

Patterns of Phytoplankton Abundance and Nutrient Concentration in the York River Estuary, Virginia: 1984-1994

WASHINGTON Yongsik Sin and Richard L. Wetzel

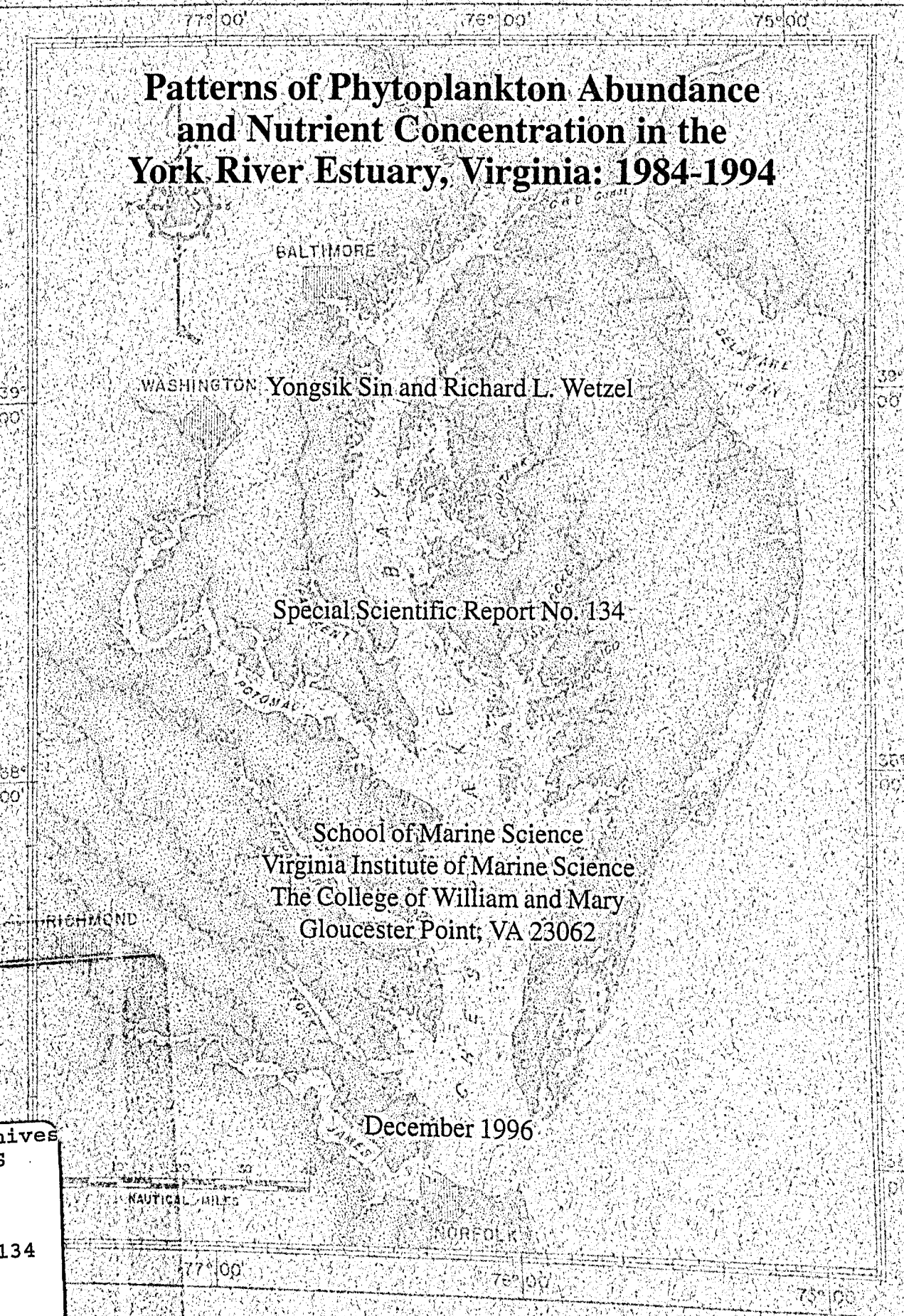
Special Scientific Report No. 134

School of Marine Science
Virginia Institute of Marine Science
The College of William and Mary
Gloucester Point, VA 23062

December 1996

Archives
VIMS
SH
1
V48
no.134
c.2

NAUTICAL MILES



Archives
VIMS
SH
1
V48
no.134
c.2

**Patterns of phytoplankton abundance and nutrient concentration in the York River
Estuary, Virginia: 1984-1994**

Yongsik Sin and Richard L. Wetzel

Special Scientific Report No. 134

School of Marine Science
Virginia Institute of Marine Science
The college of William and Mary
Gloucester Point, VA 23062

December 1996

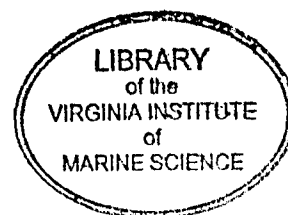


TABLE OF CONTENTS

	Page Number
INTRODUCTION	1
PROCEDURE AND METHODS	1
RESULTS AND DISCUSSION	3
FIGURES	7
REFERENCES	38

ACKNOWLEDGMENTS

The authors wish to acknowledge the EPA Chesapeake Bay Program and the Virginia Department of Environmental Quality as sources of the data in this report. Actual field collections were made by the Virginia Institute of Marine Science and Old Dominion University.

INTRODUCTION

The Commonwealth of Virginia established the Tributary Water Quality Monitoring Program in 1984 as part of the Chesapeake Bay Monitoring Program which includes water quality and biological monitoring of the main stem Bay and its tributaries since 1984. The tributary program includes 10 stations in the York River system. Physical, chemical and biological parameters are measured twenty times a year (Virginia Water Control Board 1987). This report includes the data collected from 6 stations along the Pamunkey and York Rivers from June 1984 to December 1994.

The York River system, a subestuary of the Chesapeake Bay, is composed of three rivers, i.e. the York, Pamunkey, and Mattaponi (Fig. 1). The York River is formed by the confluence of the Pamunkey and Mattaponi rivers at West Point (48 km (30 miles) from its mouth). Total average freshwater discharge to the river system is $70 \text{ m}^3 \text{ sec}^{-1}$. Discharge rates near the fall line on the Pamunkey at Hanover average 27.3 and on the Mattaponi at Beulaville 16.4 (Hyer 1977). Tides reach about 96 km (60 miles) up the Mattaponi and 60 km (38 miles) up the Pamunkey and tidal range varies from 0.7 m at the mouth of the York River to 1.2 m at the fall line in the Mattaponi River (Bender 1986). Average tidal currents increase from 30 cm sec^{-1} at the mouth to 54 cm sec^{-1} at West Point but then decrease upstream (Hyer 1977). The salinity distribution of the York River system is affected by the interaction of freshwater, salt water, tidal cycle and wind etc. Salinity gradients between the surface and bottom layers are influenced by neap and spring tidal cycles with homogeneity developing at high spring tides and stratification during the intervening periods (Haas 1975). During low flow conditions, salt water extends 20 (13) to 30 km (19 miles) upriver from West Point (Bender 1986).

PROCEDURES AND METHODS

The Chesapeake Bay Monitoring Program (CBMP) / Virginia State Water Control Board has collected data from 10 stations in the York River system. Water quality data were collected by the Virginia Institute of Marine Science and Old Dominion University through the Virginia Department of Environmental Quality. This report includes analyses of the water quality data from 6 stations; i.e., TF4.2, RET4.1, RET4.3, LE4.1, LE4.2, and LE4.3 (see Fig. 1) from June 1984 to December 1994. Data were collected monthly between November and February. During the periods of March through October, when biological activity is highest and water quality problems are most apparent, samples were taken biweekly (Virginia Water Control Board 1987).

For biological and living resources data, station TF4.2, RET4.1 and WE4.2 (off mouth of the York River) have been monitored since July 1986. Zooplankton data were collected by Old Dominion University through the Virginia Department of Environmental Quality. Mesozooplankton ($> 202 \mu$) data from July 1986 to December 1994 were analyzed whereas microzooplankton data from January 1993 to December 1994 were analyzed for this report. Daily mean river discharge data of the Pamunkey River were collected by U.S. Geological Survey.

Monthly mean averages were used for analyses of the data in this report. Linear regression was employed to investigate relationships between parameters at the 95 % confidence interval.

RESULTS AND DISCUSSION

The nutrient data indicate that the York River is weakly eutrophic, since maximum nutrient concentrations (Fig. 4, 7, 9) are much less than river systems characterized as highly eutrophic; e.g. nutrient levels of the Loire River in France were 2.613 mg l^{-1} for dissolved inorganic nitrogen (DIN), 0.079 mg l^{-1} for orthophosphate (Meybeck et al. 1988). However, nitrate and total phosphorus loads have increased significantly in the Pamunkey River over the period July 1989 to December 1995 (Bell et al. 1996).

Temporal distributions of chlorophyll *a* at 6 stations along the axis of the Pamunkey and York River are depicted in Fig. 2. The stations are located at the tidal freshwater zone (TF4.2), transitional zone (RET4.1: upriver region, RET4.3: downriver region), mesohaline zone (LE4.1: upper estuary, LE4.2: mid estuary, LE4.3: lower estuary) respectively (Fig. 1). Station designations are those used by the Virginia State Water Control Board (1987). Over 10 consecutive years, each station showed a repeating pattern of seasonal phytoplankton blooms (Fig. 2). In the tidal freshwater, the blooms usually occurred during the summer (blooms were arbitrarily designated when chlorophyll *a* exceeded $10 \mu\text{g l}^{-1}$). At the transitional stations, blooms were likely to occur during the winter-spring or summer-fall periods (Fig. 2B, 2C). Station RET4.3 revealed extraordinarily high concentrations during winter-spring except for the summer bloom in 1989 (Fig. 2C). The upper and mid estuary stations had winter-spring blooms and smaller-scale summer blooms (Fig. 2D, 2E). Generally, the lower estuary station experienced small-scale winter-spring and summer blooms (Fig. 2F).

Fig. 3 shows monthly chlorophyll distributions over the salinity gradient (0-30‰) of the Pamunkey and York River system for ten years (1985-1994). The chlorophyll maxima occurred at 10-15‰ between January and April (June in 1989). The upper river (5-15‰) appears to experience slight peaks during the summer and fall. Chlorophyll concentrations were particularly low in the entire York river system in November and December.

Figures 4 to 13 present relationships between river discharge, nutrients, light and chlorophyll *a* distributions at each station. River discharge rates had an annual cycle with maxima during winter-spring and minima during fall (Fig. 4). River discharges were clearly correlated with distributions of chlorophyll *a*. In the upper river (Pamunkey River), chlorophyll *a* peaks were negatively correlated with rate of river discharge (Fig. 4A, 4B, 4C) whereas in the lower river (York River) phytoplankton blooms were more closely correlated with high rates of discharge with some lag time in response (Fig. 4D, 4E, 4F). Regressions of chlorophyll *a* vs. river discharge rate of the Pamunkey River (1986 & 1990) show a negative correlation in the upper river (Fig. 5A, 5B, 5C) as opposed to a positive correlation in the lower river (Fig. 5D, 5E, 5F).

Fig. 4 also shows the relationship between river discharge and NO_x (NO₂+NO₃) concentrations in the water column. The relationship between nitrite and nitrate concentrations and river discharge is strongest upriver. Downstream, the influence weakens, perhaps due to dilution by the increasing water volume downstream and uptake by phytoplankton or bacteria. These results imply that river discharge has a direct impact on phytoplankton dynamics in the entire York river system.

In Fig. 4A and 4B, it is clear that high ambient nutrient (NO₂ + NO₃) levels don't stimulate phytoplankton production in the Pamunkey River (station TF4.2, RET4.1). Other mechanisms are apparently limiting phytoplankton growth at these sites. Based on Fig. 4A&4B, phytoplankton play a role in depleting nitrite and nitrate in the water column during summer. During winter, growth of phytoplankton in the Pamunkey River is limited by some mechanism other than N limitation such as residence time, P limitation, temperature or light limitation. Ambient nitrite and nitrate levels in the mesohaline water appear to be affected by phytoplankton standing stocks since low nutrient levels corresponded to chlorophyll *a* peaks (Fig. 4C, 4D). Conversely, low nutrient levels may limit phytoplankton blooms. The unusually high summertime peak of chlorophyll *a* at station RET4.3 in 1989 (Fig. 4.C) and non-bloom during summer at station TF4.2 (Fig. 4A) in 1989 may be explained by the effect of N input and short residence time and/or light limitation due to relatively high rates of river discharge during the summer of 1989 compared with other years.

The relationship between ammonium in the water column and phytoplankton

biomass (Fig. 6) or between silica and chlorophyll *a* (Fig. 7) is not clear-cut. Phosphate levels appear to be highest in summer-fall and lowest in winter-spring and are generally negatively correlated with phytoplankton biomass (Fig. 8). There is no clear relationship between phosphate distribution and river discharge or between ammonium and river discharge (Fig. 6) whereas there is a close correlation between silica and river discharge (Fig. 7). These results and Fig. 9 suggest that transport from upper river (Pamunkey River) of nutrients is the main source for phytoplankton growth in the York River. That is, runoff is a major non-point source of Dsi (Fig. 9D) and NO_x (Fig. 9E) whereas other mechanisms control ammonium (Fig. 9C) and phosphate (Fig. 9F) dynamics.

Fig. 10 illustrates the generally close relationship between chlorophyll concentration and temperature suggesting that phytoplankton biomass in the York river system is generally affected by temperature all of the time except during winter-spring blooms in the lower estuary (Fig. 10D, 10E, 10F). Regressions of chlorophyll *a* vs. temperature for 1986 present a positive correlation at the upper river (Fig. 11A, 11B, 11C) and a negative correlation at the lower river (Fig. 11D, 11E, 11F).

Fig. 12 shows that station RET4.1 is the turbidity maximum zone and light attenuation coefficients ($K_d = 1.45/\text{Secchi Disk Depth}$) are affected by river discharge rate. Regressions of chlorophyll *a* vs. K_d suggests RET4.1 station is limited by light (Fig. 13B). The lower estuary appears to experience photo inhibition (Fig. 13D, 13E, 13F). Fig. 14 describes the generally close relationship between mesozooplankton and water temperature. Microzooplankton abundance appears to be positively correlated with chlorophyll *a* but negatively with mesozooplankton abundance (Fig. 15). DO distribution is positively correlated with river discharge rate as shown in Fig. 16 and Fig 17.

Two year's data (1986 and 1990 for low and high discharge rate respectively) were analyzed to examine nutrient and chlorophyll dynamics (Fig. 18, 19). River discharge appears to determine the scale of blooms which in turn rapidly depletes nutrients. Fig. 20 shows the difference between 1986's and 1990's chlorophyll patterns; i.e., small-scaled winter-spring bloom and no summer bloom in 1986 versus large winter bloom and smaller summer bloom in 1990.

Data shown in Fig. 21 of N:P ratios vs. chlorophyll suggest that in tidal fresh water phosphates are limiting with winter-spring peaks of limitation triggered by enhanced riverine nitrogen input during winter and spring (Fig. 21A). Station RET4.1 in the transition zone showed a pattern similar to that for the freshwater stations (although not as clear-cut) except for a short period of nitrogen limitation during the summer. Light may be a principal factor controlling phytoplankton growth at this station due to the high level of turbidity (see Fig. 12B).

At stations RET4.3, LE4.1, LE4.2 and LE4.3 nitrogen limitation was observed during summer when phosphate concentrations were high and extreme phosphorus limitation during winter-spring periods due to nitrogen input from runoff. These patterns of seasonal variation in nutrient limitation which appears to limit the accumulation of algal biomass during the winter-spring and summer in the estuarine waters are supported by results of nutrient enrichment studies carried out in the lower York River (Webb 1988), in the Patuxent River (D'Elia et al. 1986), and in the main stem of Chesapeake Bay (Fisher et al. 1992). Webb (1988) also described a similar scenario for seasonal variations in nutrient limitation with phosphorus limitation shifting to N limitation as you move down the tributaries during the fall and winter and in turn shifting to N limitation as you move up the tributaries during summer for salinity gradients of 3.8-25 ppt. These results are based on experiments carried out in the Patuxent River (D'Elia et al. 1986) and in the lower York River (Webb et al. unpublished; 1985-1987). Further evidence showing a seasonal variation of nutrient limitation over "salinity gradients" and a direct effect of winter runoff as proposed by Webb (1988) can be seen in Fig. 21 and 22. Haas and Wetzel (1993) reported that phytoplankton biomass in tidal freshwater in the Rappahannock river is weakly limited by phosphorus and by light throughout the year. At a station located at the mouth of the Rappahannock river phytoplankton experienced prolonged nitrogen limitation throughout the year except for a period of phosphorus limitation during March to May. Fig. 23-30 present distributions of nutrients from surface and bottom water for 10 years (85-94). Ammonia, nitrate + nitrite and silica showed the greatest difference between surface and bottom layers (esp., RET4.3) while orthophosphate concentrations showed no surface to bottom differences.

Phytoplankton growth in tidal fresh water is limited since the residence time (dependent on the river discharge rate) can be less than the cell division rate. In the transition zone (turbidity maximum zone), phytoplankton are limited mainly by light. In mesohaline water riverine nitrite + nitrate input during the winter may result in winter-spring blooms at locations experiencing nitrogen limitation (around 20 to 30 miles upriver from the mouth). Tidal mixing also appears to influence phytoplankton dynamics in the mesohaline zone (Fig. 31); chlorophyll *a* peaks generally responded to well-mixing of salinity in the water column. Since river discharge determines the location of the turbidity maximum the chlorophyll maximum may move responding to the quantity of river discharge during winter.

It should be noted (Fig. 4C) that the transitional station RET4.3 had relatively high concentrations of chlorophyll *a* during the summer at a time when nitrite + nitrate input from freshwater was low. The blooms may be supported by nutrients discharged from a major industry located at West Point. The mesohaline station LE4.1 also showed small summer or fall blooms. I hypothesize that the blooms are due to the dominance of small sized cells which can grow fairly well at low ambient nutrient concentrations and high temperature along with a rapid rate of nutrient recycling in the

water column or/and benthic environments. The nutrient recycling is thought to be induced by high activity of heterotrophic metabolism stimulated by warm temperature and allochthonous food materials from freshwater or ungrazed phytoplanktons during the winter.

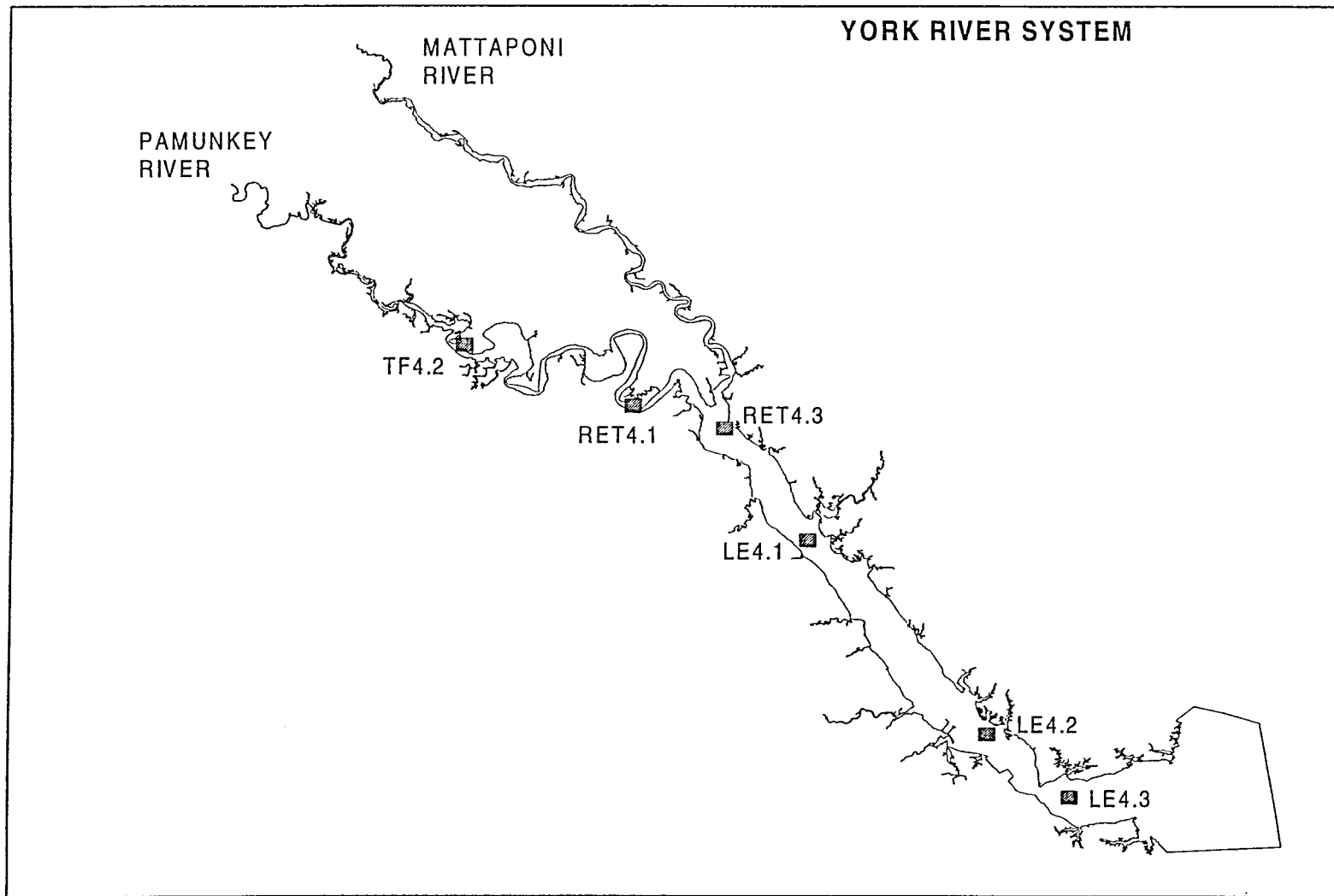


Fig. 1. The Chesapeake Bay monitoring stations in the York River system.

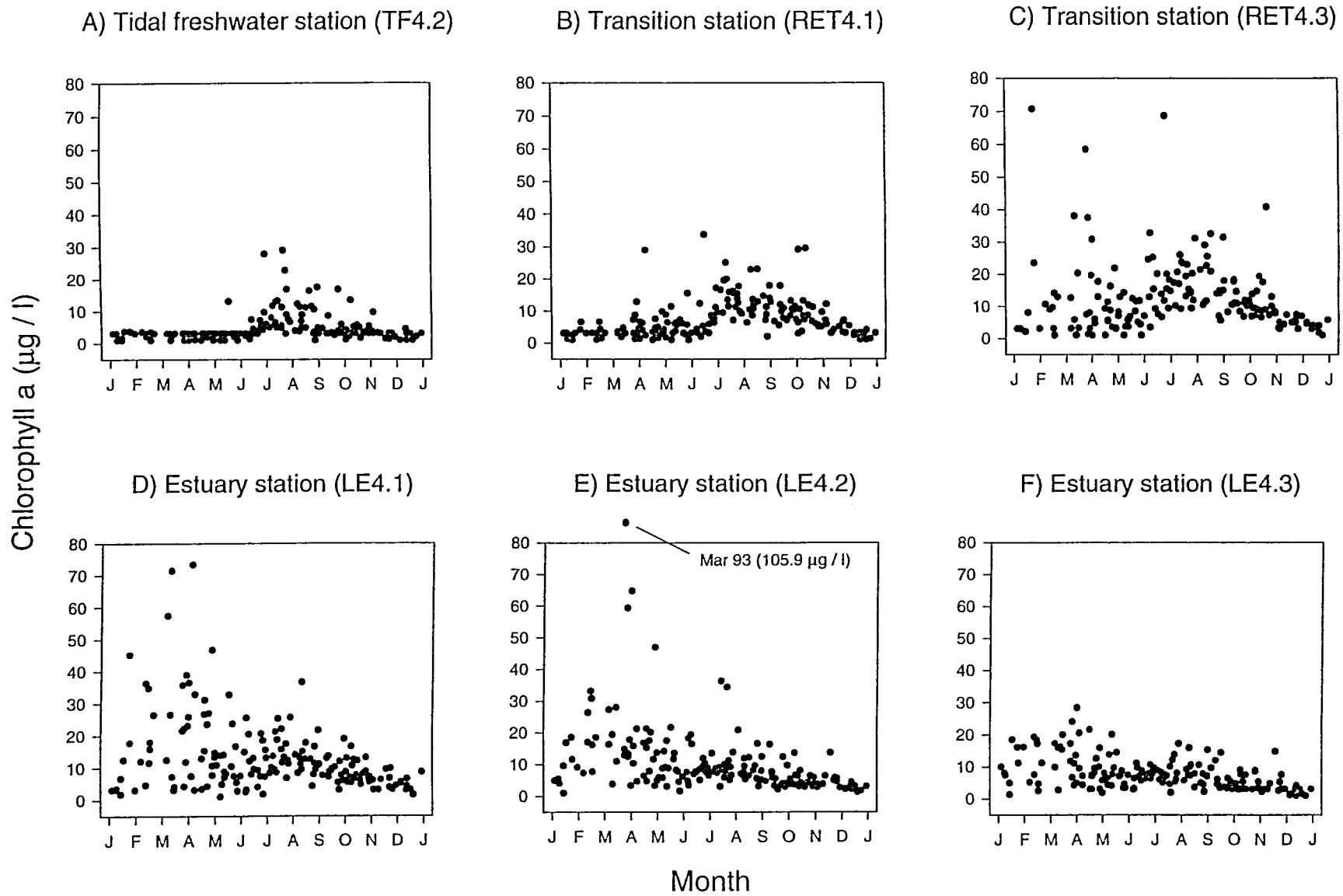


Fig. 2. Seasonal distributions of chlorophyll *a* for 10 years (85-94) in the York river system.

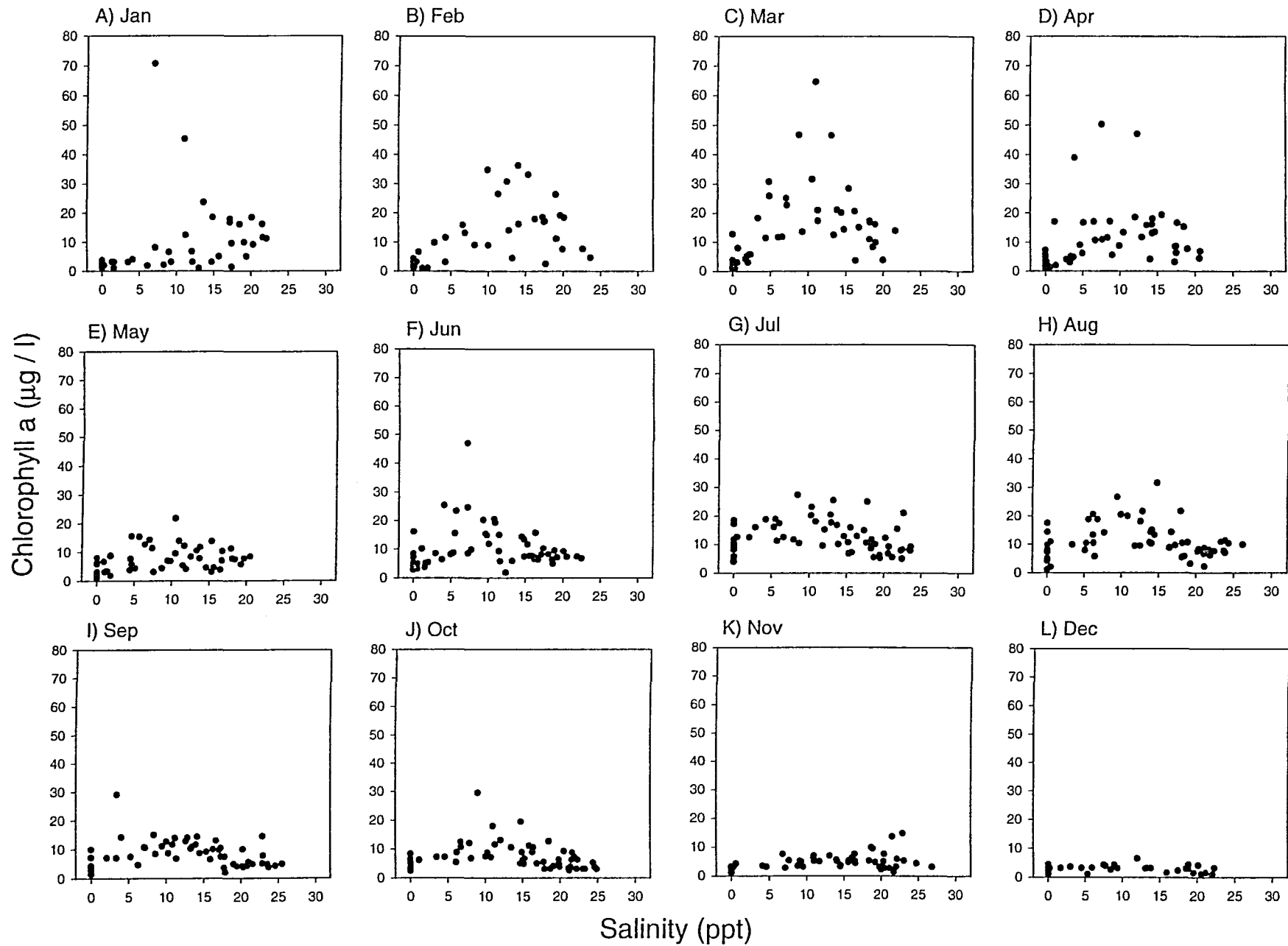


Fig. 3. Spatial distributions of chlorophyll *a* over salinity gradients from January to December (1985-1994) in the York river system.

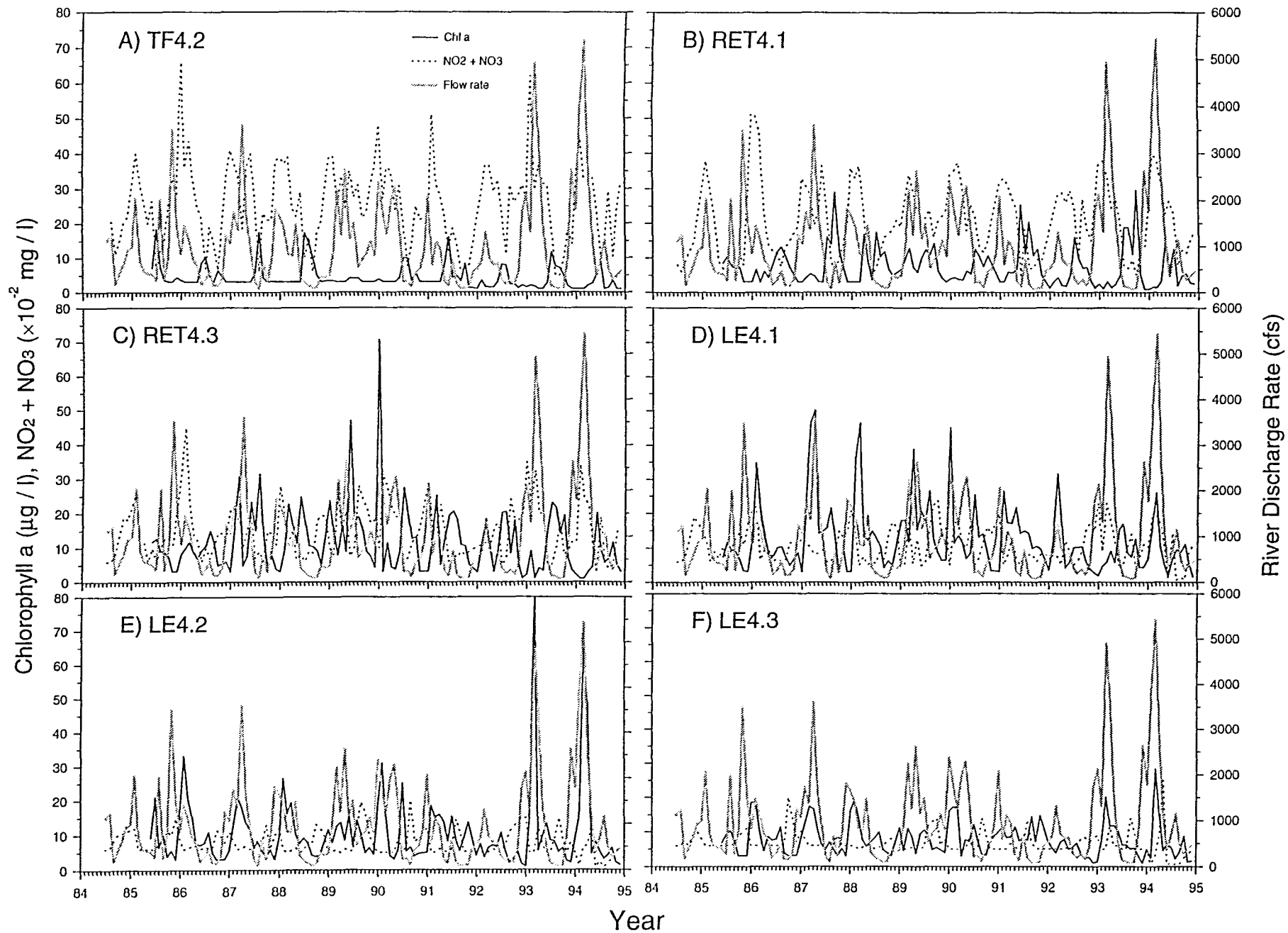


Fig. 4. Temporal distributions of chlorophyll a, nitrate + nitrite and river discharge rate from June 1984 to December 1994.

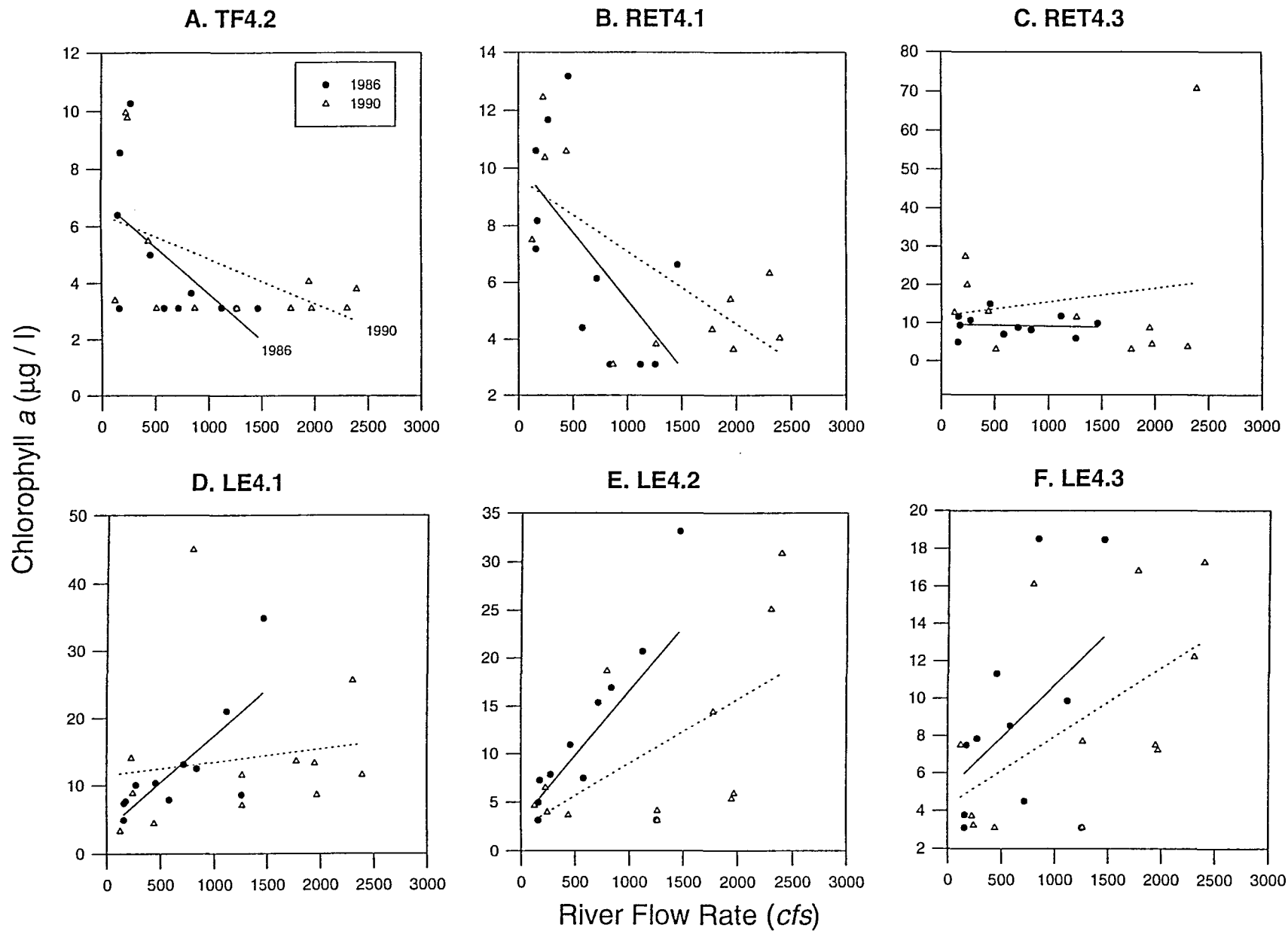


Fig. 5. Correlation between chlorophyll *a* and river discharge rate. One month-lag was considered from January to May and 2 month-lag from June to December for LE4.1, LE4.2 and LE4.3

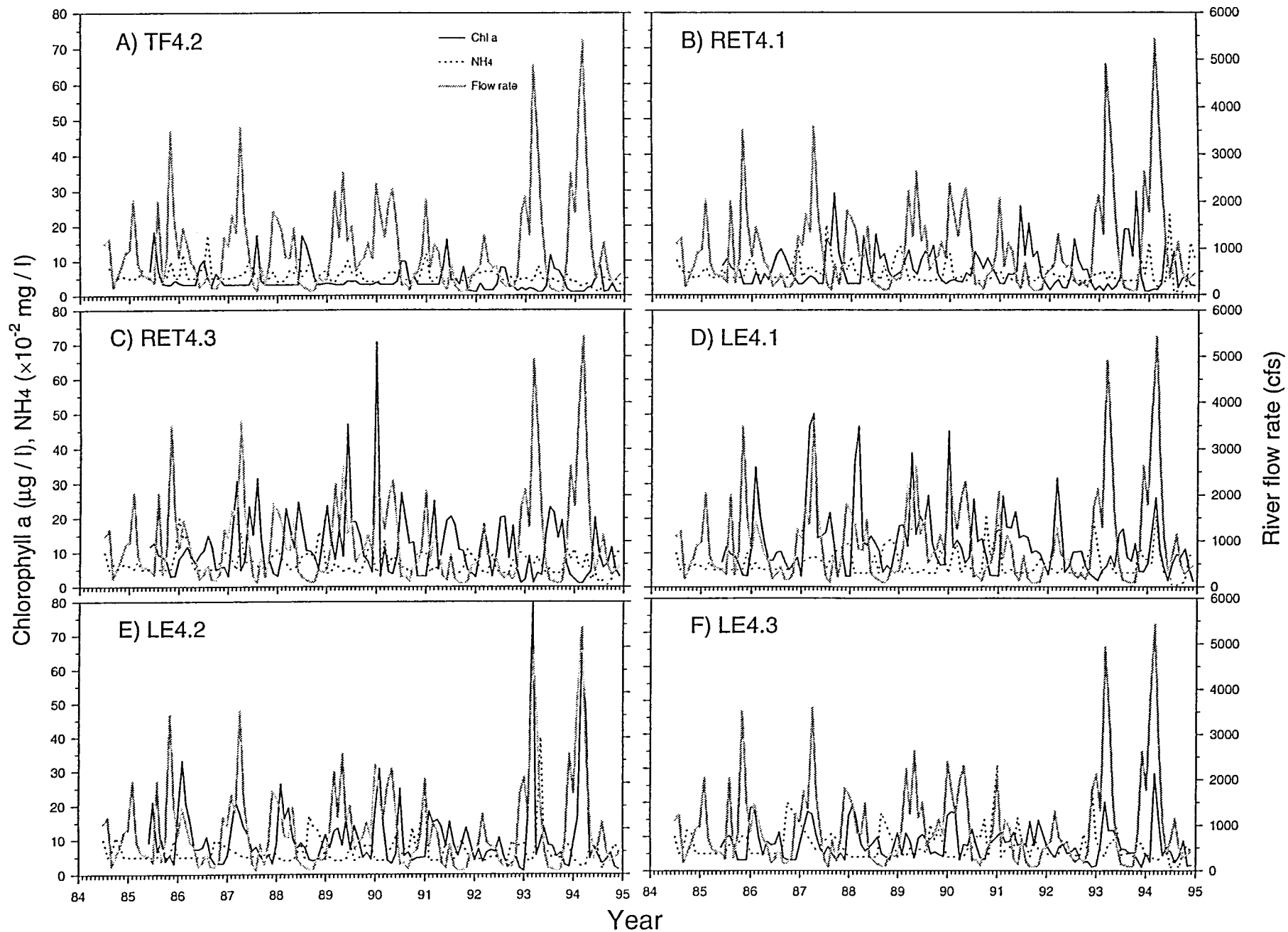


Fig. 6. Temporal distributions of chlorophyll *a*, ammonia and river discharge rate from June 1984 to December 1994.

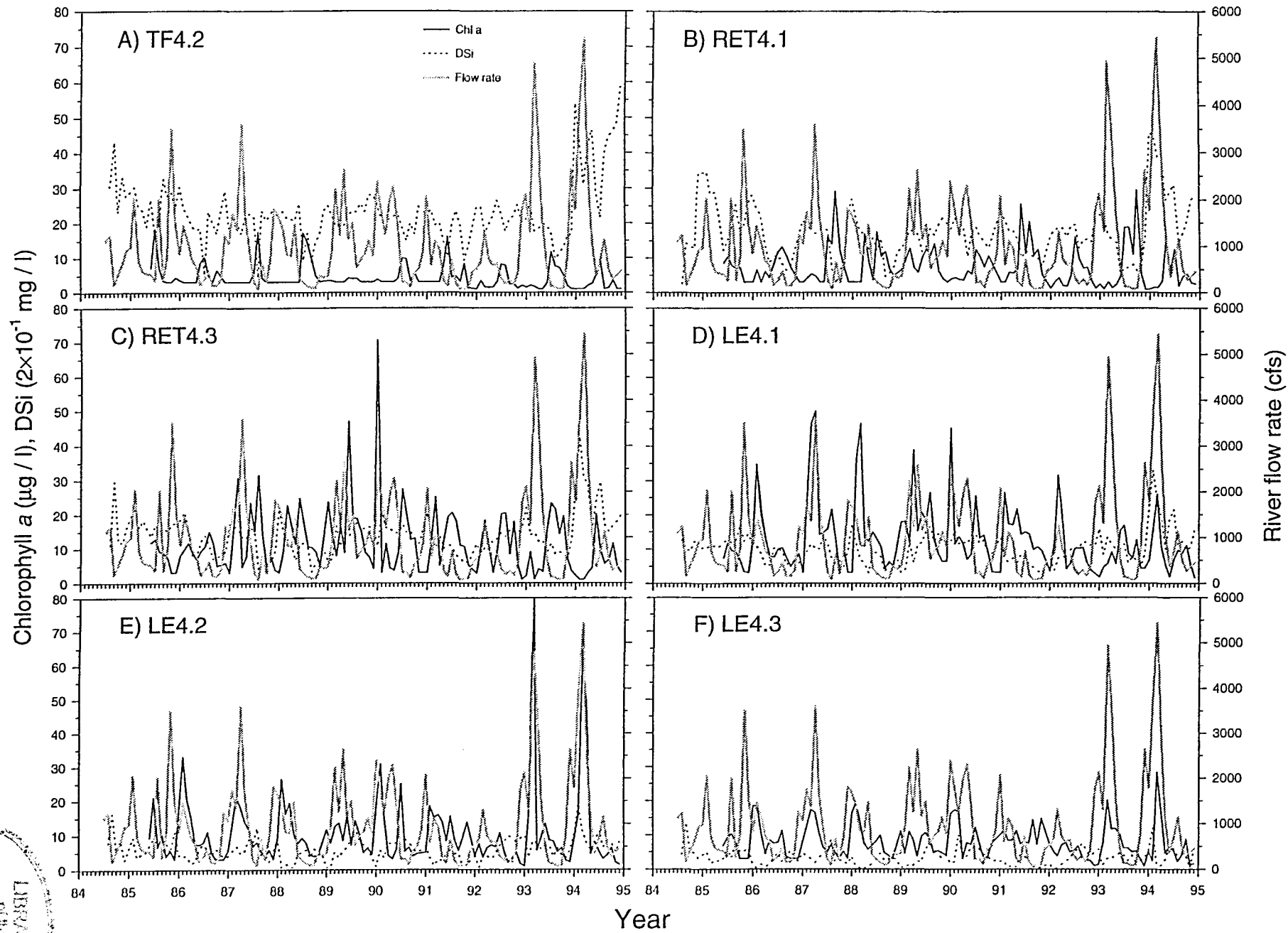
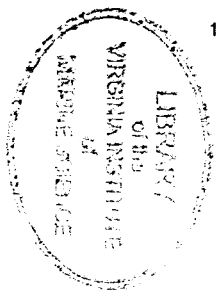


Fig. 7. Temporal distributions of chlorophyll *a*, silica and river discharge rate from June 1984 to December 1994.



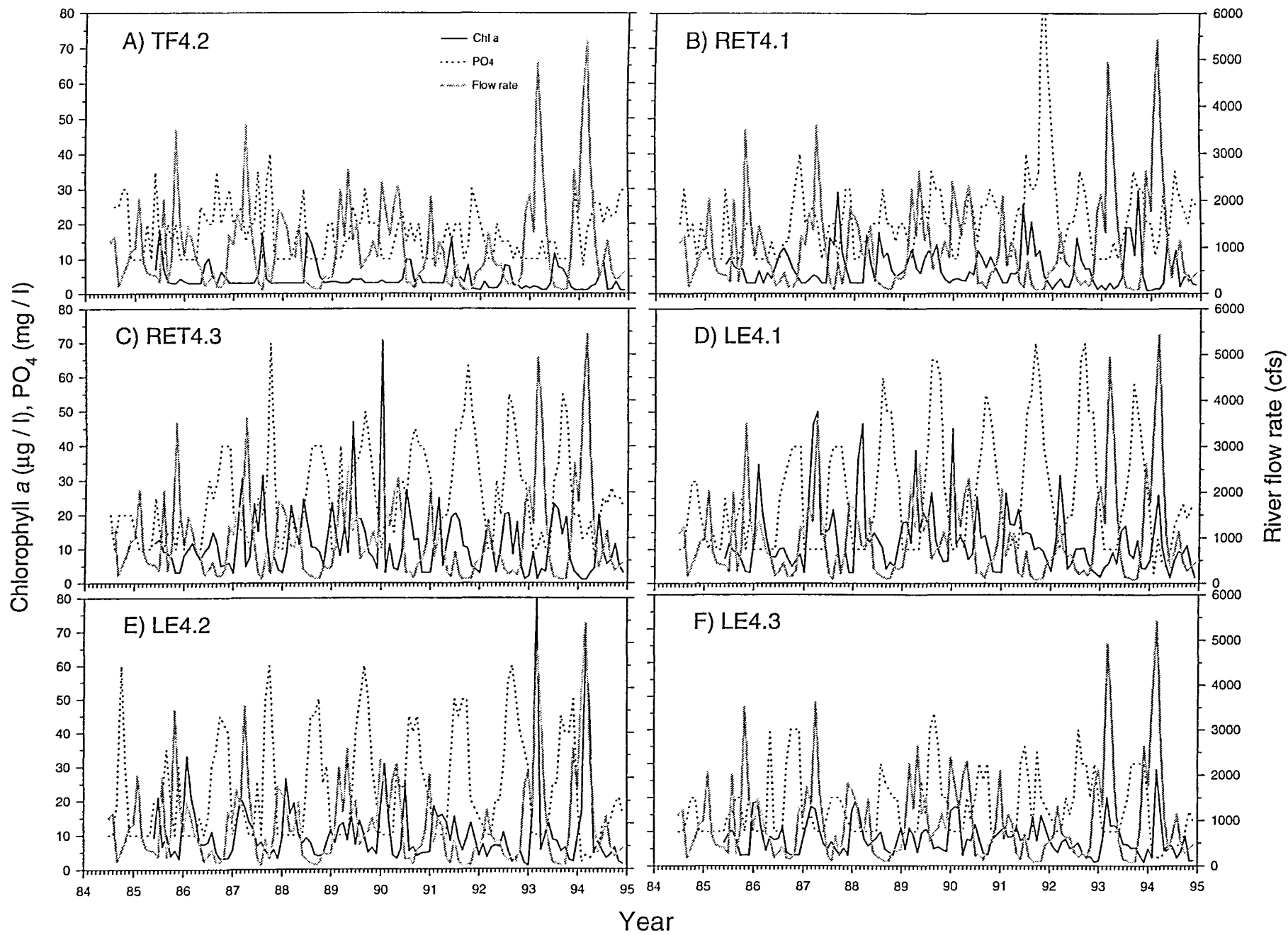


Fig. 8. Temporal distributions of chlorophyll *a*, orthophosphate and river discharge rate from June 1984 to December 1994.

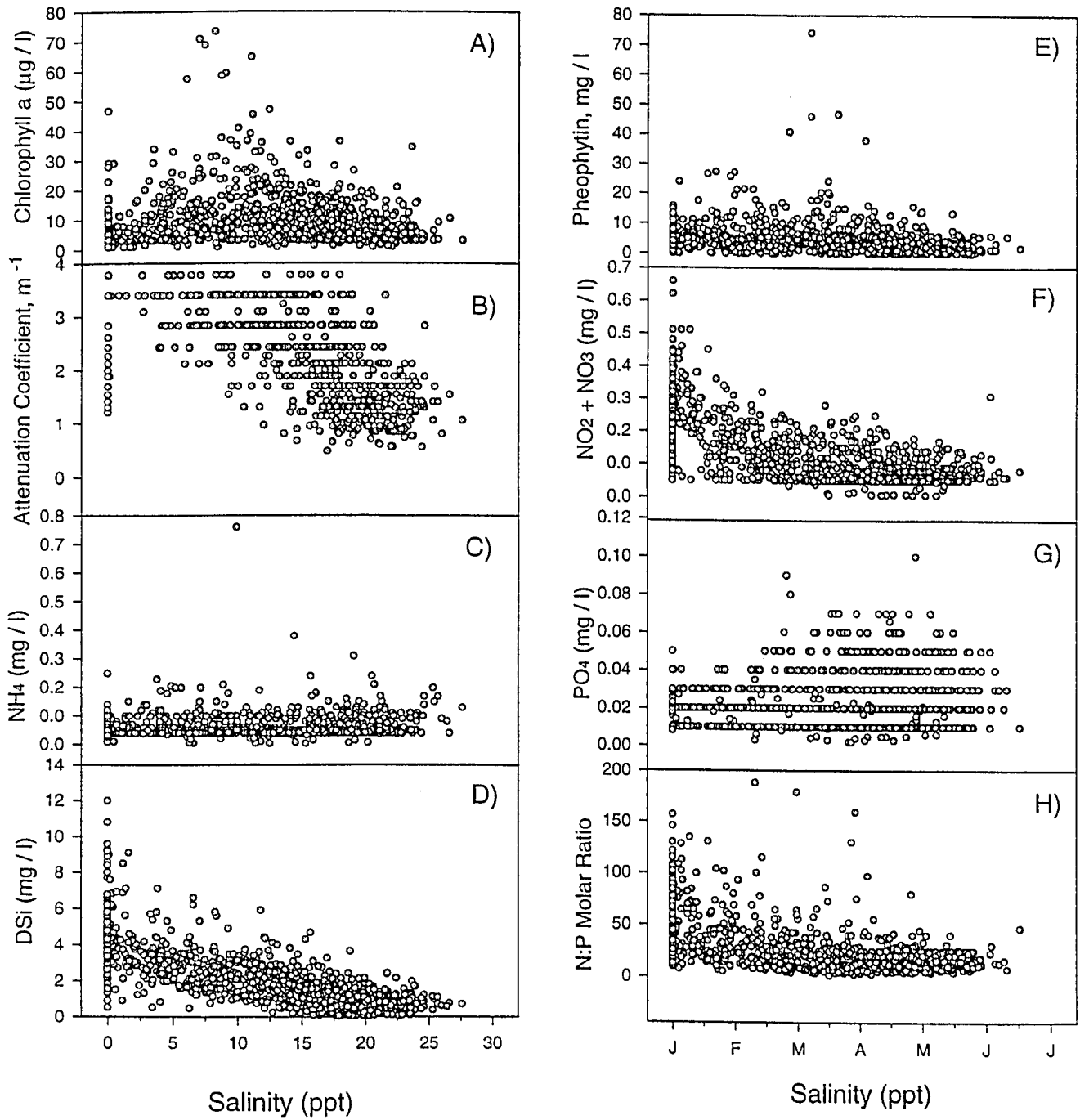


Fig. 9. Distributions of chlorophyll a, pheophytin, light attenuation coefficient and nutrients over salinity gradient (0-30‰).

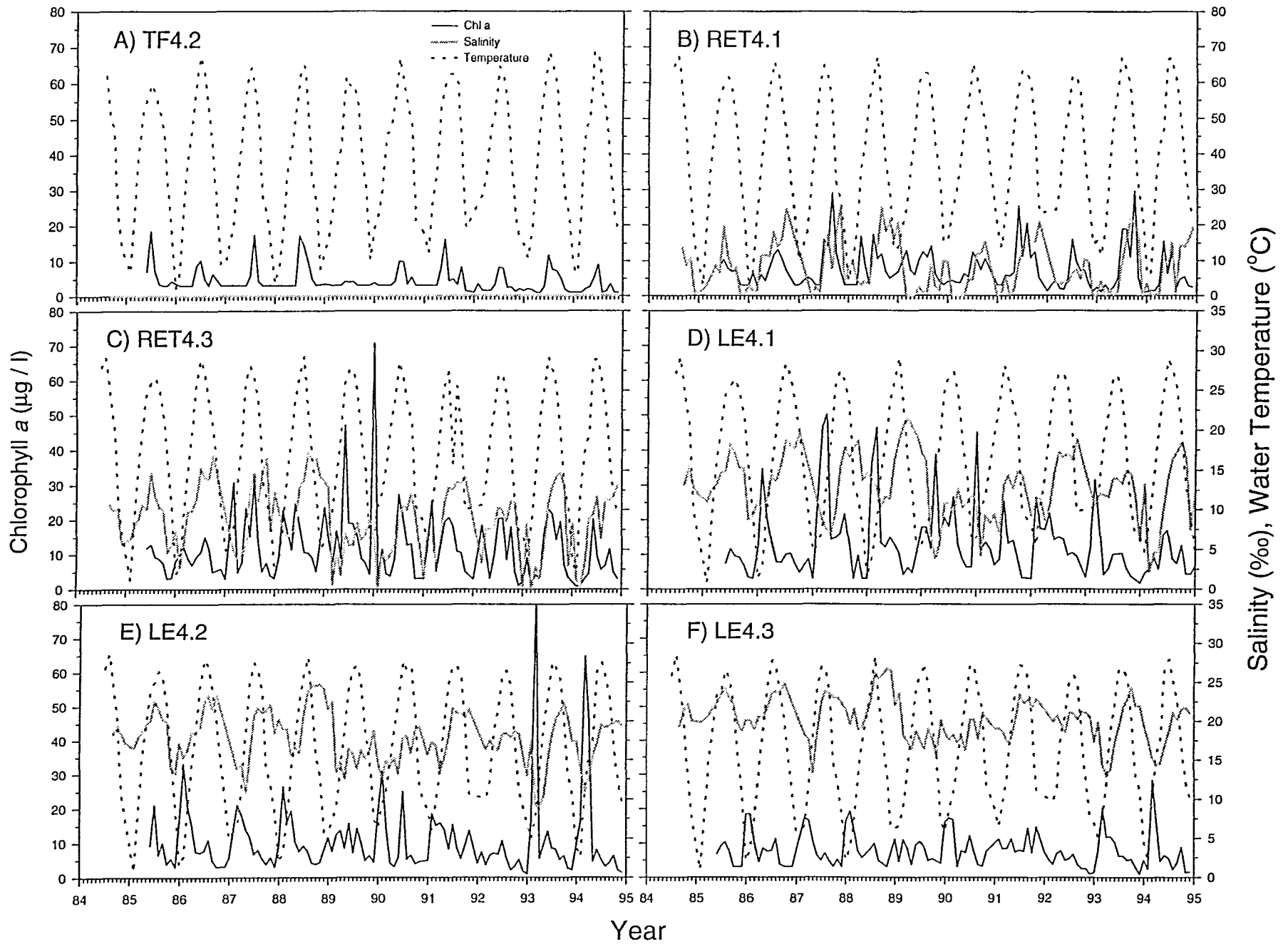


Fig. 10. Temporal distributions of chlorophyll a, salinity and water temperature from June 1984 to December 1994.

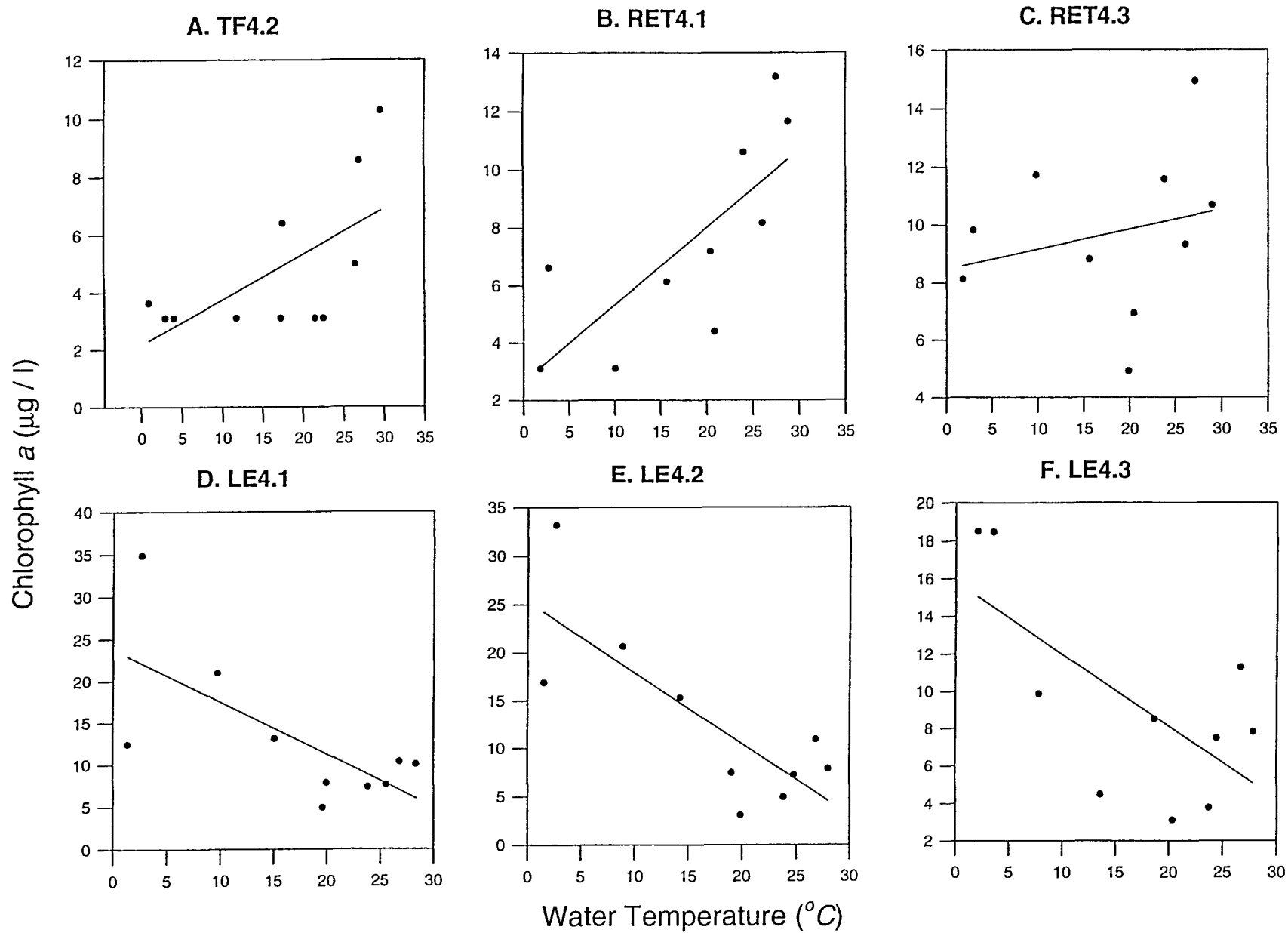


Fig. 11. Correlation between chlorophyll *a* and water temperature in 1986.

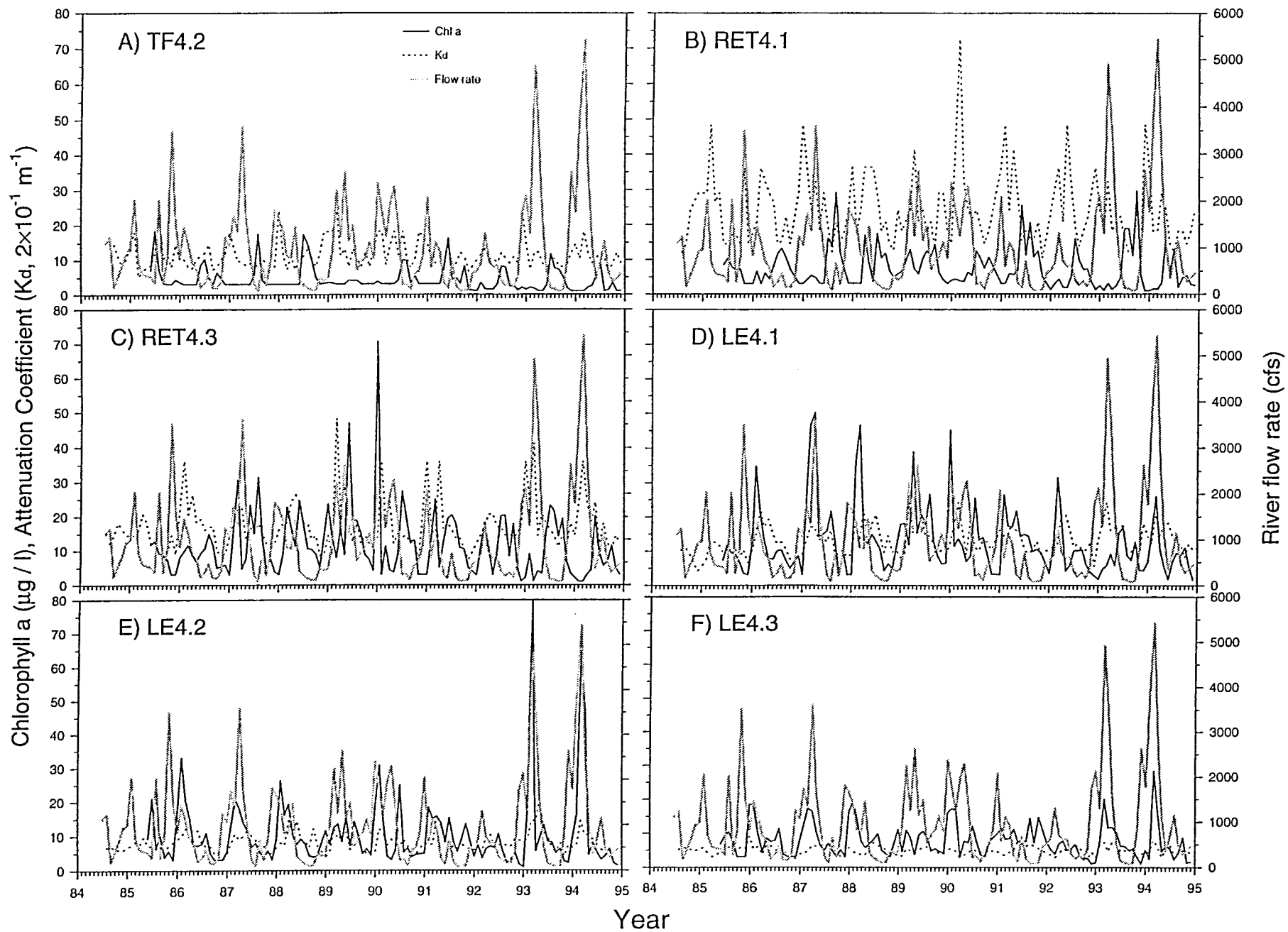


Fig. 12. Temporal distributions of chlorophyll a, light attenuation coefficient and river discharge rate from June 1984 to December 1994.

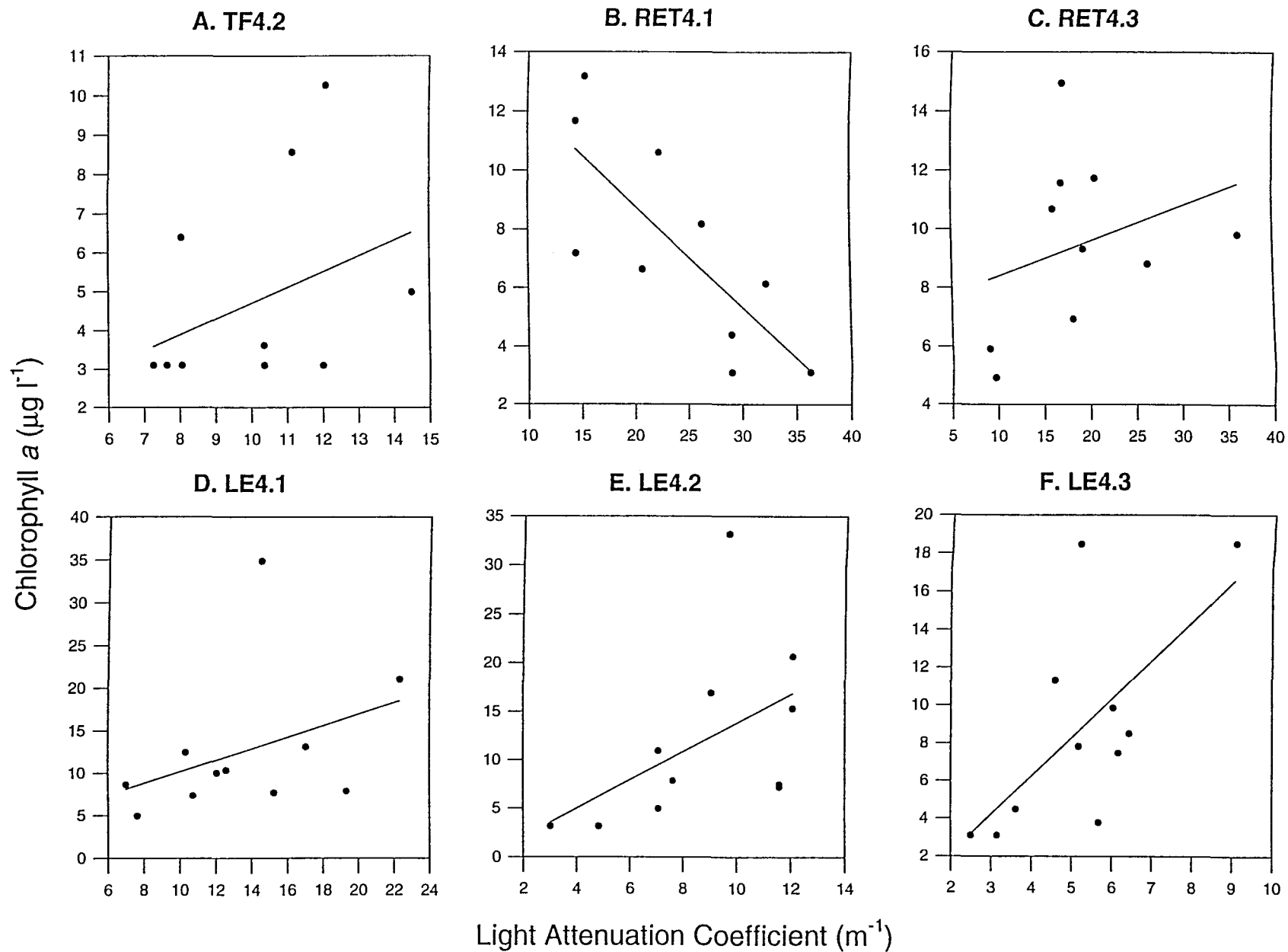


Fig. 13. Correlation between chlorophyll *a* and light attenuation coefficient in 1986.

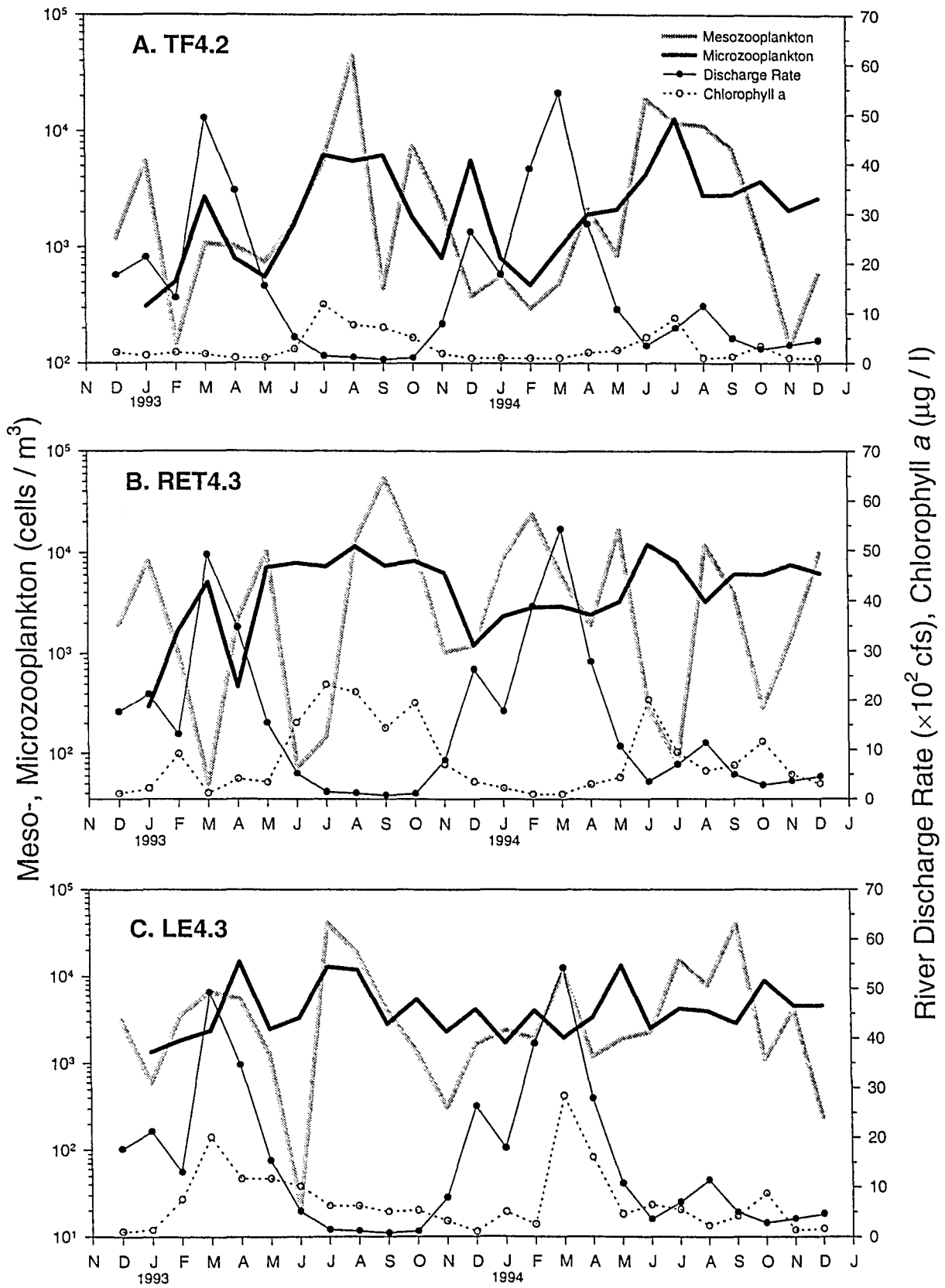


Fig. 15. Temporal distributions of micro- and mesozooplankton, chlorophyll *a* and river discharge rate (1993-1994).

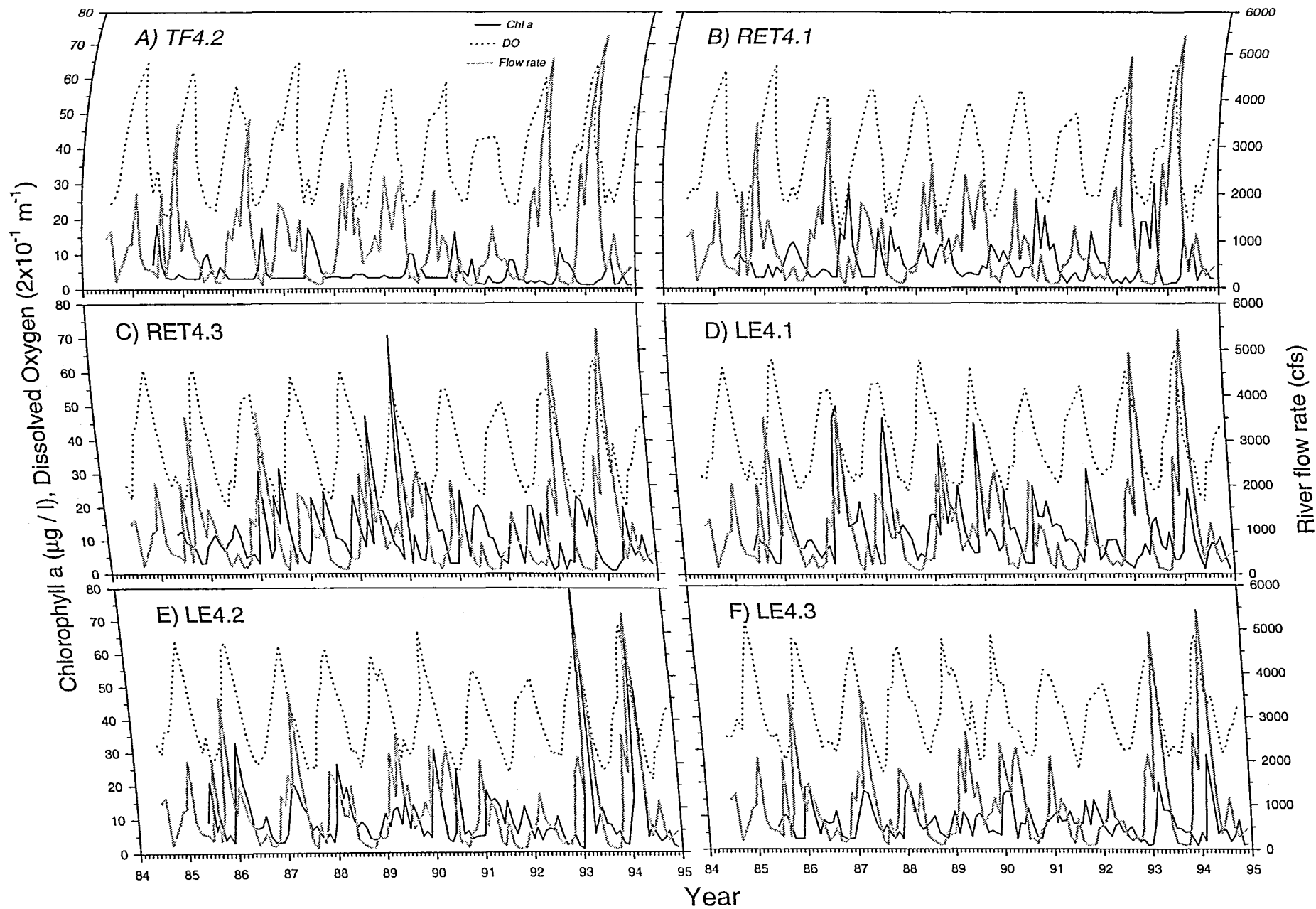


Fig. 16. Temporal distributions of chlorophyll *a*, dissolved oxygen and river discharge rate from June 1984 to December 1994.

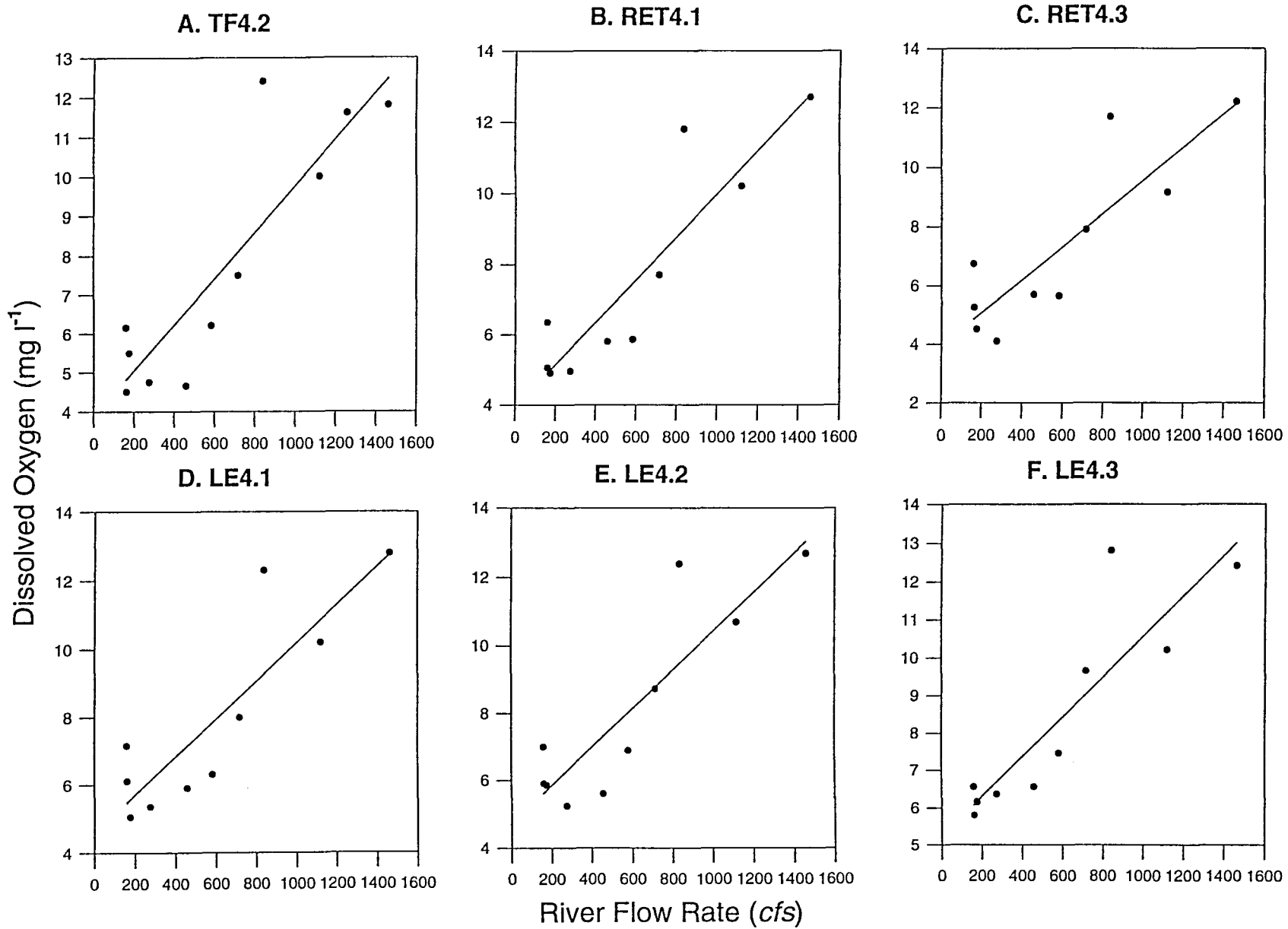


Fig. 17. Regression analysis of dissolved oxygen vs. river flow rate in 1986.

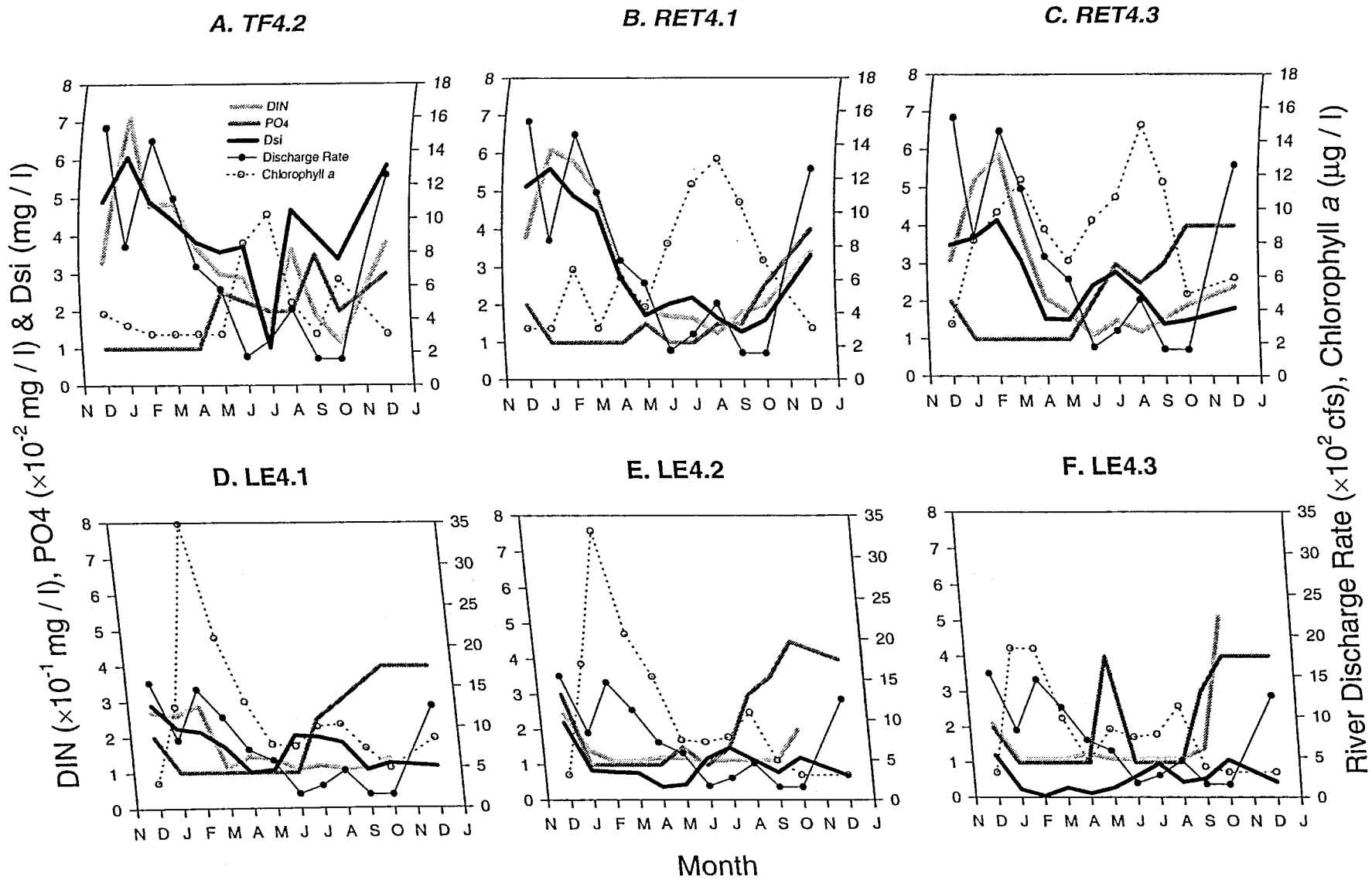


Fig. 18. Nutrients and chlorophyll *a* dynamics in 1986 (mean river discharge rate = 621 cfs).

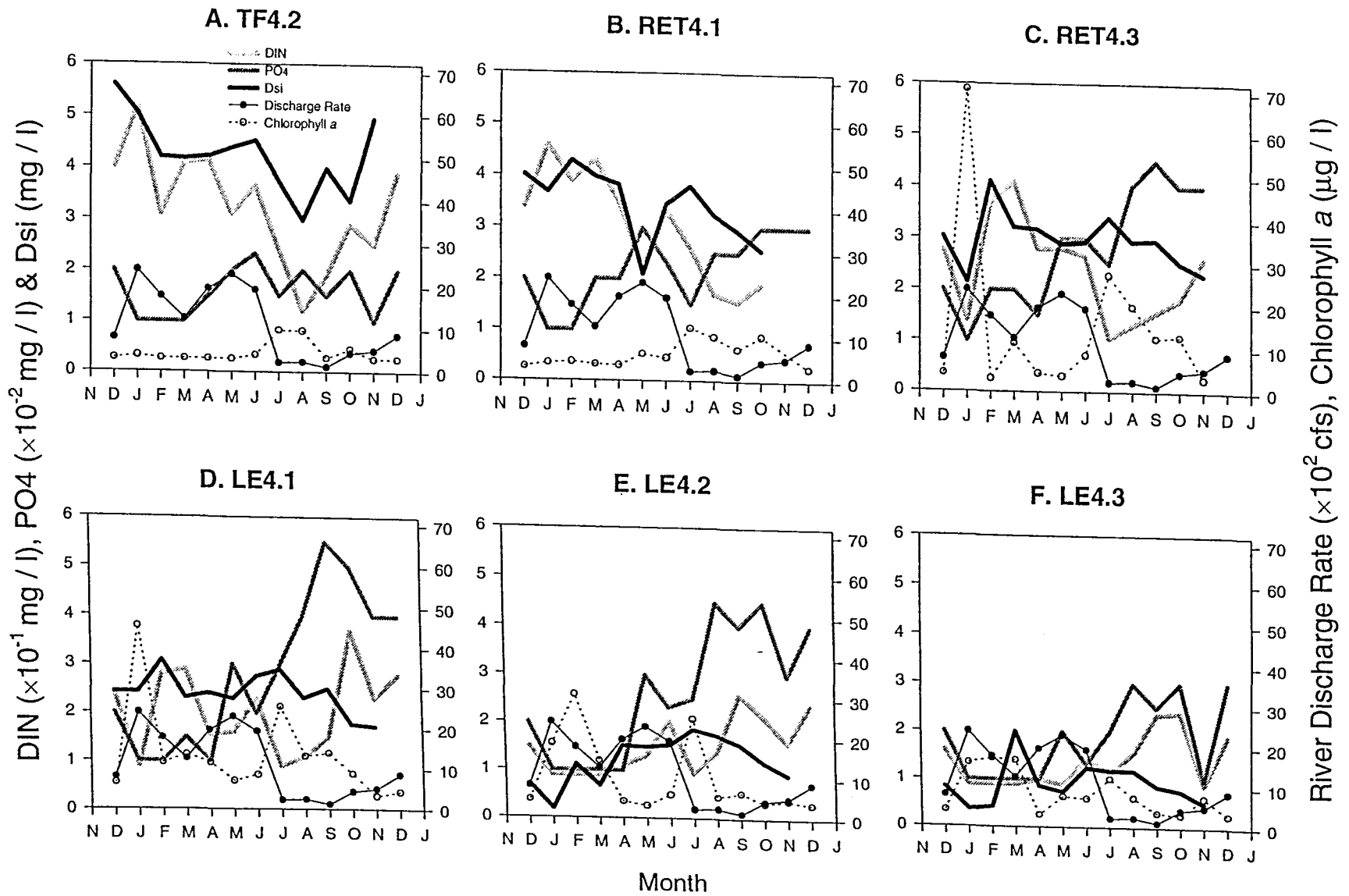
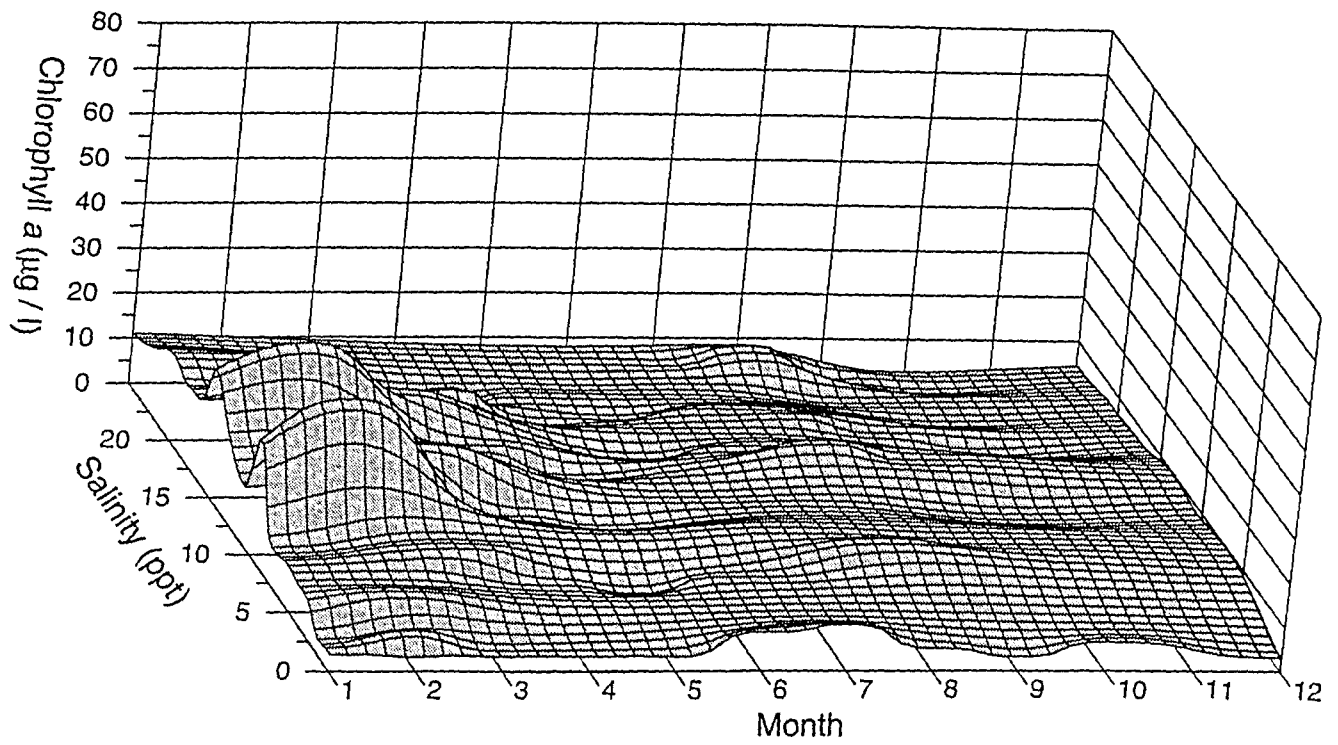


Fig. 19. Nutrients and chlorophyll a dynamics in 1990 (mean discharge rate = 1128 cfs).

A) 1986



B) 1990

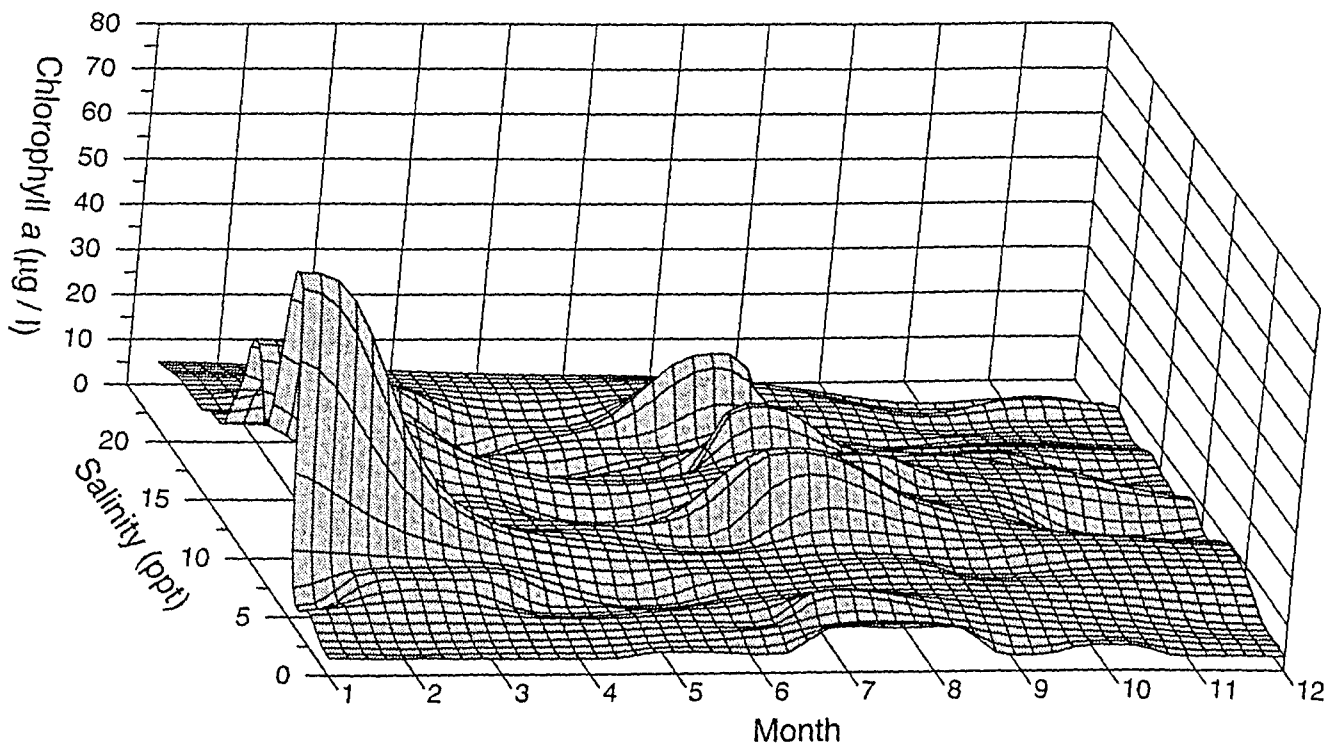


Fig. 20. Temporal and spatial distribution of chlorophyll *a* of 1986 and 1990.

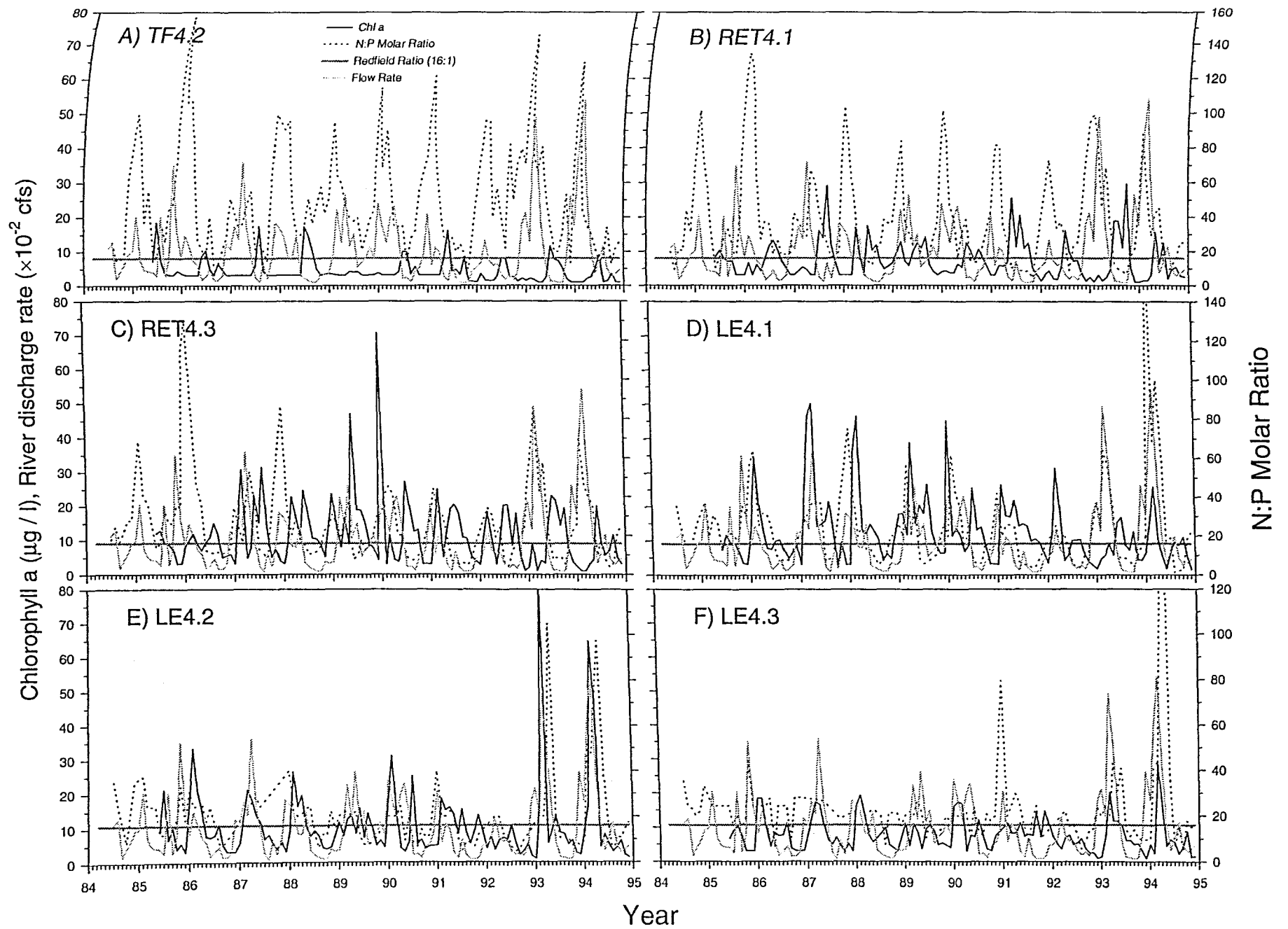


Fig. 21. Temporal distributions of chlorophyll a and N:P molar ratio from June 1984 to December 1994.

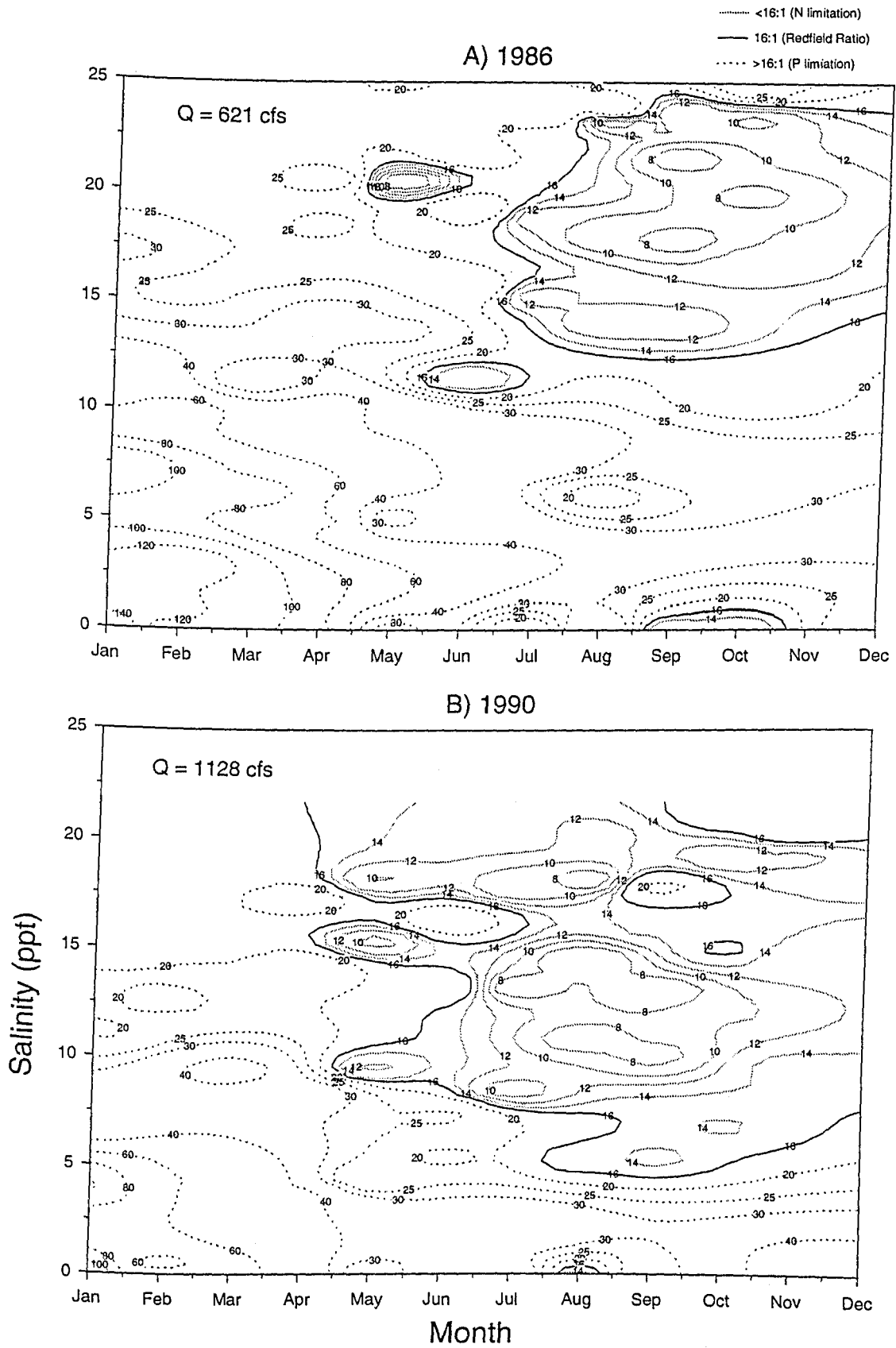


Fig. 22. Temporal and spatial distributions of molar N:P ratio in 1986 and 1990.

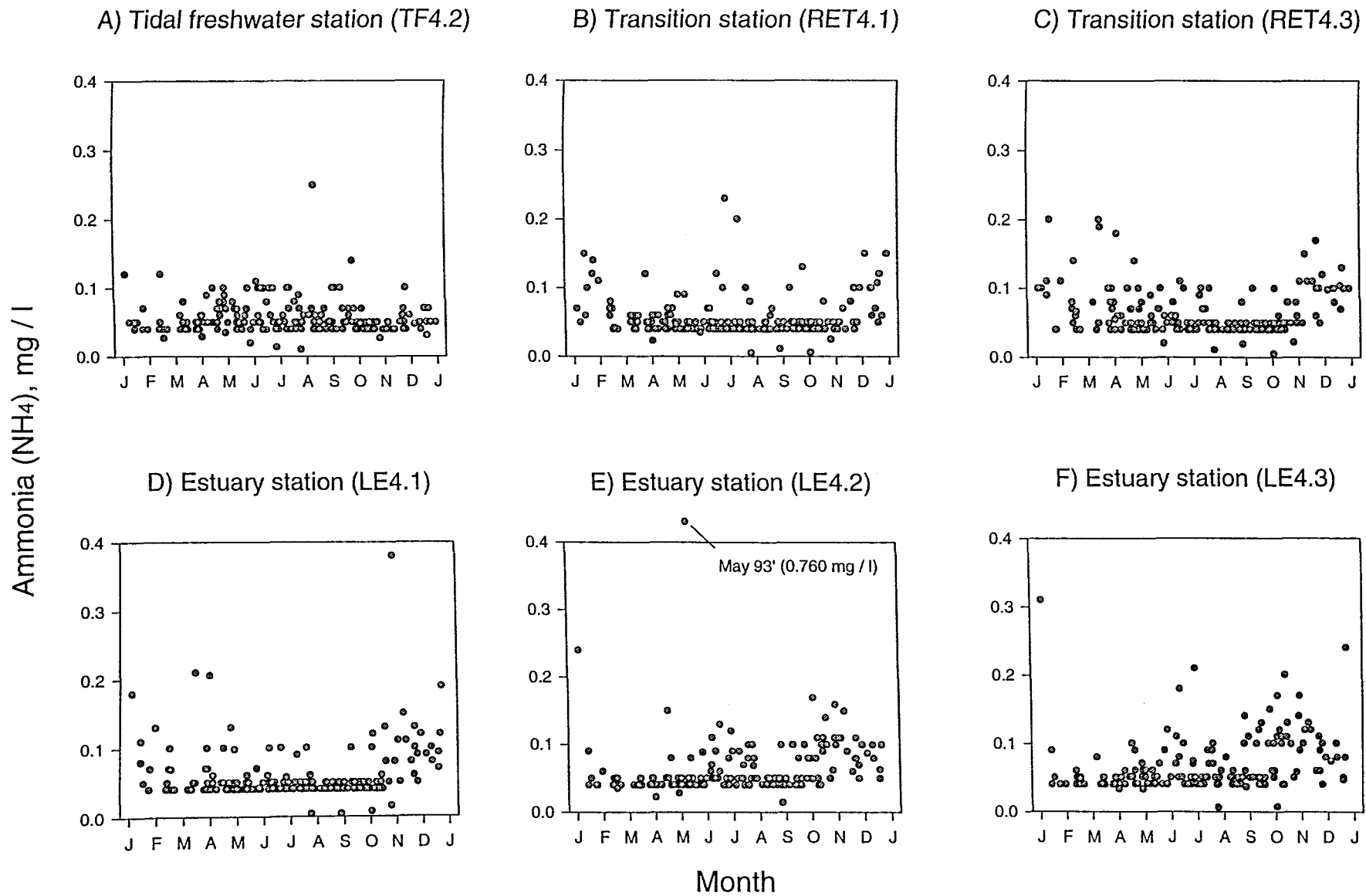


Fig. 23. Seasonal distributions (85-94) of ammonia at six stations from surface water

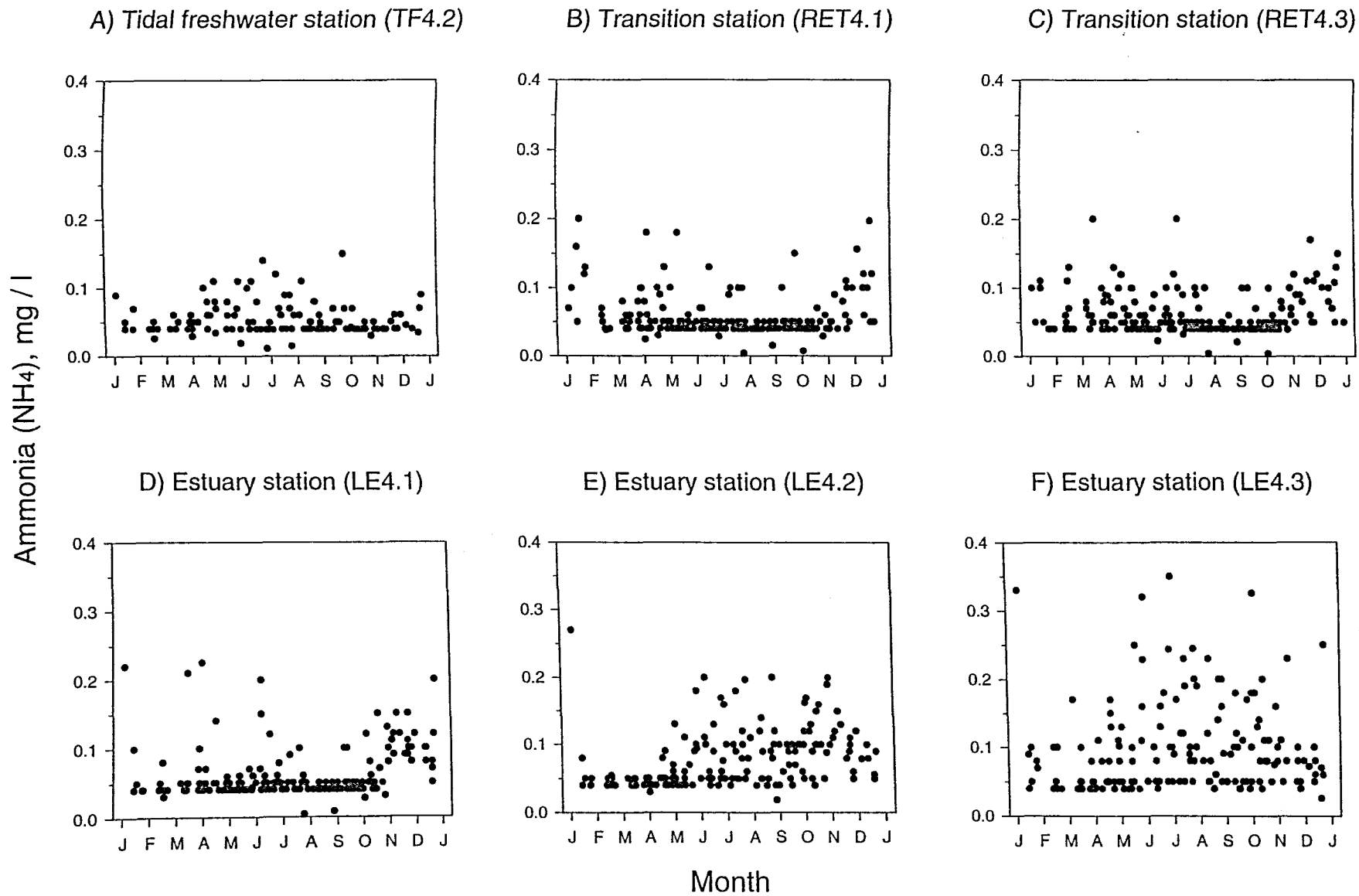


Fig. 24. Seasonal distributions (85-94) of ammonia at six stations from bottom water

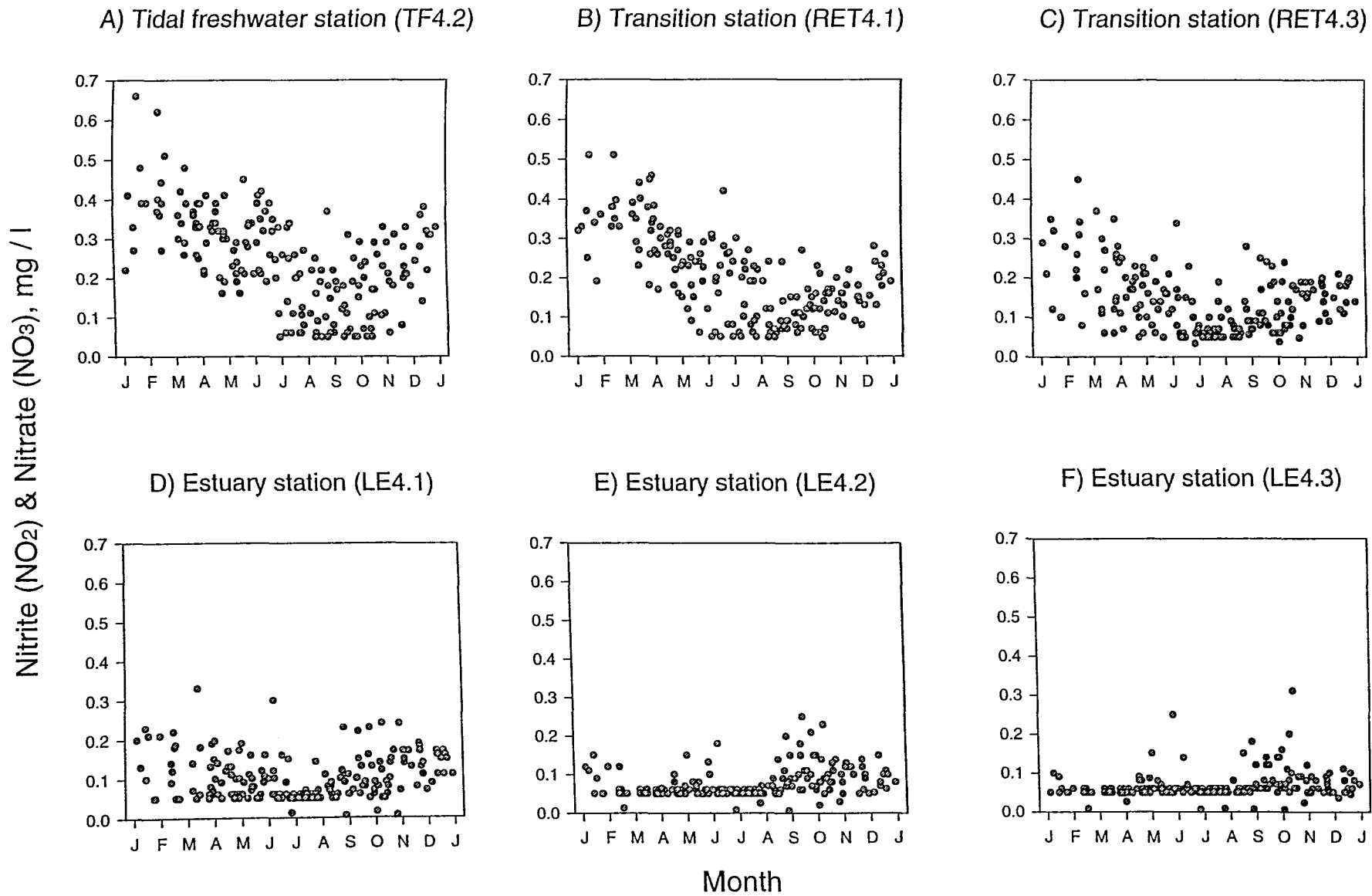


Fig. 25. Seasonal distributions of nitrite + nitrate (85-94) from surface water.

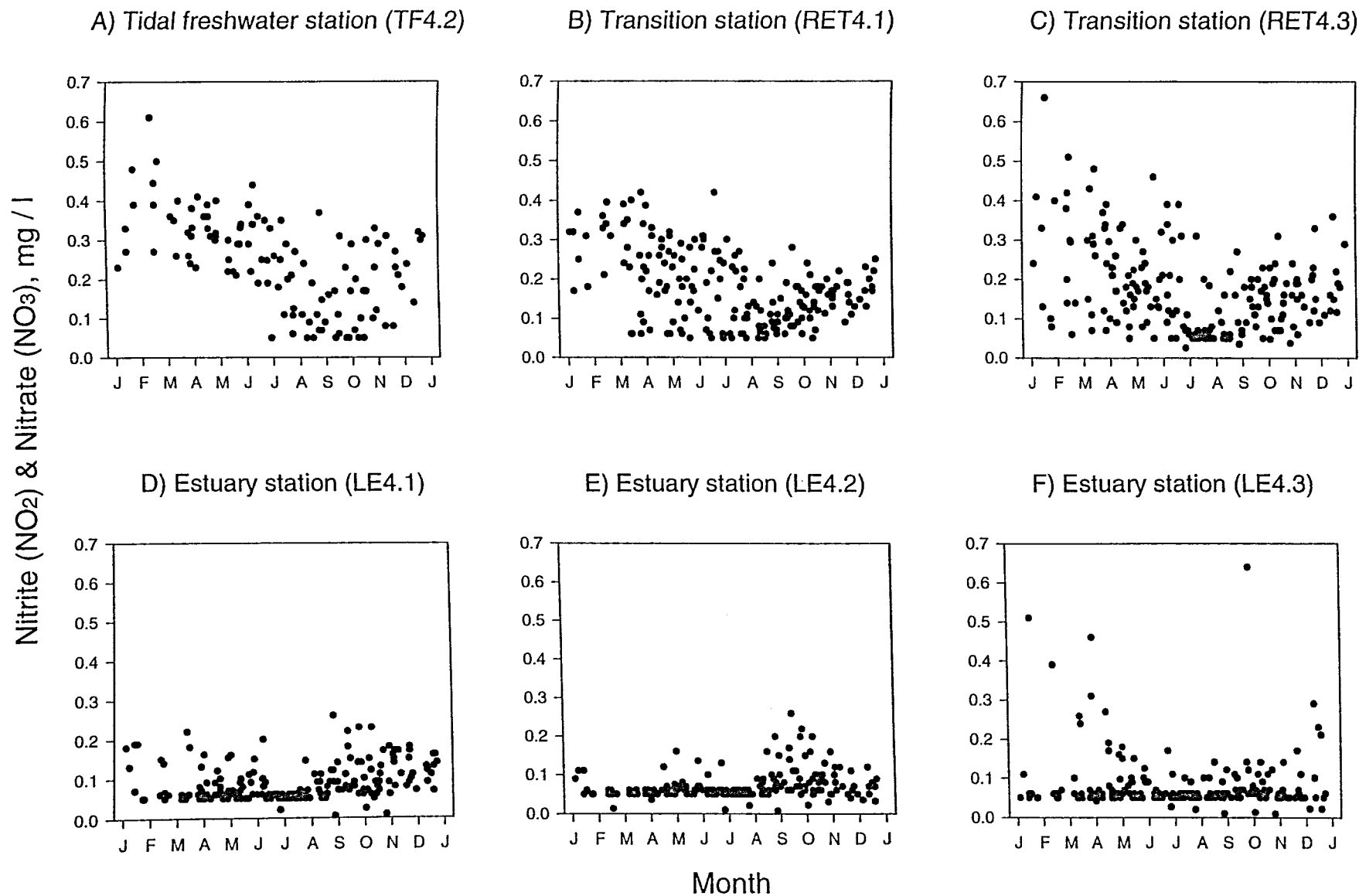


Fig. 26. Seasonal distributions of nitrite + nitrate (85-94) from bottom water.

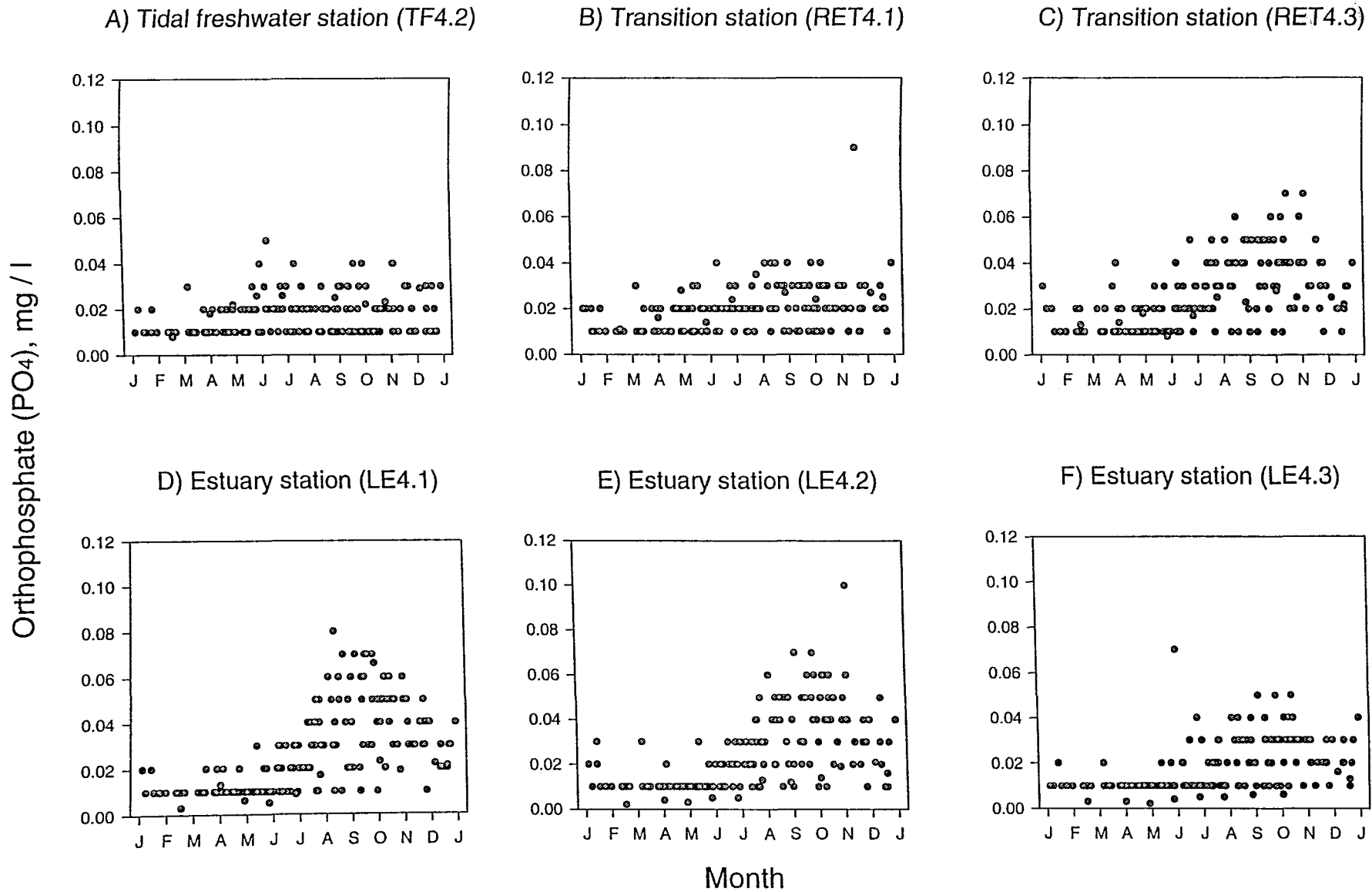


Fig. 27. Seasonal distributions of orthophosphate (85-94) from surface water.

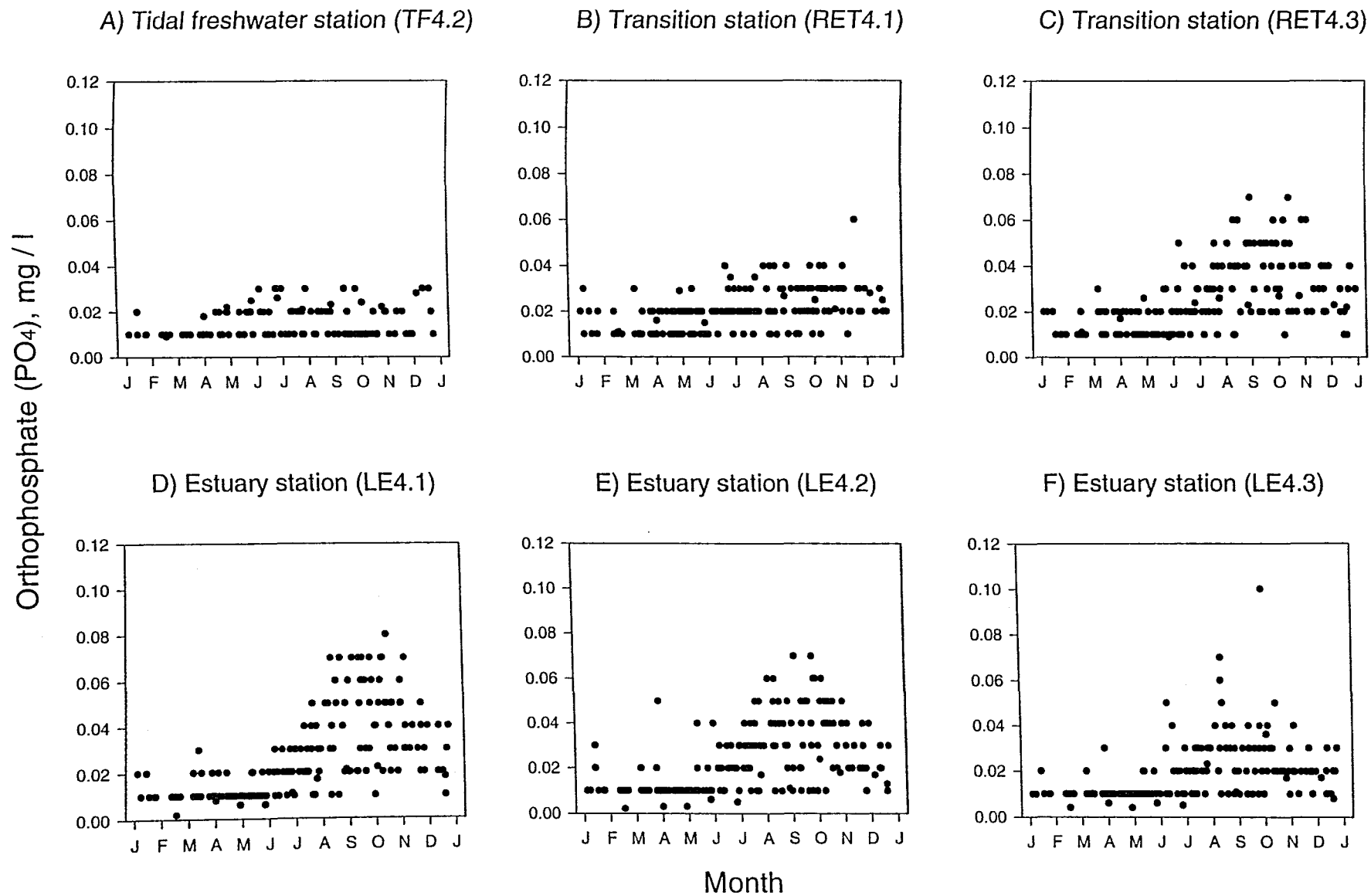


Fig. 28. Seasonal distributions of orthophosphate (85-94) from bottom water.

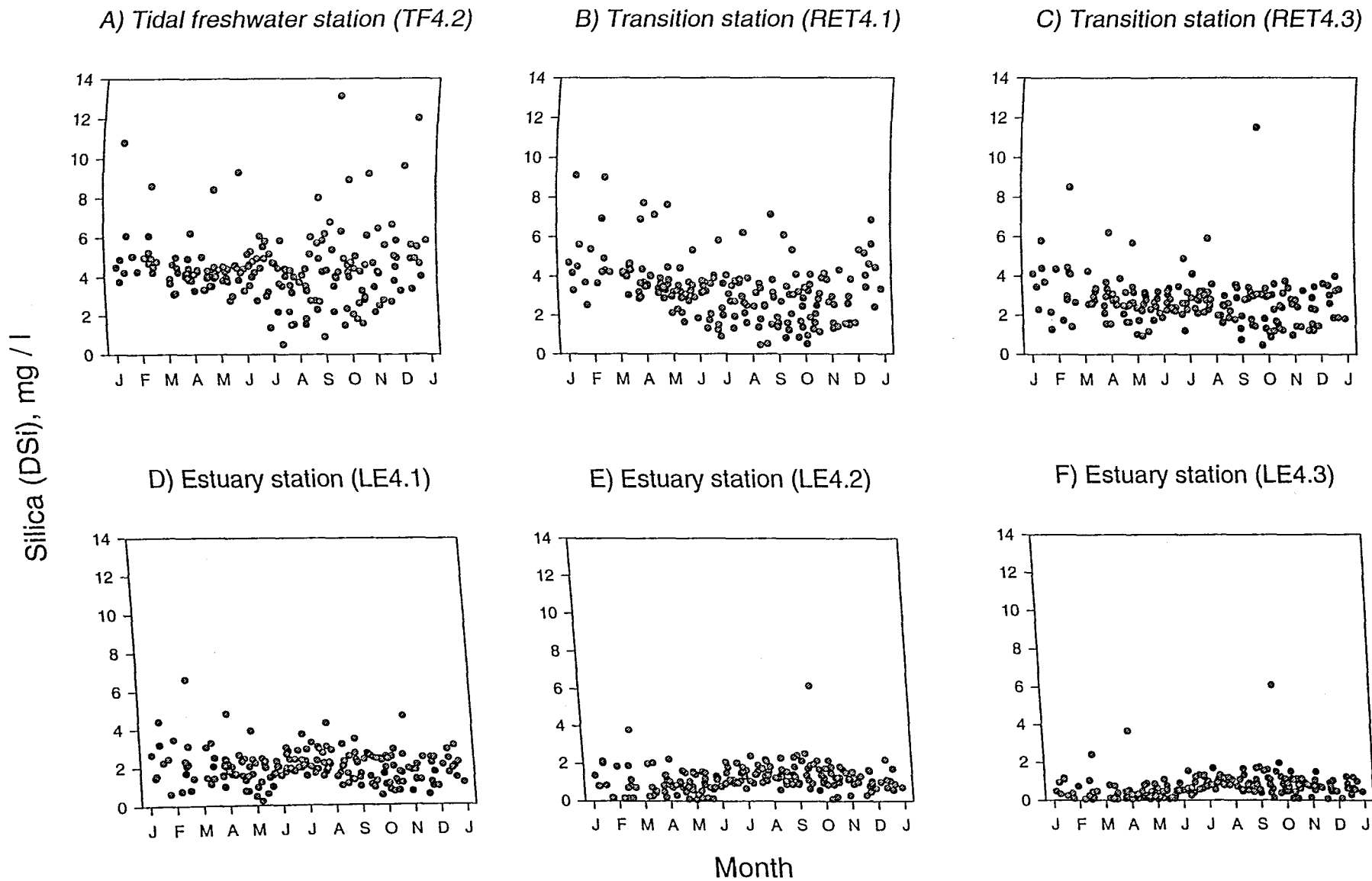


Fig. 29. Seasonal distributions of silica from surface water for 10 years (85-94).

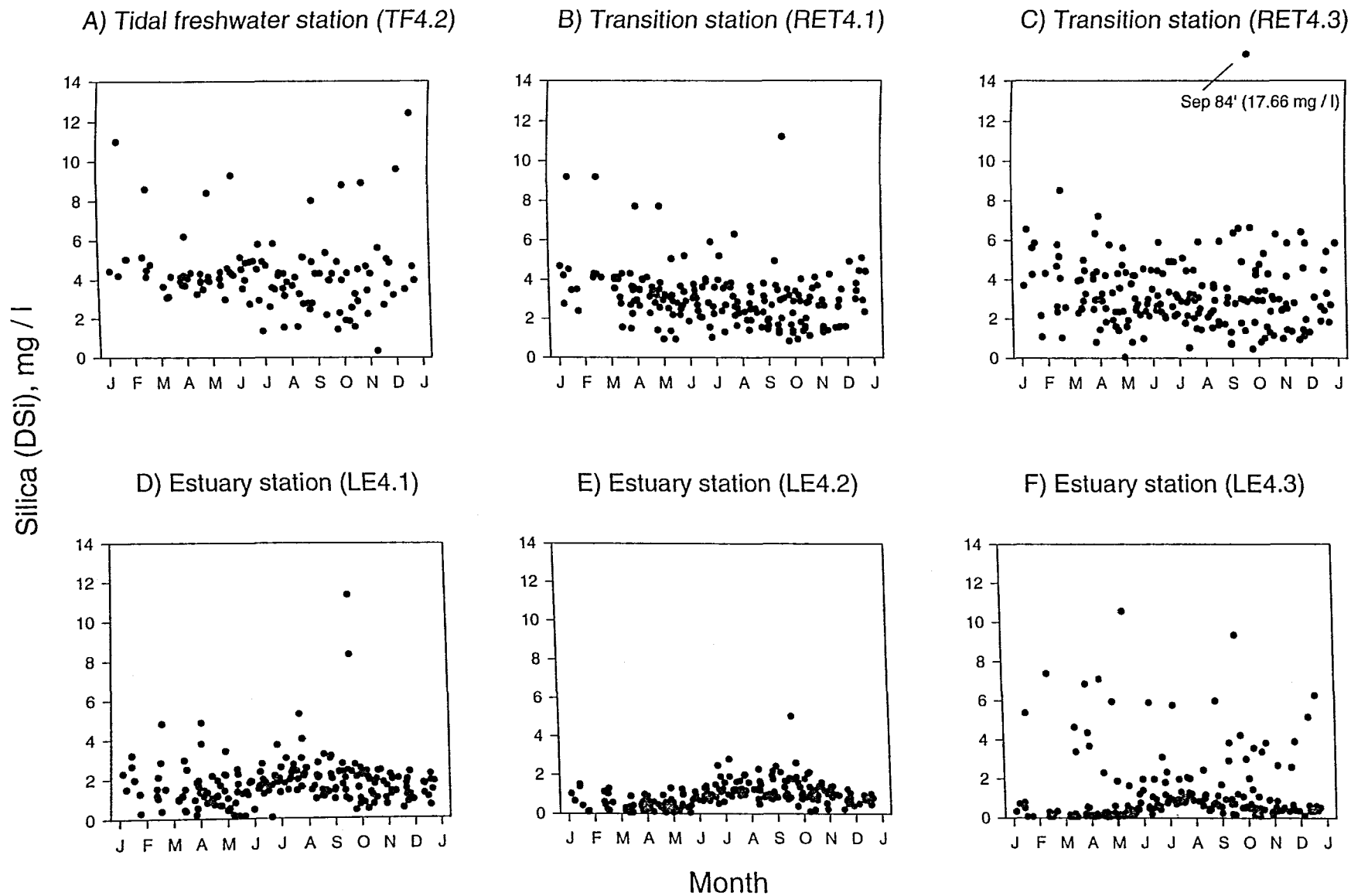


Fig. 30. Temporal distributions of silica from bottom water for 10 years (85-94).

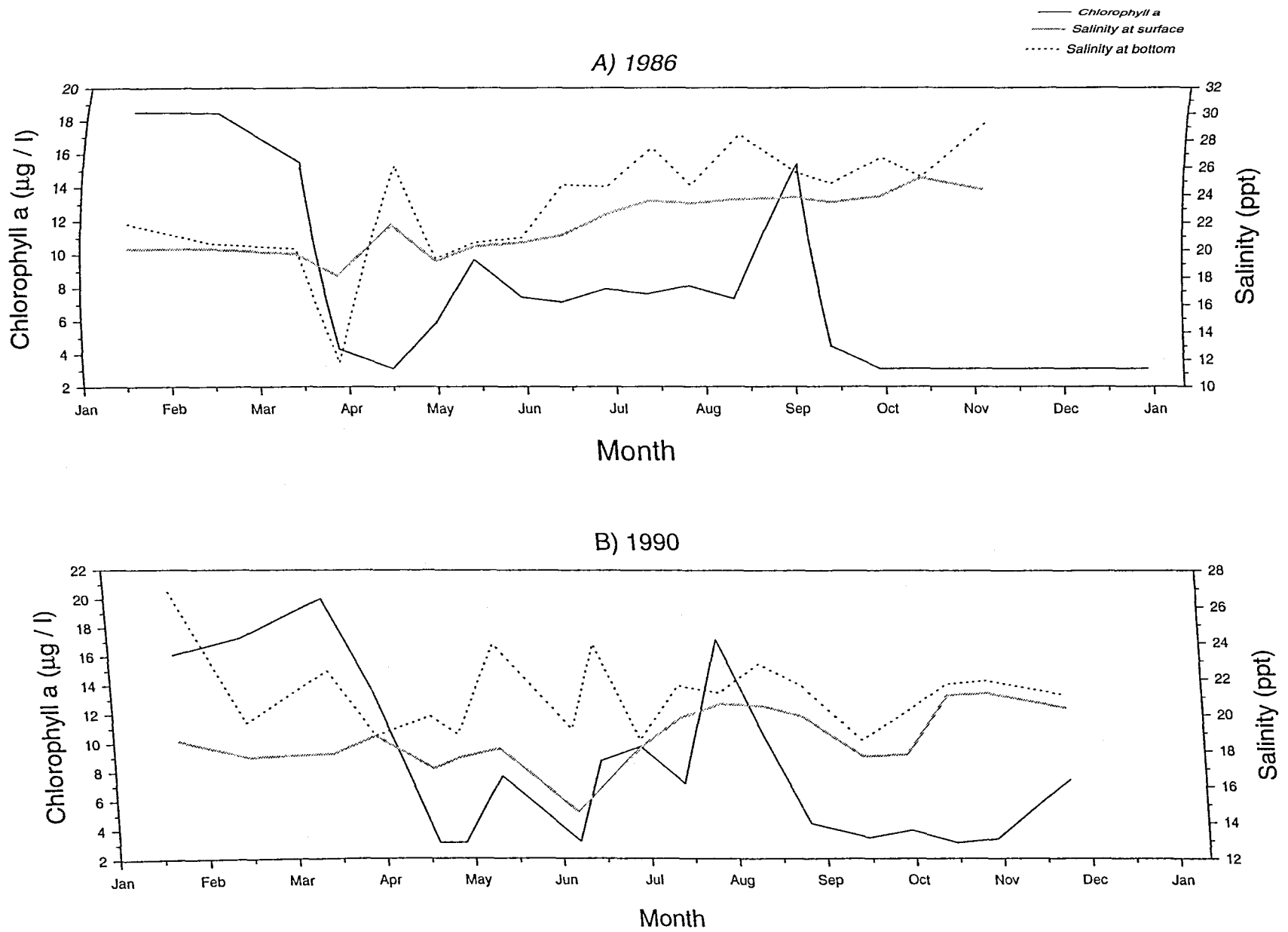


Fig. 31. Distributions of chlorophyll *a* and salinity from surface and bottom water in 1986 and 1990.

REFERENCES

- Bell, C. F., D. L. Belval, and J. P. Campbell. 1996. Trends in Nutrients and Suspended Solids at the Fall Line of Five Tributaries to the Chesapeake Bay in Virginia, July 1988 through June 1995. Water-Resources Investigations Report 96-4191. U.S. Geological Survey, Richmond, VA.
- Bender, M. E. 1986. The York River: A brief review of its physical, chemical and biological characteristics. Virginia Institute of Marine Science, School of Marine Science, The College of William and Mary, Gloucester Point, VA 23062.
- D'Elia, C. F., J. G. Sanders, and W. R. Boynton. 1986. Nutrient Enrichment Studies in a Coastal Plain Estuary: Phytoplankton Growth in Large-Scale, Continuous Cultures. *Can. J. Fish. Aquat. Sci.* 43:397-406.
- Fisher, T. R., Peele, E. R., Ammerman, J. W., Harding, Jr. L. W. 1992. Nutrient limitation of phytoplankton in Chesapeake Bay. *Mar. Ecol. Prog. Ser.* 82:51-63.
- Haas, L. W. (1975). Plankton dynamics in a temperate estuary with observations on a variable hydrographic conditions. Doctoral dissertation, School of Marine Science, College of William and Mary, Gloucester Point, Virginia.
- Haas, L. W. and R. L. Wetzel. 1993. Nutrient limitation in the Chesapeake Bay: Nutrient Bioassays in the Virginia Bay System. Final Report to Virginia Coastal Resources Management Program.
- Hyer, P. V. 1977. Water quality model of York River, Virginia. Special Scientific Report No. 146. Virginia Institute of Marine Science.
- Meybeck, M., G. Cauwet, S. Dessery, M. Somville, D. Gouleau and G. Billen. 1988. Nutrients (Organic C, P, N, Si) in the Eutrophic River Loire (France) and its Estuary. *Estuar. Coast. Shelf Sci.* 27:595-624.
- Virginia Water Control Board, 1987. Tributary water quality 1986, Characterization report. Chesapeake Bay Water Quality Monitoring Program, Chesapeake Bay Office, Virginia Water Control Board.
- Webb, K. L. 1988. Comment on "Nutrient Limitation of phytoplankton Growth in Brackish Coastal Ponds" by Caraco, Tamse, Boutros, and Valiela (1987). *Can. J. Fish. Aquat. Sci.* 45:380