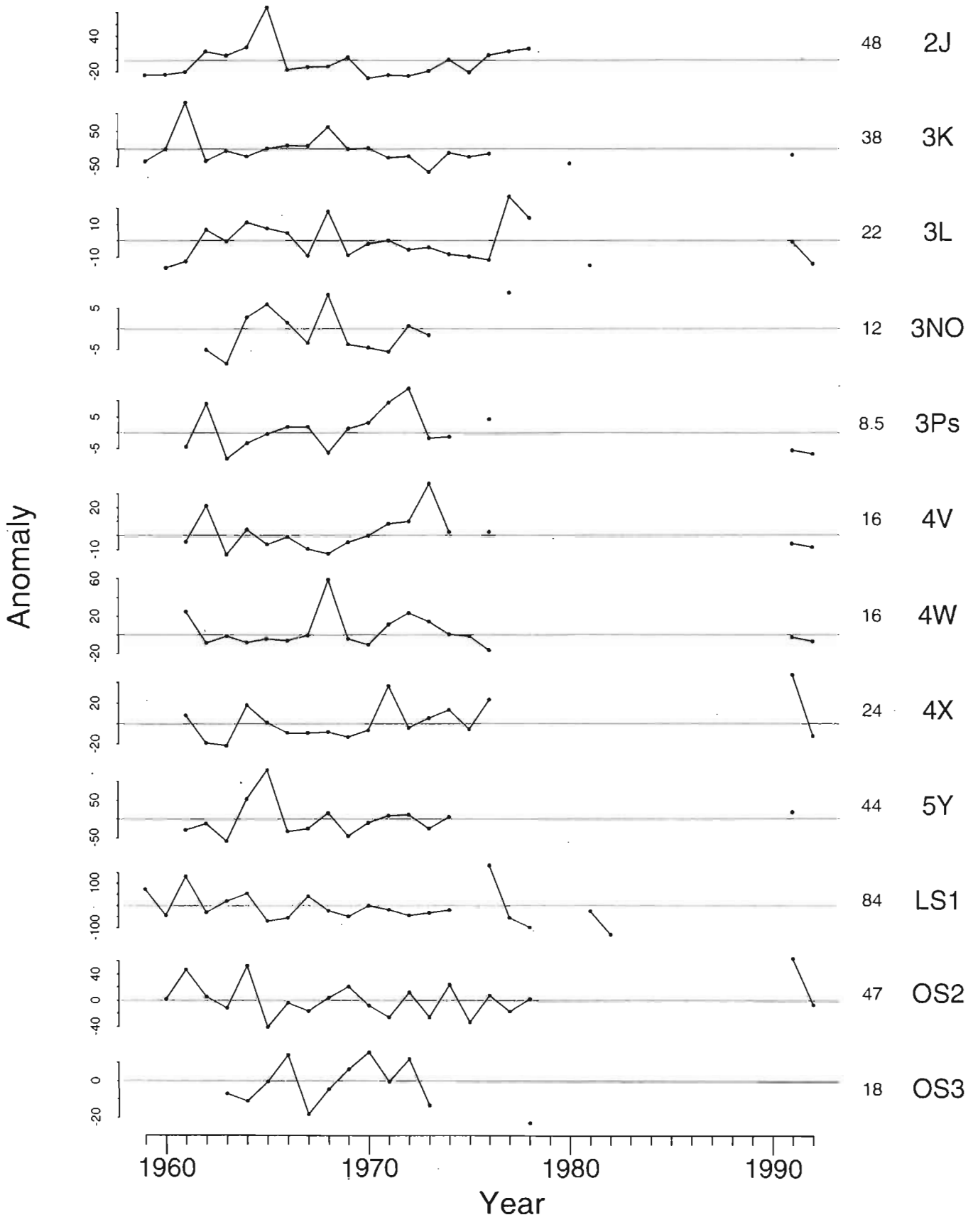
Calanus I-IV


Anomaly
400
-200
220
2J
200
-200
150
3K
200
50
-100
150
3L
50
-50
72
3NO
20
-20
43
3Ps
80
20
-40
73
4V
100
-100
100
4W
0
-200
110
4X
0
1000
220
5Y
400
-200
110
LS1
200
0
-200
140
OS2
50
-100
88
OS3
1960
1970
1980
1990
Year

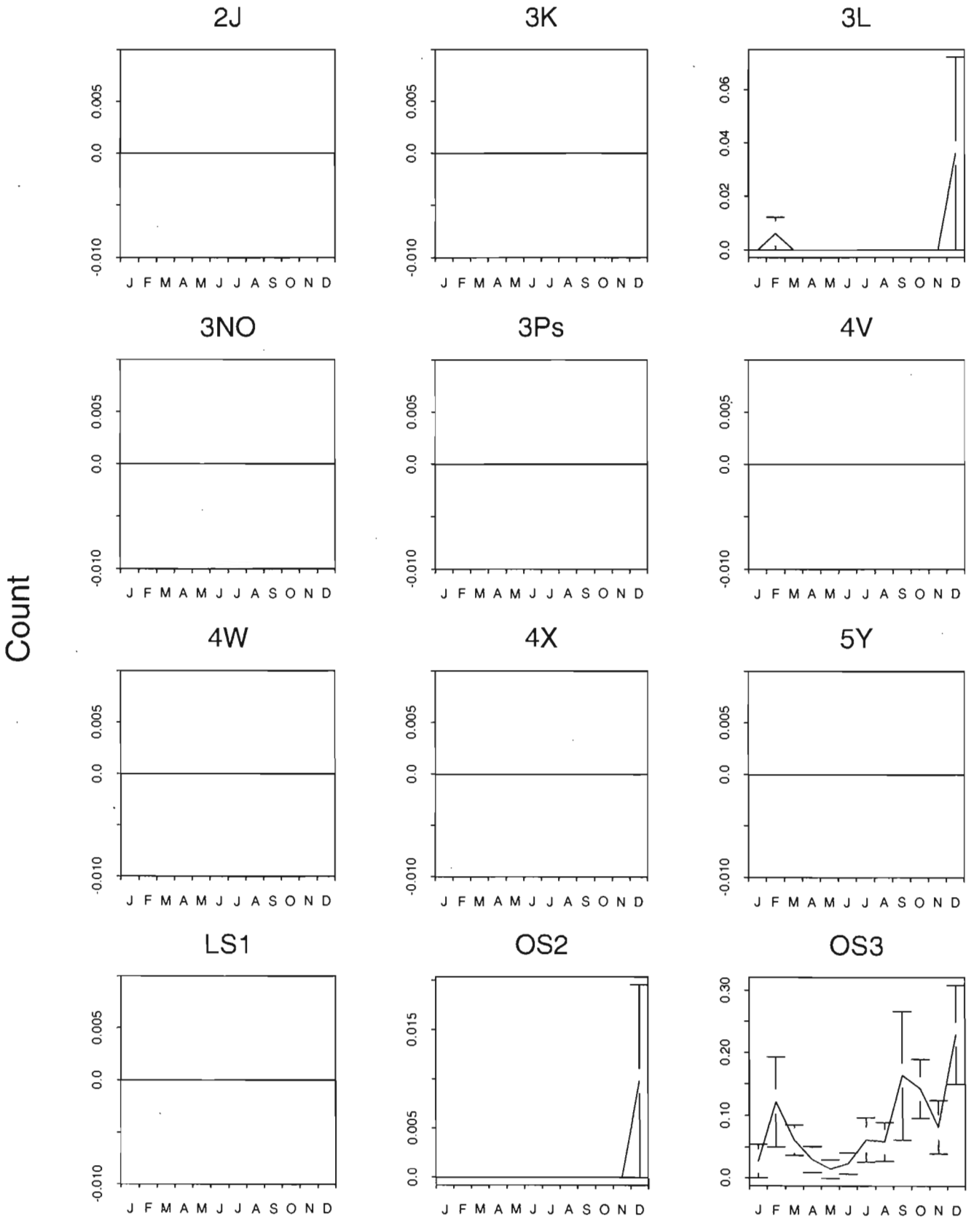
Calanus V-VI Total



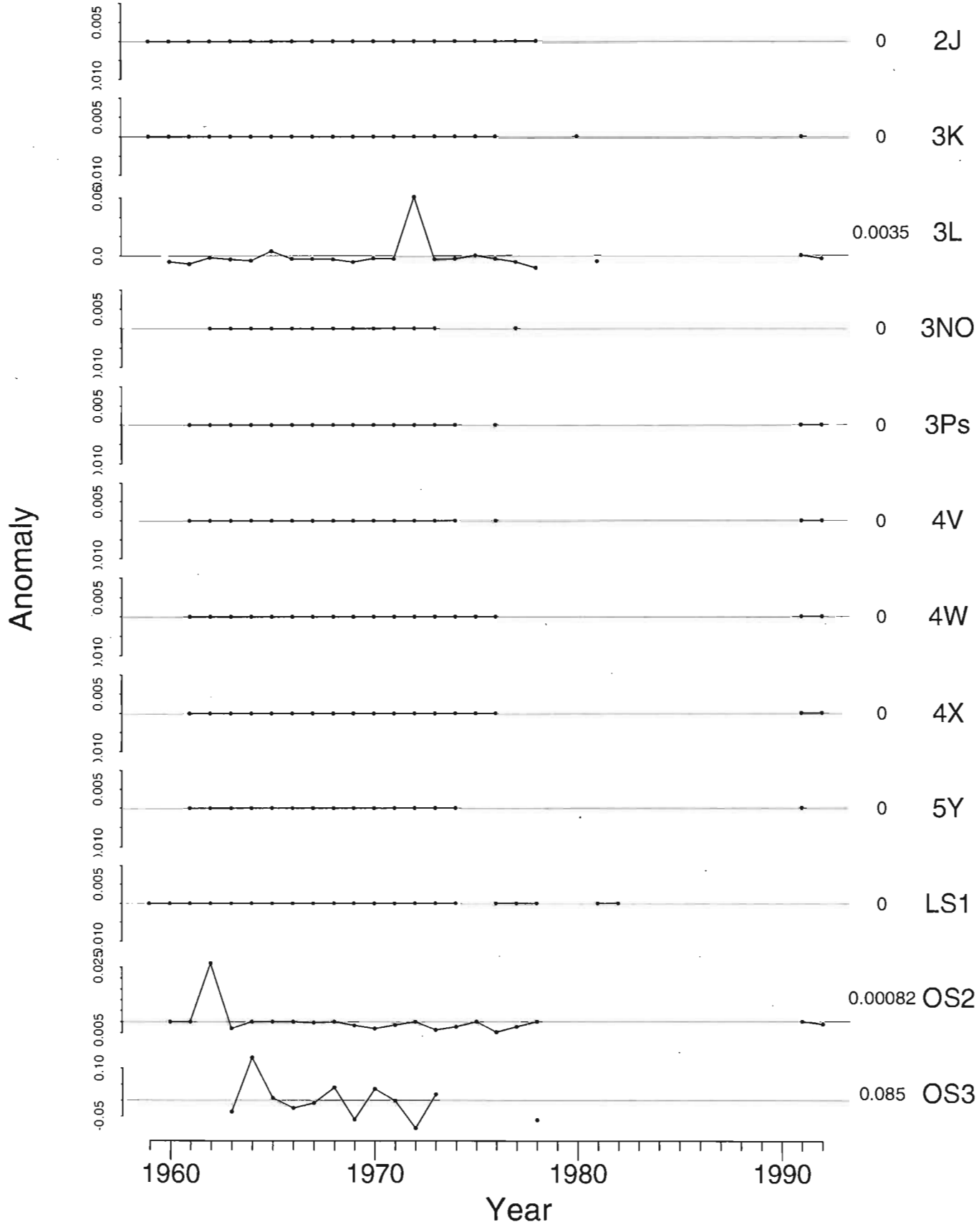
Calanus V-VI Total



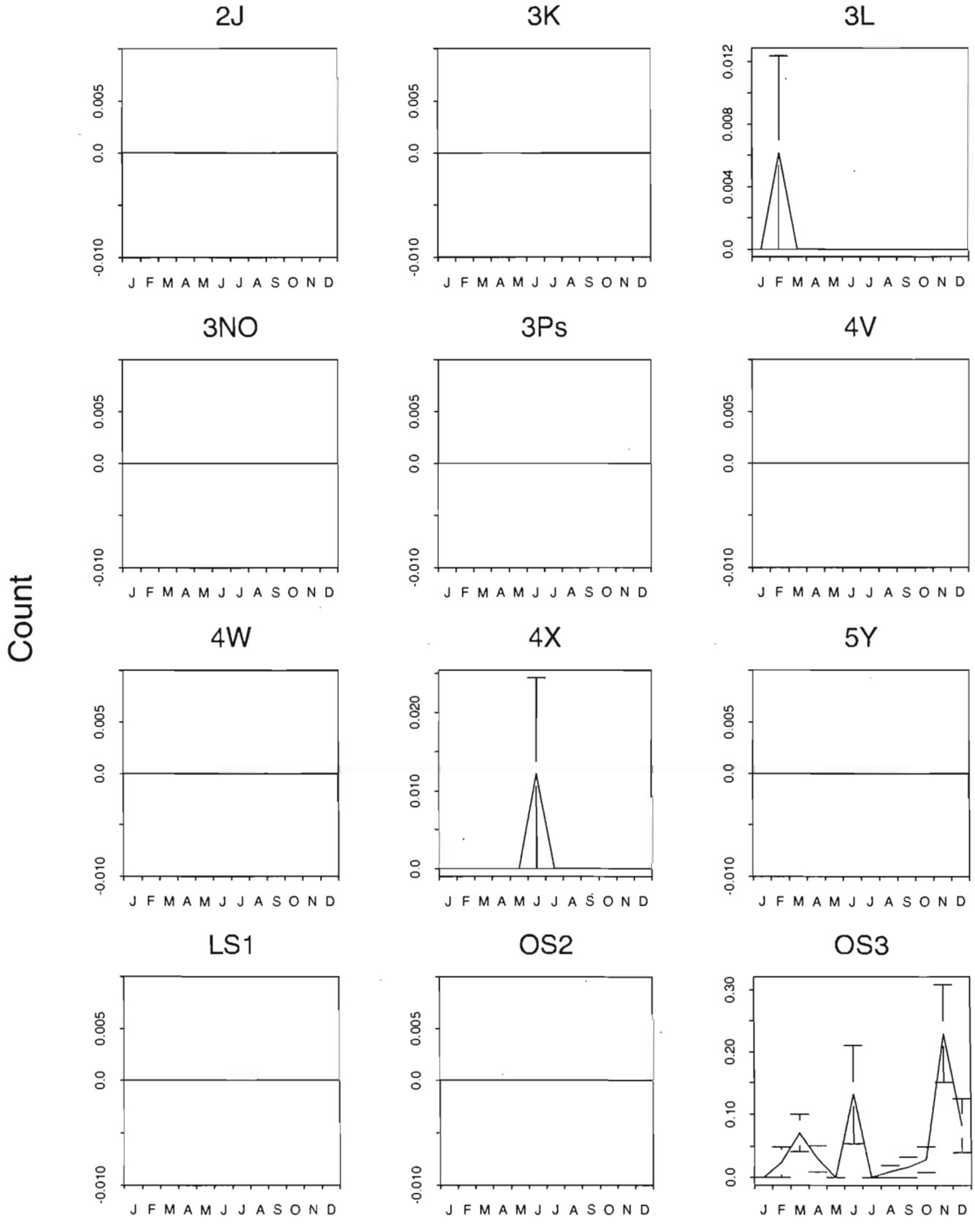
Neocalanus gracilis



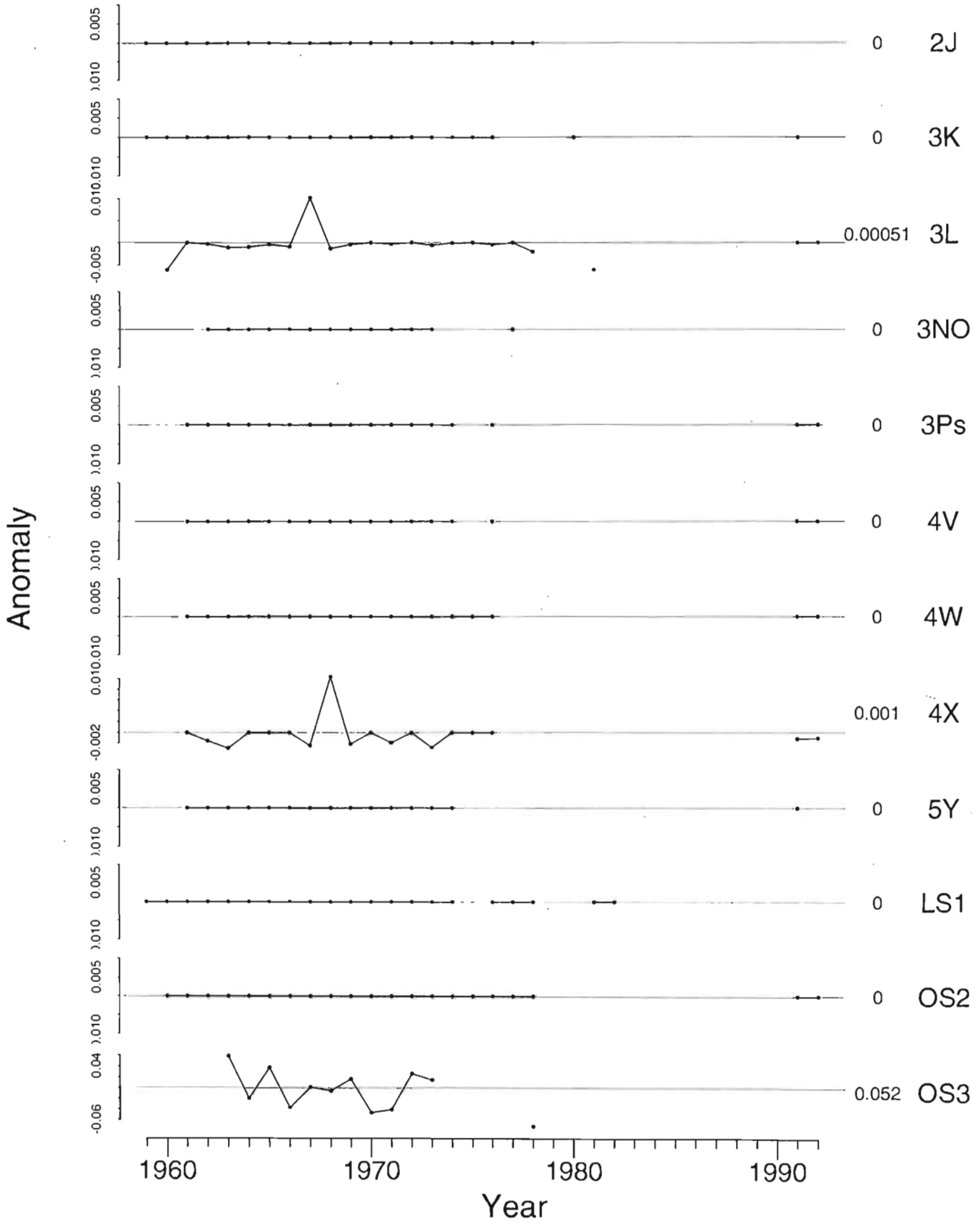
Neocalanus gracilis



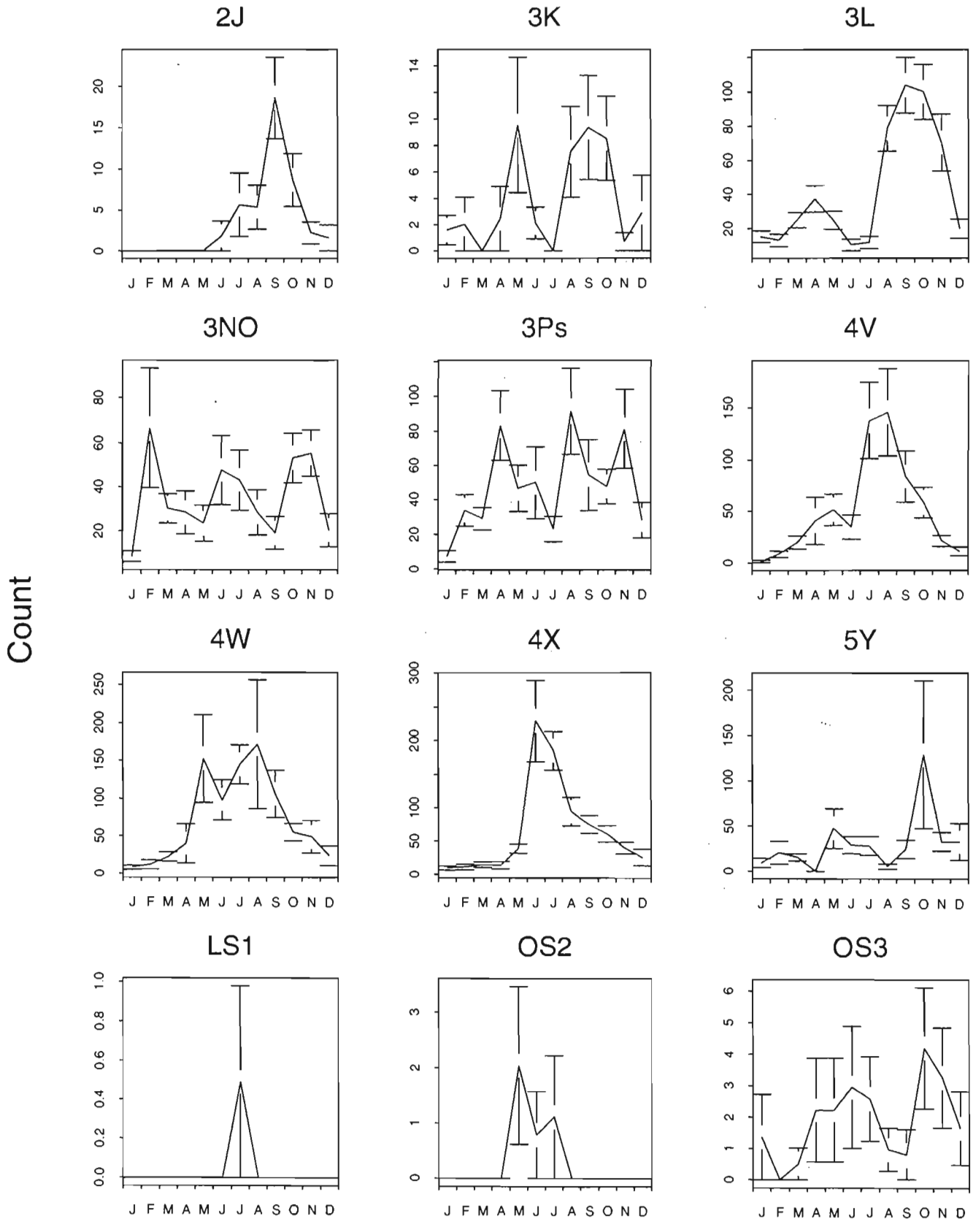
Rhincalanus nasutus



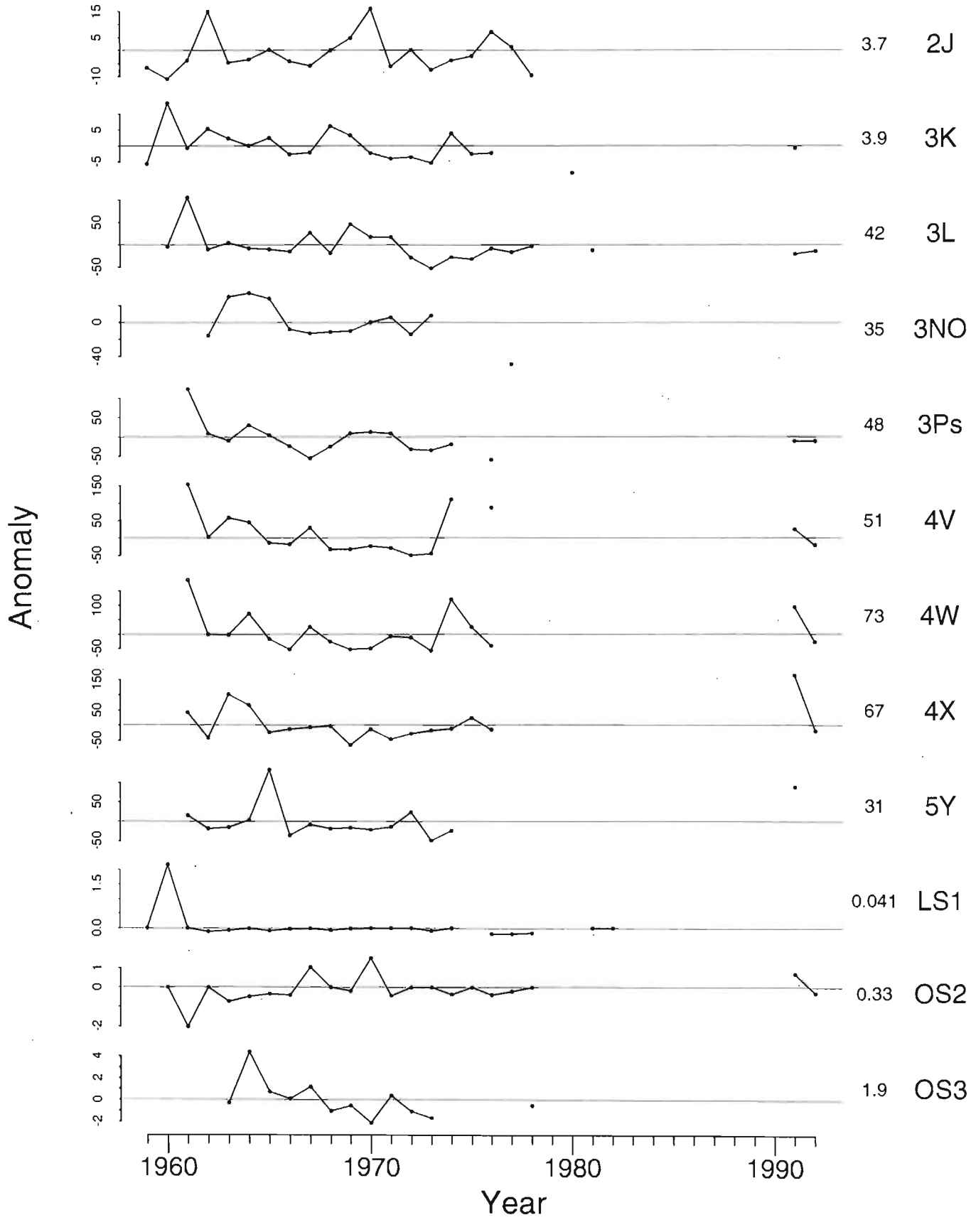
Rhincalanus nasutus



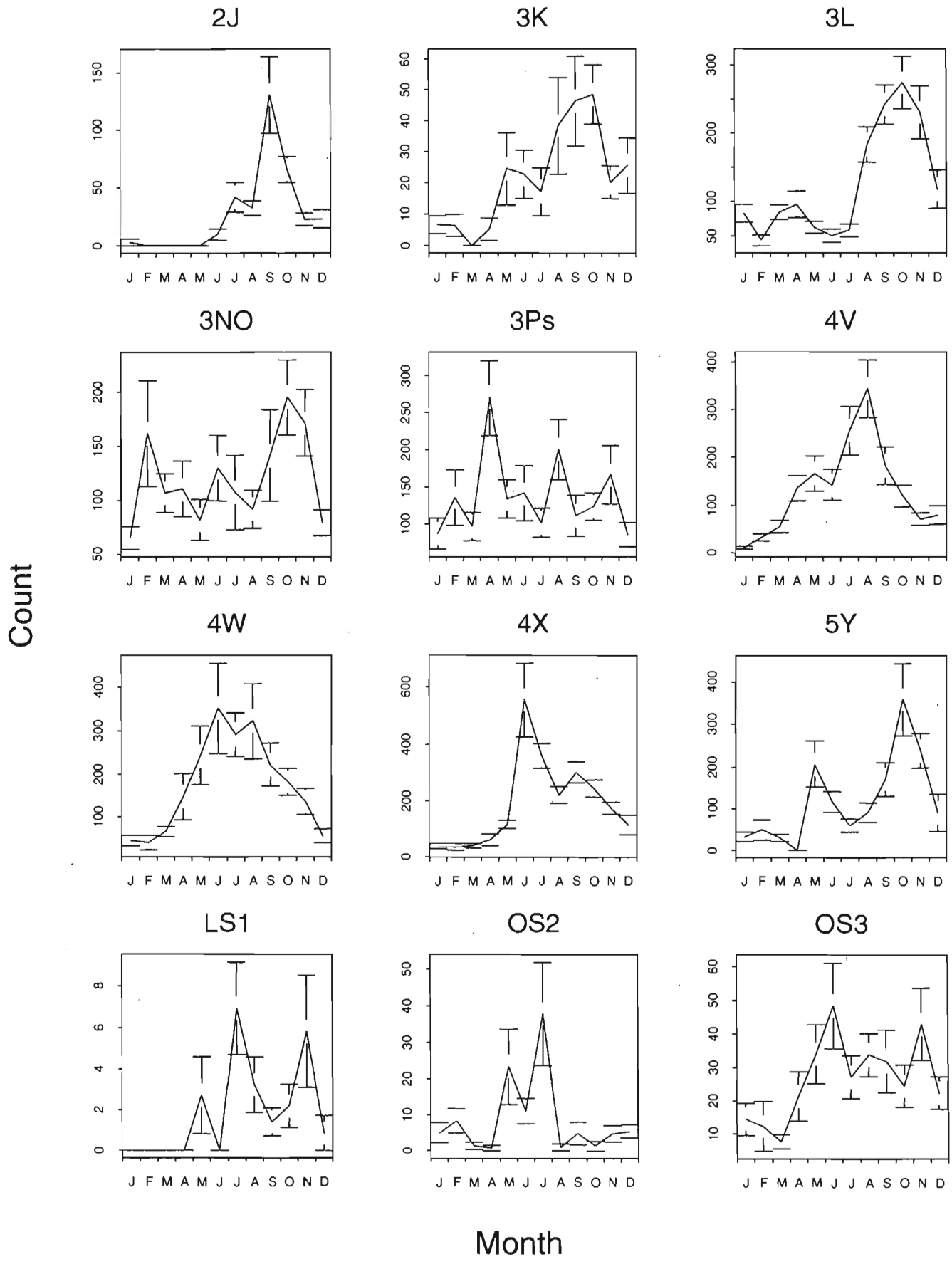
Pseudocalanus elongatus Adult



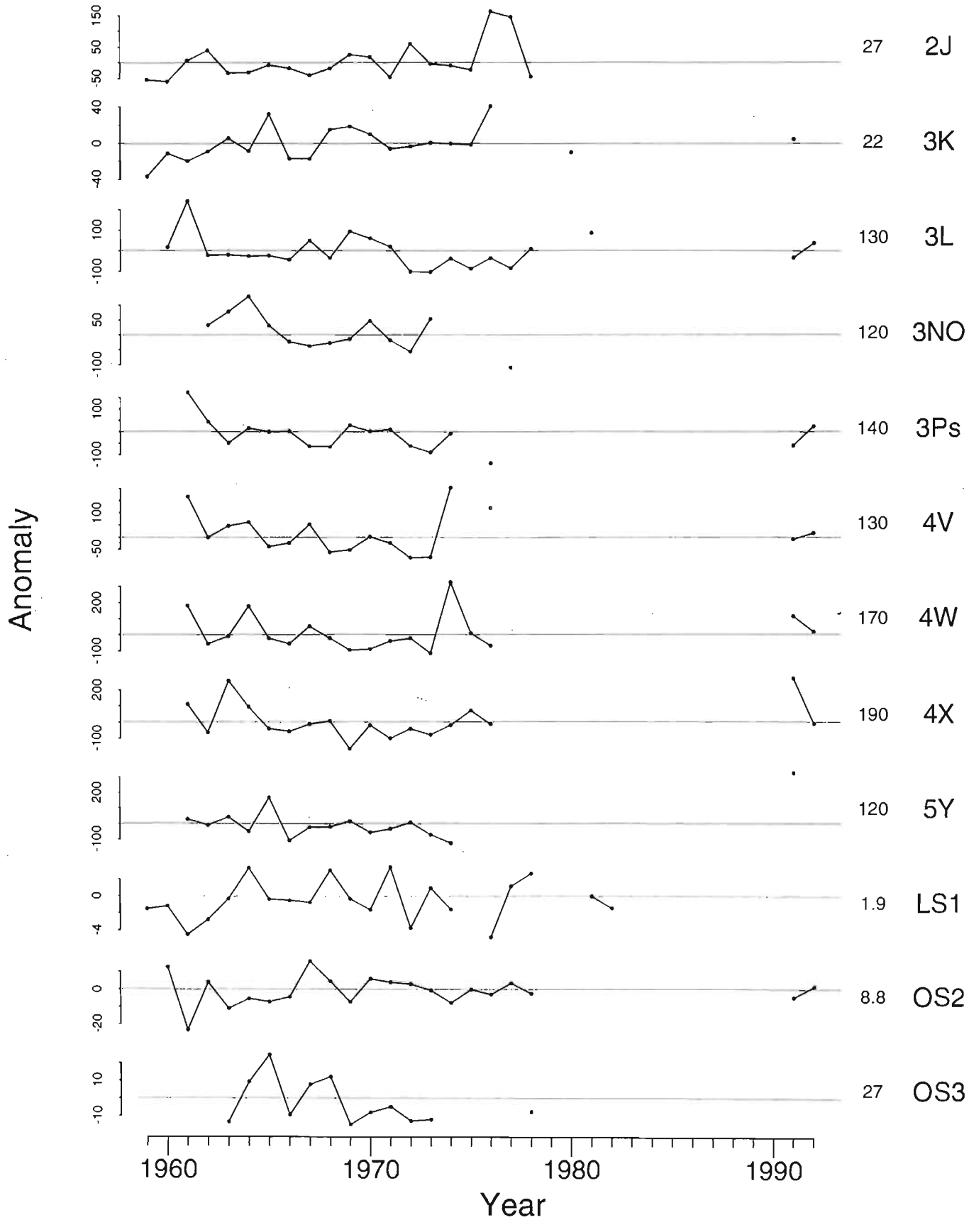
Pseudocalanus elongatus Adult



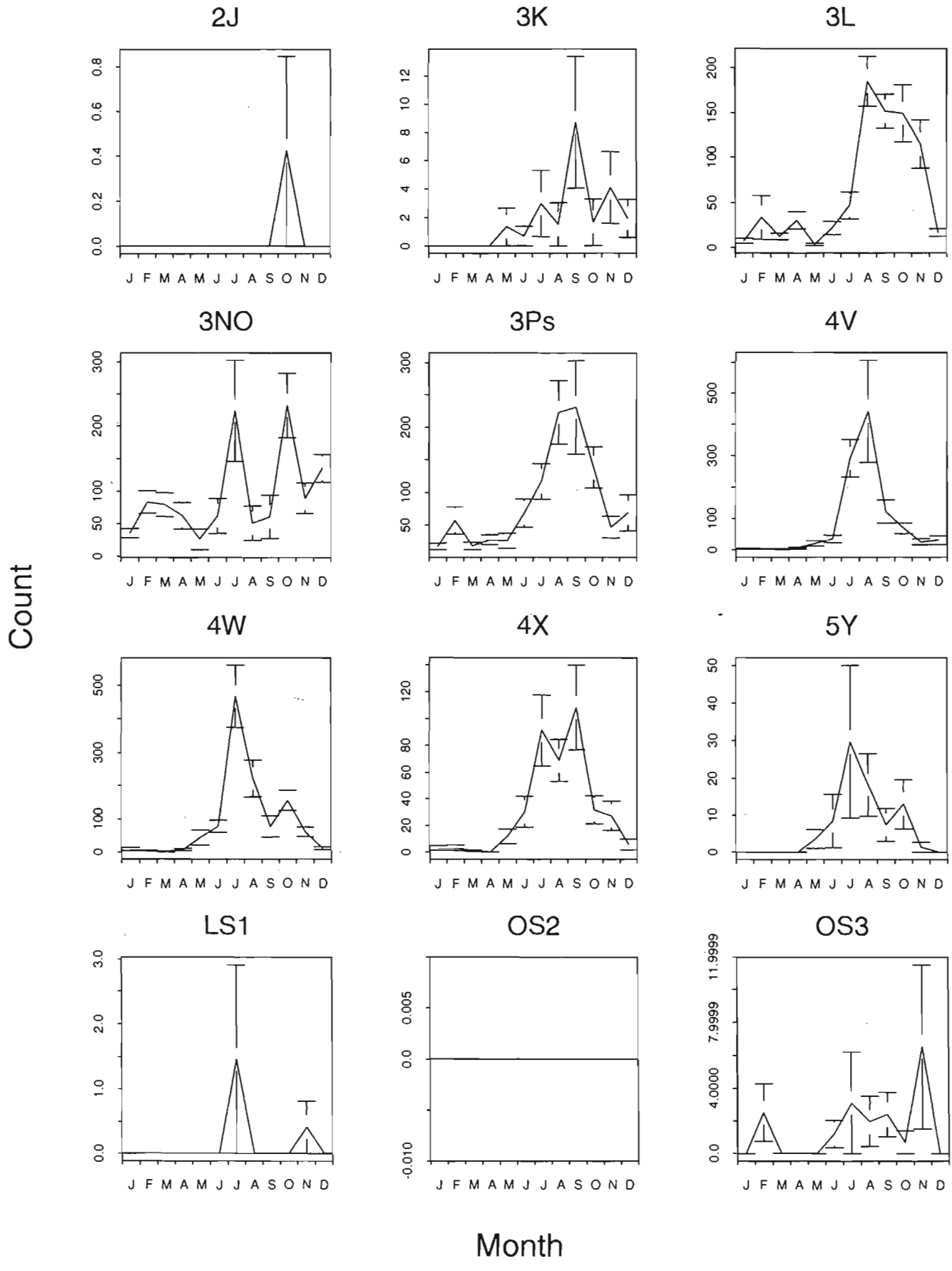
Para-pseudocalanus spp.



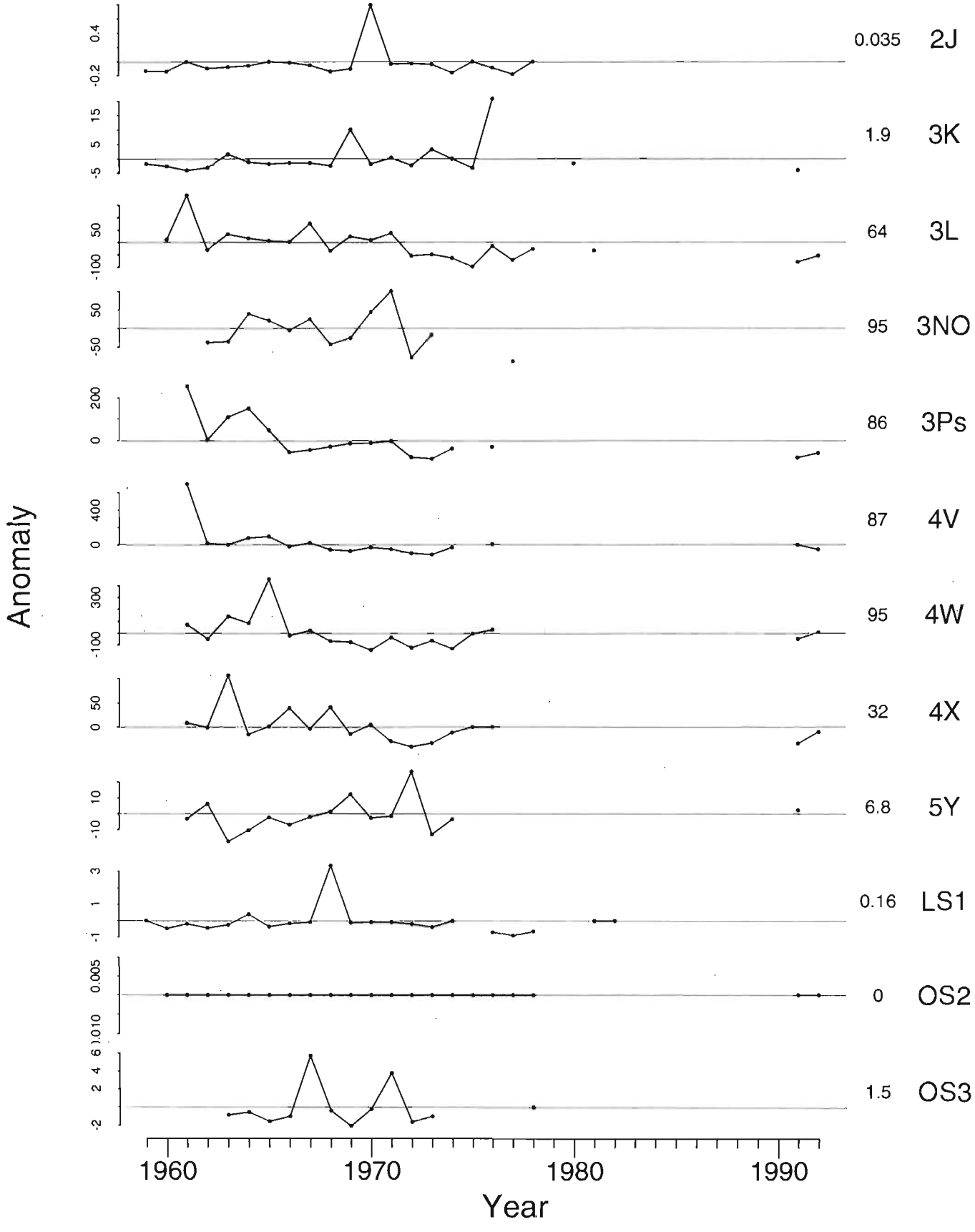
Para-pseudocalanus spp.



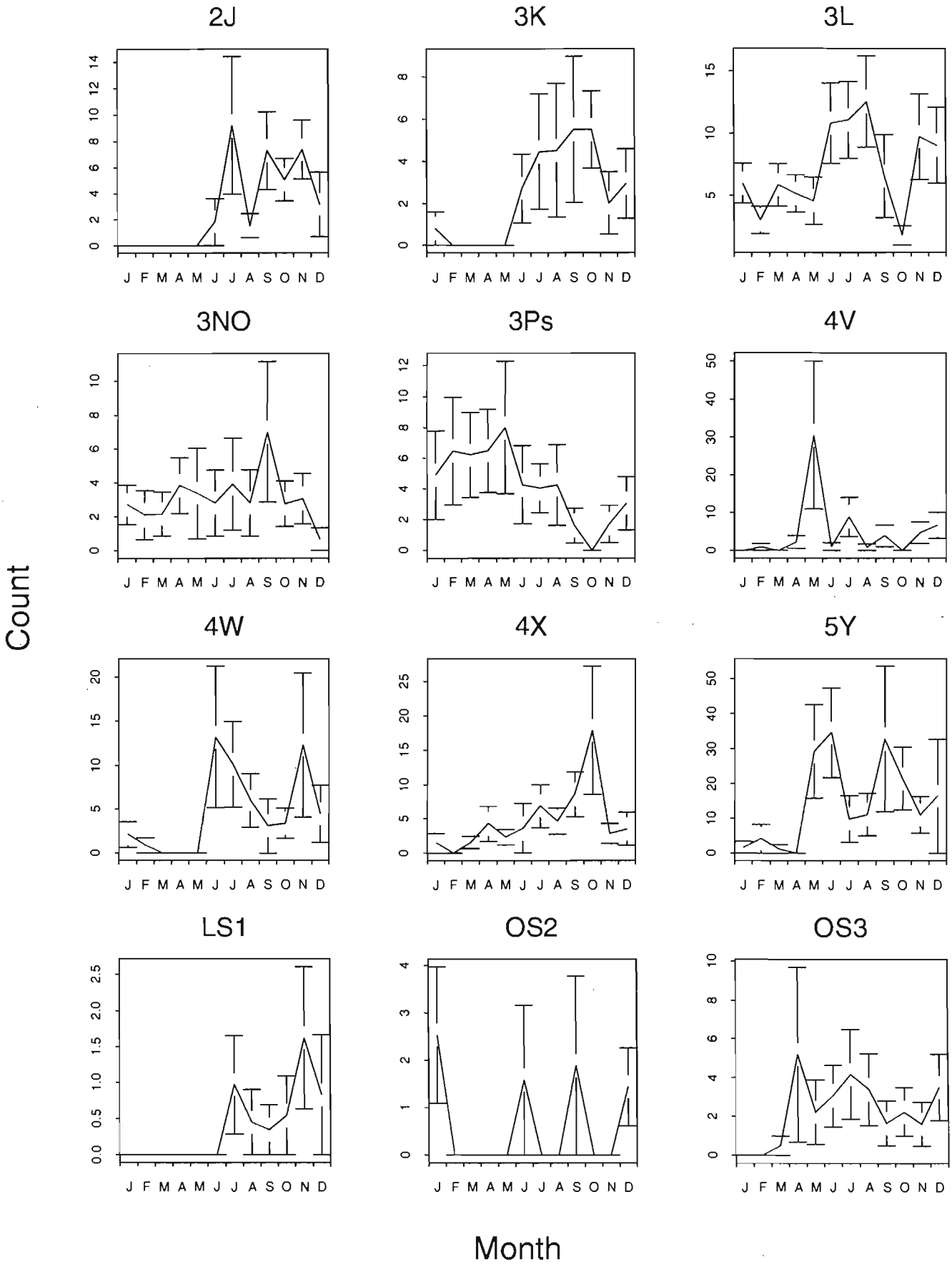
Temora longicornis



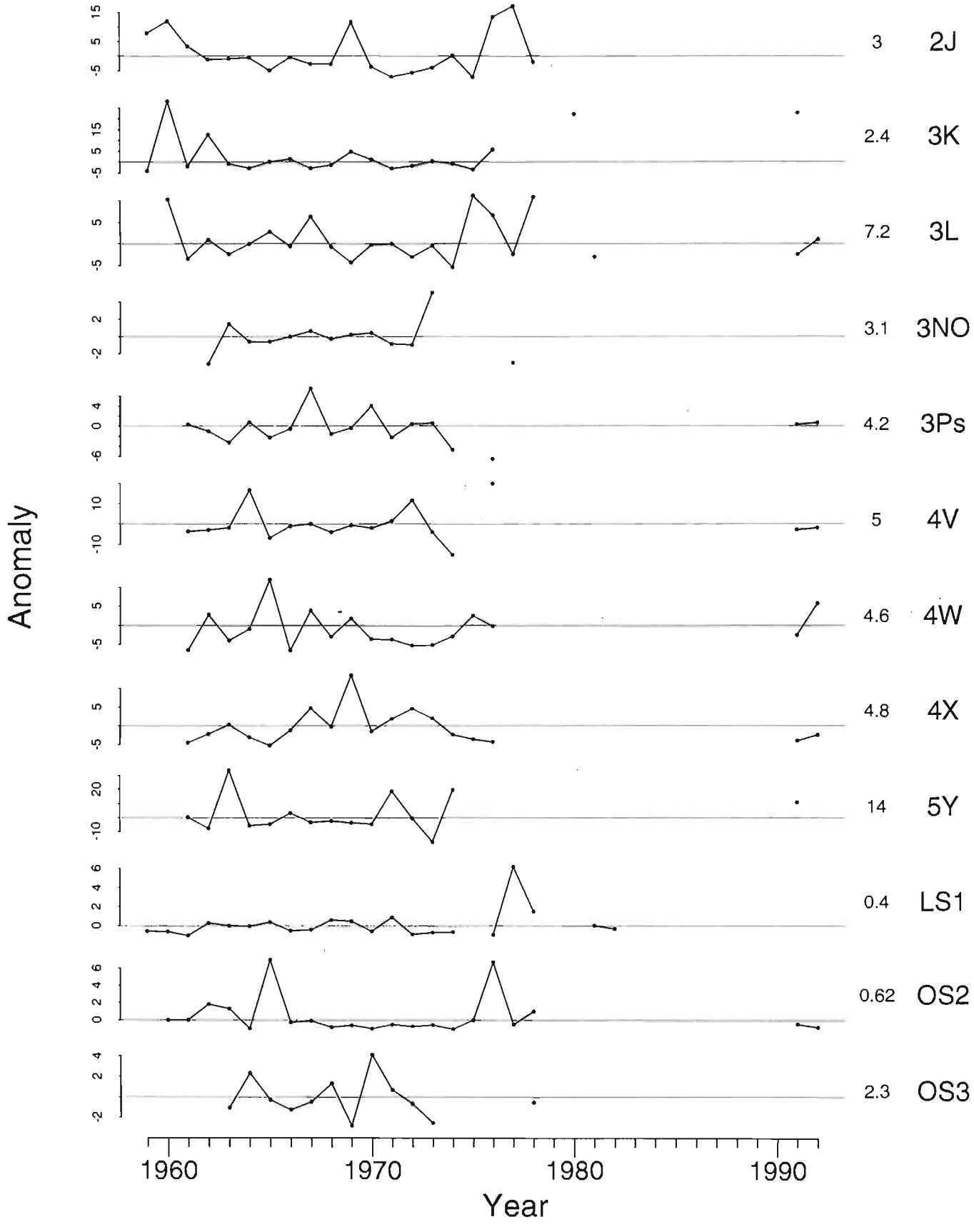
Temora longicornis



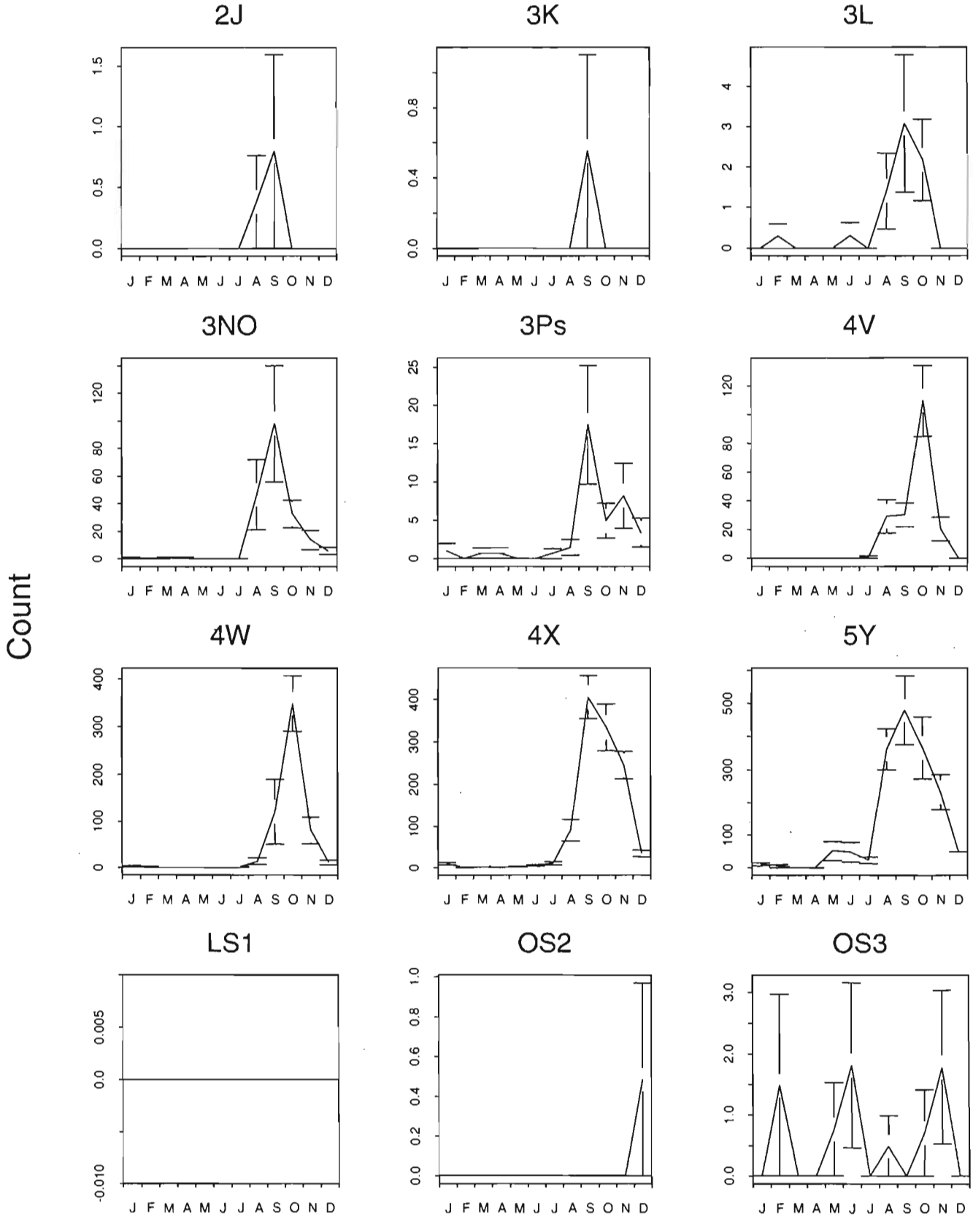
Acartia spp.


2J
3K
3L
3NO
3Ps
4V
4W
4X
5Y
LS1
OS2
OS3
J F M A M J J A S O N D
Count
Month

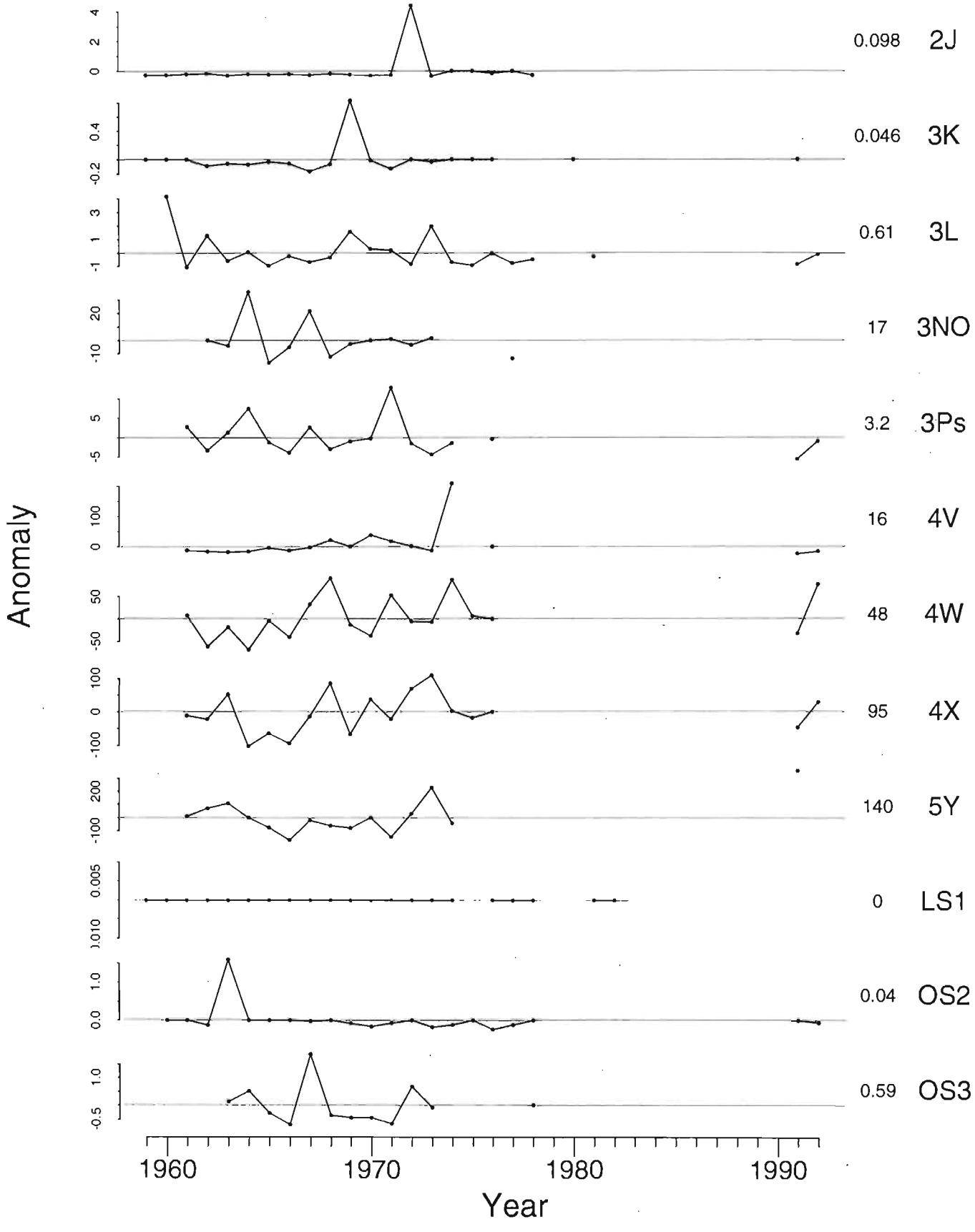
Acartia spp.


Anomaly
3 2J
2.4 3K
7.2 3L
3.1 3NO
4.2 3Ps
5 4V
4.6 4W
4.8 4X
14 5Y
0.4 LS1
0.62 OS2
2.3 OS3
1960
1970
1980
1990
Year

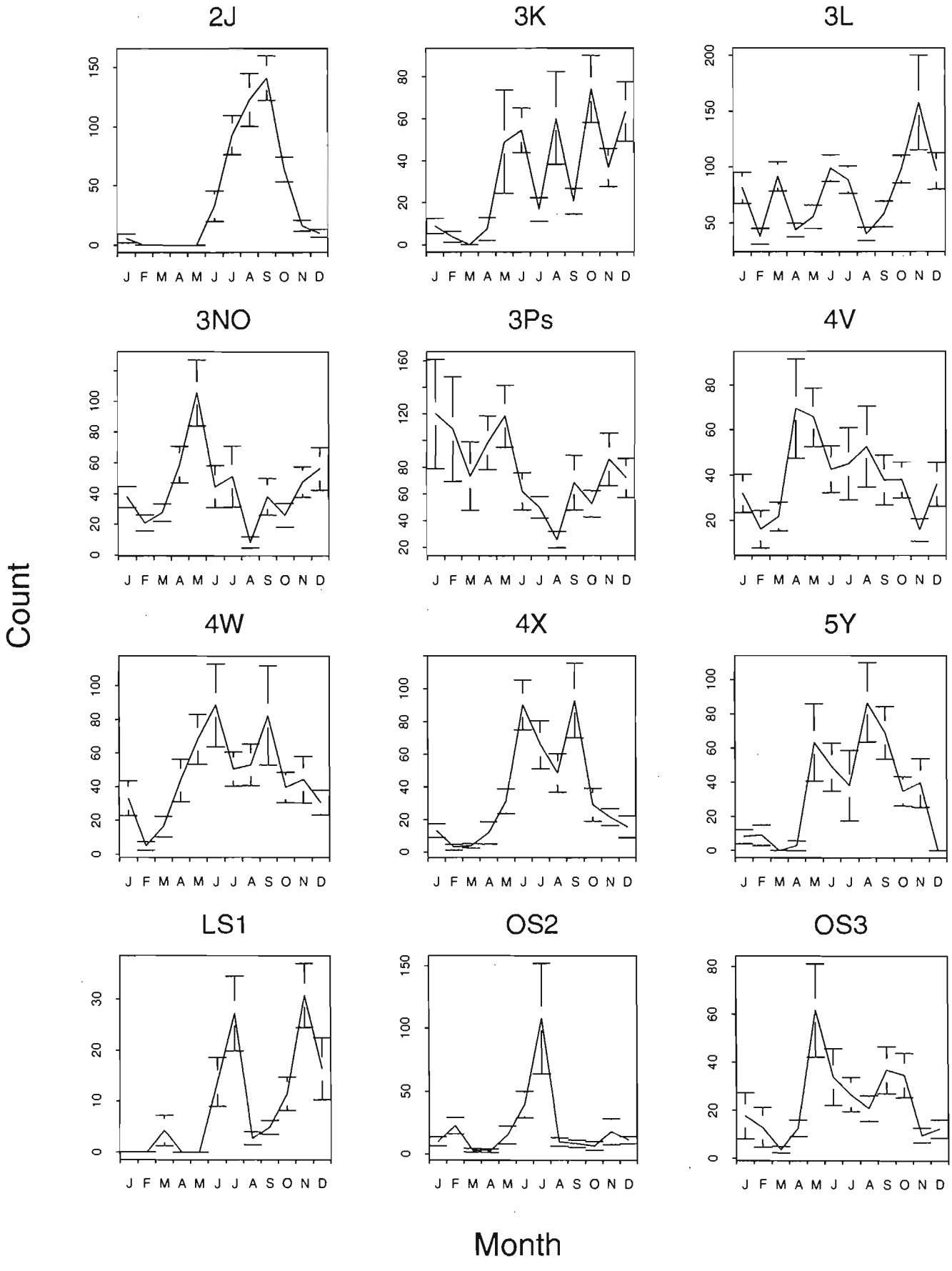
Centropages typicus



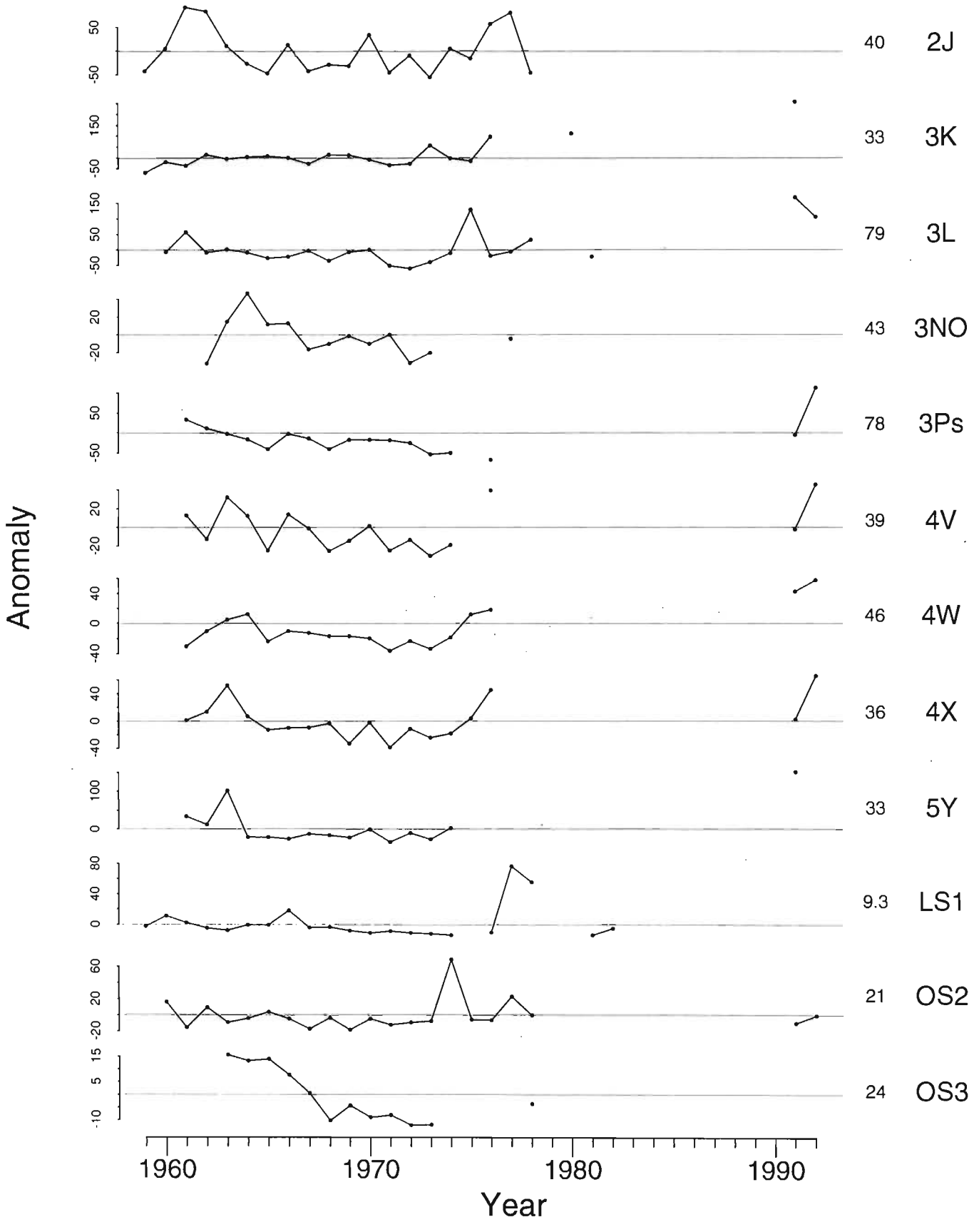
Centropages typicus



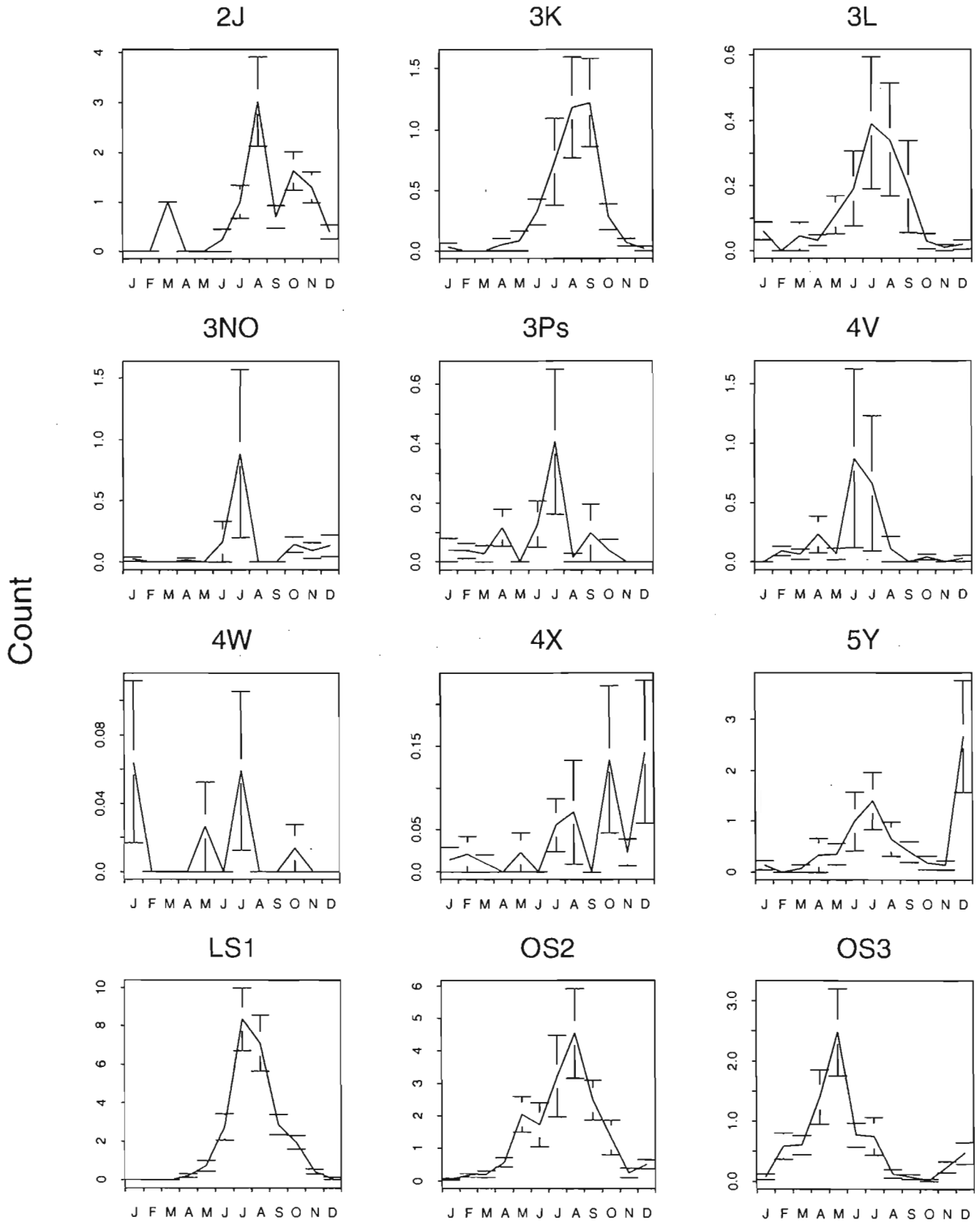
Oithona spp.


2J
3K
3L
3NO
3Ps
4V
4W
4X
5Y
LS1
OS2
OS3
J F M A M J J A S O N D
Count
Month

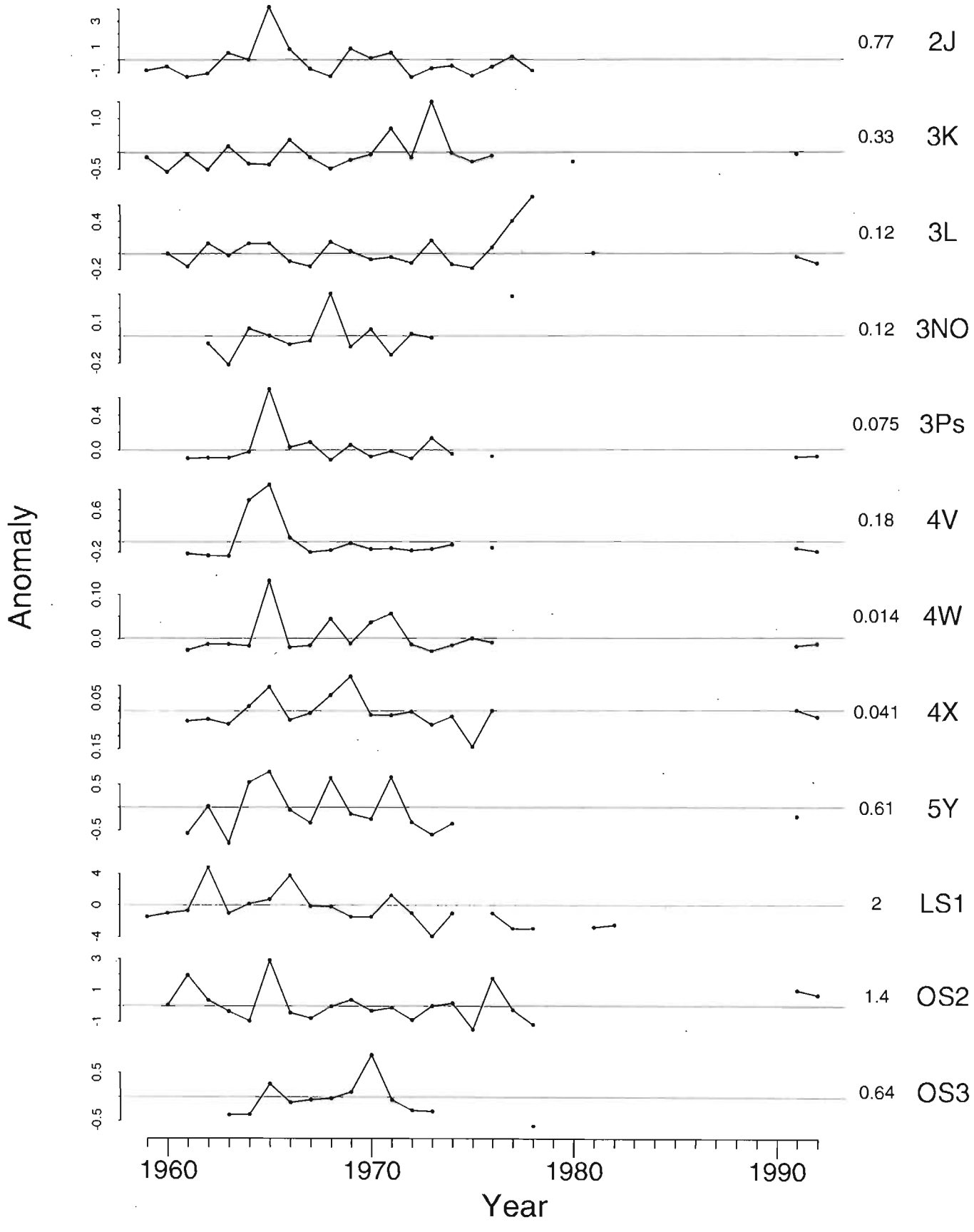
Oithona spp.


Anomaly
50
-50
150
-50
150
50
-50
20
-20
50
-50
20
-20
40
0
-40
40
0
-40
100
0
80
40
0
60
20
-20
15
5
-10
40
2J
33
3K
79
3L
43
3NO
78
3Ps
39
4V
46
4W
36
4X
33
5Y
9.3
LS1
21
OS2
24
OS3
1960
1970
1980
1990
Year

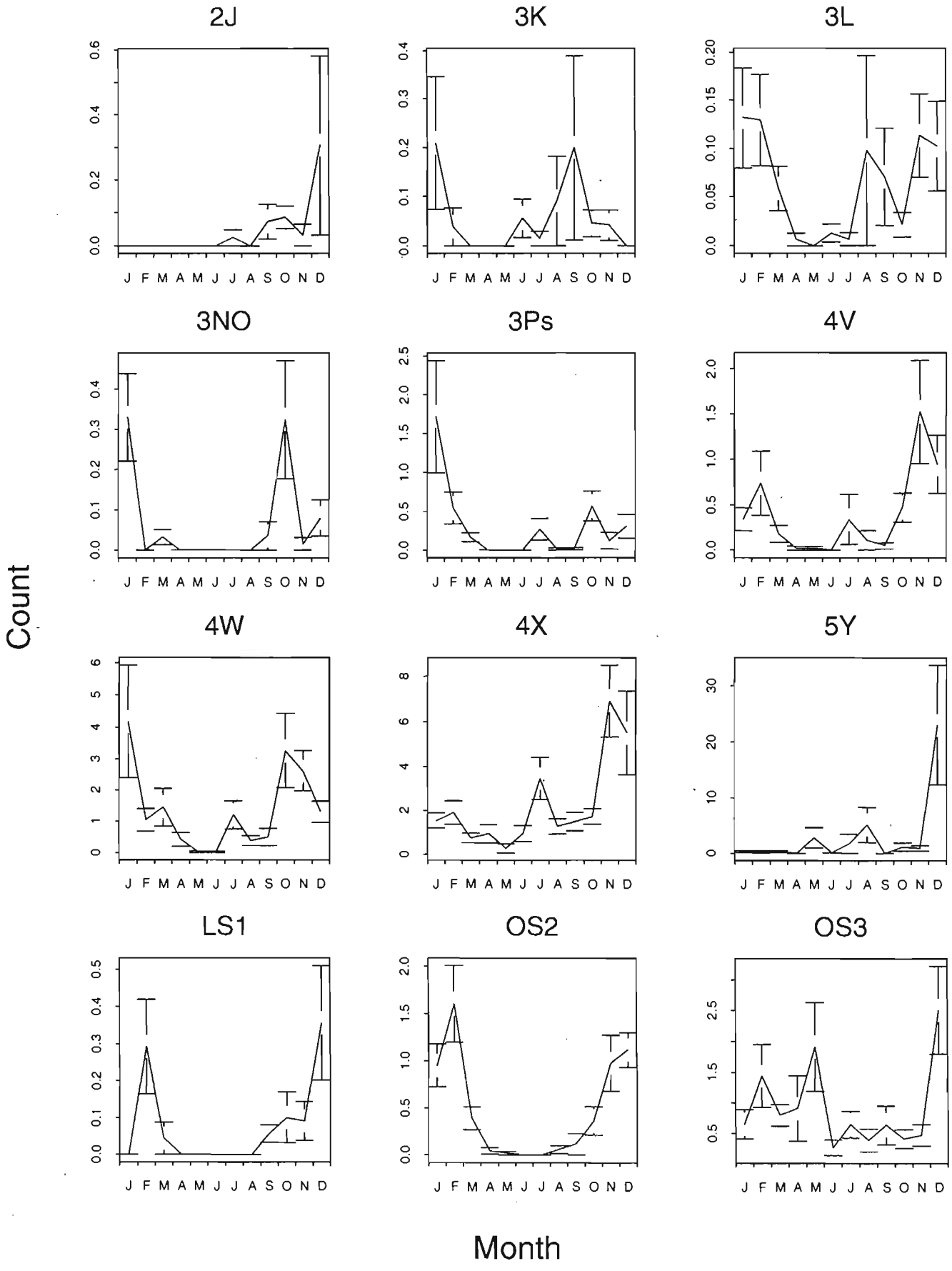
Euchaeta norvegica



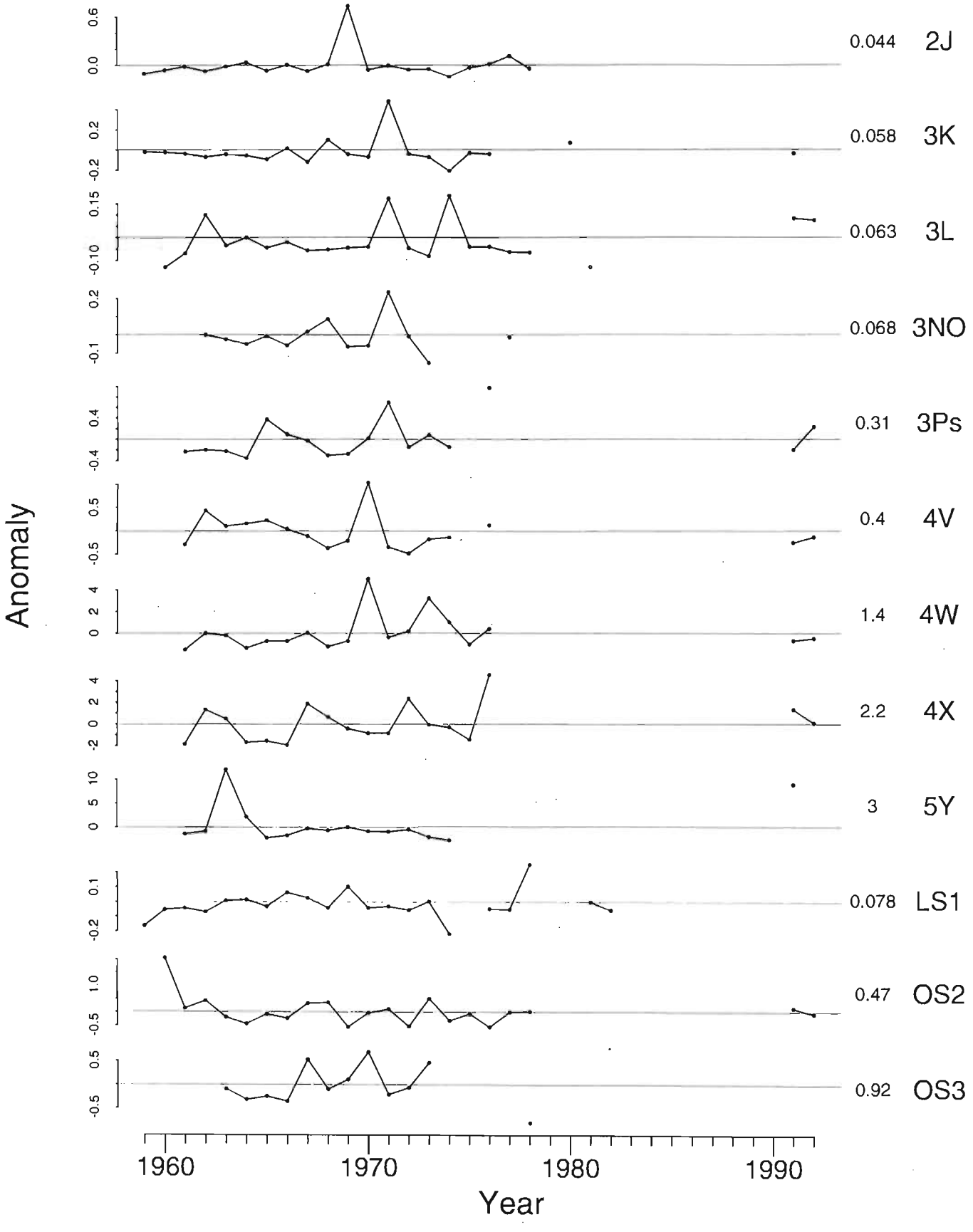
Euchaeta norvegica



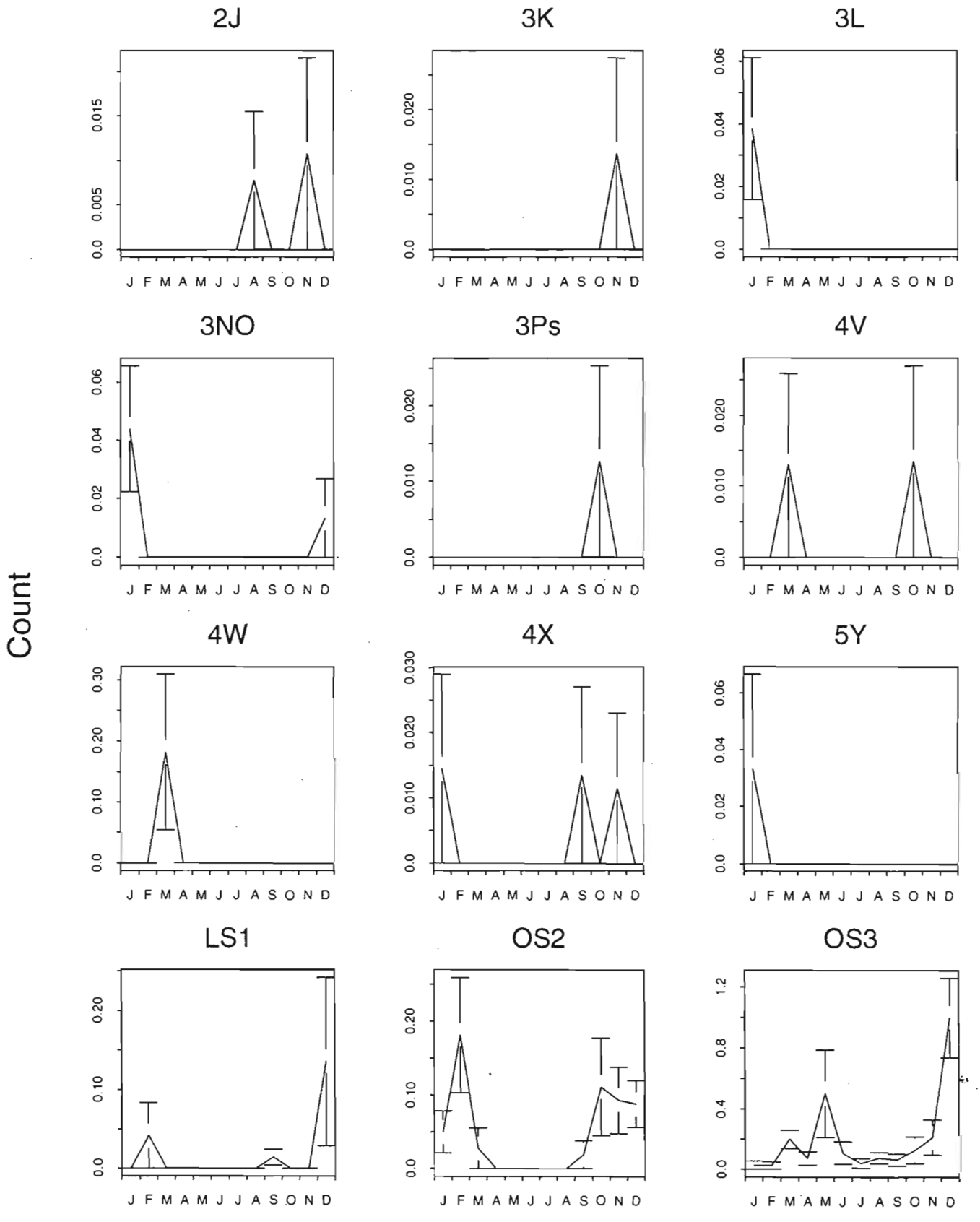
Metridia lucens



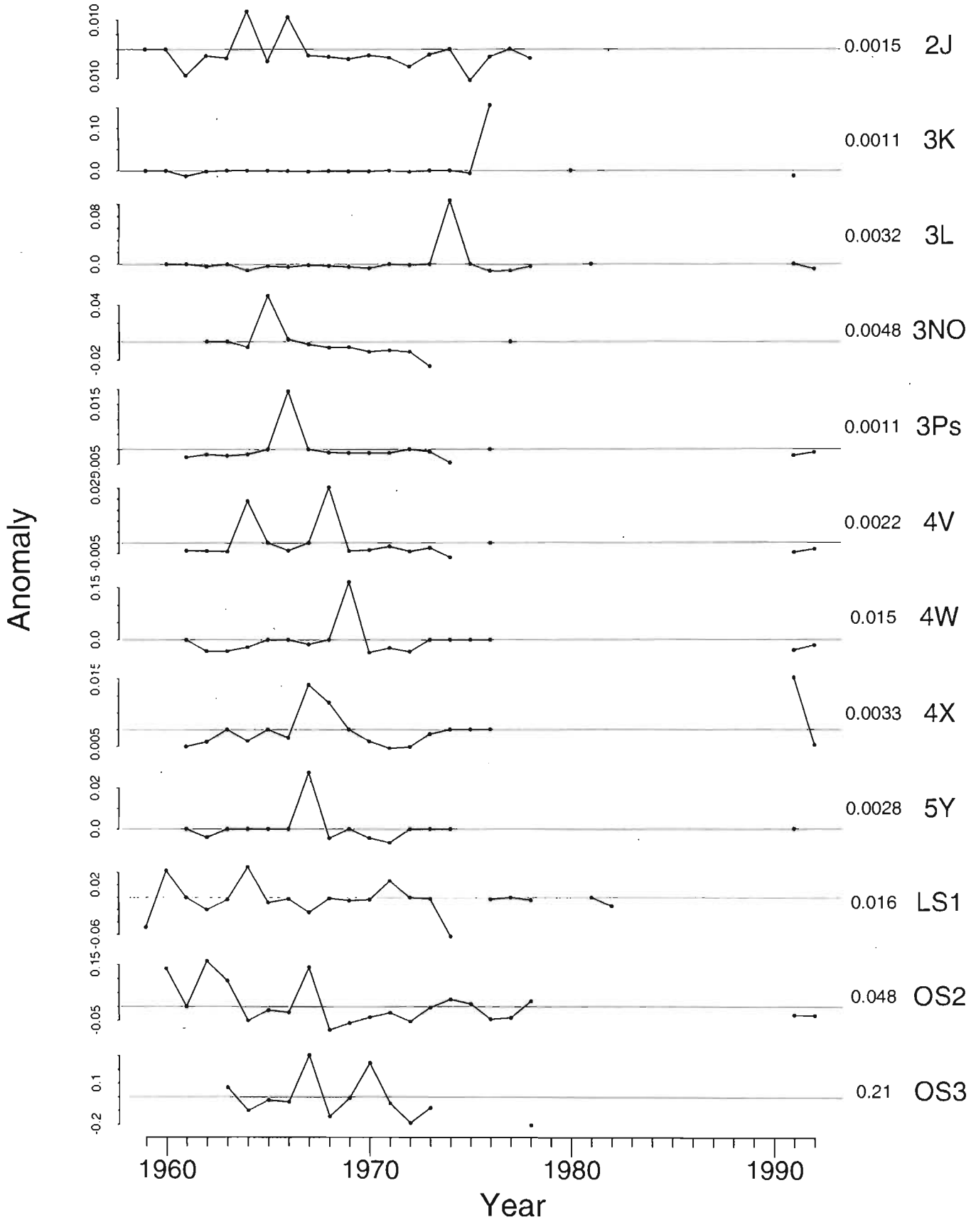
Metridia lucens



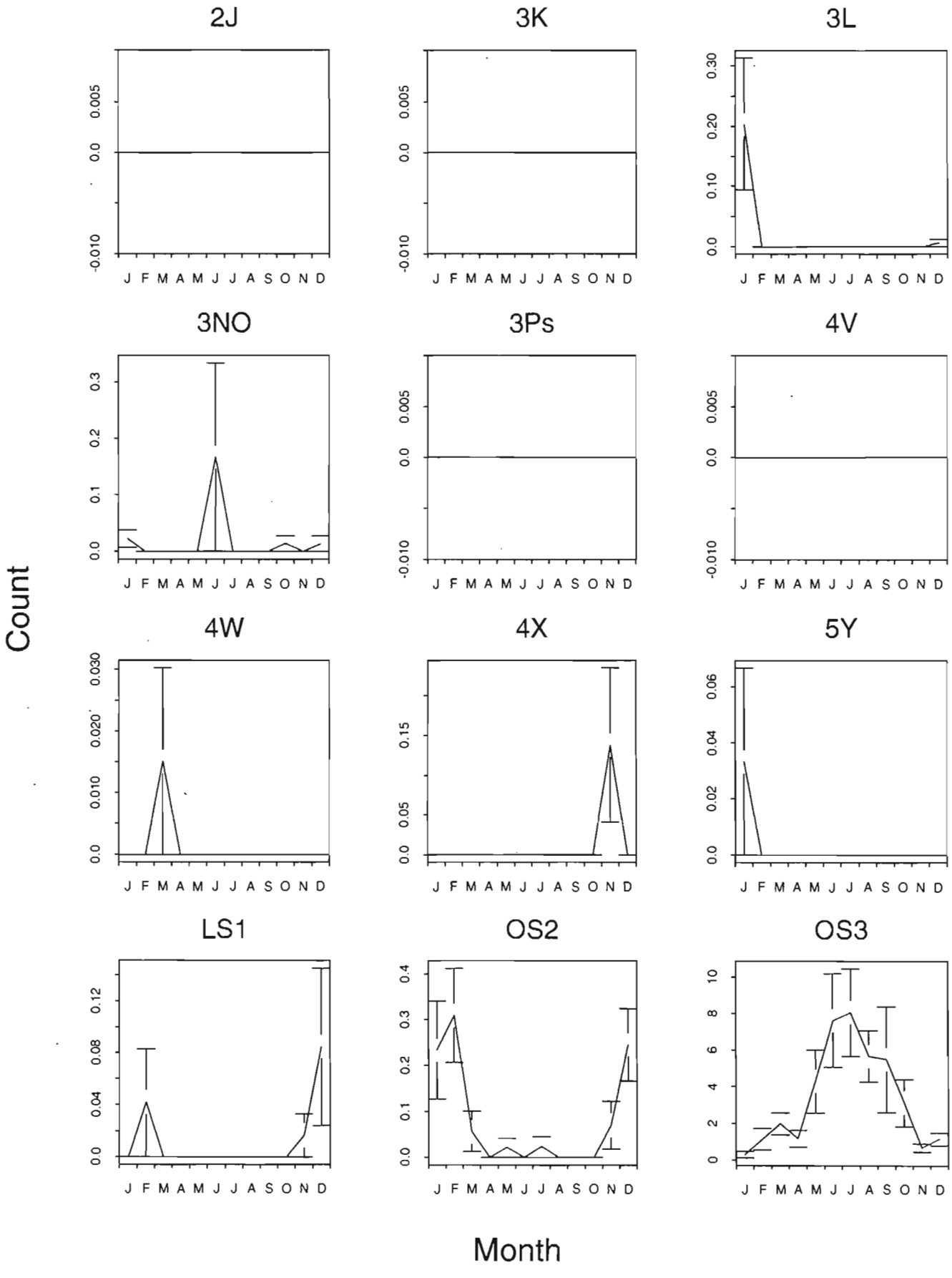
Pleuromamma robusta



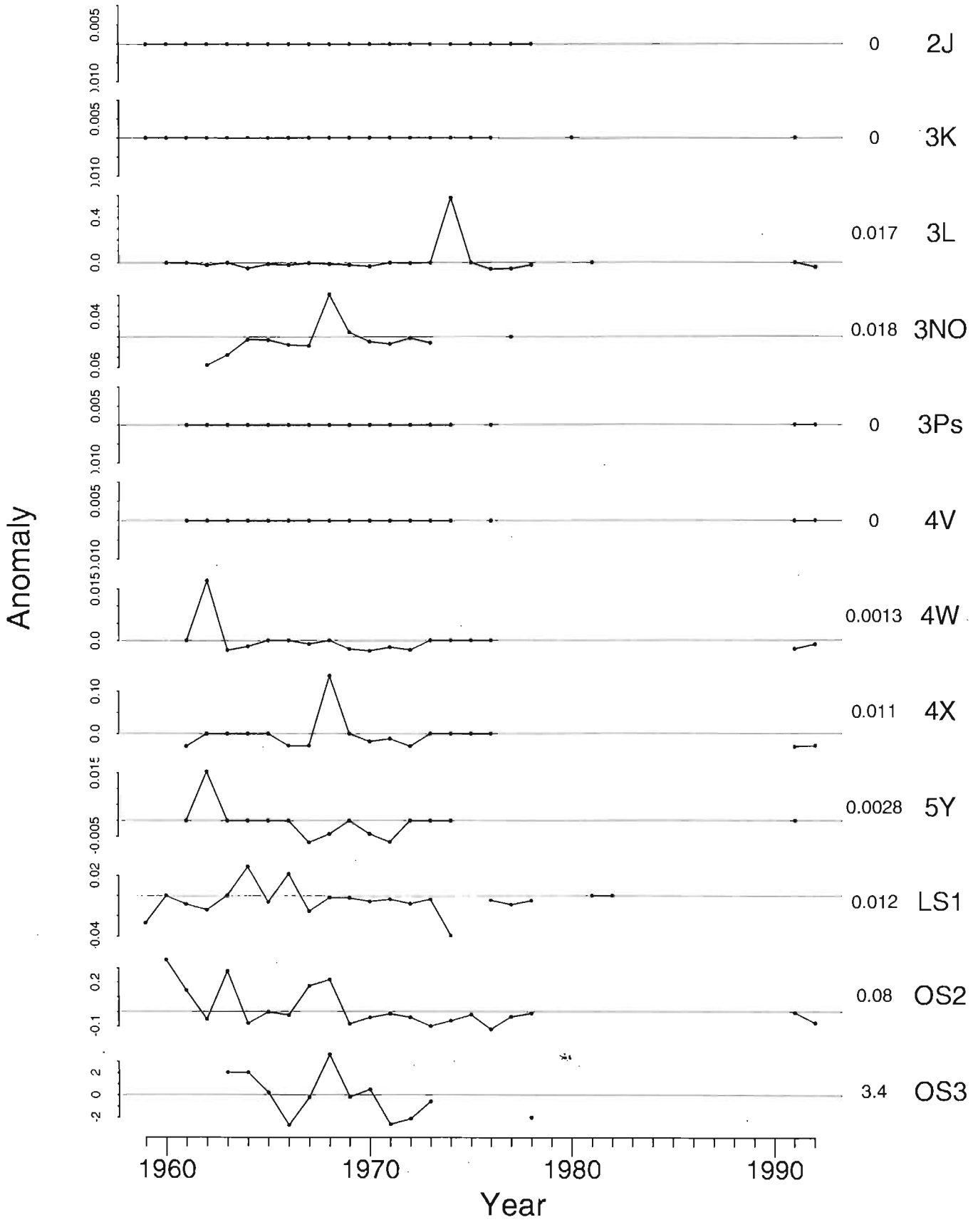
Pleuromamma robusta



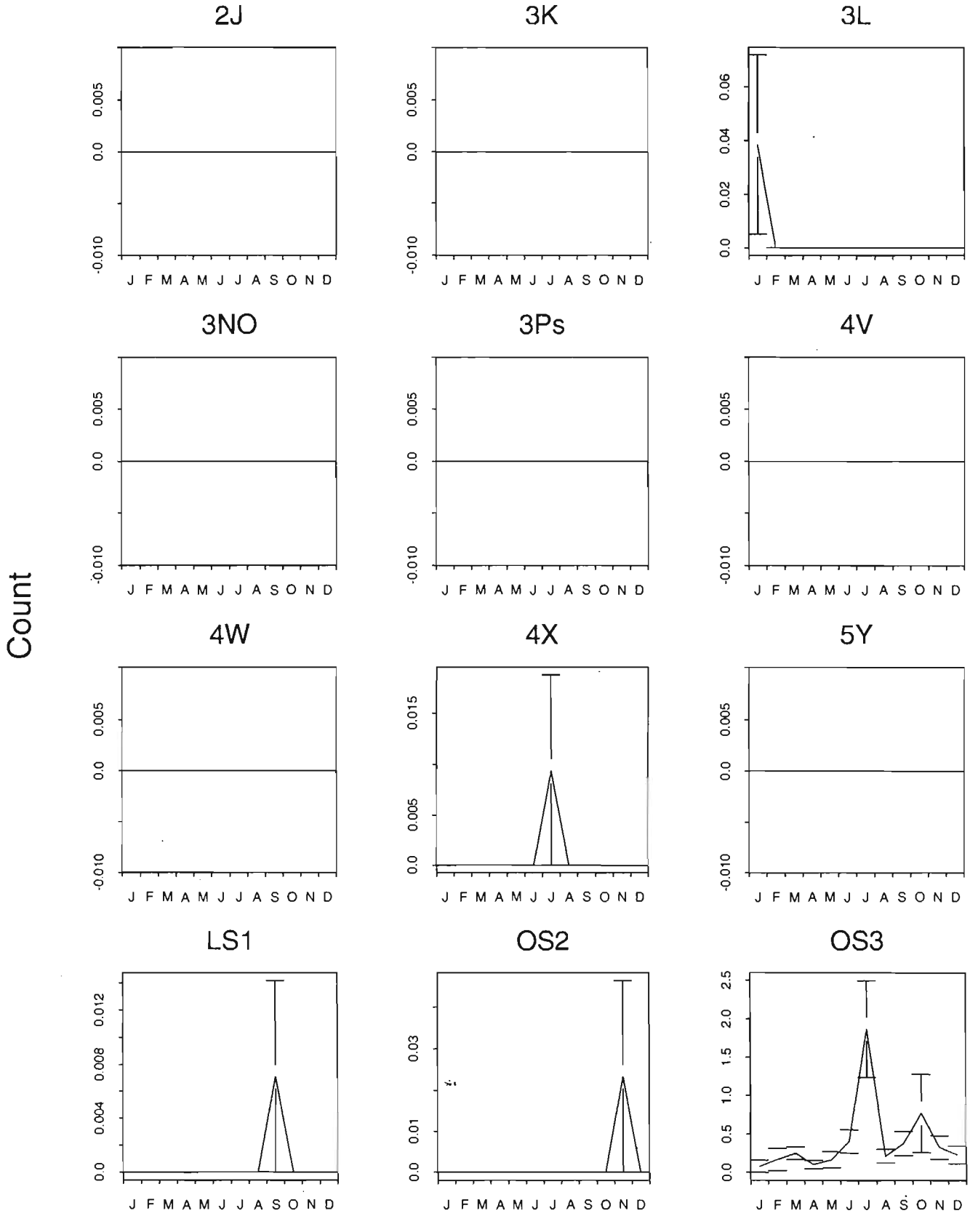
Pleuromamma borealis



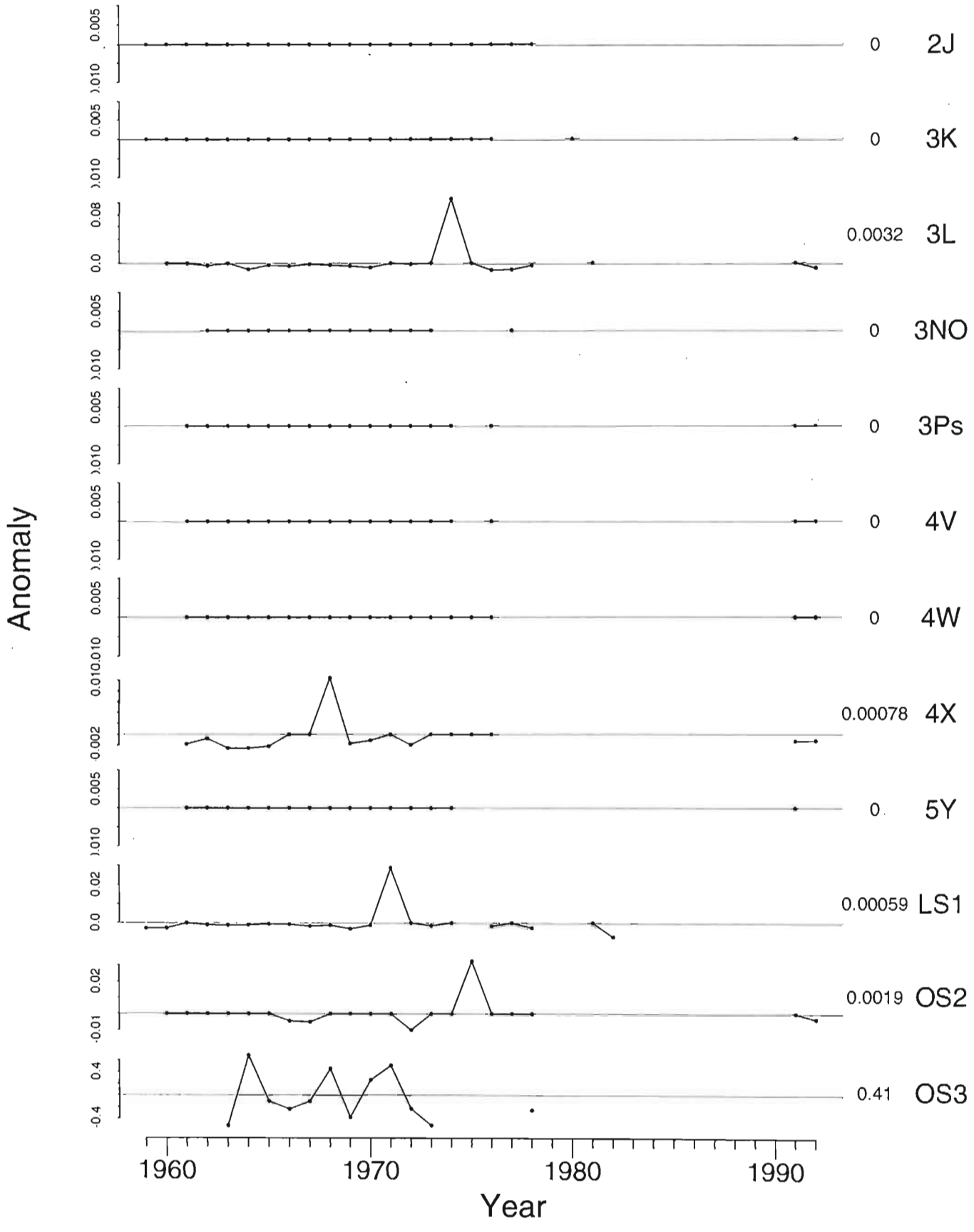
Pleuromamma borealis



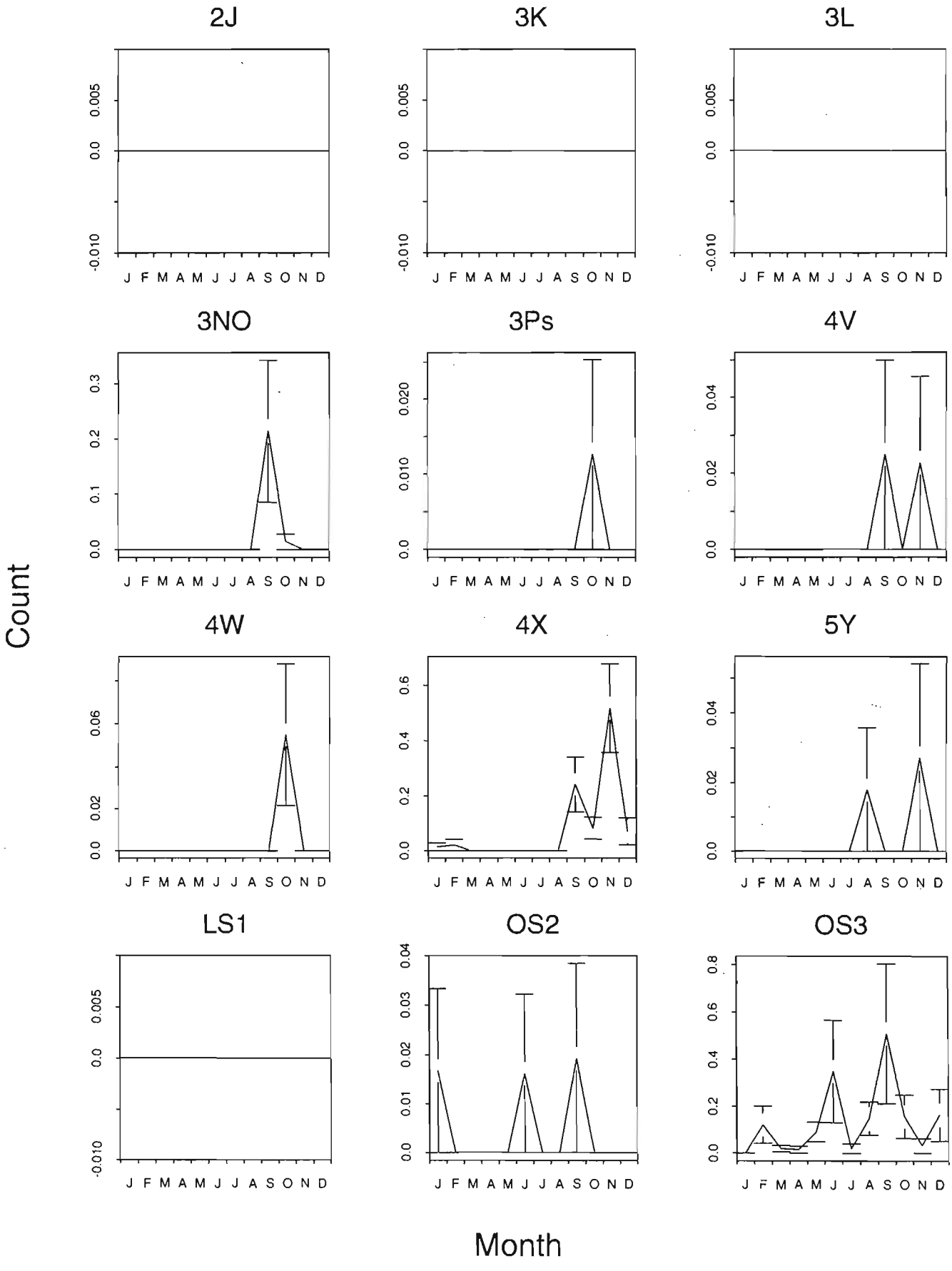
Pleuromamma gracilis



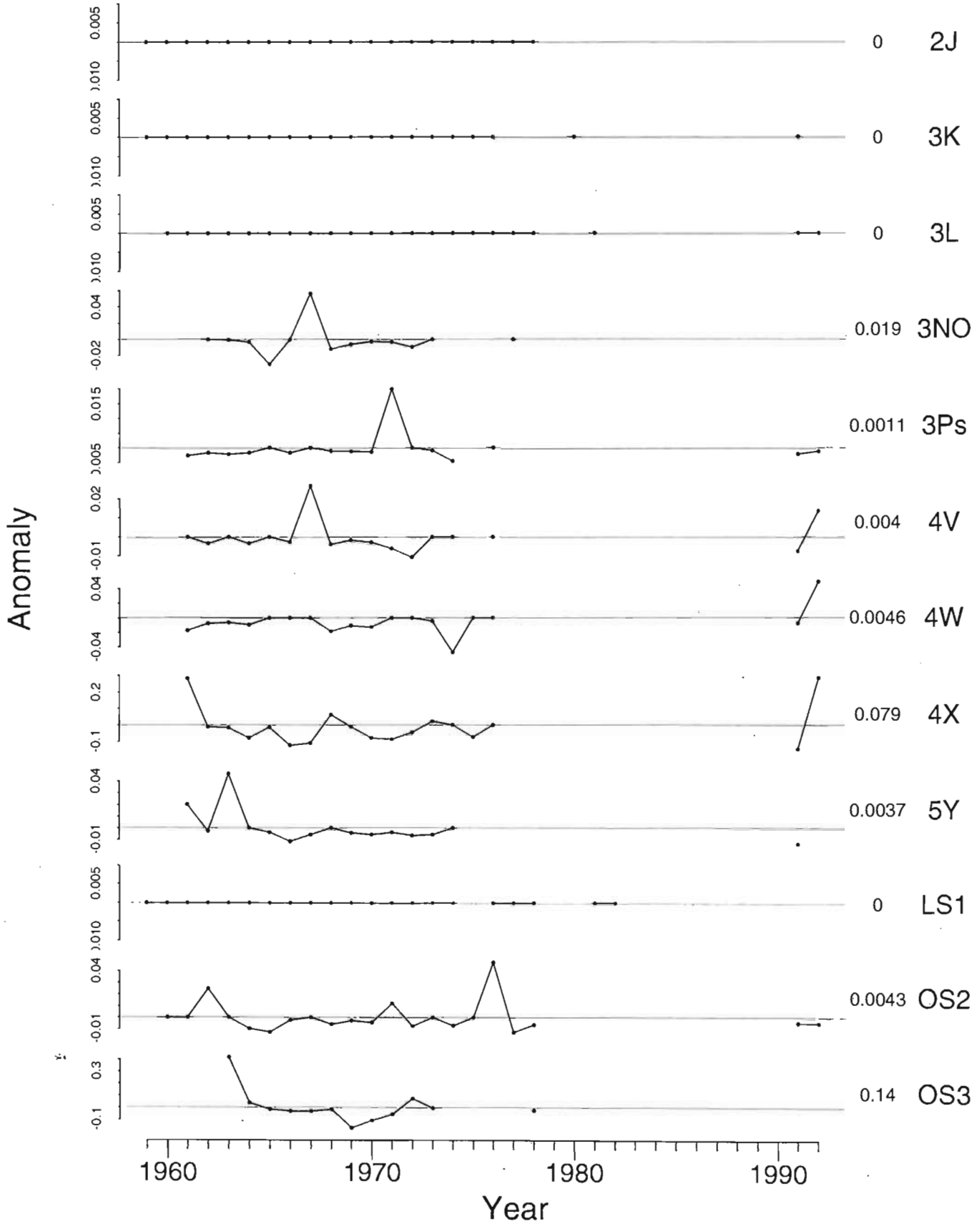
Pleuromamma gracilis



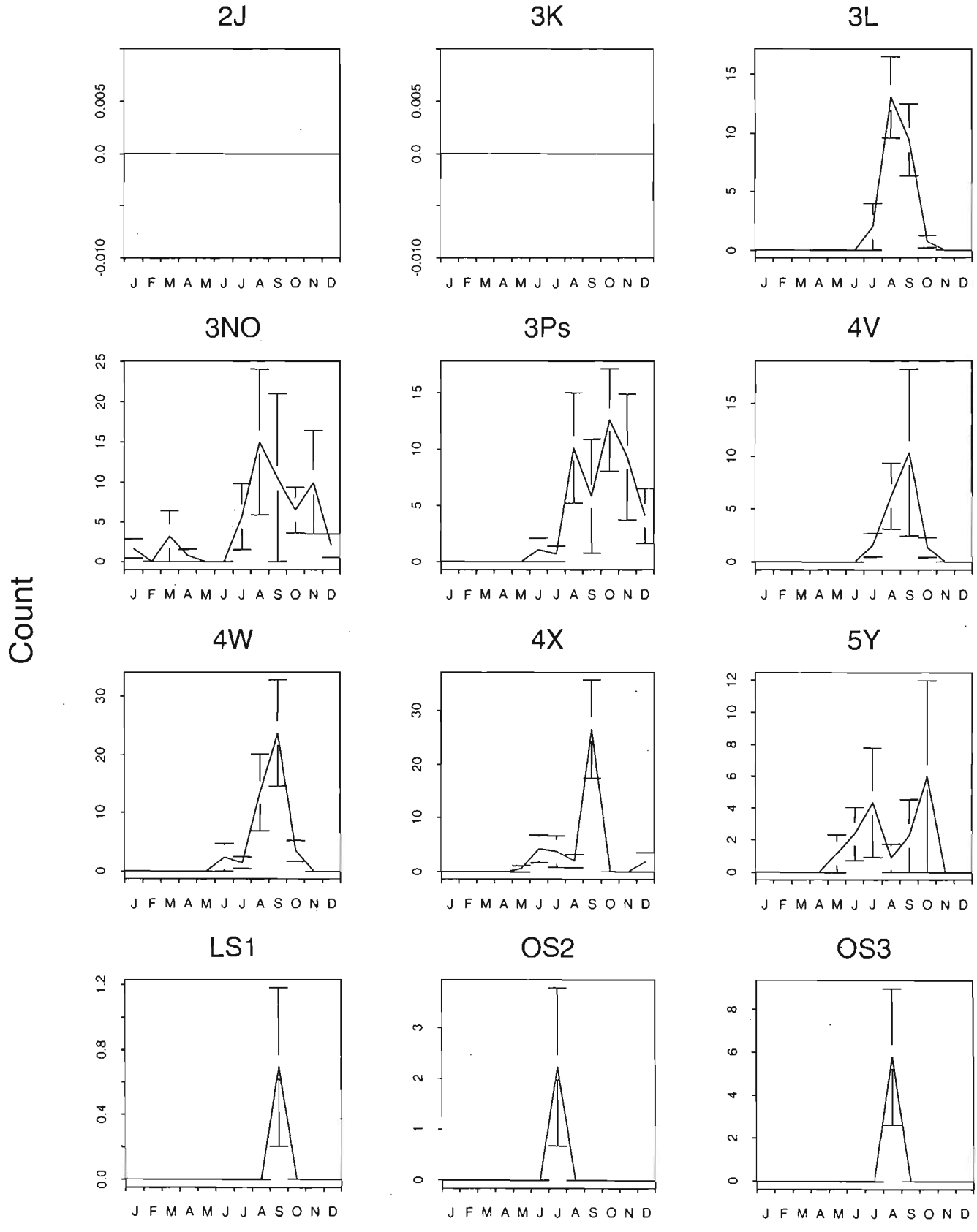
Candacia armata



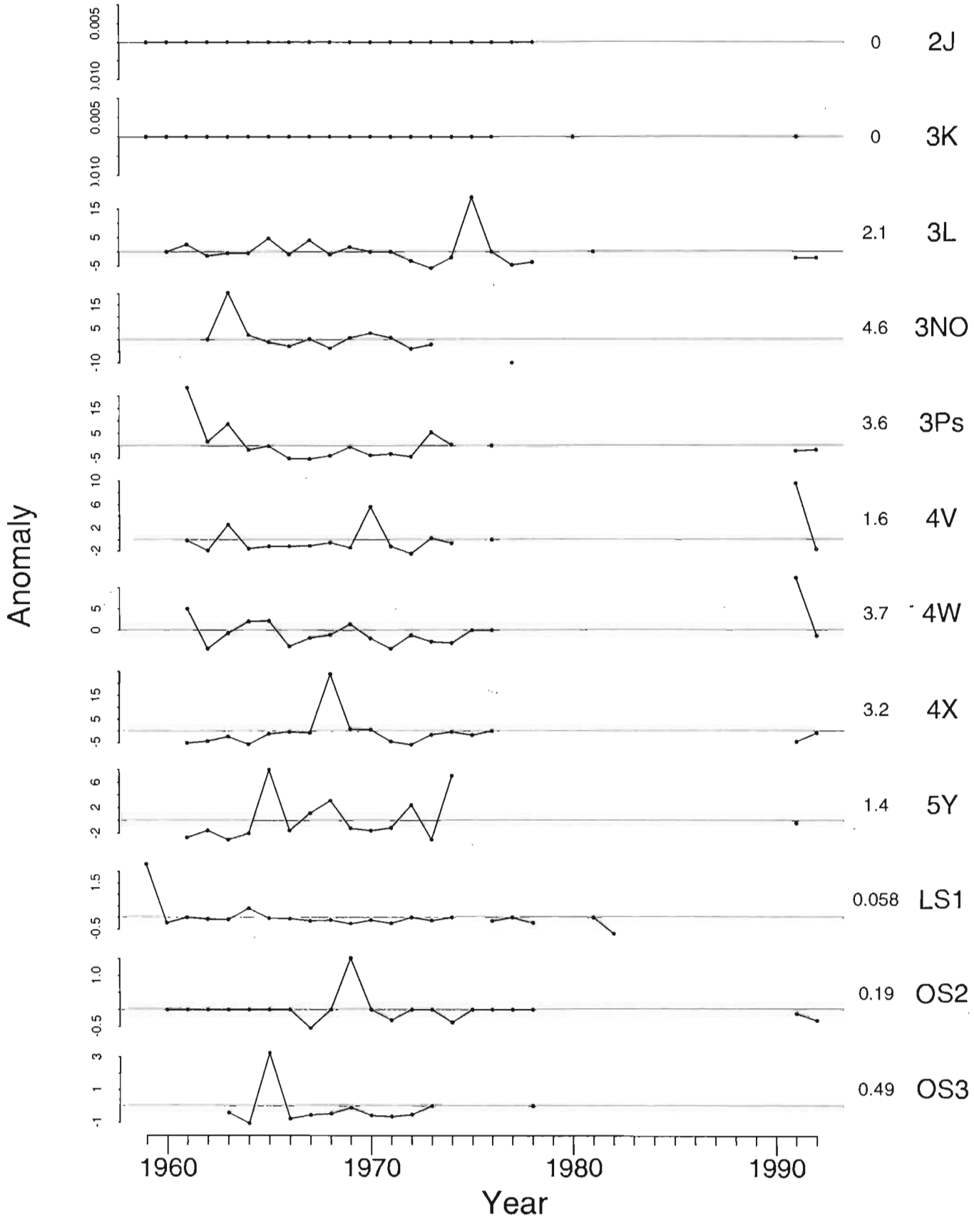
Candacia armata



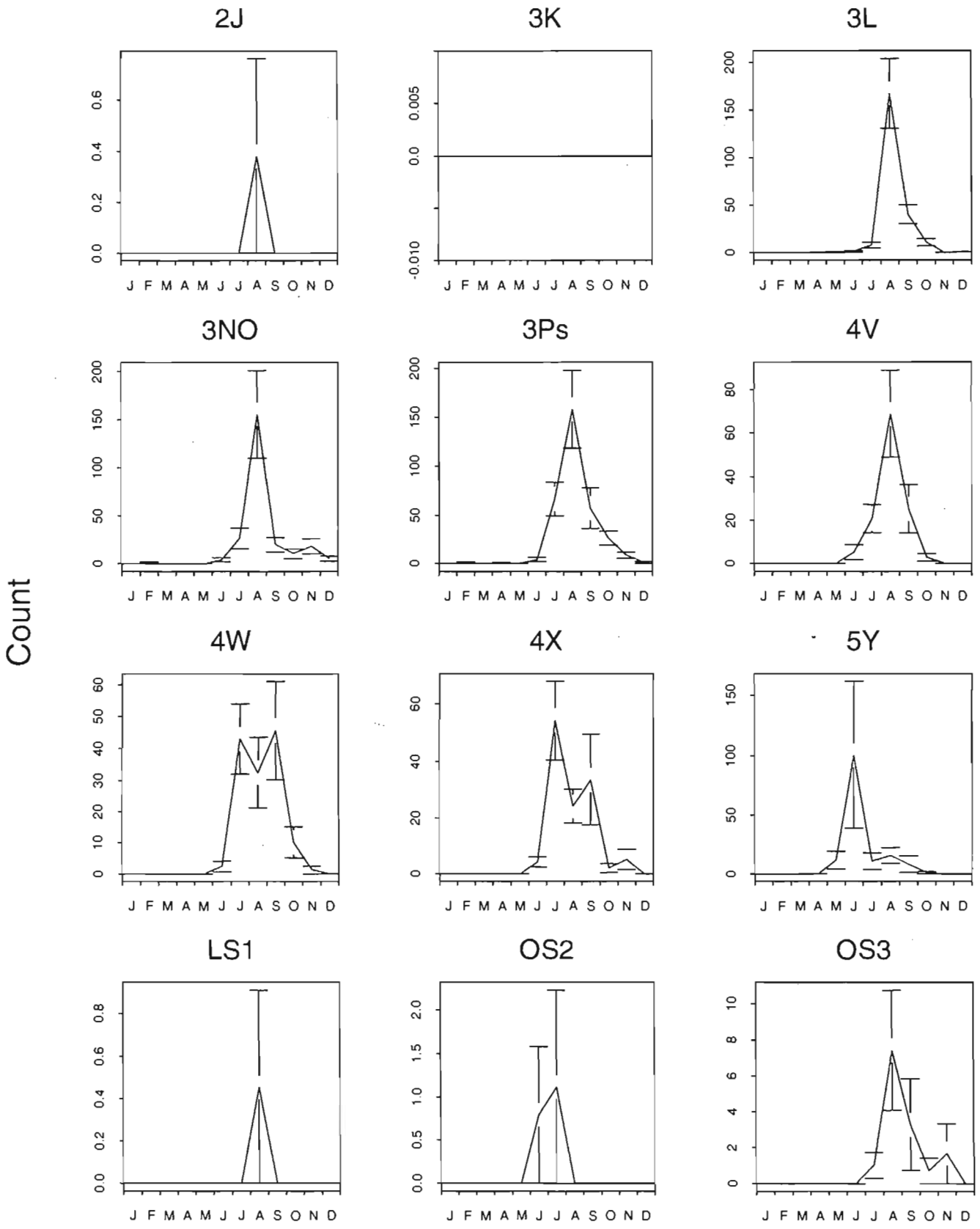
Podon spp.


2J
3K
3L
3NO
3Ps
4V
4W
4X
5Y
LS1
OS2
OS3
J F M A M J J A S O N D
Count
Month

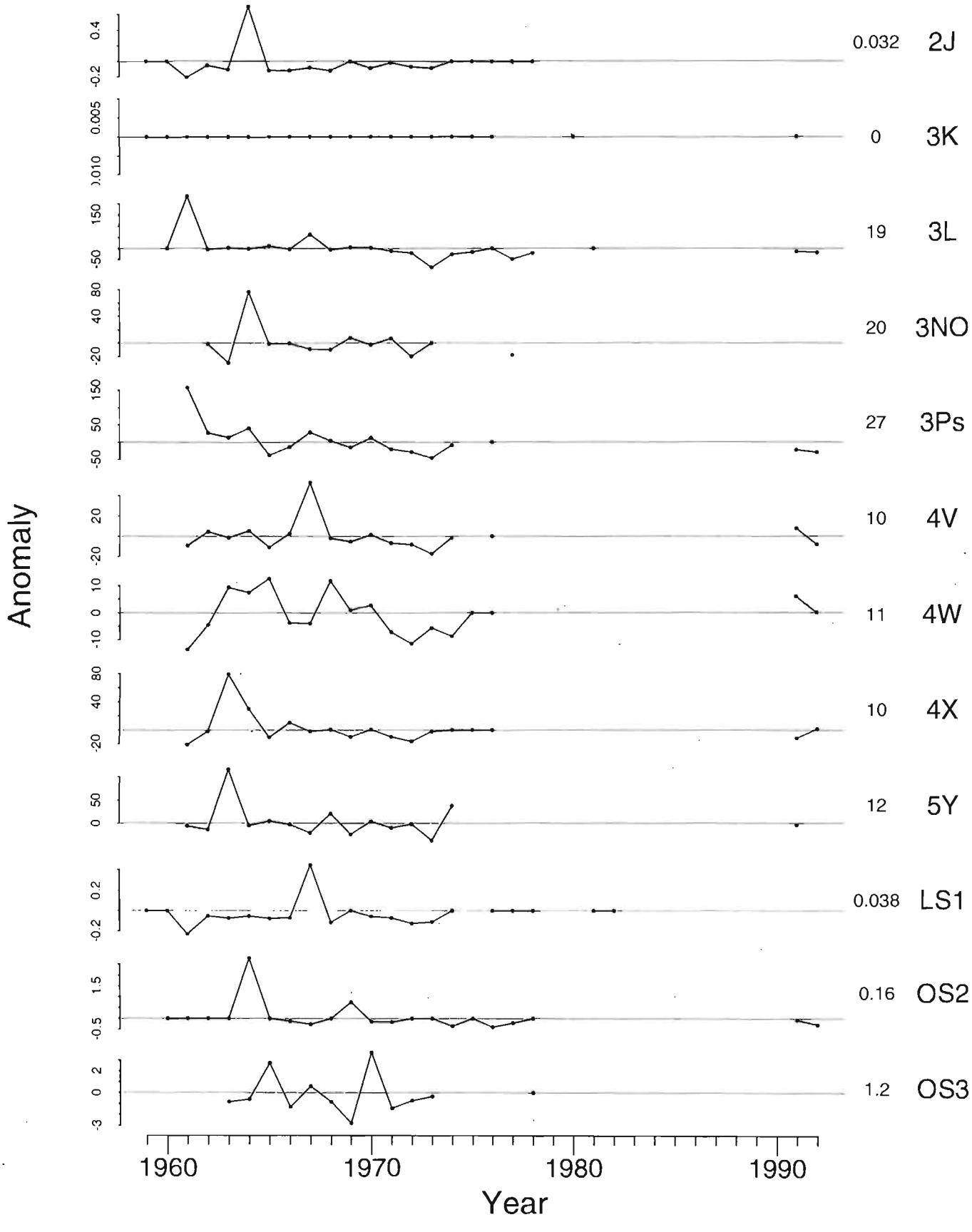
Podon spp.


Anomaly
0.005
0.010
0.005
0.010
-5 5 15
-10 5 15
-5 5 15
-2 2 6 10
0 5
-5 5 15
-2 2 6
-0.5 1.5
-0.5 1.0
-1 1 3
0 2J
0 3K
2.1 3L
4.6 3NO
3.6 3Ps
1.6 4V
3.7 4W
3.2 4X
1.4 5Y
0.058 LS1
0.19 OS2
0.49 OS3
1960
1970
1980
1990
Year

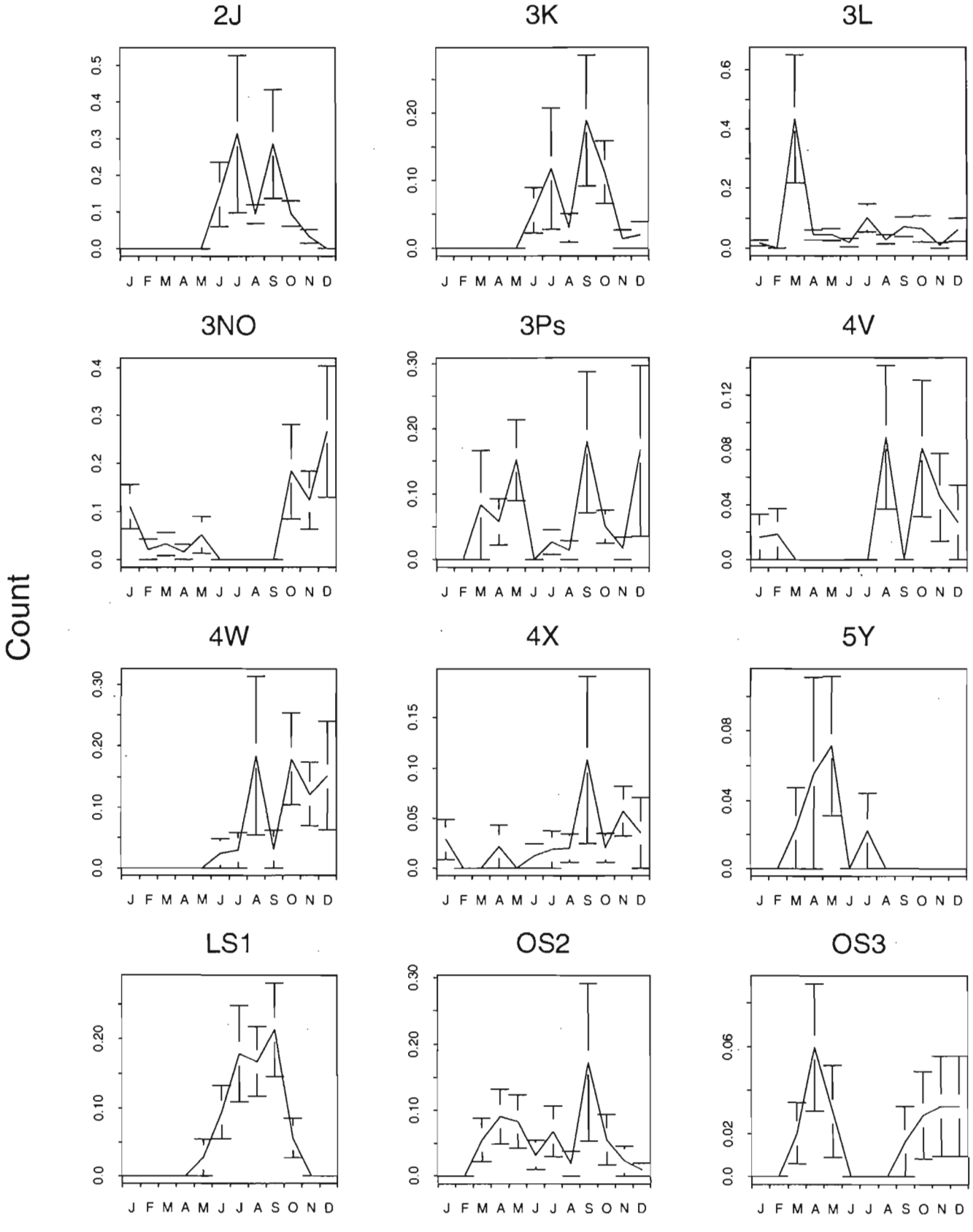
Evadne spp.


2J
3K
3L
3NO
3Ps
4V
4W
4X
5Y
LS1
OS2
OS3
J F M A M J J A S O N D
Count
Month

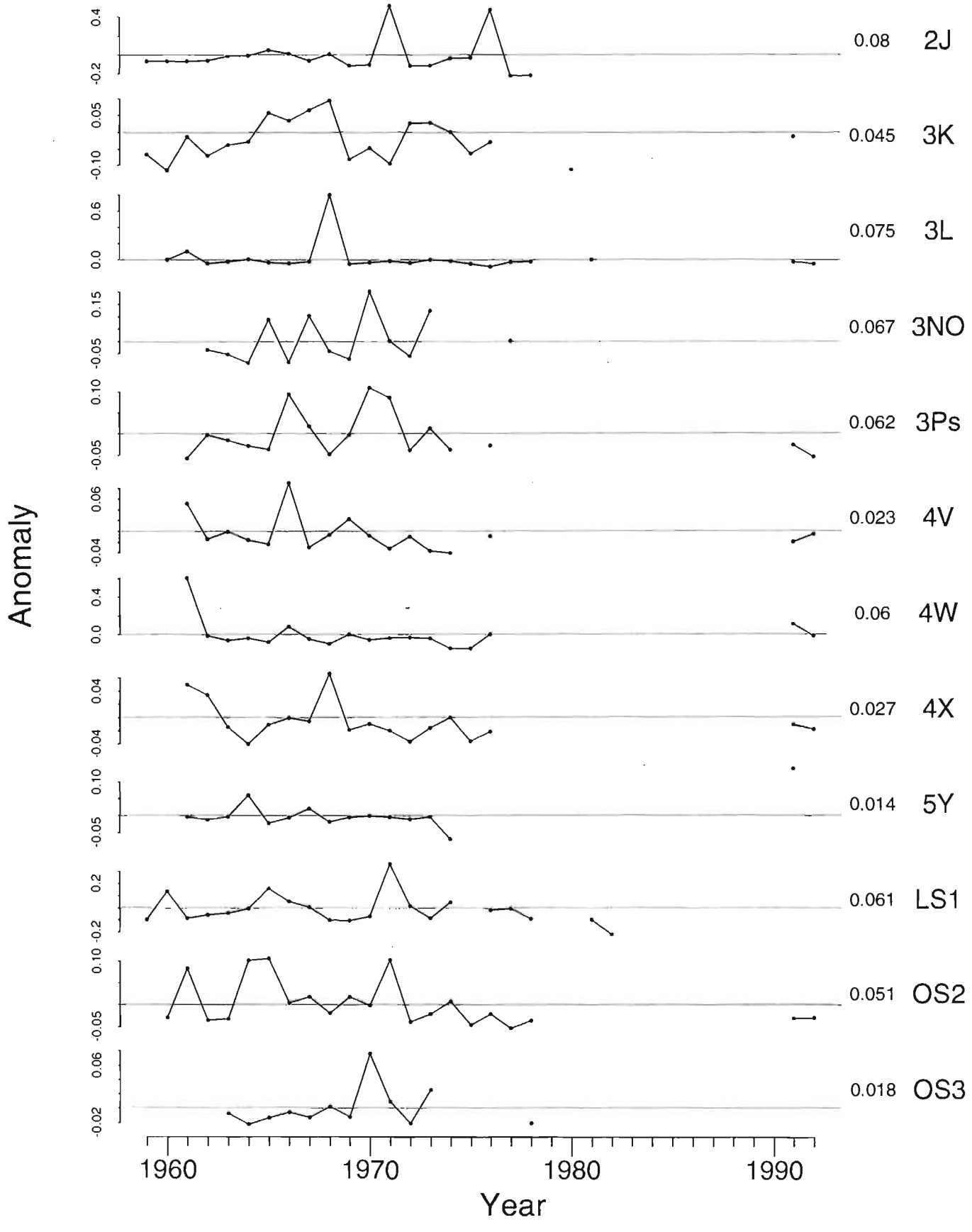
Evadne spp.


Anomaly
0.4
-0.2
0.032
2J
0.005
0.010
0
3K
150
-50
19
3L
80
40
-20
20
3NO
150
50
-50
27
3Ps
20
-20
10
4V
10
0
-10
11
4W
80
40
-20
10
4X
50
0
12
5Y
0.2
-0.2
0.038
LS1
1.5
-0.5
0.16
OS2
2
0
-3
1.2
OS3
1960
1970
1980
1990
Year

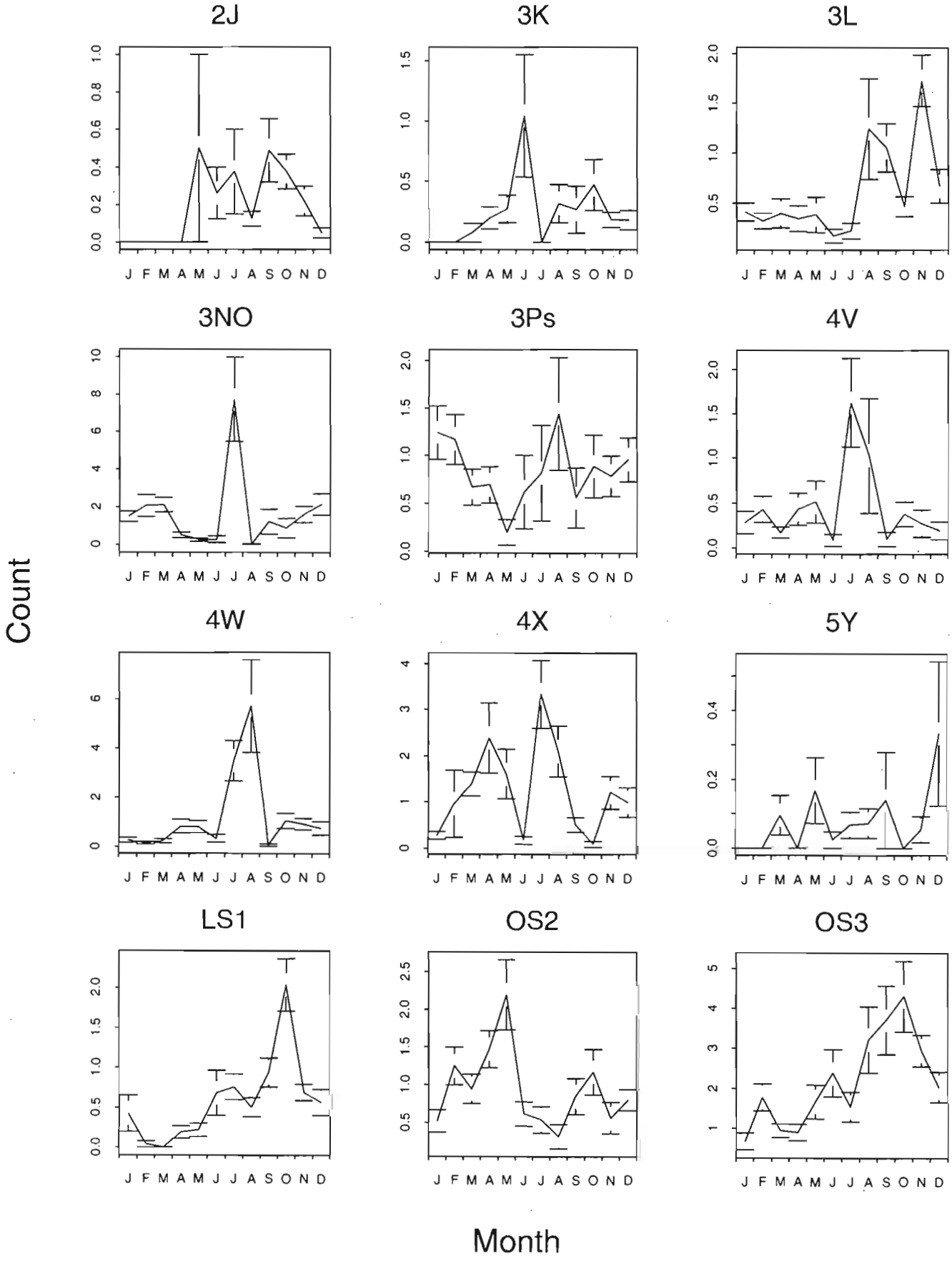
Clione limacina



Clione limacina



Chaetognatha Eyecount



Chaetognatha Eyecount