MICROPLANKTON DIVERSITY INDICES AS INDICATORS OF EUTROPHICATION IN THE NORTHERN ADRIATIC SEA

Noelia REVELANTE & Malvern GILMARTIN

Department of Oceanography, University of Maine, Orono, Maine 04469
Center for Marine Studies, University of Maine, Orono, Maine 04469

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Abstract

Phytoplankton community diversity indices are used to characterize the effects of eutrophication in the Northern Adriatic Sea. A derived Shannon diversity frequency spectrum provided a single biological quantification which allowed an interpretation of temporal and regional differences and which can also be used to evaluate future changes in species diversity. The data base comprised a 4+ year time series involving 300 taxa.

Introduction

A species diversity index is a biological indicator which integrates information on the kinds and numbers of organisms present in a community, in a single datum, which can be treated heuristically like another environmental parameter. A positive relationship between low phytoplankton species diversity and high productivity (e.g. Margalef, 1964, 1966; Platt & Subba Rao, 1970) implies significant negative correlations between diversity and most measures of standing crop. This concept, accepted *a priori* by many ecologists, has rarely been comprehensively tested under field conditions. Moreover large scale culture experiments (Parsons *et al.*, 1977) failed to support the concept in 30+ days experiments in which nutrient enrichment increased standing crops and primary production, twofold and threefold, respectively.

If species diversities are related to productivity, they become useful tools in interpreting eutrophication processes; in many cases more so than the chemical characteristics of the water *per se*. Such characteristics, for example nutrients, can only reflect 'instantaneous residual' conditions. In addition, diversity indices provide an insight into eutrophication processes complementing that provided by standing crop data: data which primarily reflect the net balance between increases in primary production and crop losses, e.g. grazing. Consequently diversity indices could be powerful interpretive tools for understanding the response of a phytoplankton system to environmental pressures, whether nutrient loadings or/and anthropomorphic stress. However, single diversity values are often difficult to interpret if not accompanied by information on the spectrum of diversity (Margalef, 1970), and all data were thusly reduced.

The Northern Adriatic is a marine ecosystem that undergoes marked fluctuations in phytoplankton crop from a combination of seasonal cycles and the eutrophicating influence of northern Italian rivers such as the Po. Standing crops range from 0.5 to 110 mg $Chl_a m^{-2}$ and primary production rates from 2 to 60 mgC $m^{-3}hr^{-1}$. An analysis of phytoplankton species diversities in the region was therefore used to evaluate whether diversity indices could prove useful in interpreting eutrophication processes, and to provide a quantitative baseline from which to evaluate future changes.

This study differs from other reports in the literature in that the observational time series exceeded four years, and whole water sample phytoplankton analyses (rather than net samples) were used for the species diversity analyses. Noteworthy, the community data are internally consistent: the same taxonomist (NR) identified all 300+ taxa used for diversity calculations during the course of the four year study.

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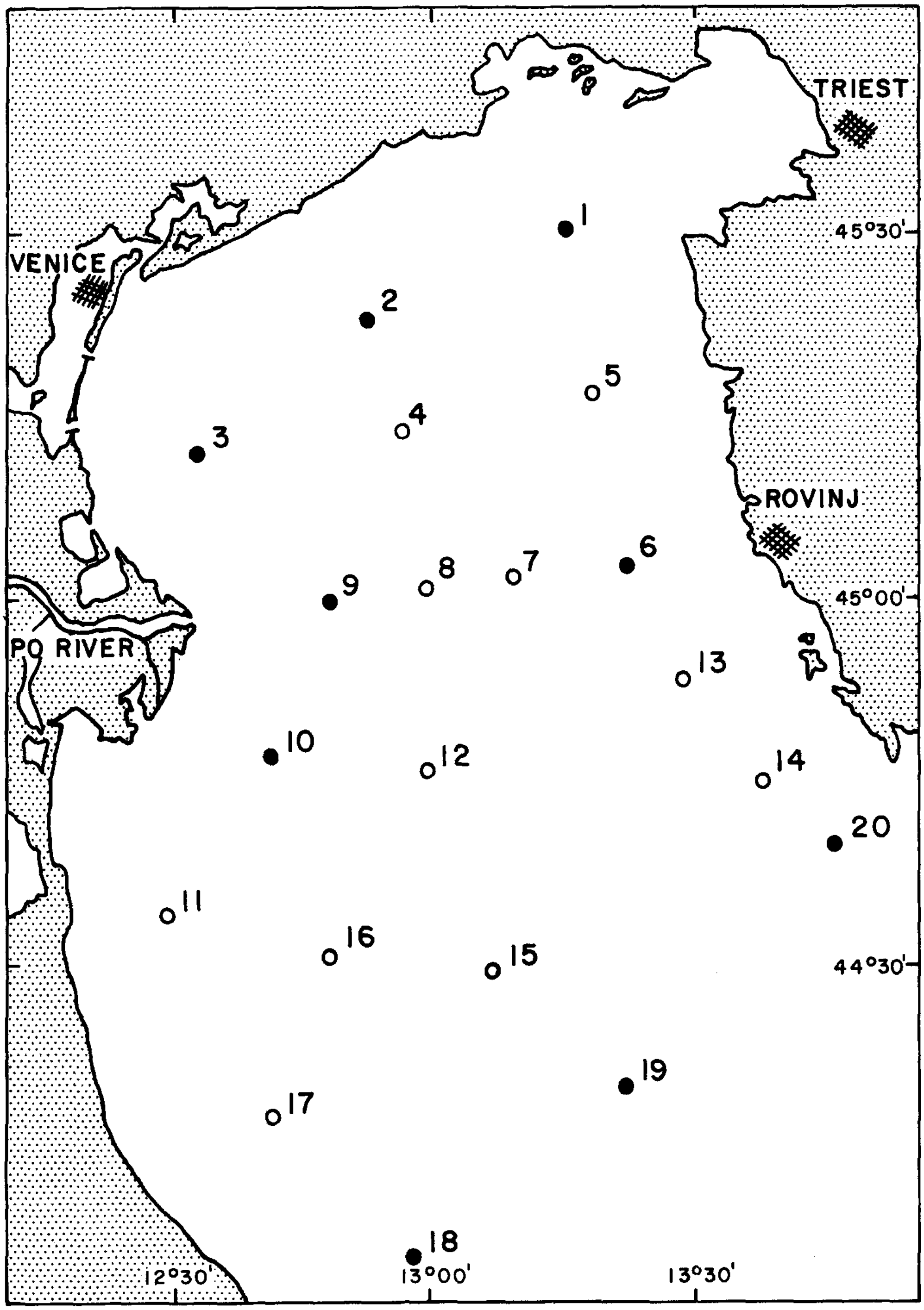

Fig. 1. Oceanographic station positions in the Northern Adriatic Sea. Solid symbols mark phytoplankton sampling stations (eastern = 6, 20; western = 3, 9, 10, 18).

Materials and methods

A number of diversity indices have been developed from different theoretical and empirical bases. Which one is 'best' depends only upon which one proves *in practice* to give useful insights to the ecosystem under study. Some of the more commonly used indices of diversity were tested with a comprehensive set of Adriatic phytoplankton data, and a correlation matrix analysis of the data components identified the Shannon index as the most suitable for quantifying phytoplankton community diversity in that region (Revelante & Gilmartin, *in press*). The matrix indicated that in the Adriatic the Shannon index was an acceptable compromise accomodating the variations encountered in 'species richness' and 'populations density', and was relatively independent of sample size. The range of Shannon diversity indices (H') observed during the study is presented in Table I, along with regionally comparable Margalef, Fisher and Menhenick indices (i.e. taxonomically based on the Utermöhl settling technique). The diversities were estimated according to Shannon & Weaver (1963), and information is presented as bits $cell^{-1}$. The diversity frequency spectra are scaled in H' units of 1.0, and time intervals of a month. With an increased sampling density and frequency grid, it would be possible to develop spectra with increased resolution. However given the 'biological noise' in phytoplankton systems, and the time scale of their response to environmental change, 0.5 H' and 15 day spectrum units probably represent the practical limit to which this analytical approach can be carried.

The analysis treated that portion of the community larger than 10 microns, as observed with the Utermöhl settling technique. Species smaller than 10 microns (mostly μ-flagellates) were omitted from the diversity calculations to eliminate biases that might be introduced due to taxonomic uncertainties in their identification by light microscopy.

Phytoplankton samples for the diversity analyses were collected monthly (or biweekly) from 1972 to 1975 at some or all of 9 'phytoplankton' stations in a 20 oceanographic station set (Fig. 1). The chlorophyll *a* standing crop was sampled at all 20 stations. Simultaneously, various biological and physio-chemical properties were also monitored at all 20 stations, which, except for salinity and temperature are not reported herewith. These data and details on sampling and analytical procedures are presented elsewhere (Gilmartin *et al.*, 1972, 1973, 1974, 1975; Revelante & Gilmartin, 1976a).

Results and discussion

Diversity frequency spectra for the Adriatic Sea defined three regions: the western north Adriatic, the eastern north Adriatic and the open central and south Adriatic (Fig. 2). Phytoplankton communities in the open central Adriatic, and data from the offshore western Mediterranean (remote from upwelling), formed a characteristic diversity spectrum with a maximum in the 3-4 H' class. These regions are oligotrophic and oceanographically relatively stable compared with eastern and western regions of the Northern Adriatic. In contrast, communities of the eastern north Adriatic region formed a frequency spectrum with a maximum in the 2-3 H' class, and the western north Adriatic communities, under the direct influence of the Po and other northern Italian rivers, had a spectrum maximum shifted down about two H' classes from the open central Adriatic... with a maximum in the 1-2 H' class.

The principal species establishing the characteristics of regional frequency spectra were, in order of importance: western north Adriatic – *Skeletonema costatum, Nitzschia seriata, Prorocentrum micans, Asterionella japonica;* eastern north Adriatic – *Nitzschia seriata, Chaetoceros curvisetus, Prorocentrum micans, Leptocylindrus danicus;* open Adriatic – *Thalassiothrix frauenfeldii, Rhizosolenia alata f. gracillima, Thalassionema nitzschioides, Syracosphaera pulchra.* Details on temporal and regional distributions of species are presented elsewhere (Revelante & Gilmartin, 1976b; 1977).

Temporal changes in the diversity frequency spectrum for the entire northern Adriatic are also presented in Figure 2. During the January to March, and May to September periods, diversity frequency spectra closely resembled the characteristic 'western' region spectrum. In contrast, during April and the October to January period, the spectra were characteristic of the 'eastern' region. The 'western' community diversity character of the Northern Adriatic, which predominates until September, can be attributed to the dominating Po influence and the well-documented eastward horizontal advection of Po waters during that period (Franco 1970; 1972).

The seasonal Po River influence on the northern Adriatic can also be characterized by temperature–salinity data (Figs. 3, 4), which temporally demarcate the vertically stratified and mixed periods and document lower salinities at western than at eastern stations under similar temperature regimes. Since vertical mixing cannot introduce lower salinity water from depth in these regions

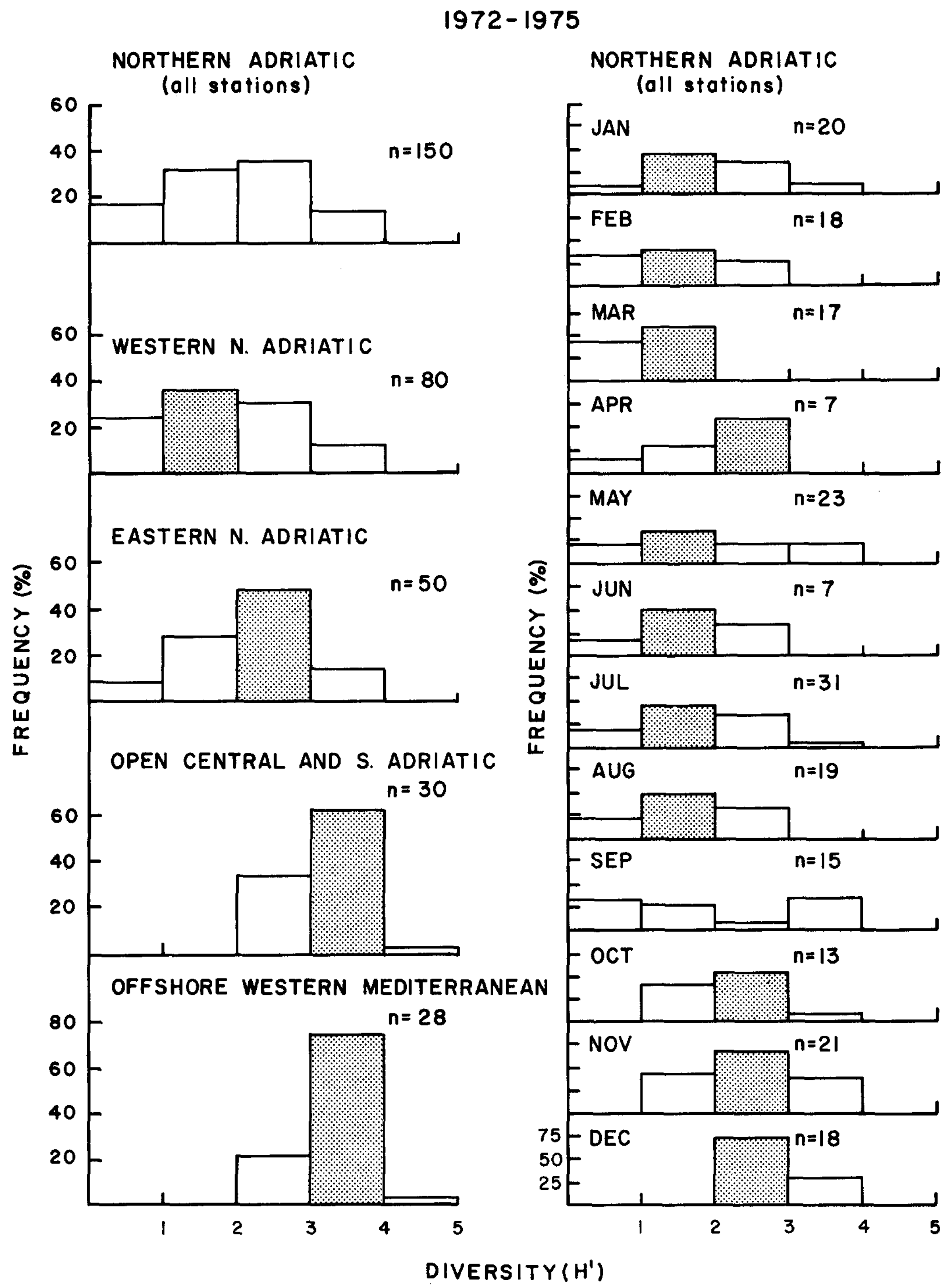

Fig. 2. Regional and temporal diversity frequency spectra from the Adriatic and Mediterranean Seas (Mediterranean data from Margalef, 1963, 1969).

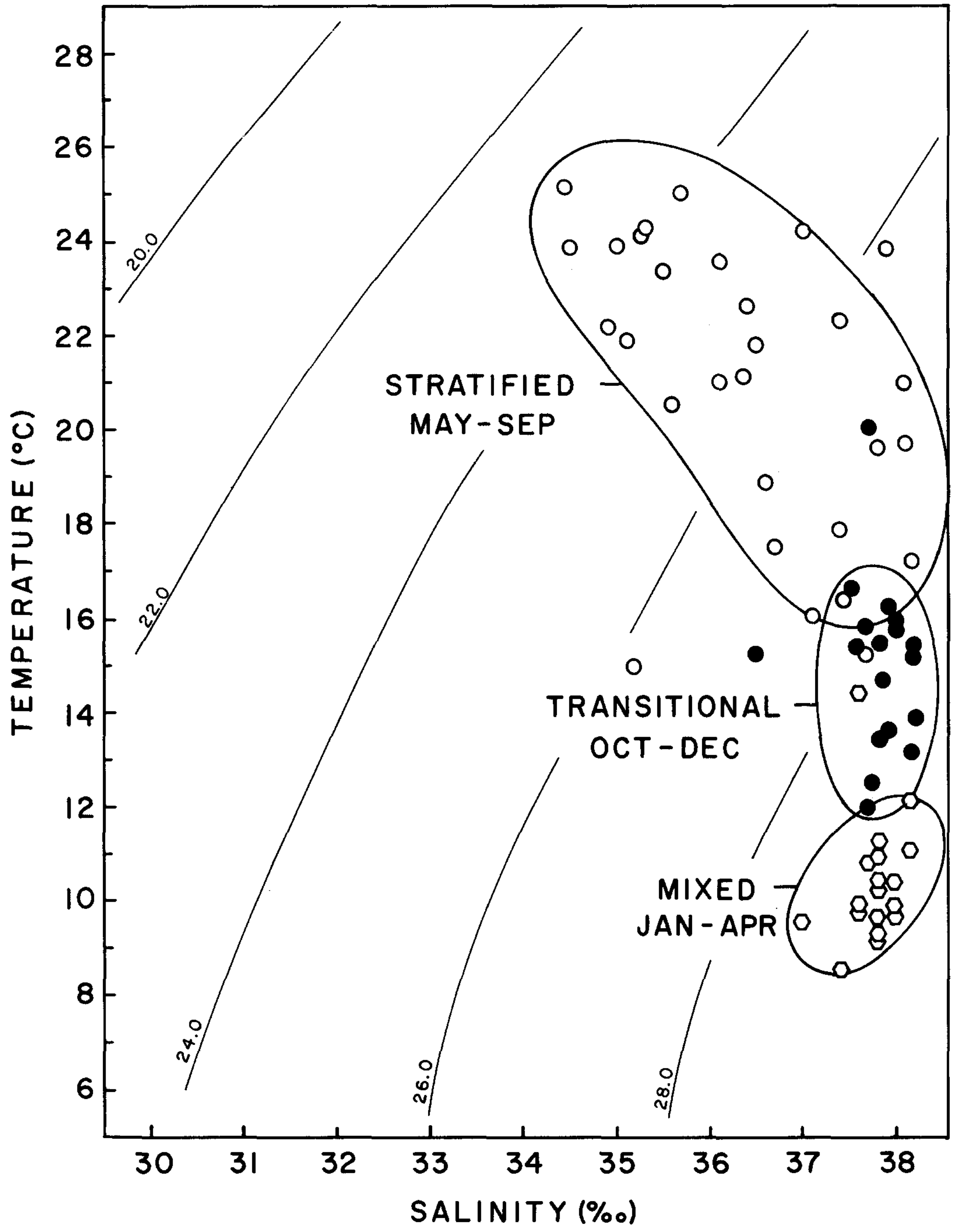

Fig. 3. Temperature, salinity and density characteristics of surface waters of the eastern North Adriatic, pooled by oceanographic period.

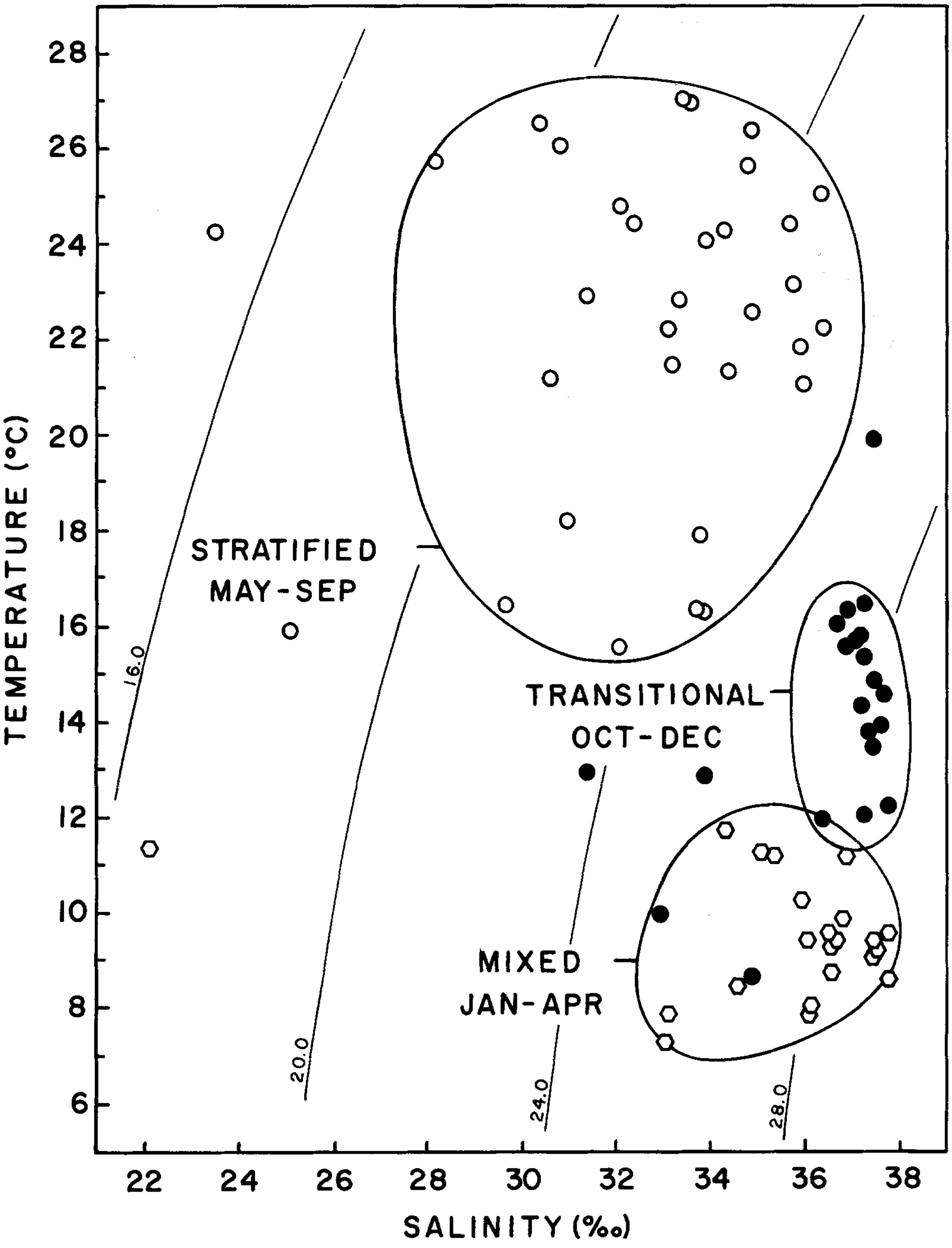

Fig. 4. Temperature, salinity and density characteristics of surface waters of the western North Adriatic, pooled by oceanographic period.

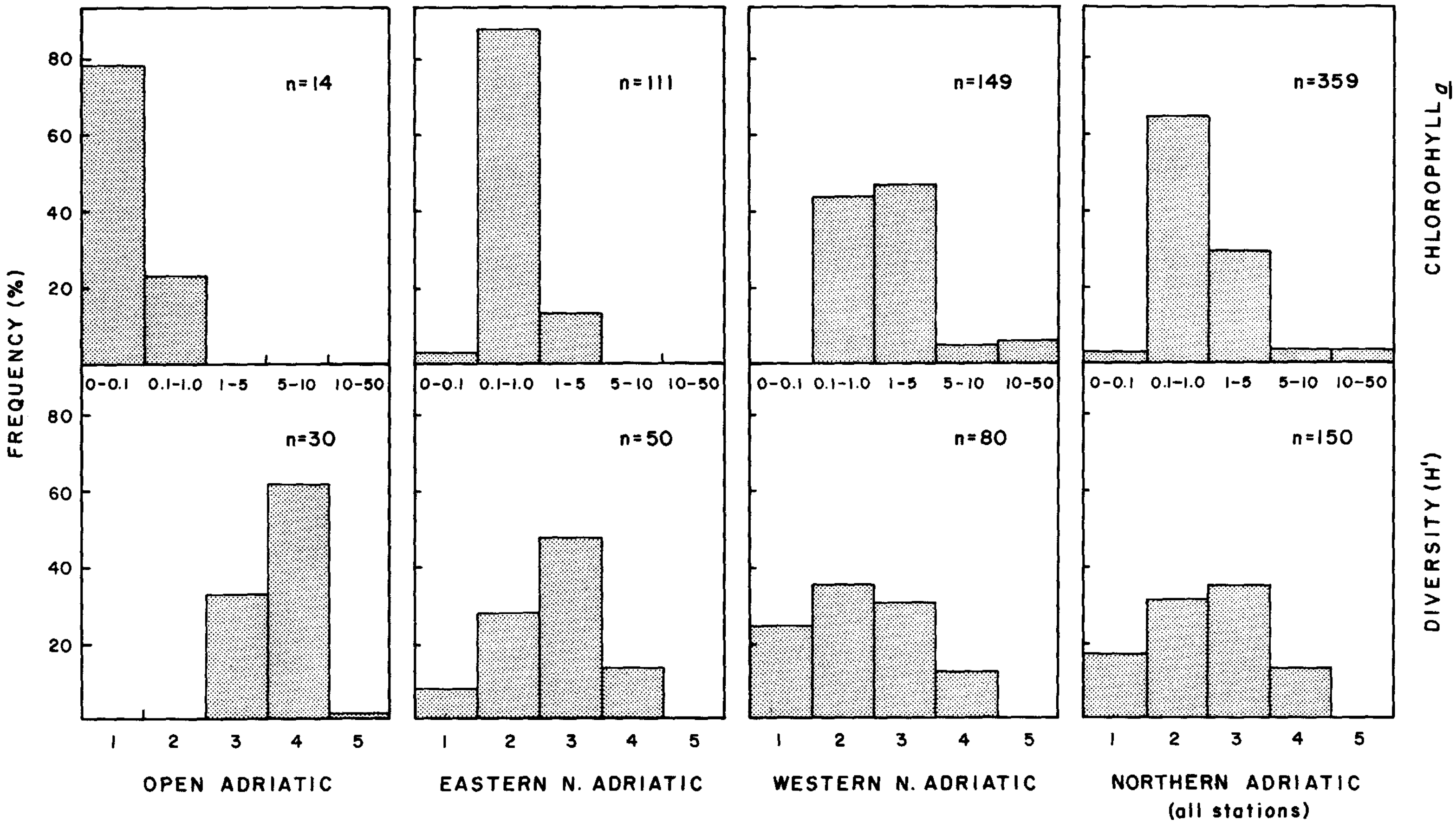

Fig. 5. Regional frequency spectra for chlorophyll *a* biomass and phytoplankton community diversity.

(Buljan & Zore-Armanda, 1966; Gilmartin *et al.*, 1972, 1973; 1974, 1975), lower salinities primarily reflect Po River influence. Noteworthy, a unique frequency spectrum characterized September, and the changeover from a stratified water column to a vertically mixed system (Figs. 4, 5).

The predominantly 'eastern' diversity character of the Northern Adriatic during the October to December period (Fig. 2) most likely reflects an intensified cyclonic northward inflow of surface waters from the open Adriatic and eastern Mediterranean (Zore-Armanda, 1968), with associated high diversity communities (Table I), as well as strong vertical mixing resulting from the seasonal breakdown of stratification (Figs. 3, 4). As evidenced by temperature-salinity characteristics, the period from October to December was the least influenced by Po discharge in *both* eastern and western regions (Figs. 3, 4), with high salinities in all the Northern Adriatic. The conditions indicate the input of central Adriatic waters to the region. This, combined with low Po discharge, and a distribution of phytoplankton biomass concentrated to a narrow western zone (Revelante & Gilmartin, 1976a, 1977), contributed to the general trend to increased diversities and a shifting up of the diversity frequency spectra. Seasonally, low diversities were correlated with lower salinities, which in turn were linked to increased nutrient input (e.g. Degobbis, 1974) and reflected in increased phytoplankton biomass (Revelante & Gilmartin, 1976a). The crude inverse relation between the 1972-1975 chlorophyll *a* biomass spectra and diversity frequency spectra (Fig. 5) illustrates that the increased biomass resulting from Po induced eutrophication was characterized by markedly decreased diversities.

If it is assumed that nutrients and/or anthropogenic compounds associated with river discharge were the main environmental factors lowering phytoplankton community diversity, as experimentally suggested by Fedorov (1973), an interpretive model of the northern Adriatic can be conceptualized. Regionally, the combined 'all stations' spectrum (Fig. 2) for the northern Adriatic strongly resembled and reflected 'western' station diversities, and illustrated the overall dominating influenced of the Po River on the entire region. Temporally, the eastern character of the Northern Adriatic was most pronounced during the October–December transition period (Fig. 2) illustrating an open central and southern Adriatic influence on conditions during the period. These spatial and temporal patterns can be contrasted to open central and southern Adriatic diversities, which in turn closely resemble offshore western Mediterranean diversities indicating similar nutrient fluxes.

Conclusion

The poor relationship between diversity and total productivity noted in some studies may be related to the fact that the 'microplankton' diversity of net samples (sometimes of organisms 50-75 μ) are often correlated with the productivity or biomass of the *total* phytoplankton community, thus excluding the 'nanoplankton' component.

Table 1. Adriatic phytoplankton diversity ranges, and those of adjacent regions, based on Utermohl settling technique.

	Shannon $H' = -\Sigma p_i \log_2 p_i$	Margalef $d = \frac{S-1}{\ln N}$	Fisher $\alpha = \frac{S}{\ln(1+\frac{N}{\alpha})}$	Menhenick $d = \frac{S}{\sqrt{N}}$
Northern Adriatic	0.11-3.58	0.8-5.0	0.9-6.3	0.01-0.57
Open Adriatic	2.35-3.69	4.1-7.8	4.9-13.2	0.25-2.0
Eastern Coastal Med.		5.1-8.3(1)		
Western Coastal Med.	0.5-3.9(2)	1.0-7.0(3)		
Western Offshore Med.	2.0-4.0(4)			

(1) Taslakian & Hardy, 1976
(2) Margalef, 1970
(3) Travers, 1971
(4) Margalef, 1963, 1969

This component frequently represents 80-95% of total community productivity. Under such circumstances a poor correlation would be expected in nanoplankton dominated oligotrophic or quasi-oligotrophic environments. In contrast, during phytoplankton blooms and/or under eutrophic conditions, microplankton often dominate and the inverse relationship between the diversity of predominantly microplankton communities and productivity is often pronounced and clearly apparent despite the use of net rather than whole water phytoplankton samples.

In our study, analyses of diversity were based on a four year sampling of the phytoplankton of the Northern Adriatic, using whole water samples which collected the entire phytoplankton community over a wide range of nutrient conditions. An interpretation of the diversity frequency spectra derived from these data supports the theory that a strong inverse relationship between diversity and productivity exists, particularly when there are environmental changes (i.e. non-steady state conditions) which favor rapid phytoplankton growth. Under such conditions, for example when plant nutrients associated with river discharge create bloom conditions, phytoplankton communities with high biomass and low species diversity develop. Conversely with lower nutrient fluxes, and decreased phytoplankton biomass, species diversities increase.

We conclude that appropriate phytoplankton diversity analyses can be very useful in understanding and describing eutrophication processes in a region. The spectra document temporal and regional patterns of eutrophication, and represent primary baselines from which to quantify future changes. In the case of the Northern Adriatic any future downward shifts in spectrum frequency maxima can be assumed strongly indicative of increased eutrophication and/or environmental stress.

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References

Buljan, M. & Zore-Armanda, M. 1966. Hydrographic data on the Adriatic Sea collected in the period from 1952 to 1964. Acta adriat. 7 (12): 1-438.

Degobbis, D. 1974. The nitrogen cycle and budget in the Northern Adriatic. 154 pp., M.Sc. Thesis, University of Zagreb (in Croatian).

Fedorov, V. D. 1973. Connection of the phytoplankton species diversity with changes in the mineral nutrition conditions. Hidrobiol. 9 (3): 21-24.

Franco, P. 1970. Oceanography of northern Adriatic Sea. I. Hydrologic features: Cruises July-August and October-November 1965. Arch. Oceanogr. Limnol. 15 (Suppl.): 1-93.

Franco, P. 1972. Oceanography of northern Adriatic Sea. Cruises January-February and April-May 1966. Ibid. 17: 1-97.

Gilmartin, M., Kveder, S., Degobbis, D., Revelante, N. & Smodlaka, N. 1972. Hydrographic data collected during cruises in the Northern Adriatic, July-December, 1972. Thalassia jugosl. 8 (1): 149-213.

Gilmartin, M., Kveder, S., Degobbis, D., Revelante, N. & Smodlaka, N. 1973. Hydrographic data collected during cruises in the Northern Adriatic, January-December, 1973. Data Report, Center for Marine Research, Rovinj, Yugoslavia.

Gilmartin, M., Kveder, S., Degobbis, D., Revelante, N. & Smodlaka, N. Ibid., January-December 1974.

Gilmartin, M., Kveder, S., Degobbis, D., Revelante, N. & Smodlaka, N. Ibid., January-December 1975.

Margalef, R. 1963. Algunas regularidades en la distribucion a escala pequena y media de las poblaciones marines de fitoplancton y en sus caracteristicas functionales. Inv. Pesq. 23: 169-230.

Margalef, F. 1964. Correspondence between the classic types of lakes and the structural and dynamic properties of their populations. Int. Verh. theor. angew. Limnol. 15: 169-175.

Margalef, F. 1965. Ecological correlations and the relationship between primary productivity and community structure. In: Primary Productivity in Aquatic Environments. Mem. Ist. Ital. Idrobiol., 18 Suppl., pp. 355-364.

Margalef, R. 1969. Estudios sobre la distribucion a pequena escala del fitoplancton marino. Mem. Acad. Cienc. Art. Barcelona 40 (1): 3-22.

Margalef, R. 1970. Diversidad y productivadad del fitoplancton en el Mediterraneo occidental. Inv. Pesq. 34 (2): 565-573.

Parsons, T. R., Thomas, W. H., Seibert, D., Beers, J. R., Gillespie, P. & Bawden, C. 1977. The effect of nutrient enrichment on the plankton community in enclosed water columns. Int. Revue ges. Hydrobiol. 62 (5): 565-572.

Platt, T. & Subba Rao, D. V. 1970. Primary production measurements on a natural plankton bloom. J. Fish. Res. Bd. Canada 27 (5): 887-899.

Revelante, N. & Gilmartin, M. 1976a. The effect of Po River discharge on phytoplankton dynamics in the northern Adriatic Sea. Mar. Biol. 34: 259-271.

Revelante, N. & Gilmartin, M. 1976b. Temporal succession of phytoplankton in the Northern Adriatic. Neth. J. Sea Res. 10 (3): 377-396.

Revelante N. & Gilmartin, M. 1977. The effects of northern Italian rivers and eastern Mediterranean ingressions on the phytoplankton of the Adriatic Sea. Hydrobiol. 56 (3): 229-240.

Revelante, N. & Gilmartin, M. 1979. Po River induced low

phytoplankton diversities in the Adriatic Sea. Rapp. Comm. int. Mer. Medit. (in press).
Shannon, C. E. & Weaver, W. 1963. The Mathematical Theory of Communication. University of Illinois Press, Urbana, 117 p.
Taslakian, M. J. & Hardy, J. T. 1976. Sewage nutrient enrichment and phytoplankton ecology along the central coast of Lebanon. Mar. Biol. 38: 315-325.
Travers, M. 1971. Diversité du microplancton du Golfe de Marseille en 1964. Mar. Biol. 8: 308-343.
Zore-Armanda, M. 1968. The system of currents in the Adratic Sèa. Stud. Rev. gen. Fish. Count. Medit. 34: 1-48.