Science for Solutions

NOAA COASTAL OCEAN PROGRAM
Decision Analysis Series No. 4

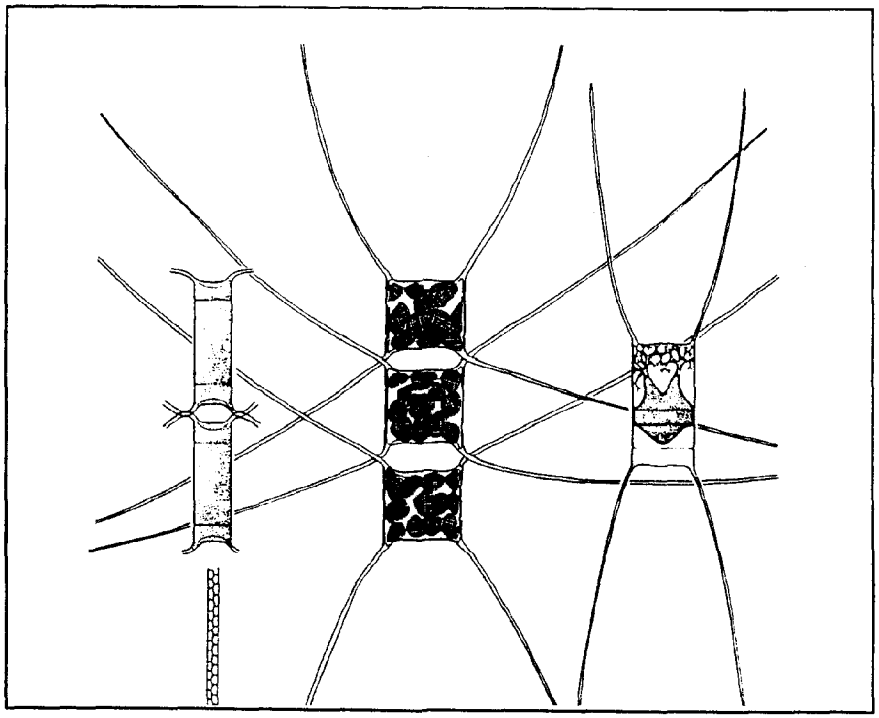
MARINE EUTROPHICATION REVIEW

PART 1: QUANTIFYING THE EFFECTS OF NITROGEN ENRICHMENT ON PHYTOPLANKTON IN COASTAL ECOSYSTEMS

PART 2: BIBLIOGRAPHY WITH ABSTRACTS

Kenneth R. Hinga
Heeseon Jeon
Noëlle F. Lewis

January 1995



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Coastal Ocean Office

QH91.8
.M34
H45
1995

The Decision Analysis Series has been established by NOAA's Coastal Ocean Program (COP) to present documents for coastal resource decision makers which contain analytical treatments of major issues or topics. The issues, topics, and principal investigators have been selected through an extensive peer review process. To learn more about the COP or the Decision Analysis Series, please write:

NOAA Coastal Ocean Office
1315 East-West Highway (NCOP)
Silver Spring, MD 20910

phone: 301-713-3338
fax: 301-713-4044

Cover illustration: Three views of* Chaetoceros lorenzianus *and detail of seta structure. Drawing by Jan Rines.

Science for Solutions

NOAA COASTAL OCEAN PROGRAM
Decision Analysis Series No. 4

MARINE EUTROPHICATION REVIEW

PART 1: QUANTIFYING THE EFFECTS OF NITROGEN ENRICHMENT ON PHYTOPLANKTON IN COASTAL ECOSYSTEMS

PART 2: BIBLIOGRAPHY WITH ABSTRACTS

Kenneth R. Hinga
Heeseon Jeon
Noëlle F. Lewis

Graduate School of Oceanography
University of Rhode Island
Narragansett, RI 02882

January 1995

MAR 14 1997

U.S. DEPARTMENT OF COMMERCE
Ronald H. Brown, Secretary
National Oceanic and Atmospheric Administration
D. James Baker, Under Secretary
Coastal Ocean Office
Donald Scavia, Director

Property of CSC Library
US Department of Commerce
NOAA Coastal Services Center Library
2234 South Hobson Avenue
Charleston, SC 29405-2413

This publication should be cited as:

Hinga, Kenneth R., Jeeseon Heon and Noëlle F. Lewis. 1995. Marine Eutrophication Review--Part 1: Quantifying the Effects of Nitrogen Enrichment on Phytoplankton in Coastal Ecosystems; Part 2: Bibliography with Abstracts. NOAA Coastal Ocean Program Decision Analysis Series No. 4. NOAA Coastal Ocean Office, Silver Spring, MD. Part 1, 36 pp.; Part 2, 120 pp.

This publication does not constitute an endorsement of any commercial product or intend to be an opinion beyond scientific or other results obtained by the National Oceanic and Atmospheric Administration (NOAA). No reference shall be made to NOAA, or this publication furnished by NOAA, in any advertising or sales promotion which would indicate or imply that NOAA recommends or endorses any proprietary product mentioned herein, or which has as its purpose an interest to cause directly or indirectly the advertised product to be used or purchased because of this publication.

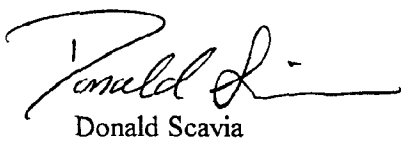
Note to Readers

The NOAA Coastal Ocean Program (COP) provides a focal point through which the agency, together with other organizations with responsibilities for the coastal environment and its resources, can make significant strides toward finding solutions to critical problems. By working together toward these solutions, we can ensure the sustainability of these coastal resources and allow for compatible economic development that will enhance the well-being of the Nation now and in future generations. The goals of the program parallel those of the NOAA Strategic Plan for 1995-2005.

A specific objective of COP is to provide the highest quality scientific information to coastal managers in time for critical decision making and in a format useful for these decisions. To help achieve this, COP inaugurated a program of developing documents that would synthesize information on issues that were of high priority to coastal managers. To develop such documents, a three-step process was used: 1) to compile a list of critical topics in the coastal ocean through a survey of coastal resource managers and to prioritize and select those suitable for the document series through the use of a panel of multidisciplinary technical experts; 2) to solicit proposals to do research on these topics and select principal investigators through a rigorous peer-review process; and 3) to develop peer-reviewed documents based on the winning proposals.

Marine Eutrophication Review is the third title published of the seven topics and associated principal investigators which were selected in the initial round. A bibliography of synthesis documents was added to the series on the recommendation of a COP management committee and is in print (see inside back cover). Other volumes will be published over the next two years on the following topics: seagrass restoration technology, coastal watershed restoration, restoring streams and anadromous fish habitat affected by logging, and management of cumulative coastal environmental impacts.

As with all of its products, COP is very interested in ascertaining the utility of the Decision Analysis Series particularly in regard to its application to the management decision process. Therefore, we encourage you to write, fax, call, or Internet us with your comments. Please be assured that we will appreciate these comments, either positive or negative, and that they will help us direct our future efforts. Our address and telephone and fax numbers are on the inside front cover. My Internet address is DSCAVIA@HQ.NOAA.GOV.



Donald Scavia
Director
NOAA Coastal Ocean Program

MARINE EUTROPHICATION REVIEW

PART 1: QUANTIFYING THE EFFECTS OF NITROGEN ENRICHMENT ON PHYTOPLANKTON IN COASTAL ECOSYSTEMS

TABLE OF CONTENTS

ABSTRACT	1
INTRODUCTION	1
DEFINING TERMS	1
APPROACHES TO FINDING A RELATIONSHIP BETWEEN EUTROPHICATION AND NUTRIENT INPUTS	2
NITROGEN AND PRIMARY PRODUCTION IN MARINE ECOSYSTEMS	4
PHYTOPLANKTON ABUNDANCE AND OTHER MEASURES THAT MAY BE RELATED TO EUTROPHICATION	5
OTHER COMPLICATING ISSUES	6
NITROGEN LOADINGS OR NITROGEN CONCENTRATIONS?	6
RELATIONSHIPS BETWEEN NITROGREN AND EUTROPHICATION	8
THE ROLE OF ANOTHER FACTOR	10
CURVE FITS TO CROSS-SYSTEM AND MERL DATA AND COMPARISON TO THE EFFECT FACTORS FROM CHANGES OVER TIME	11
CONCLUSIONS	11
TABLE	12
FIGURES	14
LITERATURE CITED	33

ABSTRACT

The results of three different approaches are used to investigate relationships between nitrogen availability and phytoplankton primary production and abundance in coastal ecosystems. The three approaches are controlled experiments in marine enclosures, history of changes in coastal ecosystems, and cross-system comparisons. Most systems can be expected to have increased primary production with increased nitrogen loadings or long-term average concentration. Nitrogen availability alone is not a very precise predictor of phytoplankton production or abundance. The magnitude of the change in phytoplankton production or abundance found for most systems is typically in the range of 1.4 to 3 times for a doubling in nitrogen loading or concentration. However, there are coastal ecosystems which have not followed the general relationships found. Until the characteristics which sets those systems apart from other systems can be identified, there is no guarantee that any individual system will have the typical response.

INTRODUCTION

Perhaps the paramount question placed before the modern ecologist is "What will happen if....?" As this review considers anthropogenic nutrient inputs to coastal environments, the question becomes: "What will happen if nutrient loads to a body of water increase?" And, conversely: "What will happen if (usually at great expense) nutrient inputs to a coastal body of water are reduced?" The answers to these questions are far from trivial to obtain. Ecology as a predictive science is still in its infancy. There have been remarkably few planned and controlled experiments at the ecosystem level to learn from, and to test the ecologist's ability to accurately predict changes.

Nevertheless, marine ecologists can certainly observe present conditions in coastal ecosystems, and they have observed what are presumed to be nutrient-related changes in estuaries. Certainly some insights have been gained as to the behavior of coastal ecosystems under increased nutrient loadings.

This review will consider relationships between nutrient loading and phytoplankton production in coastal ecosystems. Specifically, the review will examine if there is a simple relationship between nutrient loading and phytoplankton production, or surrogates for production, in coastal ecosystems. In other words, how well can we predict how much change will occur in a coastal ecosystem for any specific change in nutrient loading?

DEFINING TERMS

Before starting on any dialogue it is useful to make sure that participants are using the same meanings for their vocabulary. The word "eutrophication" has had a variety of uses when applied to coastal ecosystems, and probably many more uses when applied to other ecosystems. For this review the definition of eutrophication as proposed by Nixon (1994) will be used. His proposed definition is:

Eutrophication (noun) -- an increase in the rate of supply of organic matter to an ecosystem.

The rate of supply of organic carbon may be by either primary production by autotrophs within the system (autochthonous carbon) or by an input of organic matter from outside the system (allochthonous carbon). The central feature of the definition is the rate of supply of organic carbon. At first consideration, the definition seems distant from the common informal use of "eutrophication" to denote an increase in anthropogenic nutrient loading (i.e., cultural eutrophication). However, use of Nixon's definition has considerable advantages.

First, the definition is simple. The definition is based upon a single parameter. There is a lot to be said for simplicity.

Second, the definition makes it easy to separate eutrophication from its causes and its consequences. The causes of eutrophication may include increased input of inorganic nutrients, decrease in water turbidity, change in hydraulic residence time of the water, a decline in grazing pressure or increase in direct inputs of organic matter. The consequences of an increased rate of supply of organic carbon may include changes in ecosystem community structure, increased rates of oxygen depletion, fish kills, etc.

Finally, focusing on the rate of organic carbon supply as the central issue makes it a straightforward matter to classify the trophic status of coastal ocean ecosystems. The trophic status of a coastal ecosystem is simply a measure of the rate of organic carbon supply. Definitions of various trophic states were also proposed by Nixon (1994):

	Organic Carbon Supply g c M^{-2} $Year^{-1}$
oligotrophic	≤100
mesotrophic	101-300
eutrophic	301-500
hypertrophic	>500

The trophic classification states are value neutral. The definition does not imply that one trophic state is better, more desirable, or more valuable than another.

APPROACHES TO FINDING A RELATIONSHIP BETWEEN EUTROPHICATION AND NUTRIENT INPUTS.

In order to quantify "what will happen in a coastal ecosystem if nutrient inputs go up or down," it is necessary to have or to establish a relationship between nutrient loading and rate of carbon supply. Carbon supply can be from two sources, primary production within the ecosystem and external loadings to the ecosystem. External loadings are likely to be the dominant source of carbon in the vicinity of sewage outfalls with primary or no treatment. In such areas one would not expect to find a cause-effect relationship between nutrient loadings and carbon supply (unless one is considering the processes and procedures used in sewage treatment plants themselves).

For most open-water areas of coastal ecosystems, the carbon supply is likely dominated by autotrophic primary production within the system. A very useful relationship to identify would then be a relationship between nutrient loadings and primary production. Some care must be taken to make sure that coastal systems, or parts of coastal systems, with significant particulate loadings are avoided in the development of a nutrient loading vs. production relationship from empirical data.

A number of approaches might be applied to the development of a relationship between nutrient loading and primary production. These include:

1. Controlled experiments with marine ecosystems (mesocosm and enclosure experiments).

2. Historical records of the response of coastal ecosystems to changes in nutrient loads.

3. Cross-system comparisons of different coastal ecosystems to see if the primary production in those systems is systematically related to nutrient inputs (comparative ecology).

4. Calculation (modeling) from first principles of physics, chemistry, and ecology.

Conducting controlled experiments with representative coastal ecosystems would be the most direct way to determine the effects of nutrient loadings on coastal ecosystems. Such a direct approach was instrumental in determining the response of lakes to nutrient loadings (i.e., Shindler et al., 1971; Shindler 1973). Given that coastal ecosystems are considered public domain and we are unlikely to want to deliberately damage such an ecosystem, it seems unlikely that natural coastal ecosystems will be made available for direct experimentation.

Direct experiments are possible with coastal ecosystems in miniature. This is the realm of enclosures and mesocosms. A variety of marine enclosures have been established to attempt to create ecosystems in large containers that have chemical and biological properties of coastal ecosystems. Descriptions of, and arguments for the use of, enclosures have been made by Davies and Gamble (1979), Steele (1979), Parsons (1981), Lundgren (1985), and Santschi (1988). It has been within the marine ecologist's ability for nearly two decades to establish enclosures containing ecosystems that, over long periods of time (many months), have biota and ecosystem function that are hard to tell apart from natural coastal ecosystems.

It seems remarkable that given this ability there has not been a widespread use of enclosures. Direct experimentation is a powerful, if not the most powerful approach, in scientific investigation. Although there have been a number of short term (i.e., up to about a month's duration) nutrient experiments in marine enclosures, there has been only one long-term eutrophication experiment in marine enclosures. There was a 28-month nutrient-addition experiment at the Marine Ecosystems Research Laboratory of the University of Rhode Island (Nixon et al., 1984; Kelly et al., 1985; Oviatt et al., 1986a, 1986b, 1989; Keller 1988, 1989; Keller & Rice 1989; Hinga 1990). Results of that experiment will appear in the analyses later in this paper.

One might expect it would be possible to learn a great deal from observations on the changes that have taken place in coastal ecosystems over time. However, the number of coastal ecosystems where adequate measurements exist under two different loading conditions is remarkably small. While current conditions and loadings are known in a good number of coastal ecosystems, records of conditions under earlier loadings and records of earlier loadings are relatively rare. Coastal ecosystems for which adequate data have appeared in the literature will be considered below.

A comparative ecology approach was used by Volenweider (1976) to develop a quantitative relationship between nutrient loadings in lakes and the abundance of lake phytoplankton. The results of his comparative study demonstrated a clear relationship between phosphorus loadings to lakes and the phytoplankton standing stock in lakes. Comparative approaches have been applied to marine ecosystems by Boynton et al. (1982), Nixon (1983), Nixon and Pilson (1983) and Monbet (1992).

A modeling approach, while a very desirable goal, is likely out of reach for the near future. Modeling the physics and chemistry of a coastal ecosystem on first principles may be currently possible. Unfortunately, the first principles of ecology are not yet sufficiently understood to permit useful predictions. At the very least, an ecosystem model requires the ability to predict when and why different species appear at various times. This ability is surely not yet achieved, even in an unperturbed (by human activities) system. The ability to predict how communities will change under novel conditions is even further off.

There are those who might argue that a functional model of the ecosystem is all that is needed for prediction of at least some of the consequences of changes in nutrient loadings. In this approach, specific species are not modeled. Related groups of species are assumed to have the same function (nutrient dynamics, etc.). Functional modeling will certainly provide insights into ecosystem functioning and perhaps eventually into effects of external changes on ecosystems. Functional modeling is a valuable tool of the ecologist, but at present is more likely to be useful as a diagnostic than a predictive tool. In order to use functional models to provide predictions of response to change, it is necessary to know the coefficients, rates, and equations that describe the functioning of the communities in the modeled system before and after change in the parameters of interest. As noted above, it is not yet possible to confidently predict which populations will comprise communities after a change in conditions. Unless one can demonstrate that all coastal marine communities that could exist in a particular area are functionally similar, or one can demonstrate how the functionality will change, it is inappropriate to expect functional models to be reliable predictors of change.

Which of the possible approaches should be used to gain an understanding of the relationship between nutrient loadings and the eutrophication of coastal ecosystems? The best answer is probably "all of the above." When different independent approaches to the problem provide the same results, then marine ecologists can start to have confidence that they have gained a defensible ability to predict the response of coastal ecosystems to changes in nutrient loadings.

The history of lake eutrophication investigations provides a good example of the value of having support from independent approaches. In the 1960's there was a great deal of discussion and debate concerning the cause(s) of conspicuous thick algal blooms and algal-mat growths appearing in many lakes. Were the mats and the blooms a result primarily of phosphorus additions or of other agents? When the results of a direct experimental approach (Shindler 1971, 1973) and a comparative approach (Vollenweider 1976) both clearly implicated phosphorus as the primary causative agent, a firm basis was provided for the regulation of phosphorus in detergents and other sources.

NITROGEN AND PRIMARY PRODUCTION IN MARINE ECOSYSTEMS

The nutrient central in discussions of coastal eutrophication is nitrogen. Early in the relatively brief history of concern about marine eutrophication, Ryther and Dunstan (1971) demonstrated that additions of nitrogen stimulated growth of marine phytoplankton. Phosphorus additions had little if any effect. Nutrient limitation studies have been conducted many times since (e.g. Goldman, 1976; Laws and Redalje, 1979; Granéli and Sundbäck, 1985; D'Elia et al., 1986; Granéli et al., 1986; and Granéli et al., 1988, Granéli et al., 1990; Montgomery et al., 1991; Oviatt et al., 1994). In general, additions of nitrogen alone, as either nitrate or ammonium, promote enhanced growth of phytoplankton (also see the review by Howarth, 1988). However there are times when phosphorus limitation is found in environments usually limited by nitrogen (e.g. Granéli et al., 1990) and marine environments where phosphorus limitation is more common than nitrogen limitation (Myers and Iverson, 1981). Silica limitation, resulting from nitrogen and phosphorus enrichment, may also have an important influence on the composition of phytoplankton communities.

With the general result that nitrogen is usually the limiting nutrient in coastal ecosystems, and provided that long-term responses (i.e., yearly averages) are investigated, it seems reasonable to attempt to find relationships between nitrogen and eutrophication, without consideration of phosphorus. This assumption has been made in many previous studies, and will be adopted here. Should it not be possible to find a satisfactory relationship(s) between nitrogen and eutrophication, it may be necessary to retreat and consider phosphorus, and other factors.

PHYTOPLANKTON ABUNDANCE AND OTHER MEASURES WHICH MAY BE RELATED TO EUTROPHICATION

Primary production becomes the basis of the definition, as given above, of eutrophication in coastal systems where external carbon loadings are not significant. Unfortunately, primary production is not measured very regularly in many coastal ecosystems. It would be useful if surrogate measures related to primary production based upon a more regularly measured parameter could be found. This would expand the number of systems available for investigation of nitrogen-eutrophication relationships.

The primary production of phytoplankton is dependent, in part, upon the abundance of the phytoplankton. If phytoplankton is of low abundance, there are few "machines" to do the work of production and the total production cannot be high. Hence phytoplankton abundance and production may be expected to be somewhat related. Measurement of the standing stock of phytoplankton is conducted much more often than measurement of production. The standing stock of phytoplankton carbon is usually estimated by measuring chlorophyll-a and assuming a fixed carbon to chlorophyll-a ratio.

The instantaneous (i.e., short-term) depth-integrated primary production (i.e., total production under 1 m^2 of surface) in marine systems can be estimated very well by knowing the phytoplankton abundance, the depth of the photic zone (as calculated from the light extinction coefficient), and the amount of incident light (Cole and Cloern, 1987; Keller, 1988, 1989). Hence, if ambient light and turbidity were the same for all coastal ecosystems, chlorophyll-a alone could be used to predict primary production.

Ambient light availability varies by latitude and local climate. Nixon (1983) assembled light data for a variety of coastal embayments and found a modest range in annual average ambient light ranging from 329 Ly day^{-1} (Narragansett Bay, and New York Bay) to 461 Ly day^{-1} (San Francisco Bay). The effect of local climate was larger than the latitude effect (30 °N to 41 °N in North America).

Light extinction also varies in coastal systems. Data also assembled by Nixon (1983) showed attenuation coefficients ranging from about 1 m^{-1} to 8 m^{-1} with most of the high values at low salinity. (This translates to 1 % light levels at about 1 to about 10 meters depth.) Of course, a major determinant of light level in the water column is the amount of phytoplankton material itself.

The abundance of phytoplankton is not always measured at multiple depths. It is more common to find measurements of chlorophyll a, and of primary production made only on near-surface samples. It is far less useful, from a whole ecosystem point of view, to consider possible relationships between phytoplankton abundance and primary production for just near-surface samples. It is the total carbon input to a coastal ecosystem that is relevant to eutrophication as defined here. How well the total water column production can be estimated from only near-surface measurements will not be considered in detail here.

If cross-system comparisons and consideration of changes in coastal ecosystems over time were restricted to only those systems for which there is a good record of areal production, there would not be much data to consider. In order to attempt to find relationships between nutrients and eutrophication, measures of near-surface phytoplankton abundance, and near-surface primary production will be considered. It will need to be kept in mind that mixing the various types of measures of phytoplankton may obscure relationships for any single parameter.

OTHER COMPLICATING ISSUES

Phytoplankton abundance is often estimated from measurement of chlorophyll-a. It should be noted that the carbon-chlorophyll ratio is not a constant (e.g., Falkowski, 1980). More importantly, it appears that carbon to chlorophyll-a ratios vary systematically with eutrophication (Nixon, 1992). The carbon to chlorophyll a ratio in the MERL eutrophication experiment, referred to above, decreased by a factor of three from controls to the higher enriched tanks. It seems probable that this is a result of shade adaptation and not a result of changes in species composition (Oviatt et al., 1989). Such variability may interfere with efforts to find a relationship between phytoplankton abundance and eutrophication.

Phytoplankton abundance may also be derived from direct counts of phytoplankton cells. A change in cell count will not be directly proportional to change in biomass if there has been a change in average cell size. In one of the ecosystems that will be considered later (Helgoland Reede), cell counts were coupled with the volume per cell to provide a better estimate of biomass change over time than raw cell counts.

Some comment must also be made concerning primary production measurements themselves. There are a variety of basic techniques used to measure primary production and variability in the practice of techniques based upon the same principle. Even the use of a single basic technique, such as ^{14}C-based production measurements, the depths of water samples, bottle size and material, bottle agitation, and how bottles are incubated, are far from uniform in practice. Such variability in technique undoubtedly affects results and may make comparisons between different systems misleading.

NITROGEN LOADINGS OR NITROGEN CONCENTRATIONS?

Should a relationship be expected between eutrophication and nitrogen loading, or between eutrophication and the achieved in-system nitrogen concentration (resulting from changes in nitrogen loadings and the other processes affecting nitrogen concentrations)? A priori, there is no way to determine which will be a more fruitful approach. Ideally, a description of the availability of nitrogen is desired. It is not safe to assume that either inorganic nitrogen concentrations or loadings of nitrogen adequately represent nitrogen availability.

Where measured nitrogen concentrations are used for a basis for a relationship, a long-term average concentration of nitrogen must be used. In short time scales, the relationship between nitrogen concentrations and phytoplankton abundance, may be inversely related, reflecting short-term uptake by blooms. Further, consideration of just the dissolved species of nitrogen, or dissolved inorganic nitrogen (DIN; nitrate plus nitrite, plus ammonia), may not represent the real availability of nitrogen to the phytoplankton. Some portion of the particulate and dissolved organic nitrogen may be subject to rapid remineralization and hence be biologically available. If the fraction of the biologically available nitrogen in organic matter is variable in different coastal ecosystems, use of DIN only may not provide clear relationships between nitrogen and eutrophication.

If loadings are used as a basis for a relationship, do changes in loadings necessarily reflect a corresponding change in availability of nitrogen to phytoplankton? Should loadings calculated on a volume basis or loadings on an areal basis be used to represent availability? How does flushing rate (or the inverse, the residence time of water) affect the achieved availability of nitrogen in the coastal ecosystem? The later question is addressed briefly as follows.

For a conservative (non-reactive) material introduced into an ideal well-mixed system, loadings and achieved concentrations would be directly proportional. In a steady state

(constant loadings and concentration not increasing) a mass balance can be set up for a conservative material where material entering the system must equal the material leaving the system (or else the concentration of the material would either be rising or falling). Expressed in mathematical shorthand:

$$M_{in} = M_{out}$$

M_{in} is the loading, at a constant rate, of the material M. (This assumes the offshore concentration is negligible.) M_{out} depends upon how much water is exchanged per unit of time between the system and more offshore waters.

$$M_{out} = \text{volume of water lost per day} * \text{Concentration of M in water}$$

$$[\text{Following the units: g/day=liters/day} * \text{g/liter}]$$

As the flushing of a coastal system does not depend upon a material like nitrogen dissolved in the water, the volume of water lost per day is constant (long-term average). Hence, in a single ideal system, the achieved concentration of a conservative material is directly proportional to the loadings. A doubling of a loading would lead to a doubling of achieved concentration, once a new steady-state is achieved. (This requires a period of time equal to about three times the residence time of the water in the system.) A similar exercise can be done for non-negligible offshore concentrations, where the net result is that the net difference between the in-system concentration and the offshore concentration is proportional to loading.

Nitrogen is not a conservative material. The forms of nitrogen undergo many reactions. As nitrogen enters a coastal ecosystem from the landward side and passes through a coastal system to the open ocean, it may be taken up from dissolved forms into organic matter and remineralized (both in the water column and at the benthos) a number of times. In addition there can be essentially permanent losses of nitrogen, through long-term burial in sediments and denitrification (the conversion of fixed nitrogen to nitrogen gas). While there are very few very well constrained nitrogen budgets for coastal ecosystems, it appears that burial is generally a small term. Denitrification on the other hand may be quite significant and quite variable. In a fast-flushing estuary, there may be little time for denitrification. In a system where water has a long residence time, denitrification may account for a major loss. For example, it is estimated than 90% of the nitrogen introduced into the Baltic Sea is denitrified (Larsson et al., 1985).

The net result is that in coastal ecosystems with fairly short residence times, the achieved concentrations of nitrogen in the system will be at least approximately proportional to changes in nitrogen loadings. Even in systems where there is significant denitrification, if the fraction of nitrogen lost to denitrification is approximately the same at different loadings, then the proportionality between changes in concentration and changes in loading will hold.

For systems where there is a long residence time of water, it is probable that the relationship between nitrogen loadings and concentrations will not be proportional. This is especially true where the relative concentrations of the nitrogen species may have also changed over time. A higher fraction of nitrate in the inputs (as may happen when sewage treatment plants convert more ammonia to nitrate to reduce the oxygen demand of their effluent) may be expected to alter the fraction of nitrogen lost to denitrification. (Nitrate is the nitrogen species converted to nitrogen gas during denitrificaion.)

RELATIONSHIPS BETWEEN NITROGEN AND EUTROPHICATION

There have been a few studies attempting to determine a general relationship between nitrogen and eutrophication, or properties related to eutrophication. As might be expected from the discussions above, a variety of different measures of nitrogen availability have been used. Similarly, different measures of phytoplankton abundance and production have been considered. The reader is advised to note the exact parameters plotted on each graph. Many of the graphs appear similar but are of different parameters. In addition, some of the plots (those generated new for this report) are provided in two versions showing the same data, a log-log-axes version and a linear-axes version. The perspective obtained from inspection of plots may be influenced by the log or linear construction of the plot. The dual versions are provided to give multiple perspectives.

This section will look at some previous efforts to find relationships between nitrogen and eutrophication from comparative studies and mesocosm experimentation. A new analysis of the changes in coastal ecosystems over time will also be presented. In order to compare the results obtained from the different measures of nitrogen availability and of phytoplankton abundance and production, a factor-of-change of effect (abundance or production) per factor of change in nitrogen (loading or DIN concentration) will be calculated. For example, it may be found that in a system where the nitrogen loading doubled over time, the phytoplankton abundance went up by a factor of 1.5. It may eventually be shown that it is inappropriate to compare the results of abundance changes with production changes. For now, the approach allows a quantitative look at eutrophication from a variety of types of information.

Nixon (1992) prepared plots of primary production and chlorophyll-a against DIN input (both on an areal and volume basis) for a variety of marine systems ranging from the open ocean to heavily nutrient-loaded estuaries (Figures 1 to 4). Both the production and abundance of phytoplankton correlate with nitrogen loadings.

In viewing Figures 1 to 4 it should be kept in mind that the plots are log-log plots. Hence the scatter of points is a significant magnitude. If a more limited range is examined, the significance of the scatter becomes evident. Nixon and Pilson (1983) and Nixon (1983) prepared cross-system plots for estuaries only. Their results are replotted in Figure 5. In these graphs, the correlation between nitrogen and production is not so evident. Two estuaries with the same DIN input rate may have up to a factor of five difference in production.

The results of two other cross-estuary approaches appear in Figures 6 and 7. Figure 6 shows an effort similar to that of Nixon and Pilson (1983) except that the estuaries were broken into segments (typically 4 segments), so as not to average high and low nutrient portions of estuaries, and the segments were plotted individually. Nixon and Pilson (1983) used whole-estuary averages. Figure 7 shows an annual average DIN vs. annual average chlorophyll plot for individual stations in a variety of estuaries (from Monbet, 1992).

While there may be a general trend of increasing phytoplankton abundance with increasing nitrogen availability, nitrogen alone is an imprecise predictor for a public official faced with a decision as to whether the benefit will be worth the expense to reduce, for example, the nitrogen inputs to an estuary by 30%. Estuaries, portions of estuaries, and individual stations in estuaries with similar nitrogen loadings or DIN concentrations may have quite different (at least from a practical management perspective) phytoplankton abundance and production.

From a historical perspective, examination of a portion, limited to high nutrient levels, of the Vollenweider plot of corrected phosphate concentrations vs. chlorophyll (which was an

influential milestone in lake management), on a linear plot (Figure 8) shows scatter much like that in Figures 5 and 6. While the general principle of phosphorus control on lake trophic status was strongly supported by the original Vollenweider relationship, the relationship established also did not have the precision to accurately (i.e., within a factor of 2) predict the chlorophyll abundance in any individual lake.

The scatter in the cross estuary studies begs the question of how have individual coastal ecosystems responded to changes in nitrogen. Will each individual coastal ecosystem respond to nitrogen additions with an increase in phytoplankton abundance or production? If so, would all ecosystems have the same magnitude of response for the same change in nitrogen loading or concentration? Or, do coastal ecosystems of vary in sensitivity to changes in nitrogen?

What has been learned from controlled experiments? A 28-month eutrophication experiment was conducted in the MERL marine enclosures using 9 enclosures. Three of the enclosures were kept as controls and 6 enclosures received daily additions of nitrogen, phosphorus, and silicate to create a gradient of loading. Figures 9, 10, and 11, show that measures of phytoplankton abundance and production increase reasonably steadily with increasing nitrogen loading or average concentration. The variability about the trend appears to result primarily from influence of the benthic communities (which developed into quite different communities in the different enclosures) on the phytoplankton in the water column. Nevertheless, at least for this one environment, increases in nutrient loading resulted in eutrophication as defined earlier.

What has been the record of changes in coastal ecosystems over time? Table 1 provides details on a number of systems where a history of the conditions in the system is reasonably well constrained. For most systems, the available parameters are phytoplankton abundance (either as directly-measured chlorophyll or as calculated chlorophyll from cell counts) and nitrogen concentrations. The measured average abundance at two nitrogen concentration levels (usually near the begining and end of the reported period of changes in nitrogen concentration) are plotted in Figure 12. While many of the trends for individual systems combine to create an overall trend consistant with those in Figures 1-4, is clear that the slopes of the trends are not all parallel. For two of the systems, the change in abundance decreases with higher nitrogen concentrations, running counter to the expected overall trend.

Additional systems and production data can be considered by calculating a normalized parameter for each system. The parameter calculated here is the magnitude of change of abundance or production that is calculated to result from a doubling in nitrogen concentration or loading. A calculated "change factor" of 2, for example, indicates that there was a doubling in abundance or production for a doubling in nitrogen loading or concentration. A change factor of 1 would indicate that there was no change in abundance or production with a change in nitrogen concentration or loading. A change factor of less than one indicates that there was a decrease in abundance or production while there was an increase in nitrogen concentration or loading. (See the legend for Figure 13 for details on the method of calculation.) The values for the magnitude of the effect are plotted against the average DIN concentration for the system (i.e., midpoint of the system's DIN concentrations).

Changes observed in different systems for a doubling in nitrogen ranged from a value of 0.60 to 6.99. The values 0.60 for a region of the Upper Chesapeake indicated that there was a decrease in abundance of phytoplankton over a period in which there was increasing DIN concentrations. Similarly, the value of 0.64 for the Upper Pamlico, indicated that there was an increase in abundance of phytoplankton over a time period in which there was decreasing DIN concentrations. Most of the calculated change factors fall between about 1.1 and 3. It is interesting that for the three stations in the system for which there are measures of both abundance and production, Kanaehoe Bay, the increase in production was, at two of the three

stations, far greater than the increase in abundance. The Kanaeohe Bay results are from a relatively short-duration study after a sewage diversion and may suffer from averaging a relatively short period (Table 1). There was no clear trend in the magnitude of response in relation to the overall DIN concentrations in the various systems. However, the data do not clearly rule out a trend.

It is not possible to determine how much of the range in factors found in Figure 13 and slopes in Figure 12 may result from inadequacies in the data and the use of different measures of phytoplankton abundance and production. It is discouraging to note that two studies of a similar portion of Chesapeake Bay (Upper Chesapeake Bay and Chesapeake Region VI in Table 1) which encompass different but overlapping time periods, provide very pictures of the response of phytoplankton abundance to increases in nitrogen concentrations. Yet, it seems improbable that the variability can be accounted for simply by scatter. It is unlikely a single magnitude of response to nitrogen increases applies to all the systems. The two systems with trends running counter to the general trend are particularly telling. There are also systems where, without any change in DIN, phytoplankton concentrations have increased. (Such examples cannot be plotted on Figure 13 as the effect value would be infinity.) For example, the Bokniseck station in the Keil Bight had increases in phytoplankton abundance and production over a period when there is no apparent increase in DIN (see Gerlach, 1990).

THE ROLE OF ANOTHER FACTOR

Perhaps it is simply unrealistic to expect that nitrogen availability alone will be a precise predictor of (long-term) phytoplankton abundance or production in coastal ecosystems. At the very least, phytoplankton abundance is also controlled by grazing. Phytoplankton production is also controlled by light availability that may in turn depend upon inorganic particles, unrelated to nitrogen, suspended in the water. Coastal ecosystems are also subject to anthropogenic inputs of other chemicals that may alter phytoplankton response to nitrogen.

Revisiting the data assembled by Monbet (1992), shown earlier in Figure 7, demonstrates that an additional, somewhat subtle, factor helps control the abundance of phytoplankton in coastal ecosystems. Monbet (1992) divided the estuaries in his data set into macrotidal (tidal range >2 m) and microtidal (tidal range < 2 m). The macrotidal and microtidal points fall into 2 nearly distinct groups as shown in Figure 14. For the same concentration of nitrogen, macrotidal estuaries generally support lower phytoplankton abundances than microtidal estuaries.

Presumably, the higher tidal range estuaries have greater mixing energies which in turn exhibits some type of control on phytoplankton abundance. Two mechanisms can be readily hypothesized. First, more rapid vertical mixing may keep individual phytoplankton cells out of the photic zone a sufficient fraction of the time to slow overall growth. Second, more vertical mixing may bring phytoplankton near to the benthos where they are subject to more rapid direct grazing by benthic organisms. Cloern (1991 and personal communication) had previously noted that phytoplankton abundance in Northern San Francisco Bay was correlated to the neap-spring cycle of the tides.

Only one of the estuary segments shown in Figure 6 would be classified macrotidal (with a tidal range of only 2.1 m) by Monbet's definition. Nevertheless, if the data in Figure 6 are sorted into those segments with tidal ranges ≥1.2 m and <1.2 m, the set with the higher tidal ranges falls low relative to the set with the lower tidal range (Figure 15). Although these data do not provide a strong test of the effect of tidal height (lacking data from systems with high nitrogen concentrations and low tidal range), they are consistent with the trend found by Monbet (1992).

CURVE FITS TO CROSS-SYSTEM AND MERL DATA AND COMPARISON TO THE EFFECT FACTORS FROM CHANGES OVER TIME

Once the cross-estuary data is sorted into groups by tidal height, it is possible to calculate the magnitude of the change in abundance for a change in nitrogen for each group. This allows a comparison of the cross-estuary data to changes over time data. Figure 14 shows the Monbet (1992) data with power functions fit to the two groups of data. Of the types of equations for which curve fits were tried (power, linear, log, and exponential) the power curve provided the best combination of correlation coefficients and normal distribution of residuals for both the Monbet (1992) data and the MERL data. Figure 15 shows the MERL abundance data (previously shown in Figure 9) fit with a power function. In Figure 16, a power function is fit to the data from segments of estuaries with tidal ranges less than 1.2 m. Changes in abundance expected from doublings in nitrogen concentration may be calculated directly from the fitted curves. Both groups of Monbet (1992) data and the MERL experiment indicate that a doubling of nitrogen concentrations will lead to approximately a 1.4 times increase in phytoplankton abundance. The data from the estuary segments with tidal heights <1.2 m indicates an increase of only 1.1 times for a doubling of nitrogen concentrations (although the correlation coefficient is rather low). Doubling values from the cross-estuary studies and the MERL experiment are within the range of those found in changes over time in individual estuaries (Figure 13).

CONCLUSIONS

Cross-system comparisons, history of changes in coastal ecosystems, and experimentation all support the general idea that if an individual coastal ecosystem is enriched with nitrogen it will, probably have higher average abundances of phytoplankton and higher average phytoplankton primary production.

Unfortunately, cross-system comparisons, based only upon nitrogen loading or concentrations, do not provide a very precise predictor of the phytoplankton abundance or production that will occur in individual systems. Other factors in addition to nitrogen need to be taken into account. Tidal height in coastal systems has been shown to have a large influence on the abundance of phytoplankton that will be supported by a given average level of DIN in the system. It appears that factors that may influence phytoplankton in addition to nitrogen and tidal height will need to be considered in order to be able to provide a more precise predictive relationship for phytoplankton abundance and production.

The magnitude of the response for a doubling in nitrogen loading or average concentration is most likely to result in an increase in abundance or production by a factor between 1.4 and 3. The responses of most coastal ecosystems will probably fall within this range.

However, there are systems that have not responded in the "normal" manner to nitrogen enrichment. Some coastal ecosystems have had changes in phytoplankton abundance without, or in the opposite direction of, changes in nitrogen concentration. Some coastal ecosystems do not follow along the trend of nitrogen vs. abundance or production curves, even when the systems are sorted by tidal height.

There is, at present, no guarantee that in any individual system, reductions in nitrogen loadings will result in proportionate reductions (i.e., between 1.4 and 3 for a doubling in nitrogen) in phytoplankton abundance or production. There is no characteristic of estuaries identified here which will identify coastal ecosystems that will have unusual responses to nitrogen loadings.

Table 1. Sources of information for changes in coastal ecosystems over time (for Figure 12). The factor change in [DIN] or loading is tthe measured high nitrogen concentration to measured low concentration or loading for the system over the period of time considered.

System	Years	Salinity %	Average [DIN] µmoles/liter and factor change in [DIN] or loading	Phytoplankton Parameters Measured	Annual Averages [N] or Loading	Sources
Upper Chesapeake Bay	1965-1979	5-10	79 2.0x	Chlorophyll	ΣN (1)	Price et al., 1985
Upper Chesapeake Bay (2)						
Region IV (3)	1960-1969 1980-1990	8-16	14 1.2x	Chlorophyll	[DIN]	Harding, 1994
Region V (4)	1960-1969 1980-1990	4-13	22 1.8x	Chlorophyll	[DIN]	Harding, 1994
Region VI (5)	1960-1969 1980-1990	0-10	44 2.0	Chlorophyll	[DIN]	Harding, 1994
Kanaoe Bay						
Station OF	1976-1979		2.2 2.9x	Chlorophyll and Primary Production per volume.	[DIN]	Smith et al., 1981a, b
Station SE	1976-1979		0.97 1.5x		[DIN]	Smith et al., 1981a, b
Station CE	1976-1979	34-35	0.79 1.4x		[DIN]	Smith et al., 1981a, b
Tampa Bay	1972-1978 1985-1989	22-25	7.15 3.2x	Chlorophyll	Loading ΣN	Johansson and Lewis, 1992, and Johansson, Personal Communication

Table 1, continued.

System	Years	Salinity %	Average [DIN] µmoles/liter and factor change in [DIN] or loading	Phytoplankton Parameters Measured	Annual Averages [N] or Loading	Sources
Eastern Oosterschelde (The Netherlands)	1980-1989	27-30	52 2.1x	hlorophyll and Primary Production per area	[DIN]	Wetsteyn and Kromkamp, 1994 Nienhuis and Small, 1994
Helgoland Reed (North Sea)	1962-1984	30-32	22.6 1.6x	Cell volumes	[DIN]	Gerlach, 1990
Halsskov Rev (Belt Sea, Baltic)	1975-1982	~20	7.2 3.7x	Priamary Production per area	[ΣN] (6)	Nielsen and Ærtebjerg, 1984
Gulf of Finland (Baltic)	1972-1985	6	22.6 1.3x	Chlorophyll	[ΣN] (6)	Kononen and Niemi, 1984 Konenen, 1988
Tolo Harbor	1978-1985	25	4.4 5.0x	Cell Counts	[DIN]	Hodgkiss and Chan, 1983, 1987
Tolo Channel		*32*	*1.9* 3.2x	*Cell Counts*	*[DIN]*	*Hodgkiss and Chan, 1983, 1987*
Upper Pamlico	1972-1992	0.5-5	13.6 1.9x	Chlorophyll	[DIN]	Stanley, Personal Communication

1. Not defined, from discussion appers to be total DIN.
2. Change was calculated as the average of 1960-1969 compared to the average of 1980-1989
3. Patuxent River to South River/Annapolis.
4. South River/Annapolis to Bay Bridge/Magothy River.
5. Bay Bridge/Magothy River to susquehanna Flats.
6. Not defined.

Figure 1. From Nixon (1992). Labeled systems are: (1) Sargasso Sea; (2) North Pacific gyre; (3) Choptank River estuary; (4) the Patuxent estuary; (5) Pamlico River estuary; (6) Potomac River estuary; (7) main stem of the Chesapeake Bay; (8) Patapsco River estuary; (9) Continental Shelf off New York; (10) Georges Bank; (11) Peru Upwelling; (13) Delaware Bay; (14) Kaneohe Bay; (15) Baltic Sea. Open triangles are from the MERL eutrophication experiment. For data sources and further information see Nixon (1992).

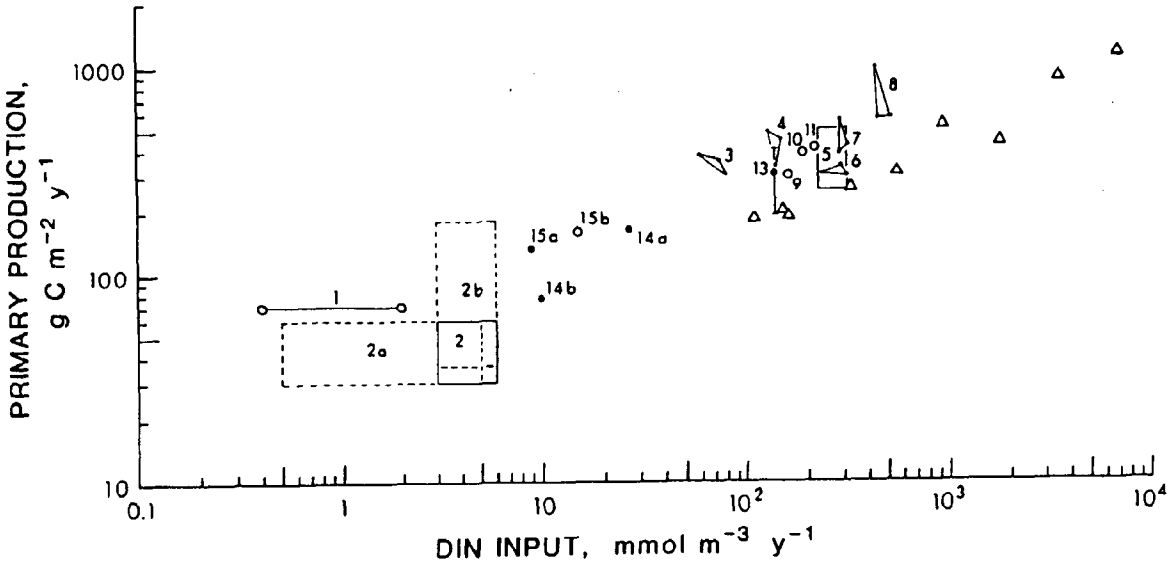


Figure 2. Primary Production by phytoplankton (^{14}C uptake) as a function of the annual input of dissolved inorganic nitrogen per unit area of a wide range of marine ecosystems. Systems are identified in Figure 1. The line represents a Redfield carbon to nitrogen molar ratio of 6.625 and gives a rough indication of how much carbon would be fixed at a given rate of nitrogen input without any recycling of nitrogen.

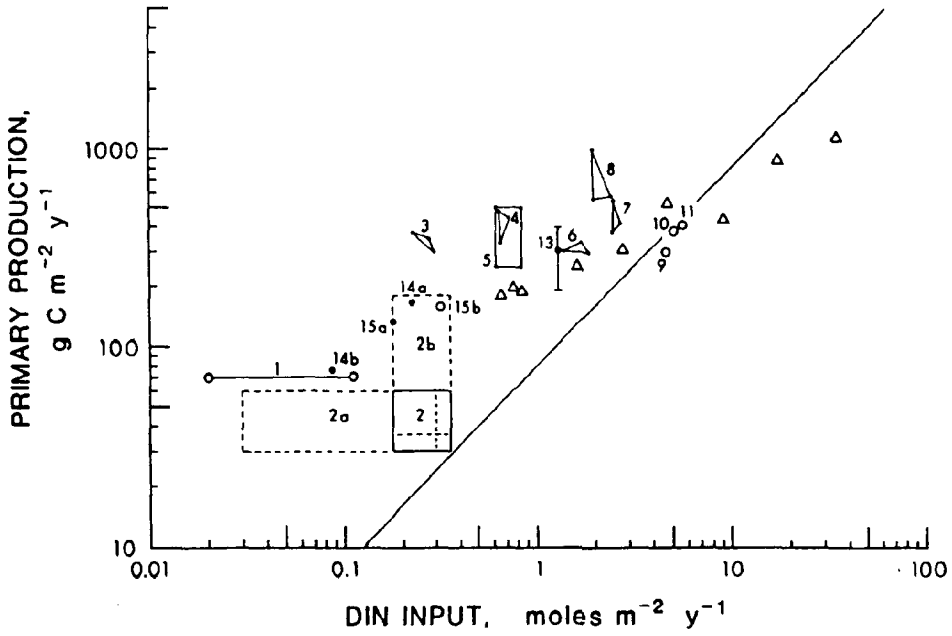


Figure 3. Mean annual concentrations of phytoplankton chlorophyll as a function of the annual input of dissolved inorganic nitrogen per unit volume of a wide range of marine ecosystems. Systems are identified in Figure 1.

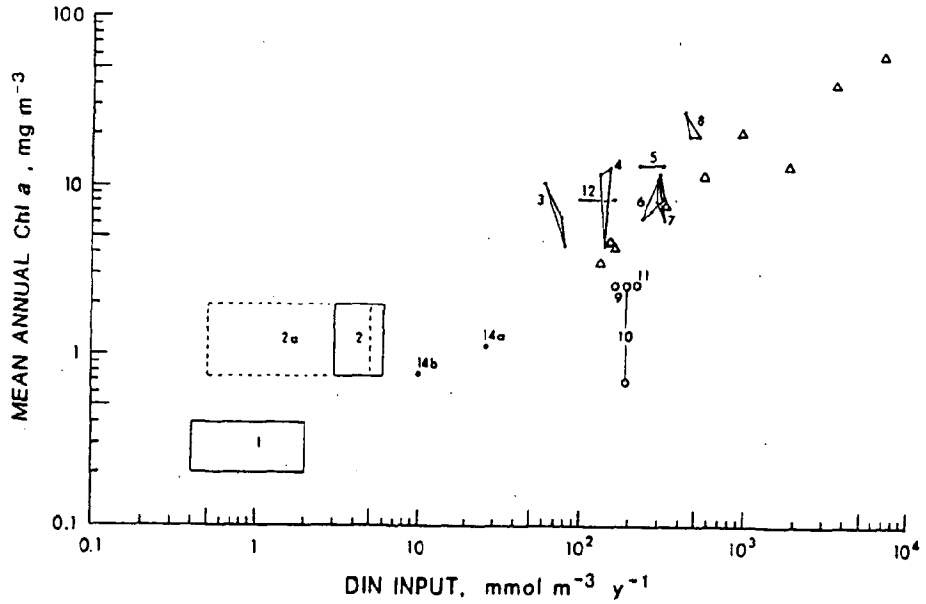


Figure 4. Mean annual concentrations of phytoplankton chlorophyll as a function of the annual input of dissolved inorganic nitrogen per unit area of a wide range of marine ecosystems. Systems are identified in Figure 1.

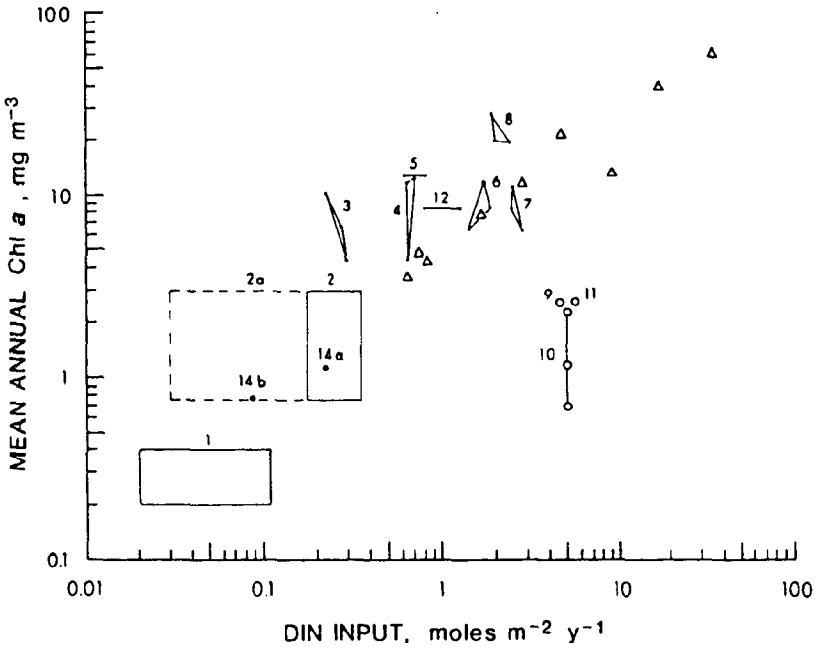


Figure 5. Redrawn from Nixon (1983) and Nixon and Pilson (1983). Coastal ecosystems represented are: Long Island Sound, Kaneohe Bay, Chesapeake Bay, Narragansett Bay, Patuxent River, Apalachicola Bay, South San Francisco Bay, North San Francisco Bay, and Lower New York Bay.

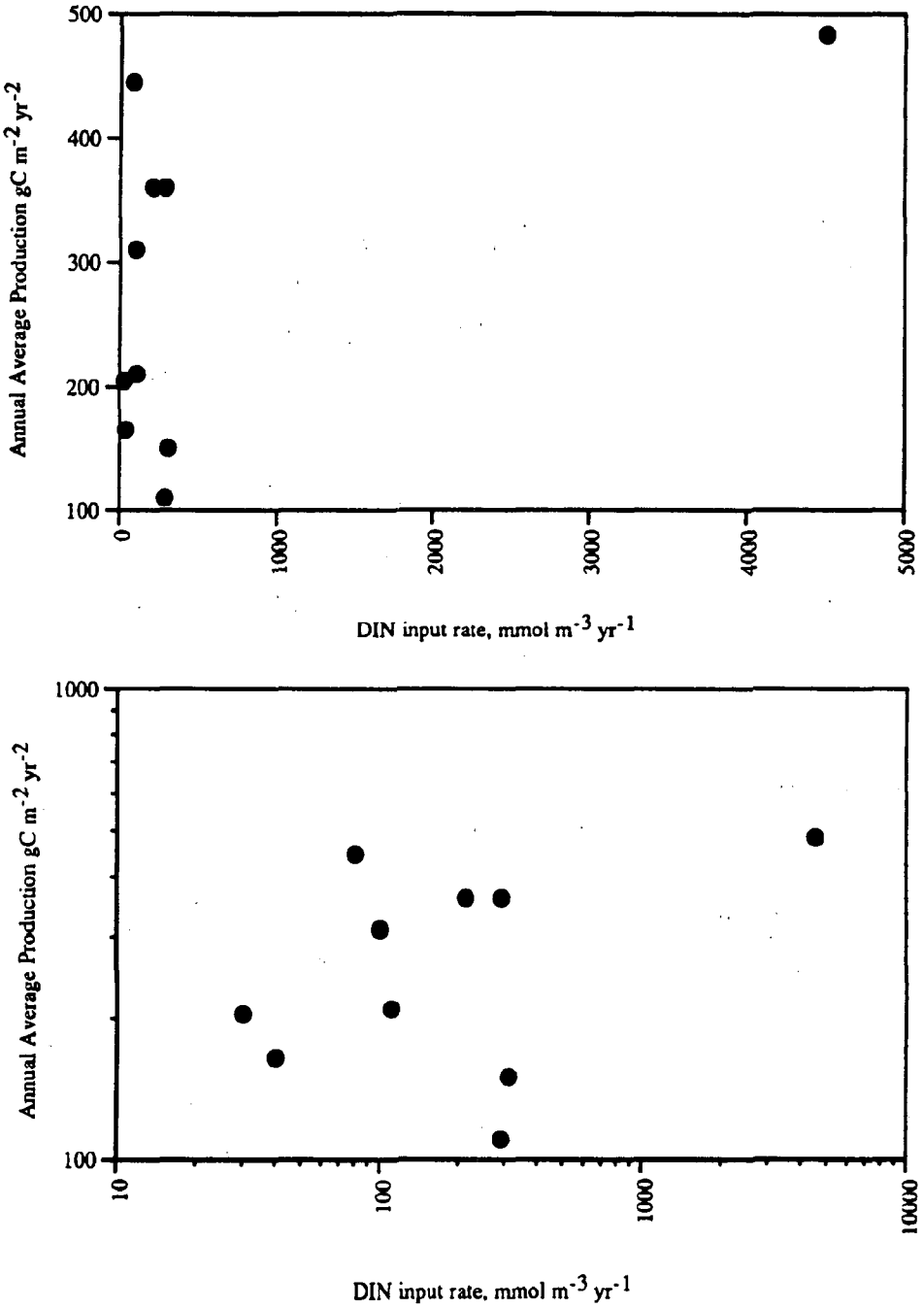


Figure 6. Unpublished data (compiled by K. Hinga, V. Berounsky, B. Kopp, A. Keller, A. Desbonnet, S. Pavignano, D. Stanley, M. Pilson, S. Nixon, and V. Lee). Each point represents a segment of an estuary. Estuaries were divided into typically four segments and data averaged for the segment. Averages may include up to 10 years of data. Estuaries represented are: Narragansett Bay, Delaware Inland Bays, Galveston Bay, Tampa Bay, San Francisco Bay, Buzzards Bay, Long Island Sound, Delaware Bay, Albemarle/Pamlico Bays, Barataria Bay, and Hudson River Estuary.

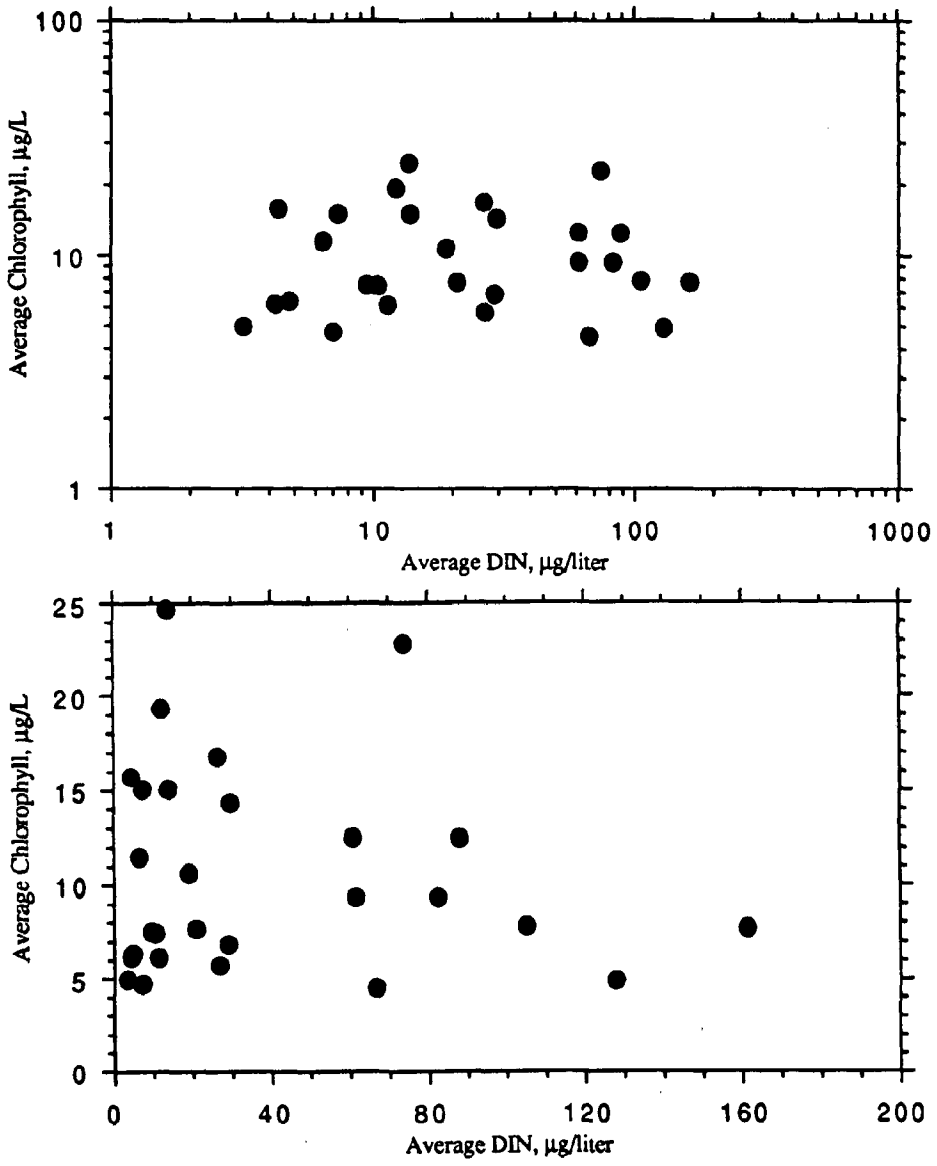


Figure 7. Data from Monbet (1992).

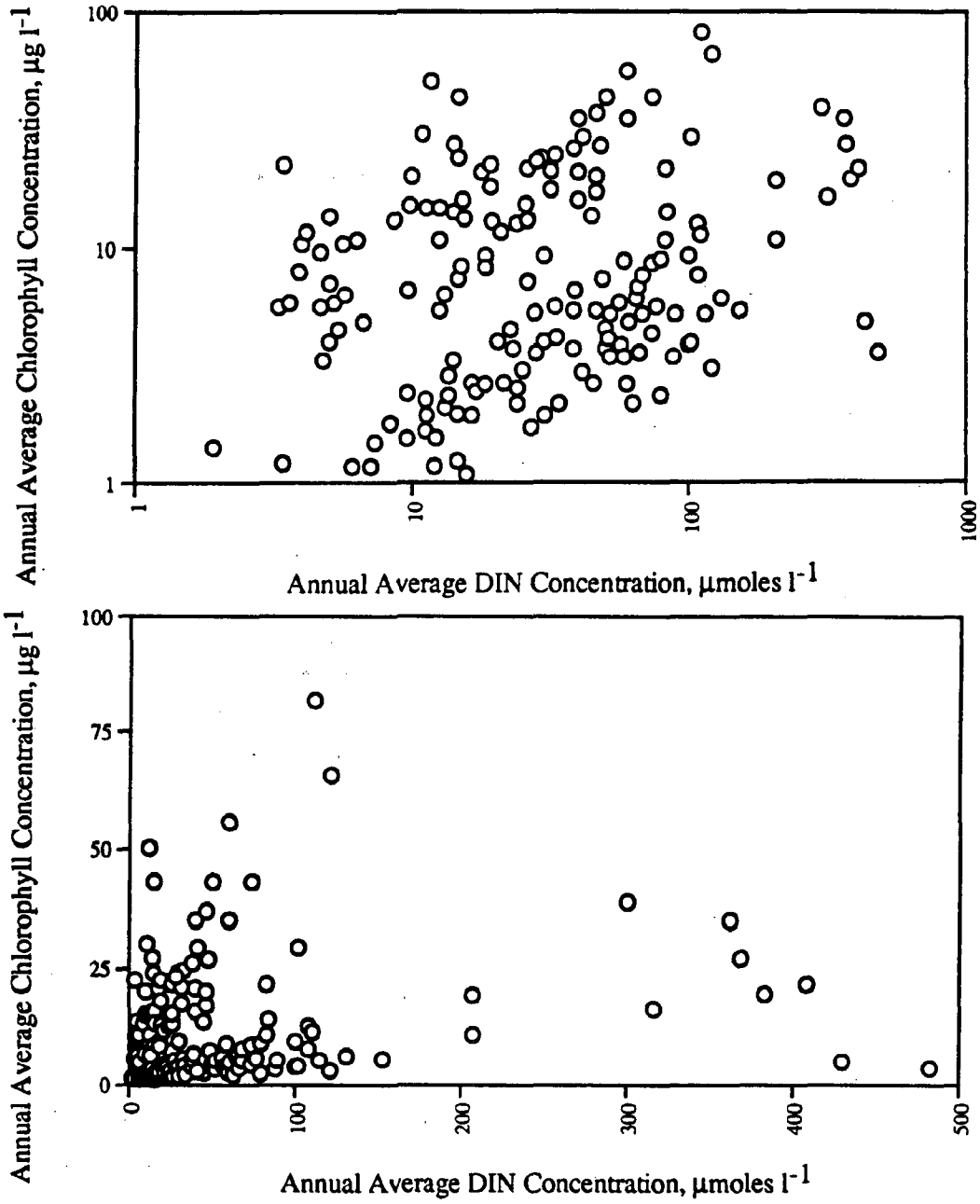


Figure 8. Vollenweider (1976) data (estimated) for 22 lakes with high phosphorus concentrations. .

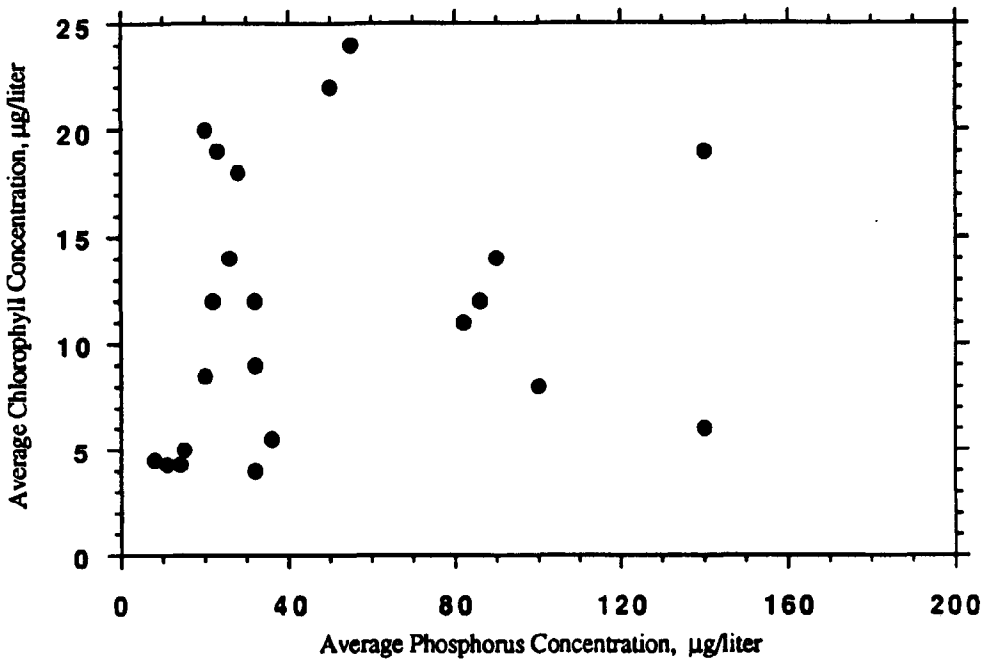


Figure 9. Data from MERL eutrophication Experiment (Frithsen et al., 1985).

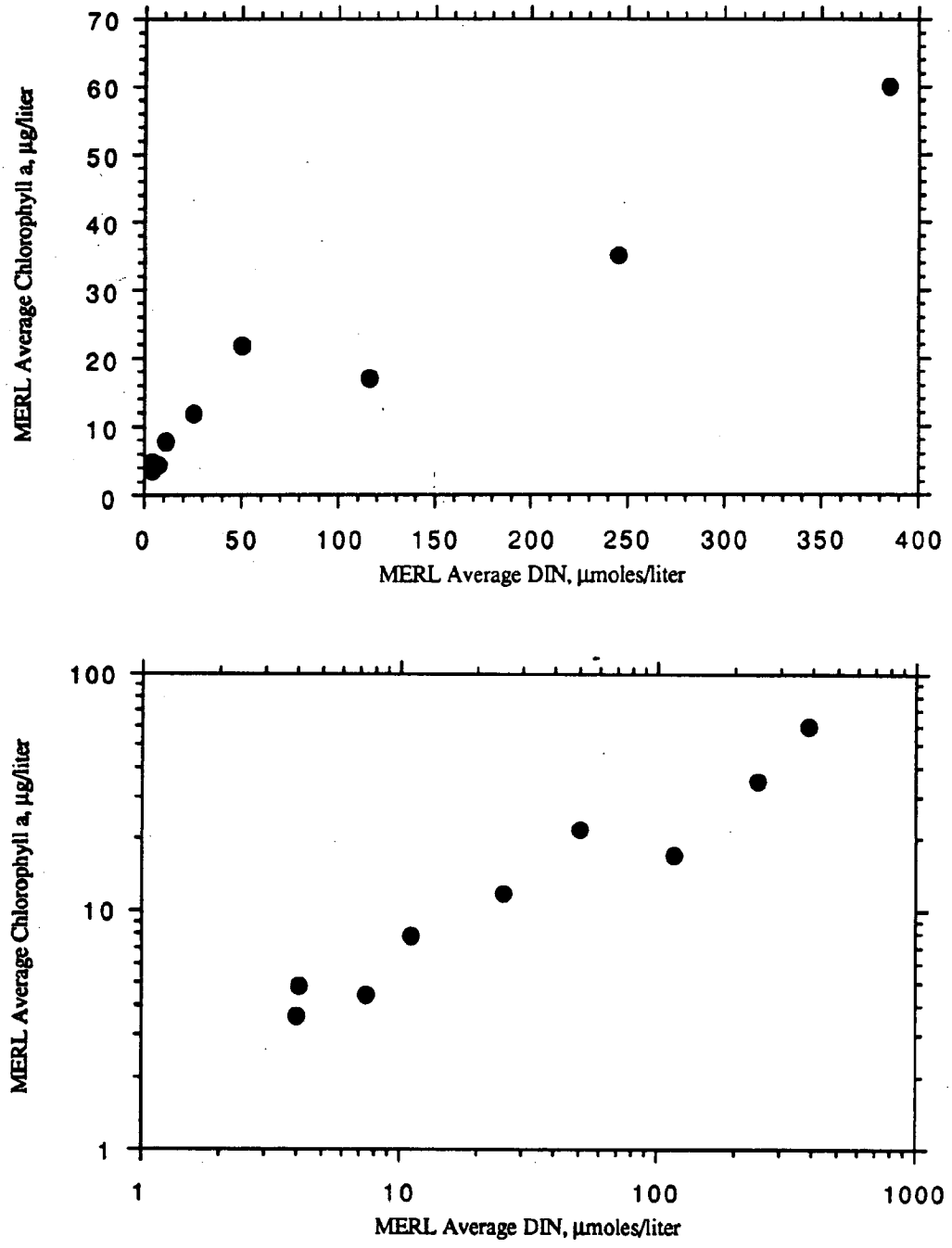


Figure 10. Data From MERL Eutrophication Experiment (Frithsen et al., 1985).

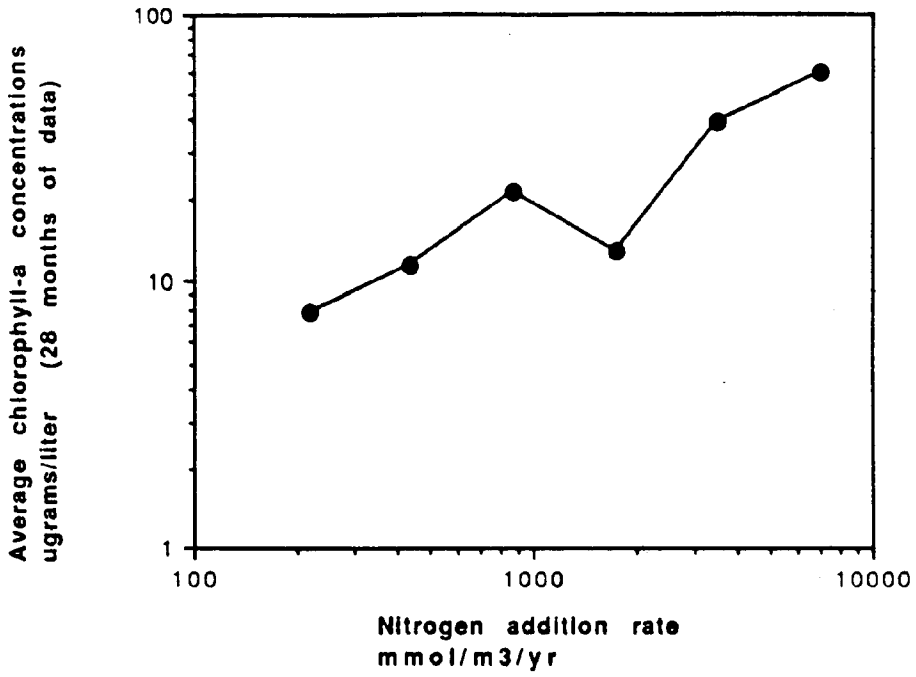


Figure 11. Data From MERL Eutrophication Experiment (Oviatt et al., 1986 and Keller, 1988). ^{14}C production is from ^{14}C uptake of water samples from the MERL enclosures. Net production is the result of whole-enclosure oxygen changes over a 24-hour period.

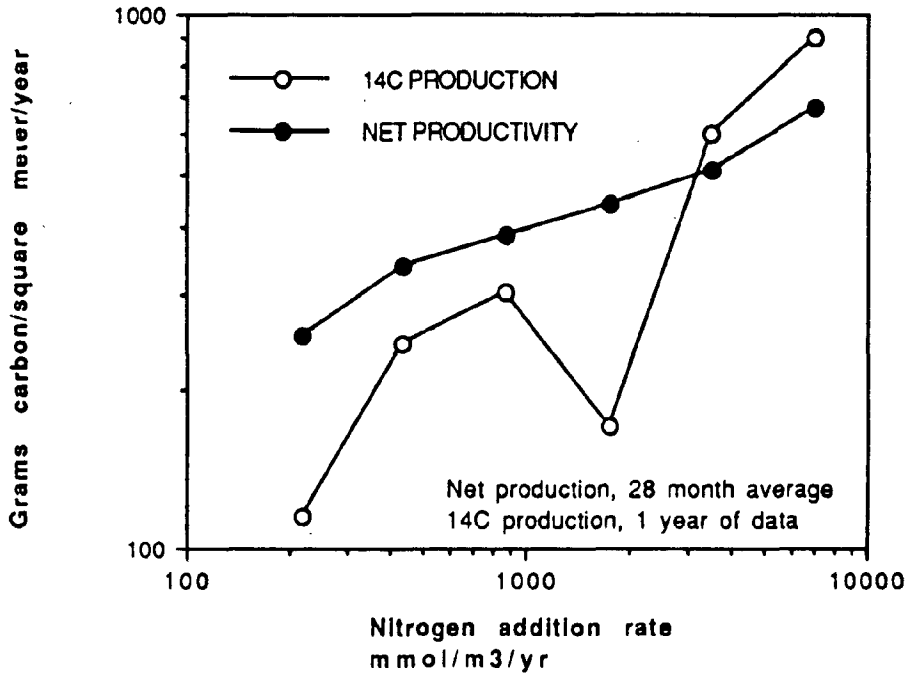


Figure 12a. Chlorophyll concentrations at two different nitrogen concentrations for each system or station. See Table 1 for details on each system.

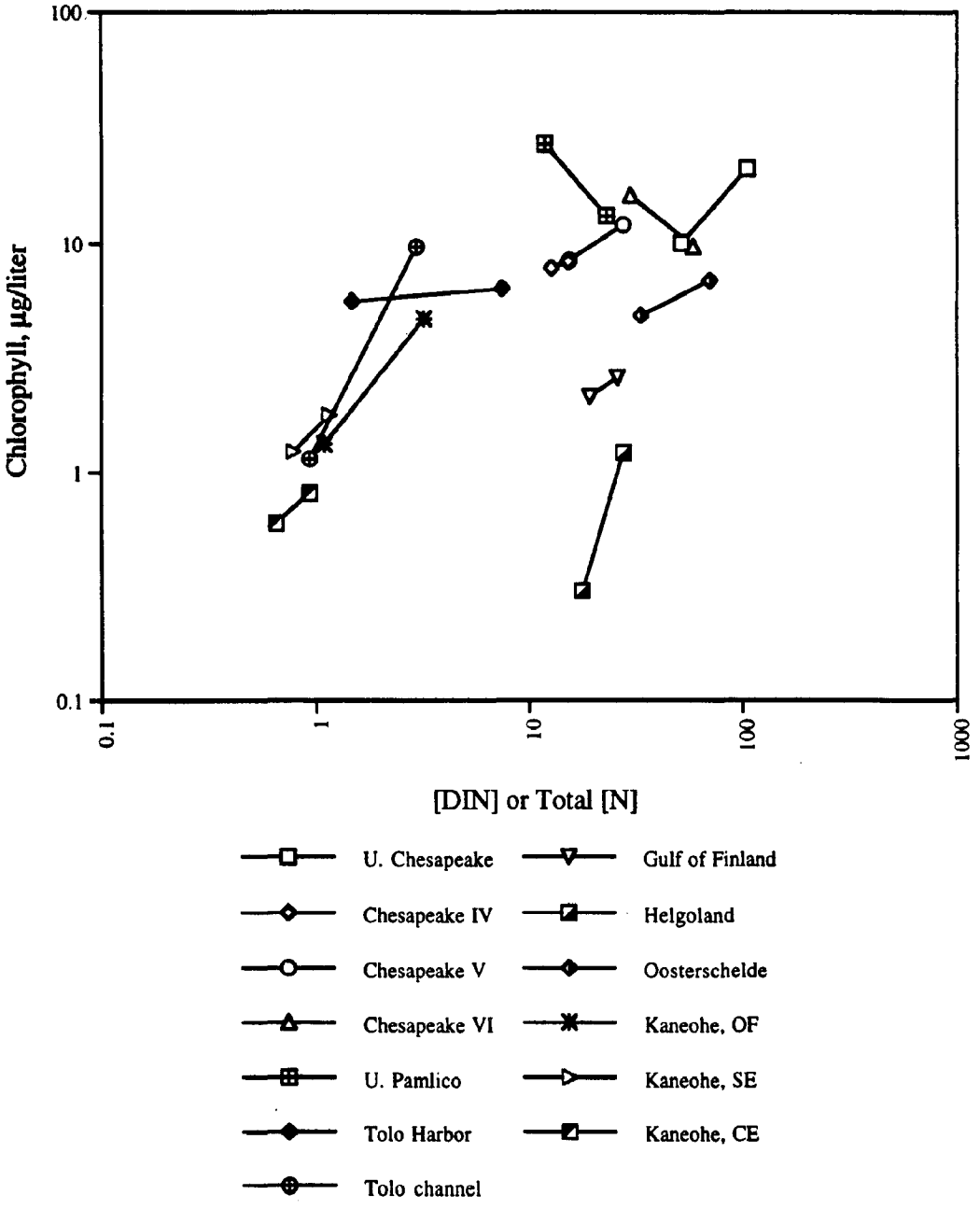


Figure 12b. Legend same as Figure 12a.

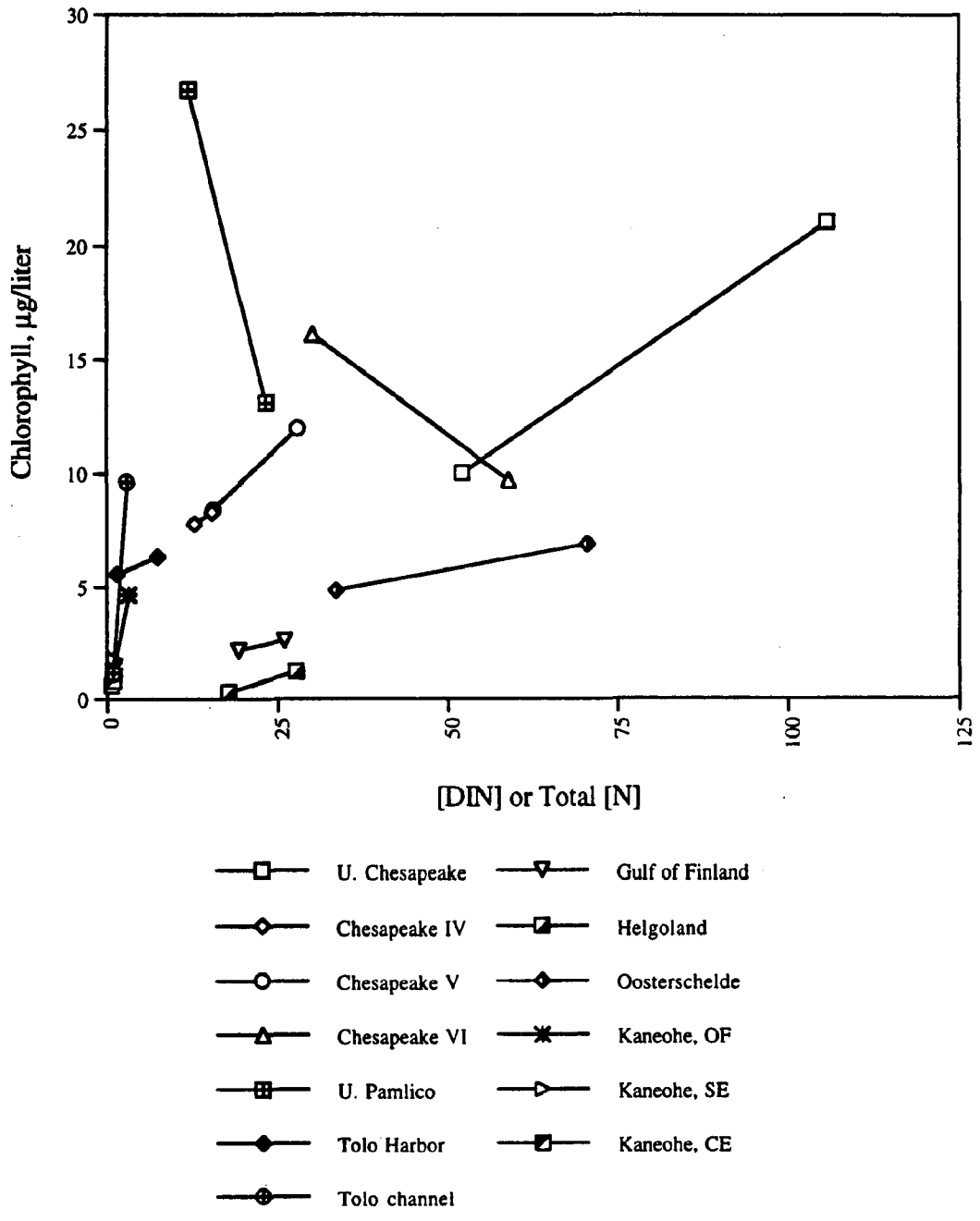


Figure 13. For each system (See Table 1), the data for the "effect" (chlorophyll, production, cell counts, or cell volume,) was regressed against the nitrogen concentration over the period of time when nitrogen and effects were changing. From the resultant linear relationship between effect and nitrogen, the predicted effect level was calculated for nitrogen values of 2/3 and 4/3 of the mean concentration for the system while the change was taking place. Thefactor for change in effect is the ratio of the calculated effects at 4/3 a d 2/3 of the mean nitrogen concentration. For all but four of the systems there was an increase in nitrogen over time. Two of the systems, Tampa Bay and Kanaehoe Bay, the change in nitrogen concentrations (and effect) were decreases resulting from sewage diversion. In the Oosterschlede nitrogen concentrations decreased as a result of a building of a storm-surge barrier. In the Pamlico river, the nitrogen concentrations were also going down over time.

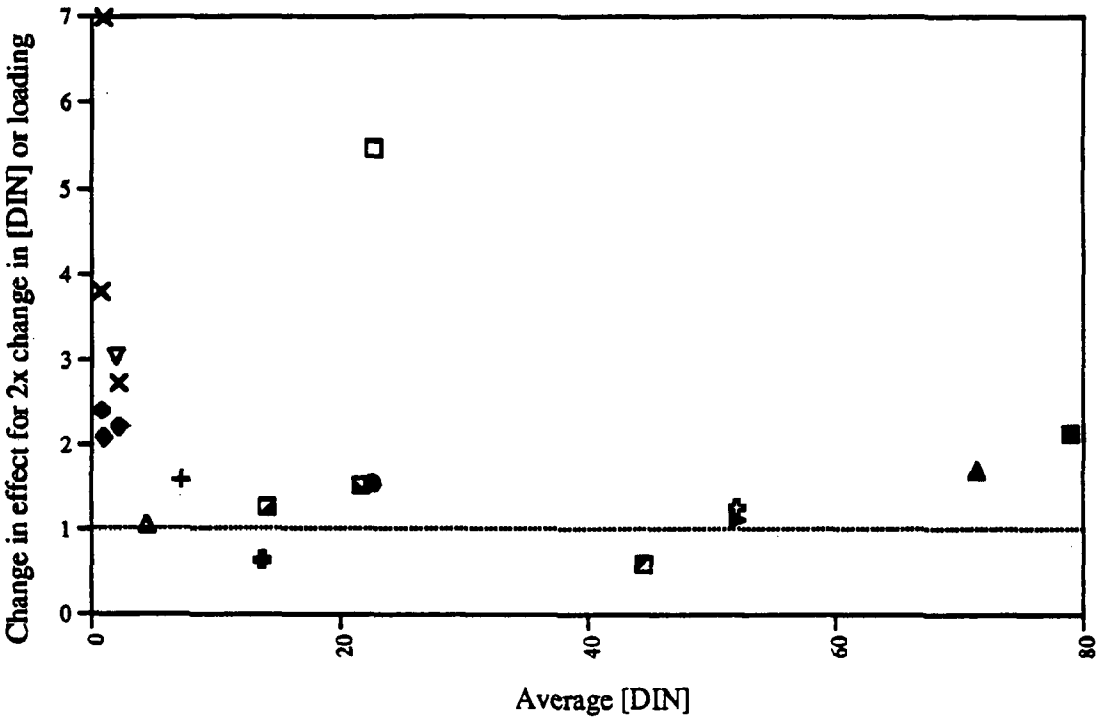
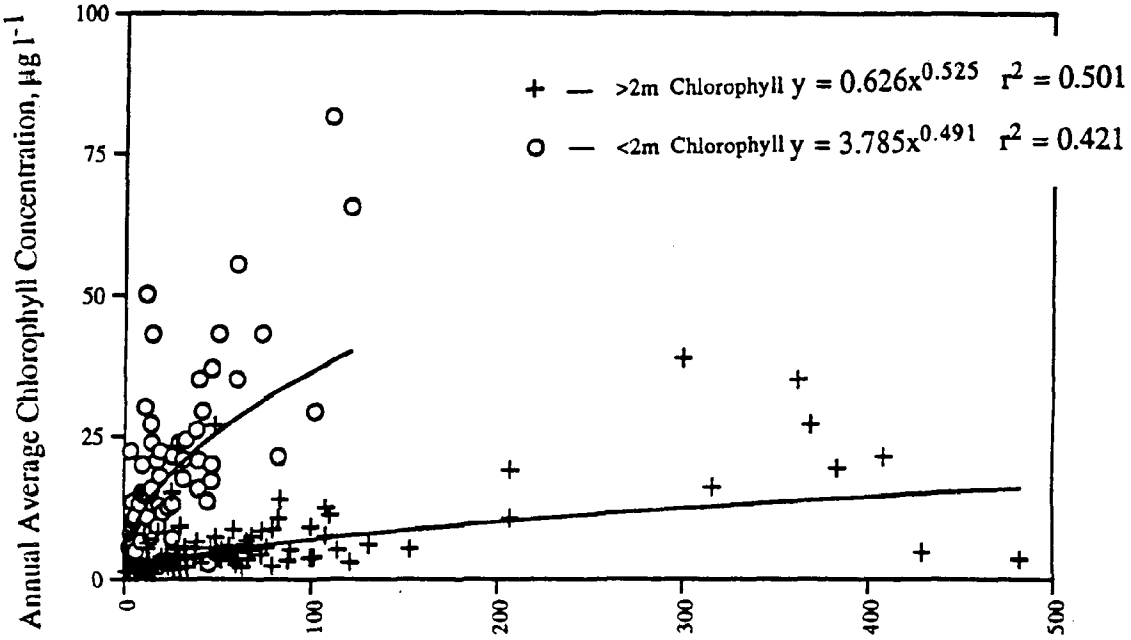


Figure 14. Data from Monbet (1992) fitted with a power function. Data is divided into stations with tidal ranges >2 m (crosses) and <2 m (open circles) and each set fit separately.



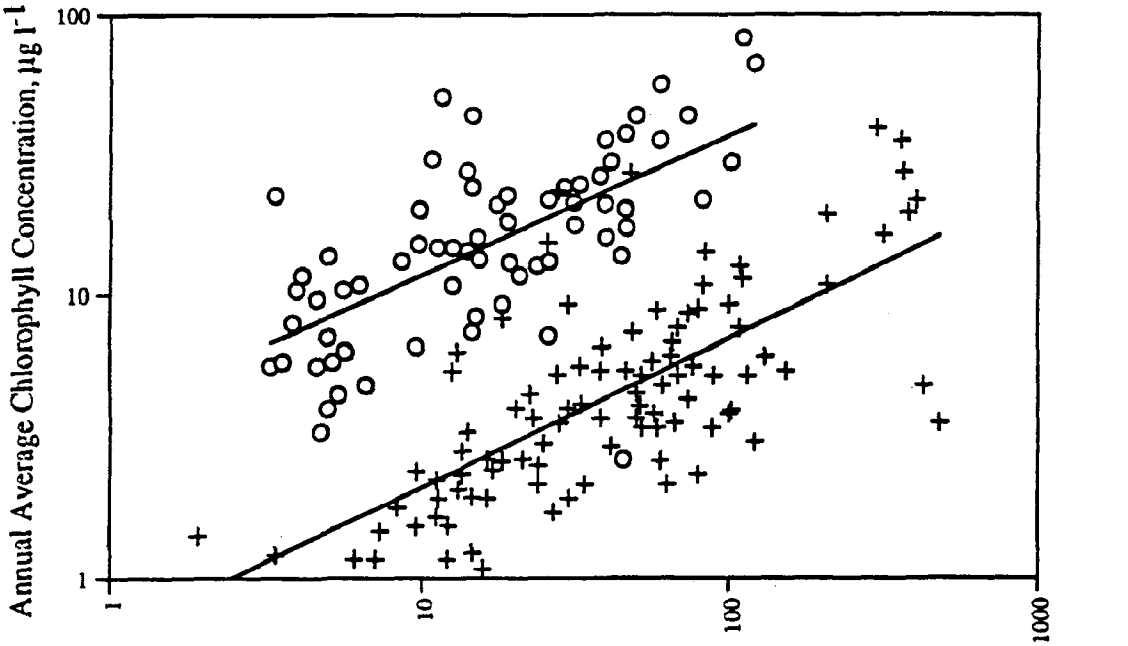


Figure 15. Data shown in Figure 6 divided into two groups by tidal height in the segment.

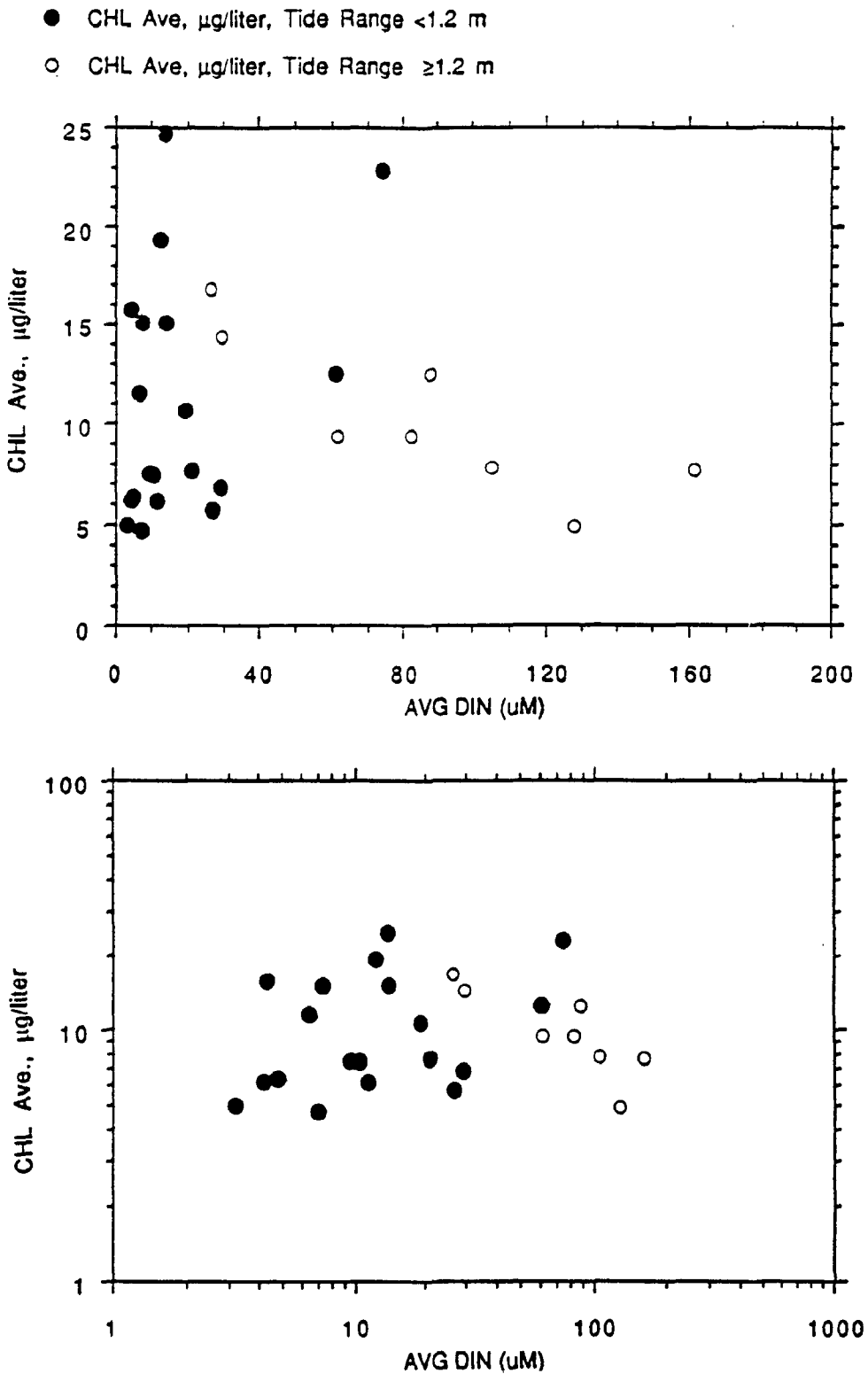


Figure 16. Data from MERL eutrophication experiment fitted with a power function.

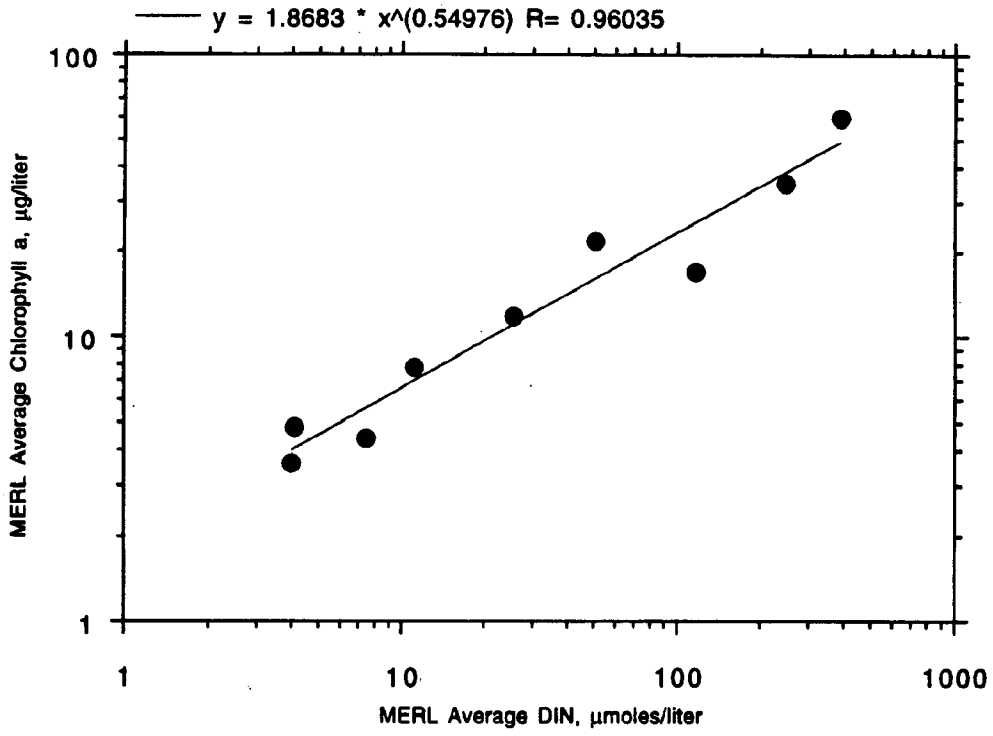
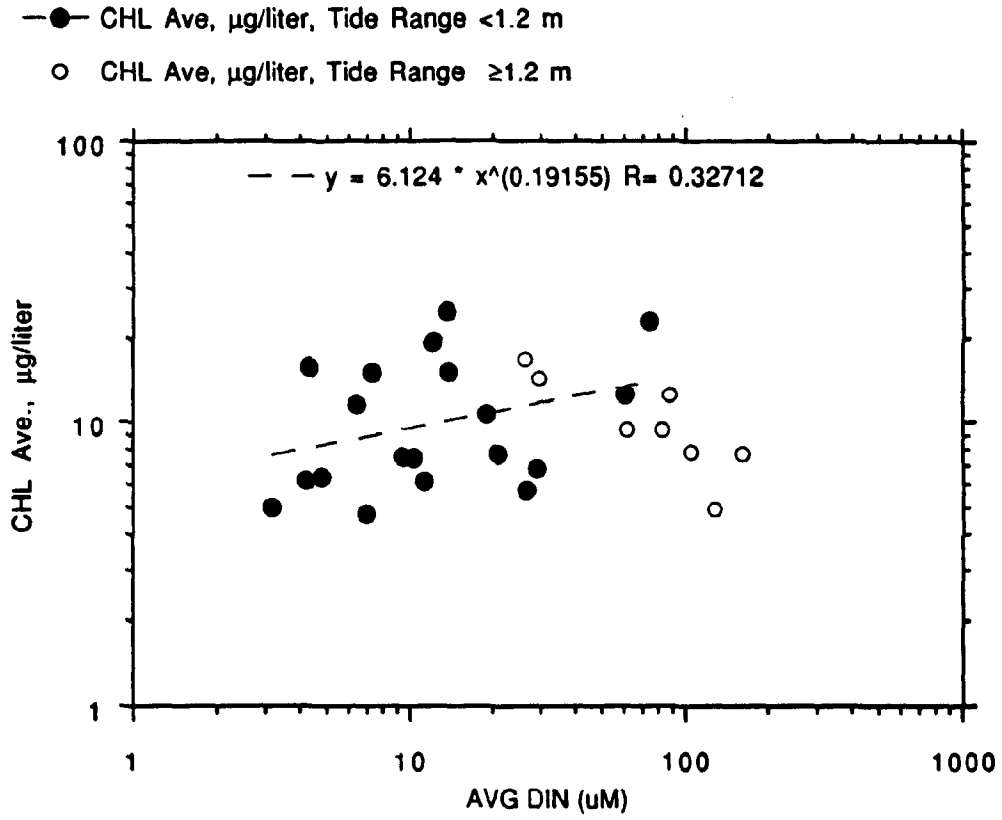


Figure 17. Data from Figures 6 and 14 with a power function fit to the data with tidal height <1.2 m.



LITERATURE CITED

Boynton, W. R., W. M. Kemp, and C. W. Keefe (1982) A comparative analysis of nutrients and other factors influencing estuarine phytoplankton production. In: V. S. Kennedy (ed.) *Estuarine Comparisons*. New York, Academic Press.

Cloern, J. E. (1991) Spatial and temporal variability of phytoplankton biomass and productivity in estuaries (abstract). In: K.R. Hinga, D.W. Stanley, C.J. Klein, D.T. Lucid, and M.J. Katz (eds.) The National Estuarine Eutrophication Project., Workshop Proceedings. National Oceanic and Atmospheric Administration, Rockville MD, 41 pages.

Cole, B. E. and J. E. Cloern (1987) An empirical model for estimating phytoplankton productivity in estuaries. *Marine Ecology-Progress Series* **36**:299-305.

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. *Canadian Journal of Fisheries and Aquatic Science* **43**:397-406.

Davies, J. M. and J. C. Gamble (1979) Experiments with large enclosed ecosystems. *Philosophical transactions of the Royal society of London, B* **286**:523-544.

Falkowski, P. G. (1980) Light shade adaption in marine phytoplankton. In: P. G. Falkowski (ed.) *Primary Productivity in the Sea*. New York, Plenum Press.

Gerlach, S. A. (1990) Nitrogen, phosphorus, plankton and oxygen deficiency in the German Bight and in the Kiel Bay. *Kieler Meeresforschungen, Sonderheft* **7**:1-341.

Goldman, J. C. (1976) Identification of nitrogen as a growth-limiting nutrient in wastewaters and coastal marine waters through continuous culture algal assays. *Water Research* **10**:97-104.

Granéli, E., W. Graneli, and L. Rydberg (1986) Nutrient limitation at the ecosystem and the phytoplankton community level in the Laholm Bay, south-east Kattegat. *Ophelia* **26**:181-194.

Granéli, E., S. Schulz, U. Schiewer, D. Gedziorwska, W. Kaiser, and M. Plinski (1988) Is the same nutrient limiting potential phytoplankton biomass formation in different coastal areas of the Southern Baltic? *Kieler Meeresforschungen, Sonderheft* **6**:191-202.

Granéli, E. and K. Sundbäck (1985) The response of planktonic and microbenthic algal assemblages to nutrient enrichment in shallow coastal waters, Southwest Sweden. *Journal of Experimental Marine Biology and Ecology* **85**:253-268.

Granéli, E., K. Wallström, U. Larsson, W. Granéli, and R. Elmgren (1990) Nutrient limitation of primary production in the Baltic Sea area. *Ambio* **19**:142-151.

Harding, L. W., Jr. (1994) Long-term trends in the distribution of phytoplankton in Chesapeake Bay: roles of light, nutrients and streamflow. *Marine Ecology Progress Series* **104**:267-291.

Hinga, K. R. (1990) Alteration of phosphorus dynamics during experimental eutrophication of enclosed marine ecosystems. *Marine Pollution Bulletin* **21**:275-280.

Hodgkiss, I. J. and B. S. S. Chan (1983) Pollution Studies on Tolo Harbour, Hong Kong. *Marine Environmental Research* **10**:1-44.

Hodgkiss, I. J. and B. S. S. Chan (1987) Phytoplankton dynamics in Tolo Harbour. *Asian Marine Biology* **4**:103-112.

Howarth, R. W. (1988) Nutrient limitation of net primary production in marine ecosystems. *Annual Reviews in Ecology* **19**:89-110.

Johansson, J. O. R. and I. R.R. Lewis (1992) Recent improvements of water quality and biological indicators in Hillsborough Bay, a highly impacted subdivision of Tampa Bay, Florida, USA. In: R. A. Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication*. Amsterdam, Elsevier.

Keller, A. A. (1988) An empirical model of primary productivity (^{14}C) using mesocosm data along a nutrient gradient. *Journal of Plankton Research* **10**:813-834.

Keller, A. A. (1988a) An empirical model of primary productivity (14-C) using mesocosm data along a nutrient gradient. *Journal of Plankton Research* **10**:813-834.

Keller, A. A. (1988b) Estimating phytoplankton productivity from light availability and biomass in the MERL mesocosms and Narragansett Bay. *Marine Ecology Progress Series* **45**:159-168.

Keller, A. A. (1989) Modeling the effects of temperature, light, and nutrients on primary productivity: An empirical and a mechanistic approach compared. *Limnology and Oceanography* **43**:82-95.

Keller, A. A. and R. L. Rice (1989) Effects of nutrient enrichment on natural populations of the brown tide phytoplankton *Aureococcus anophagefferens* (Chrysophyceae). *Journal of Phycology* **25**:636-646.

Kelly, J. R., V. M. Berounsky, S. W. Nixon, and C. A. Oviatt (1985) Benthic-pelagic coupling and nutrient cycling across an experimental eutrophication gradient. *Marine Ecology Progress Series* **26**:207-219.

Kononen, K. (1988) Phytoplankton summer assemblages in relation to environmental factors at the entrance to the Gulf of Finland during 1972-1985. *Kieler Meeresforschungen, Sonderheft* **7**:281-294.

Kononen, K. and Å. Niemi (1984) Long-term variation of the phytoplankton composition at the entrance to the Gulf of Finland. *Ophelia, supplementum* **3**:101-110.

Larsson, U., R. Elmgren, and F. Wulff (1985) Eutrophication and the Baltic Sea: Causes and consequences. *Ambio* **14**:9-14.

Laws, E. A. and D. G. Redalje (1979) Effect of sewage enrichment on the phytoplankton population of a subtropical estuary. *Pacific Science* **33**:129-148.

Lundgren, A. (1985) Model ecosystems as a tool in freshwater and marine research. *Archiv F. Hydrobiologie, Suppl.Bd. 70* **2**:157-196.

Monbet, Y. (1992) Control of phytoplankton biomass in estuaries: A comparative analysis of microtidal and macrotidal estuaries. *Estuaries* **15**:563-571.

Montgomery, R. T., B. F. McPherson, and E. E. Emmons (1991) *Effects of nitrogen and phosphorus additions on phytoplankton productivity and chlorophyll a in a subtropical estuary, Charlotte Harbor, Florida.* Report No. Water-Resources Investigations Report 91-4077.

Myers, V. B. and R. I. Iverson (1981) Phosphorus and nitrogen limited phytoplankton productivity in northeastern Gulf of Mexico coastal estuaries. In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients.* Clifton, New Jersey, Humana Press.

Nielsen, A. and G. Ærtebjerg (1984) Plankton blooms in Danish waters. *Ophelia, Supplementum* **3**:181-188.

Nienhuis, P. H. and A. C. Smaal (1994) The Oosterschelde estuary, a case-study of a changing ecosystem; an introduction. *Hydrobiologia* **282/283**:1-14.

Nixon, S. w. (1983) *Estuarine Ecology- A Comparative and Experimantal Analysis Using 14 Estuaries and the MERL Microcosms.* Graduate School of Oceanography, University of Rhode Island, Final Report to EPA for Grant No. X-003259-01.

Nixon, S. W. (1992) Quantifying the relationship between nitrogen input and the productivity of marine ecosystems. Advanced marine Technology Conference, No.5 Japan, pages 57-83.

Nixon, S. W. (1994) Coastal marine eutrophication: some social causes and future concerns. *Ophelia* , In Press.

Nixon, S. W. and M. E. Q. Pilson (1983) Nitrogen in estuarine and coastal marine ecosystems. In: E. J. Carpenter and D. G. Capone (ed.) *Nitrogen in the Marine Environment.* New York, Academic Press.

Nixon, S. W., M. E. Q. Pilson, C. A. Oviatt, P. Donaghay, B. Sullivan, S. Seitzinger, D. Rudnick, and J. Frithsen (1984) Eutrophication of a coastal marine ecosystem - An experimental study using the MERL microcosms. In: M. J. R. Fasham (ed.) *Flows of Energy and Materials in Marine Ecosystems.* New York, Plenum Publishing Co.

Oviatt, C., P. Doering, B. Nowicki, L. Reed, J. Cole, and J. Frithsen (1994) An ecosystem level experiment on nutrient limitation in temperate coastal marine environments. *Marine Ecology - Progress Series* , Submitted.

Oviatt, C. A., A. A. Keller, P. A. Sampou, and L. L. Beatty (1986a) Patterns of productivity during eutrophication: a mesocosm experiment. *Marine Ecology Progress Series* **28**:69-80.

Oviatt, C. A., D. T. Rudnick, A. A. Keller, P. A. Sampou, and G. T. Almquist (1986b) A comparison of system (O_2 and CO_2 and C-14 measurements of metabolism in estuarine mesocosms. *Marine Ecology Progress Series* **28**:57-67.

Oviatt, C. A., P. Lane, I. F. French, and P. Donaghay (1989) Phytoplankton species and abundance in response to eutrophication in coastal marine mesocosms. *Journal of Plankton Research* **11**:1223-1244.

Parsons, T. R. (1981) The use of controlled experimental ecosystems: A review. *Journal of the Oceanographical Society of Japan* **37**:294-298.

Price, K. S., D.A. Flemer, J. L. Taft, G. B. Mackiernan, W. Nehlsen, R. B. Biggs, N. H. Burger, and D. A. Blaylock (1985) Nutrient enrichment of Chesapeake Bay and its impact on the habitat of striped Bass: A speculative hypothesis. *Transactions of the American Fisheries Society* **114**:97-106.

Ryther, J. H. and W. M. Dunstan (1971) Nitrogen, phosphorus, and eutrophication in the coastal marine environment. *Science* **171**:1008-1013.

Santschi, P. H. (1988) A need to study interactive effects. *Applied Geochemistry* **3**:81.

Shindler, D. W. (1983) Experimental approaches to limnology - An overview. *Journal of the Fisheries Research Board of Canada* **30**:1409-1413.

Shindler, D. W., F. A. J. Armstrong, S. K. Holmgren, and G. J. Brunskill (1971) Eutrophication of Lake 227, experimental lakes area, Northwestern Ontario, by additio of phosphate and nitrate. *Journal of the Fisheries Research Board of Canada* **28**:1763-1782.

Smith, S. V. (1981a) Responses of Kaneohe Bay, Hawaii, to relaxation of sewage stress. In: B. J. Neilson and L. E. Eugene (ed.) *Estuaries and Nutrients.* Clifton, New Jersey, Humana Press.

Smith, S. V., W. J. Kimmerer, E. A. Laws, R. E. Brock, and T. W. Walsh (1981b) Kaneohe Bay sewage diversion experiment: Perspectives on ecosystem responses to nutritional perturbation. *Pacific Science* **25**:279-395.

Stanley, D. W. (1994) Personal Communication.

Steele, J. H. (1979) The uses of experimental ecosystems. *Philosophical Transactions of the Royal Society of London, B* **286**:583-595.

Vollenweider, R. A. (1976) Advances in defining critical loading levels for phosphorus in lake eutrophication. *Memorie dell'Istituto Italiano di Idrobiologia* **33**:53-83.

Wetsteyn, L. P. M. J. and J. C. Kromkamp (1994) Turbidity, nutrients, and phytoplankton primary production in the Oostershelde (The Netherlands) before, during and after a large-scale coastal engineering project (1980-1990). *Hydrobiologia* **282/283**:61-78.

MARINE EUTROPHICATION REVIEW

PART 2: BIBLIOGRAPHY WITH ABSTRACTS

TABLE OF CONTENTS

INTRODUCTION 1

ASSEMBLY OF THE BIBLIOGRAPHY 1

BIBLIOGRAPHY FORMAT
- Subject Lists 2
- Main Reference List 2

ELECTRONIC VERSIONS OF THE BIBLIOGRAPHY 2

RESOURCES USED IN THE BIBLIOGRAPHY (TABLES 1-4) 3

SUBJECT LISTS
- Phytoplankton Abundance 6
- Phytoplankton Composition 8
- Red Tides And Nuisance Blooms 9
- Macrophytes 9
- Oxygen Concentration 10

MAIN REFERENCE LIST 11

APPENDIX: Keyword List 117

INTRODUCTION

Modern societies have increased the rate of supply of nutrients to estuaries and coastal marine environments from many sources over the rates in the pre-industrial era and times of lower population density. The addition of nutrients, or eutrophication, is considered a major problem in coastal areas. Typical symptoms attributed to eutrophication are: increases in algal biomass and productivity, nuisance algal blooms, algal mats and scums, increased bacterial activity, odor problems, turbidity, and depletion of oxygen in bottom waters. Long term and secondary effects may include changes in the composition of pelagic and benthic communities, reduction of species diversity, decreased abundance of submerged aquatic plants due to epiphetic or planktonic shading, disruption of food chains, and the possible occurrence of toxic phytoplankton blooms (such as "red tides"). On a positve note, a reasonable level of nutrient enrichment may increase primary productivity without much negative effect and may be converted into increased abundance and yield of desireable and harvestable species.

It is likely that all the consequences of estuarine eutrophication are not known. Even for those known effects, a clear understanding of the *magnitude* of many of the effects resulting from increases in nutrient loadings is lacking. Equally important, there are likely some effects attributed to nutrient additions to coastal environments which are not actually caused by the increases in nutrients. This may occur because other materials may be added to the marine environment, or there are other alterations of the environment which are occurring simultaneously with nutrient additions.

In order to make a step toward a better understanding of the effects of eutrophication, the NOAA Coastal Ocean Program commissioned the assembly of this bibliography on marine eutrophication. Literature which may be useful in understanding marine eutrophication is in diverse sources. This bibliography is intended to facilitate the finding of literature either for the scientist or manager who may want to develop a clearer picture of marine eutrophication. The bibliography is not a compilation of data sources which might be used for new analysis of eutrophication.

ASSEMBLY OF THE BIBLIOGRAPHY

The 438 references in this bibliography were assembled by searching a number of data bases, utilization of symposia volumes concerning eutrophication, special journal volumes on eutrophication, and books on nutrients in the marine environment. The data searched, and the years covered by the sources are listed in Table 1. The keywords used for those searches are listed in Table 2.

The symposia volumes and books which were used for sources are listed in Table 3. Special journal volumes are listed in Table 4. The judgement for including papers from these sources was based upon the content of the individual papers. Our intent was to include papers which had research results or other insights concerning marine eutrophication and not to include papers which simply mentioned the topic. Nor did we attempt to compile a listing of data sources. There is not always a clear distinction between these two categories and other preparers might have sorted papers somewhat differently.

Finally, papers which were listed in the references of the papers located by the above two techniques were included where they met the criteria for inclusion.

BIBLIOGRAPHY FORMAT

Subject Indexes

There are five lists identifying papers contaning information in five major subject divisions. These are:

phytoplankton abundance
macrophytes
red tides and other nuisance blooms
phytoplankton community assemblage
oxygen concentrations

Each reference in these lists gives author and year. The complete reference is found in the main reference list described below.

Main Reference List

The references are listed alphabetically by author. The year of publication appears next, followed by the title of the work in bold text. The complete citation to the work appears next. Keywords highlighting the content of the referenced work appear in brackets after the citation. Keywords supplied with the original work were used when available. Keywords were provided for other references. Appendix A is a compiled list of the keywords found in the bibliography. The complete abstract of the paper follows the citation unless there was no abstract.

ELECTRONIC VERSIONS OF THE BIBLIOGRAPHY.

The primary version of the bibliography was assembled in Endnote Plus™ software for the Macintosh™. The file is about 985 kilobites and is supplied upon request with the hard copy. ASCII versions of the main reference list for both Macintosh™ and PC™ compatible computers can be supplied upon request (about 500 kilobites).

RESOURCES USED IN THE BIBLIOGRAPHY

Table 1. Data Bases Utilized For Preparation Of Bibliography

Electronic Data Bases	Years Covered
Aquatic Sciences and Fisheries Abstracts	1978-1992
Science Citation Index	1989-1991
NOAA Libraries Catalog	
Government Documents Catalog Service	1976-1991
Paper Copy Abstracts	
Aquatic Sciences and Fisheries Abstracts	1970-1977
Deep Sea Research	1970-1991
Dissertation Abstracts	1970-1990
Pollution Abstracts	1970-1991

Table 2. Words Used In Searches Of Electronic Databases

Abnormality	Enrichment	Organic Matter
Abundance	Epifauna	Pathology
Algae	Epiphytes	pH
Anoxia	Estuaries	Phosphate
Assemblage	Eutrophication	Phosphorus
Biomass	Eutrophied	Photosynthesis
Bivalves	Fauna	Pollution
Bloom	Fish	Population
Brown Tides	Function	Primary Production
Chlorophyll	Growth	Primary Productivity
Clams	Hypoxia	Red Tides
Coast	Infauna	Redox
Community	Light	Response
Coral	Macroalgae	Seagrass
Cycles	Macrofauna	Sewage
Deficiency	Macrophyte	Species Composition
Denitrification	Meiofauna	Standing Crop
Depletion	Metabolism	Structure
Diatom	Microalgae	Sublethal
Dinoflagellates	Nitrate	Submerged Vascular Plants
Discharge	Nitrification	Sulfate
Diversity	Nitrite	Sulfur
Dynamics	Nitrogen	Turbidity
Eelgrass	Number	Waste
Effluents	Nutrients	Water Quality
Energy	Organic	Zooplankton
Enriched		

Table 3. Symposia Volumes And Edited Books With Papers On Eutrophication Which Were Used In The Assembly Of The Bibliography

Anderson, D. M., A. W. White, and D. G. Baden (1985) ***Toxic Dinoflagellates.*** (Proceedings of The Third International Conference on Toxic Dinoflagellates, St. Andrews, New Brunswick, Canada 8-12 June, 1985). New York, Elsevier.

Carpenter, E. J. and D. G. Capone (1983) ***Nitrogen in the Marine Environment.*** New York, Academic Press.

Cosper, E. M., V. M. Bricelj, and E. J. Carpenter (1989) ***Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and other Unusual Blooms.*** (Papers from a conference at Stony Brook, NY, 27-28 October, 1988). Berlin, Springer-Verlag.

Dennis, L. and H. H. Seliger (1979) ***Toxic Dinoflagellate Blooms.*** (Proceedings of the Second International Conference on Toxic Dinoflagellate Blooms, Key Biscayne, Florida, 31 October - 5 November, 1978). North Holland, Elsevier.

Granéli, E., B. Sundström, L. Edler, and D. M. Anderson (1990) ***Toxic Marine Phytoplankton.*** (Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton, Lund, Sweden, 26-30 June, 1989). New York, Elsevier.

Hallegraeff, M. and J. L. Maclean (1989) ***Biology Epidemology and Management of Pyrodinium Red Tides.*** (Proceedings of the management and training workshop, Bandar Seri Begawan, Brunei Darussalam, Philippines, 23-30 May, 1989). Manila, Fisheries Department, Ministry of Development.

Kennedy, V. S. (1984) ***The Estuary as a Filter.*** Orlando, Academic Press.

Likens, G. E. (1972) ***Nutrients and Eutrophication: The Limiting Nutrient Controversy.*** (Proceedings of the Symposium on Nutrients and Eutrophication: The Limiting Nutrient Controversy, W.K. Kellog Biological Station, Michigan State University, 11-12 February, 1971). Lawrence, Kansas, American Society of Limnology and Oceanography and the Allen Press.

LoCicero, V. R. (1975) ***Toxic Dinoflagellate Blooms.*** (Proceedings of the First International Conference on Toxic Dinoflagellate Blooms, Boston, 4-6 November, 1974) (MIT Sea Grant Report MITSG 75-8). Wakefield, Massachusetts, Massachusetts Science & Technology Foundation.

Neilson, B. J. and L. E. Cronin (1981) ***Estuaries and Nutrients.*** Clifton, New Jersey, Humana Press.

Okaichi, T., D. M. Anderson, and T. Nemoto (1988) ***Red Tides: Biology, Environmental Science, and Toxicology.*** (Proceedings of the International Symposium on Red Tides, Takamastu Perfecture, Japan, 10-14 November, 1987). New York, Elsevier.

Smayda, T. J. and Y. Shimizu (1993) ***Toxic Phytoplankton Blooms in the Sea.*** (Proceedings of the Fifth International Conference on Toxic Marine Phytoplankton, Newport, Rhode Island, U.S.A., 28 October -1 November 1991). Amsterdam, Elsevier.

Tyson, R. V. and T. H. Pearson (1991) ***Modern and Ancient Continental Shelf Anoxia.*** Special Publication No. 58 of The Geological Society. London, The Geolocical Society.

Vollenweider, R.A., R. Marchetti, and R. Viviani (1992) ***Marine Coastal Eutrophication.*** (Proceedings of an International conference, bologna, Italy, 21-24 march 1990. Reprinted from the journal *Science of the Total Environment*, Supplement, 1992) Amsterdam, Elsevier.

Table 4. Special journal volumes concerning eutrophication used in the assembly of the bibliography

Ambio Volume 19, Issue 3 (1990) Special Issue: **Marine Eutrophication**.

Kieler Meeresforschungen, Sonderheft 6 (1988) **The Baltic Sea Environment, History-Eutrophication-Recruitment-Ecotoxicology.** (Proceedings of the 10th Symposium of the Baltic Marine Biologists, 29 September - 3 October 1987).

Marine Pollution Bulletin Volume 20, Issue 7 (1989) **Pollution in the Far East**.

Marine Pollution Bulletin Volume 23 (1991) **Environmental Management and Appropriate Use of Enclosed Coastal Seas.** (Proceedings of the International Conference on the Environmental Management of Enclosed Coastal Seas '90, held in Kobe, Hyogo Prefecture, Japan, 3-6 August, 1990).

Netherlands Journal of Sea Research Volume 19, Issue 3&4 (1984). **Nutrients in Estuaries: Eutrophication and Other Aspects.** (Proceedings of the ESBA/Hydrobiological Society Symposium, Texel, The Netherlands, 11-13 September, 1984).

SUBJECT INDEX: Phytoplankton Abundance

Words Searched for: abundance; bloom; chlorophyll; chl a; algal growth
(142 references)

Andersin, A.-B., J. Lassig, L. Parkkonen, and H. Sandler (1978)
Anderson, D. M. (1987)
Anderson, D. M. (1992)
Arzul, G. and P. Gentien (1990)
Austen, M. C., R. M. Warwick, and M. C. Rosado (1989)
Beatty, L. L. (1991)
Beukema, J. J. (1990)
Beukema, J. J. (1991)
Beukema, J. J. and G. C. Cadée (1986)
Beukema, J. J. and G. C. Cadée (1991)
Birch, P. B. and J. O. Gabrielson (1984)
Bodeanu, N. (1992)
Boni, L., E. Carpené, D. Wynne, and M. Reti (1989)
Brand, L. E., M. D. Gottfried, C. C. Baylon, and N. S. Romer (1991)
Breuer, G. and W. Schramm (1988)
Brockmann, U., G. Billen, and W. W. C. Gieskes (1988)
Brockmann, U. and E. Dahl (1990)
Brockmann, U. H., E. Dahl, and K. Eberlein (1985)
Brown, J. R., R. J. Gowen, and D. S. McLusky (1987)
Cadée, G. C. (1986)
Cadée, G. C. (1990)
Cadée, G. C. (1992)
Cadée, G. C. and J. Hegeman (1991)
Cederwall, H. and R. Elmgren (1980)
Cosper, E. M., W. Dennison, A. Milligan, E. J. Carpenter, C. Lee, J. Holzapfel, and L. Milanese (1989)
Cosper, E. M., C. Lee, and E. J. Carpenter (1990)
Costa, J. E. (1988)
Dauer, D. M. and W. G. Conner (1980)
Dauvin, J.-C. and F. Gentil (1989)
Dzurica, S., C. Lee, E. M. Cosper, and E. J. Carpenter (1989)
Emara, H.I., M.A. Shriadah, Th.H. Moustafa and M.S. El-Deek (1992)
Fanuko, N. (1984)
Friligos, N. (1985)
Gerlach, S. A. (1990)
Giovanaridi, F. and E. Tromellini (1992)
Gowen, R. J., P. Tett, and K. J. Jones (1992)
Granéli, E., P. Carlsson, P. Olsson, B. Sundström, W. Granéli, and O. Lindahl (1989)
Granéli, E., W. Graneli, and L. Rydberg (1986)
Granéli, E., S. Schulz, U. Schiewer, D. Gedziorwska, W. Kaiser, and M. Plinski (1988)
Grassle, J. P. and J. F. Grassle (1984)
Gray, J. S. (1979)
Haas, L. W., S. J. Hastings, and K. L. Webb (1981)
Hagmeier, E. (1978)
Hardy, J. T. and Z. Zubayli (1976)
Heinänen, A. P. (1991)
Hinga, K. R. (1992)
Hobbie, J. E. and J. J. Cole (1984)
Hodgkiss, I. J. and B. S. S. Chan (1987)
Howells, G. P. (1972)
Hull, S. C. (1987)
Hungspreugs, M., W. Utoomprkporn, S. Dharmvanij, and P. Sompongchaiyakul (1989)
Imai, I., S. Itakura, and K. Itoh (1991)
Jochem, F. and B. Babenerd (1989)
Johansson, J.O.R. and R.R. Lewis, III (1992)
Josefson, A. B. (1987)
Josefson, A. B. and R. Rosenberg (1988)
Kaiser, W., A. Irmisch, D. Nehring, F. Georgi, and G. Bruel (1990)
Kat, M. (1987)
Kautsky, N., H. Kautsky, U. Kautsky, and M. Waern (1986)
Keller, A. A. (1989)
Keller, A. A. and R. L. Rice (1989)
Keller, A. A. and R. L. Rice (1990)
Kononen, K. and Å. Niemi (1984)
Kröncke, I. (1990)
Laws, E. A. and D. G. Redalje (1979)
Leppäkoski, E. (1980)
Maclean, J. L. (1984)
Maclean, J. L. (1989)
Maestrini, S. Y. and E. Granéli (1991)
Mattson, J. and O. Lindén (1983)
McLusky, D. S., M. Teare, and P. Phizacklea (1980)
Millner, R. S. (1980)
Mingazzini, M., A. Rinaldi, and g. Montanari (1992)
Morton, B. (1989)
Moshiri, G. A., N. G. Aumen, and W. G. Crumpton (1981)
Murakami, A. (1973)
Nielsen, A. and G. Ærtebjerg (1984)
Nishijima, T. and Y. Hata (1991)

Nixon, S. W., M. E. Q. Pilson, C. A. Oviatt, P. Donaghay, B. Sullivan, S. Seitzinger, D. Rudnick, and J. Frithsen (1984)
Okaichi, T. (1987)
Olsen, P., M. Cohn, J. B. Mahoney, and E. Feerst (1984)
Olsson, G. E., B. Sundström, and L. Edler (1987)
Oviatt, C. A., P. Lane, F. F. III, and P. Donaghay (1988)
Paerl, H. W. (1988)
Pastorok, R. A. and G. R. Bilyard (1985)
Pearson, T. H. (1980)
Pearson, T. H. (1987)
Pearson, T. H., A. B. Josefson, and R. Rosenberg (1985)
Pearson, T. H. and R. Rosenberg (1976)
Pearson, T. H. and R. Rosenberg (1978)
Pearson, T. H. and S. O. Stanley (1979)
Pekkari, S. (1973)
Perciasepe, R. (1992)
Persson, L.-E. (1987)
Phillips, D. J. H. and S. Tanabe (1989)
Porumb, F. (1992)
Price, K. S., D. A. Flemer, J. L. Taft, G. B. Mackiernan, W. Nehlsen, R. B. Biggs, N. H. Burger, and D. A. Blaylock (1985)
Raman, A. V. and K. P. Prakash (1989)
Renk, H., J. Nakonieczny, and S. Ochocki (1988)
Revelante, N. and M. Gilmartin (1976)
Ritz, D. A., M. E. Lewis, and M. Shen (1989)
Rosenberg, R. (1985)
Rosenberg, R., J. S. Gray, A. B. Josefson, and T. H. Pearson (1987)
Schiewer, U., R. Börner, and N. Wasmund (1988)
Seliger, H. H. (1989)
Sellner, K. G. and M. M. Olson (1985)
Silva, E. S. (1985)
Skjoldal, H. R. and I. Dundas (1991)
Smayda, T. J. (1989)
Smayda, T. J. and A. W. White (1990)
Soulsby, P. G., D. Lowthion, and M. Houston (1982)
Spencer, C. P. (1985)
Stockner, J. G., D. D. Cliff, and K. R. S. Shortreed (1979)
Stockner, J. G. and K. S. Shortreed (1988)
Sukhanova, I. N., M. V. Flint, G. Hilbaum, V. Karamfilov, A. I. Kopylov, E. Matveea, T. N. Rat'kova, and A. F. Sazhin (1988)
Takahashi, M. and N. Fukazawa (1982)
Takano, H. (1987)
Tamminen, T. (1990)
Taslakian, M. J. and J. T. Hardy (1976)
Thompson, G. B. and J. Ho (1981)
Tsutsumi, H., T. Kikuchi, M. Tanaka, K. Imasaka, and M. Miyazaki (1991)
Vidakovi´c, J. (1983)
Vukadin, H. (1991)
Walker, D. I. and R. F. G. Ormond (1982)
Wallström, K. (1988)
Wang, Z. (1987)
Weigelt, M. and H. Rumohr (1986)
Weston, D. P. (1990)
Widbom, B. and R. Elmgren (1988)
Wittberg, M. and W. Hunte (1992)
Wong, P. S. (1987)
Wu, R. S. S. (1982)
Wyatt, T. and J. Horwood (1973)
Yang, D. B. (1987)
Yi, S. K., J.-S. Hong, and J. H. Lee (1982)
Zingone, A., M. Monitresor, and D. Marino (1990)

SUBJECT INDEX: Phytoplankton Composition

Words searched for: assemblage; community structure; species composition; species richness
(25 references)

Abdul-Hussein, M. M. and C. F. Mason (1988)
Anderson, N. J., B. Rippey, and A. C. Stevenson (1990)
Beauchamp, S. T. and J. Kerekes (1989)
Bodeanu, N. (1992)
Crema, R., A. Castelli, and D. Prevedelli (1991)
DeGroodt, E. G., H. F. J. Los, T. A. Nauta, A. A. Markus, and I. deVries (1992)
Dortch, Q., D. Milstead, N.N. Rabalais, S.e. Lorenz, D.G. Redalje, M.J. Dagg, M.E. Turner, and T.E. Whitledge (1992)
Gerlach, S. A. (1990)
Granéli, E., H. Persson, and L. Edler (1986)
Josefson, A. B. (1987)
Kononen, K. and Å. Niemi (1984)
Kröncke, I. (1990)
Mäkinen, A., I. Haahtela, H. Ilvessalo, and J. Lehto (1984)
Moore, C. G. and T. H. Pearson (1984)
Nixon, S. W., M. E. Q. Pilson, C. A. Oviatt, P. Donaghay, B. Sullivan, S. Seitzinger, D. Rudnick, and J. Frithsen (1984)
Oviatt, C. A., P. Lane, F. F. III, and P. Donaghay (1988)
Pastorok, R. A. and G. R. Bilyard (1985)
Schultz, S., G. Ærtebjerg, G. Behrends, G. Breuel, P. Ciszewski, U. Horstmann, K. Kononen, E. Kostrichkina, J. Leppänen, F. Møhlenberg, O. Sandström, M. Viitasalo, and T. Willén (1992)
Skjoldal, H. (1992)
Sukhanova, I. N., M. V. Flint, G. Hilbaum, V. Karamfilov, A. I. Kopylov, E. Matveea, T. N. Rat'kova, and A. F. Sazhin (1988)
Swartz, R. C., F. A. Cole, D. W. Schults, and W. A. DeBen (1986)
Thompson, G. B. and J. Ho (1981)
Tomascik, T. and F. Sander (1987)
Valente, R. M., D. C. Rhoads, J. D. Germano, and V. J. Cabelli (1992)
Wittberg, M. and W. Hunte (1992)

SUBJECT INDEX : Red Tides and Nuisance Blooms

Words searched for: red tide; brown tide; nuisance blooms
(38 references)

Anderson, D. M. (1992)
Arzul, G. and P. Gentien (1990)
Aubert, M. (1992)
Cho, C.-H. (1991)
Cosper, E. M., W. Dennison, A. Milligan, E. J. Carpenter, C. Lee, J. Holzapfel, and L. Milanese (1989)
Cosper, E. M., C. Lee, and E. J. Carpenter (1990)
Doucette, G. J. (1989)
Dzurica, S., C. Lee, E. M. Cosper, and E. J. Carpenter (1989)
Fiedler, P. C. (1982)
Hodgkiss, I. J. and B. S. S. Chan (1987)
Hungspreugs, M., W. Utoomprkporn, S. Dharmvanij, and P. Sompongchaiyakul (1989)
Imai, I., S. Itakura, and K. Itoh (1991)
Jingzhong, Z., D. Liping, and Q. Baoping (1985)
Keller, A. A. and R. L. Rice (1989)
Keller, A. A. and R. L. Rice (1990)
Lam, C. W. Y. and K. C. Ho (1987)
Liaci, L. S. (1980)
Maclean, J. L. (1984)
Maclean, J. L. (1989)
Morton, B. (1989)
Murakami, A. (1973)
Nishijima, T. and Y. Hata (1991)
Nixon, S. W. (1989)
Ochi, T. (1987)
Okaichi, T. (1987)
Olsen, P., M. Cohn, J. B. Mahoney, and E. Feerst (1984)
Phillips, D. J. H. and S. Tanabe (1989)
Reguera, B. and Y. Oshima (1990)
Seliger, H. H. (1989)
Sellner, K. G. and M. M. Olson (1985)
Silva, E. S. (1985)
Smayda, T. J. (1992)
Sukhanova, I. N., M. V. Flint, G. Hilbaum, V. Karamfilov, A. I. Kopylov, E. Matveea, T. N. Rat'kova, and A. F. Sazhin (1988)
Takahashi, M. and N. Fukazawa (1982)
Wang, Z. (1987)
Wong, P. S. (1987)
Wyatt, T. and J. Horwood (1973)
Yang, D. B. (1987)

SUBJECT INDEX: Macrophytes

Words searched for: seaweeds; macroalgae.
(20 references)

Baden, S. P., L.-O. Loo, L. Pihl, and R. Rosenberg (1990)
Birch, P. B. and J. O. Gabrielson (1984)
Cheney, D. P. (1992)
Conolly, N. J. and E. A. Drew (1985)
Fletcher, R. L., V. Cuomo, and I. Palomba (1990)
Harlin, M. M. and B. Throne-Miller (1981)
Hull, S. C. (1987)
Kautsky, N., H. Kautsky, U. Kautsky, and M. Waern (1986)
Lee, V. and S. Olsen (1985)
Lenzi, M. (1992)
Mäkinen, A., I. Haahtela, H. Ilvessalo, and J. Lehto (1984)
Menesguen, A. (1992)
Pekkari, S. (1973)
Quinlan, A. V. (1982)
Raffaelli, D., J. Limia, S. Hull, and S. Pont (1991)
Schramm, W., D. Abele, and G. Breuer (1988)
Smith, D. W. (1984)
Soulsby, P. G., D. Lowthion, and H. A. C. Montgomery (1985)
Tubbs, C. R. and J. M. Tubbs (1983)
Vogt, H. and W. Schramm (1991)

SUBJECT INDEX: Oxygen Concentration

Words searched for: anoxia; hypoxia
(65 references)

Andersin, A.-B., J. Lassig, L. Parkkonen, and H. Sandler (1978)
Andersson, L. and L. Rydberg (1988)
Aneer, G. (1987)
Baden, S. P., L.-O. Loo, L. Pihl, and R. Rosenberg (1990)
Boesch, D. F. (1983)
Brockmann, U., G. Billen, and W. W. C. Gieskes (1988)
Degobbis, D. (1989)
Dethlefsen, V. and H. v. Westernhagen (1983)
Dortch, Q., D. Milstead, N.N. Rabalais, S.e. Lorenz, D.G. Redalje, M.J. Dagg, M.E. Turner, and T.E. Whitledge (1992)
Emara, H.I., M.A. Shridah, Th.H. Moustafa, and M.S. El-Deek (1992)
Friligos, N. (1981)
Gerlach, S. A. (1990)
Griggs, G. B. and T. S. Hopkins (1976)
Herdendorf, C. E. (1986)
Hognestad, P. T. (1987)
Hosie, D. A., R. F. Uglow, L. Hagerman, T. Sondergaard, and W. Weile (1991)
Justi´c, D. (1987)
Justi´c, D. (1991)
Köhler, A. and F. Hölzel (1980)
Lam, C. W. Y. and K. C. Ho (1987)
Leppäkoski, E. (1980)
LISS, L. I. S. S. (1990)
Malone, T. C. (1991)
Millner, R. S. (1980)
Mills, C. A., S. I. Heaney, C. Butterwick, J. E. Corry, and J. M. Elliott (1990)
Morton, B. (1989)
Nehring, D., S. Schulz, and W. Kaiser (1984)
Nehring, D. (1992)
Nilsson, P., B. Jönsson, I. L. Swanberg, and K. Sundbäck (1991)
Nixon, S. W. and V. M. Berounsky (1984)
Nixon, S. W., C. A. Oviatt, J. Garber, and V. Lee (1976)
Ochi, T. (1987)
Okaichi, T. (1987)
Oviatt, C. A., A. A. Keller, P. A. Sampou, and L. L. Beatty (1986)
Oviatt, C. A., J. G. Quinn, J. T. Maughan, J. T. Ellis, B. K. Sullivan, J. N. Gearing, P. J. Gearing, C. D. Hunt, P. A. Sampou, and J. S. Latimer (1987)
Parker, C. A. (1983)
Parker, C. A. and J. E. O'Reilly (1991)
Pastorok, R. A. and G. R. Bilyard (1985)
Pearson, T. H. (1980)
Perciasepe, R. (1992)
Phillips, D. J. H. and S. Tanabe (1989)
Phoel, W. C., K. L. Webb, and C. F. D'Elia (1981)
Polak, J. and G. D. Haffner (1978)
Portnoy, J. W. (1991)
Price, K. S., D. A. Flemer, J. L. Taft, G. B. Mackiernan, W. Nehlsen, R. B. Biggs, N. H. Burger, and D. A. Blaylock (1985)
Rabalais, N. N. and D. F. Boesch (1986-1987)
Rabalais, N. N., R. E. Turner, J. W.J. Wiseman, and D. F. Boesch (1991)
Reys, E. and M. Merino (1991)
Riisgård, H. U. and E. Poulsen (1981)
Rosenberg, R. (1985)
Rosenberg, R., B. Hellman, and B. Johansson (1991)
Rosenberg, R. and L.-O. Loo (1988)
Rydberg, L., L. Edler, S. Floderus, and W. Granéli (1990)
Sales, D., A. Gómez, and D. Cantero (1983)
Sampou, P. and C. A. Oviatt (1991)
Sampou, P. A. (1989)
Stachowitsch, M. (1991)
Tolmazin, D. (1985)
Topping, G. (1976)
Van Es, F. B., V. A. M.A., L. A. Bouwman, and H. G. J. Schröder (1980)
Vollenweider, R.A., A. Rinaldi, and G. Montanari (1992)
Weigelt, M. and H. Rumohr (1986)
Welsh, B. L. and F. C. Eller (1991)
Whiteledge, T. E. (1985)
Wu, R. S. S. (1982)

Abdul-Hussein, M. M. and C. F. Mason (1988) **The phytoplankton community of a eutrophic reservoir.** *Hydrobiologia* **169**:265-277.
{phytoplankton; reservior; community; pH; composition; assemblage}

The dynamics of the phytoplankton community of a eutrophic reservoir are described for a two year period. Fifty-eight species were recorded, 25 of them common. Bacillariophyta dominated during the winter and early spring and Chlorophyta during late spring, to be replaced by a bloom of Cyanophyta. The mean and peak biomass of phytoplankton was 8.6 mg l^{-1} and 40.8 mg l^{-1} in 1981, and 8.3 mg l^{-1} and 37.6 mg l^{-1} in 1982. Temperature accounted for 67.3% and pH for 8% of the variation in total phytoplankton biomass over the two year period, using regression technique.

Both horizontal and vertical patchiness, measured as an index of mean crowding, were recorded in the reservoir. Horizontal aggregations were associated with spring blooms of Chlorophyta and summer blooms of Cyanophyta, while vertical aggregations were most marked during the summer bloom of Cyanophyta. Concentrations of phytoplankton were influenced by wind, the prevailing southwesterly wind accumulating algae in the northeasterly arm of the reservoir during much of the year.

Andersin, A.-B., J. Lassig, L. Parkkonen, and H. Sandler (1978) **The decline of macrofauna in the deeper parts of Baltic proper and the Gulf of Finland.** *Kieler Meeresforschungen Sonderheft* **4**:23-30.
{abundance; benthic; macrofauna; oxygen; hypoxia; Baltic; hydrogen sulfide}

An attempt is made to describe the large-scale changes in the benthic soft bottom macrofauna in the deep parts of the Bornholm Basin, the Gulf of Gda´nsk, the Central Basin and the Gulf of Finland, from the beginning of Baltic zoobenthos research to the present day. The authors also try to correlate these changes with fluctuations in the oxygen content and salinity in near-bottom water layer. The paper surveys the literature and presents recent and earlier unpublished results.

During the later part of last century and the first decades of the twentieth century no area of the Baltic Sea seemed to have been totally devoid of macrofauna. Unfortunately there are considerable gaps in our knowledge of the time before the middle of this century. The most striking decline has taken place, generally speaking, after the exceptionally great inflow in 1951-1952, and the subsequent prolonged stagnation.

The first records of "dead" bottoms in the Bornholm basin are from 1948, when no macrofauna was recorded below 80 m. Records from 1954 show that the deepest parts of the Eastern Gotland Basin and the deep area between Öland and Gotland were devoid of macrofauna at that time, but that the deep areas of the northernmost Baltic proper and the Gulf of Finland were still populated.

The change continued and during the 1960s the communities dominated by lamellibrachs in the Bornholm and Gda´nsk Deeps disappeared, and were subsequently replaced by polychaete communities. These have been wiped out during periods of bad oxygen conditions, but quickly re-established when conditions improved. The lammelibrach community has not been restored. In the Northern Central Basin and the Gulf of Finland the depopulation of the deep bottoms probably began later, in the late 50's. In the 70s practically no macrofauna has been recorded below the permanent halocline in the Central Basin (except the southernmost parts of it) and the Gulf of Finland.

During the 60s and 70s the area with periodically unfavorable oxygen conditions has covered about 100,000 km^2, which is 25% of the total area of the Baltic Sea.

Anderson, D. M. (1987) **Toxic algal blooms and red tides: A global perspective.** In: T. Okaichi, D. M. Anderson and T. Nemoto (ed.) *Red Tides: Biology, Environmental Science, and Toxicology*. Elsevier, New York.
{toxic; bloom}

The literature on toxic algal blooms and red tides documents a global increase in the frequency, magnitude, and geographic extent of these events over the last two decades. Some of this increase is undoubtedly a result of the increased awareness and analytical capabilities of the scientific community, but a strong correlation between the number of red tides and the degree of coastal pollution or utilization of coastal waters for aquaculture argue that there are other contributing factors. It also appears likely that toxic algal species have spread within regions over spatial scales of hundreds of kilometers, moving with major water currents and storms. Long distance transport of species across oceans may have occurred as well, but the evidence is not conclusive and the hypothesis controversial.

Anderson, D. M. (1992) **Toxic dinoflagellate blooms and red tides in New England and abroad: A biogeographic and physiologic perspective.** 31st Annual Symposium of the Northeast Algal Society, Woods Hole.
{dinoflagellate; red tide; bloom; *Alexandrium*; Gulf of Maine}

Toxic red tides of the dinoflagellate *Alexandrium fundyense* have become persistent phenomena over the last two decades in the southern Gulf of Maine, having been common occurrences for hundreds of years further to the north. This paper will explore the bloom dynamics of this organism in the Gulf, as well as the physiological characteristics of the cells that influence their toxin production. Additional studies will be presented that relate to the population biology of *Alexandrium*, both within the Gulf of Maine, and throughout the world. Through a combination of traditional field phytoplankton ecology, physical oceanographic measurements, remote sensing, toxin analysis, morphological analysis, and molecular studies, the complex and fascinating characteristics of this important organism are gradually becoming known. Topics to be emphasized include the long-distance transport and confinement of *Alexandrium* populations within a coastal current that originates in the rivers of southern Maine; the potential impact of environmental conditions on the production of toxins in *Alexandrium*; the role of dormant cysts in the bloom dynamics and population distribution of *Alexandrium*; the possible global dispersal of *Alexandrium* populations via ship traffic; and forensic RFLP analysis of globally distributed *Alexandrium* populations.

Anderson, D. M., A. W. White, and D. G. Baden (ed.) (1985) ***Toxic Dinoflagellates (Proceedings of The Third International Conference on Toxic Dinoflagellates, St. Andrews, New Brunswick, Canada 8-12 June, 1985).*** Elsevier, New York.
No abstract

Anderson, N. J., B. Rippey, and A. C. Stevenson (1990) **Change to a diatom assemblage in a eutrophic lake following point source nutrient re-direction: a palaeolimmnological approach.** *Freshwater Biology* **23**:205-217.
{diatom; assemblage; lake; nutrient}
No abstract.

Andersson, L. and L. Rydberg (1988) **Trends in nutrient and oxygen conditions within Kattegat: Effects of local nutrient supply.** *Estuarine, Coastal and Shelf Science* **26**:559-579.
{nitrogen; oxygen; phosphorus; nutrient; Baltic}
The Kattegat forms the outer part of the Baltic estuary. It is characterized by a stable two-layer stratification maintained by approximately equal supplies of low saline water from the Baltic and high saline oceanic water from the Skagerrak. The nutrient supply to these waters increased rapidly during the past decades and oxygen deficits have been reported from different parts of the estuary. In this paper, we have calculated trends in nutrient and oxygen concentrations within the surface and deep waters of the Kattegat and adjacent waters. This has been done with available data for the past decades, with reference to nutrient supply and phytoplankton production.

Oxygen concentrations within the deep water decreased from 4.58 to 4.08 ml l^{-1} between 1971 and 1982, indicating a 50% increase in oxygen consumption. Concentrations of Tot-N, Tot-P and inorganic nitrogen increased simultaneously, both in the surface water during the winter and in the deep-water during the summer. Changes in Tot-N and Tot-P were dominated by the Baltic water, while local supply to the Kattegat dominated the changes in inorganic nitrogen. Increases in Tot-N and Tot-P suggest a successively increasing biomass.

The importance of local nutrient supply to the Kattegat was studied comparing expected nutrient concentration within the surface water (due to exchange with adjacent water) with actually observed concentrations.

Aneer, G. (1985) **Some speculations about the Baltic herring (*Clupea harengus membras*) in connection with the eutrophication of the Baltic Sea.** *Canadian Journal of Fisheries and Aquatic Science* **42 (suppl.1)**:83-90.
{Baltic; herring; filamentous; algae; egg; mortality}
In this paper the hypothesis is put forward that Baltic herring's (*Clupea harengus membras*) spawning time, spring or autumn, is determined by feeding conditions during the adult phase and thus not generally fixed. The present "absence" or autumn spawners is thought to be the result of improved feeding condition during the latest decades as a result of the eutrophication of the Baltic Sea. During two spawning ground studies carried out in 1978 and 1982 unusually high mortality rates were noted for eggs in situ. In 1982, during 4 week close to peak of spawning, the mortlaity increased substantially, especially for eggs among filamentous algae. A significant difference was noted between eggs on coarser algae and those among filamentous algae ($p < 0.001$). During this period the average mortalities were 33 and 75%, respectively. Very low levels of oxygen were measured at night among the filamentous algae. An increase in the amounts of this type of algae as a response to eutrophication might constitute a new hazard to the reproductive success of the Baltic herring.

Aneer, G. (1987) **High natural mortality of Baltic herring (*Clupea harengus*) eggs**

caused by algal exydates? *Marine Biology* **94**:163-169.
{Baltic; herring; egg; toxic algal exudates; oxygen}

Results from field studies in 1978 and 1982 together with results from a laboratory study carried out in 1984 indicate that the unusually high natural mortality of Baltic herring (*Clupea harengus* L.) eggs observed *in situ* is presumably caused by toxic exudates released by filamentous brown algae during a limited period which happens to coincide with the peak of spawning. Oxygen deficiency is no longer believed to be the major cause of the observed unnaturally high mortality. It cannot, however, be entirely ruled out.

Ansari, Z. A., B. S. Ingole, and A. H. Parulekar (1986) **Effect of high organic enrichment of benthic polychaete population in an estuary.** *Marine Pollution Bulletin* **17**:361-365.
{Benthic; polychaete; productivity; diversity; biomass; density; sewage}

The benthic polychaete fauna of an estuarine region receiving domestic sewage and wastes from a nearby fish landing jetty was compared to that of a site having normal organic enrichment. The population density, biomass and species diversity were greater at the sewage receiving site. Some species showed preference for sewage site and their numbers were significantly greater at the sewage site while other species showed no differences. Total counts and the biomass were significantly higher at the site of organic enrichment. A quantitatively enhanced polychaete population indicates that input of high organic matter stimulate benthic productivity.

Antonius, A. (1985) **Coral diseases in the Indo-Pacific: A first record.** *P.S.Z.N.I: Marine Ecology* **6**:197-218.
{coral; disease; Indo-Pacific; Red Sea; Philippines}

The so-called "band" diseases of reef corals, the White Band Disease (WBD) and the Black Band Disease (BBD), were observed in the Red Sea and in the Philippines. Since they were previously known only from the western Atlantic, this is the first record for the Indo-Pacific region. WBD is neither infectious nor contagious and the pathogens is unknown. BBD is highly infectious and contagious and is caused by the cyanophyte *Phormidium corallyticum*. Susceptibility to WBD occurs throughout the order *Scleractinia*, but the effects of the disease are most severe among *Acroporidae*. Susceptibility to BBD seems to be restricted to *Faviidae*, with *Platygyra* and *Goniastrea* species the most heavily afflicted. WBD cannot be influenced by any parameter tested so far. BBD can be enhanced by light and by water eutrophication, and its advance can be stopped by antibiotics. An active WBD seems to be a precondition for the origin of BBD.

Anttila, R. (1973) **Effect of sewage on the fish fauna in the Helsinki area.** *OIKOS Supplementum* **15**:226-229.
{sewage; fish; species}

The results given are based on fishery studies begun by the City of Helsinki in 1969 on the effects of sewage on the fish fauna and fishing in the Helsinki sea area. The main research methods are test fishing with a series of nets, and fishery inquiries.

Sewage has brought about considerable changes in the quality and quantity of fish fauna in the Helsinki sea area. The changes in the fish fauna are similar to those generally recognized as deriving from sewage. The fish species susceptible to pollution have suffered a decline and/or moved to purer areas. Such species are brown trout *Salmo trutta*(L)., whitefish *Coregonus lavaretus* (L.), burbot *Lota lota* (L.) and in *Leusiscus idus* (L.). Of the major edible fish, pikeperch *Lucioperca lucioperca* L. has withstood pollution best.

The fish biomass in the more eutrophic bays is considerable in size compared with pure areas. In addition to the deterioration in the fish species structure there are also flavour defects in fish over a sea area of 3,000-4,000 hectares. Flavour defects in fish are caused by the secondary phenomena of sewage and oil that have entered the water. The mercury and pesticides contents observed in fish have been relatively low.

Arndt, H. (1988) **Dynamics and production of a natural population of *Brachionus plicatilis* (Rotaria, Monogonota) in a eutrophicated inner coastal water of the Baltic.** *Kieler Meeresforschungen, Sonderheft* **6**:147-153.
{rotifer; *Brachionus*; growth; zooplankton; Baltic}

The dynamic and production of a natural population of the rotifer *Brachionus Plicatilis* (O.F.MÜLLER) were studied by regular field sampling at routine stations in the shallow Darss Zingst estuary, southern Baltic (3-7 ‰ S). Investigations of the horizontal distribution revealed significant population growth during the summer months at salinities above 3 ‰ S and at those stations characterized by high eutrophication. The first individuals hatch from resting eggs in May. Significant reproduction occurs from June to September, when temperatures are above 15 °C. Mixing rates were highest during the exponential growth phase. Instantaneous rates of growth, birth, and mortality were estimated. Mean P/B ratios for the growing season were high (around 0.7 d^{-1}) and were in the range of values obtained from mass cultures in the field under subtropical conditions. In Barther Bodden annual biomass production for 1982 was 1.1 g fw m^{-3}. In its natural habitat, *B.*

plicatilis serves as a food source for fish juveniles and the mysid *Neomysis integer*. The seasonal dynamics of the rotifer population were not significantly affected by predators.

Arts, G. H. P., G. V. d. Velide, J. G. M. Roelofs, and C. A. M. V. Swaay (1990) **Successional changes in the soft-water macrophyte vegetation of (sub)Atlantic, sandy, lowland regions during this century.** *Freshwater Research* **24**:287-294.
{vegetation; macrophytes}
SUMMARY
1. Considerable changes in macrophyte vegetation can be noticed in 146 originally soft waters, when data on the recent aquatic vegetation are compared with historical information from the period 1900-60. Changes in nutrient status (N, P, and C) and accumulation of organic material can be regarded as the operative factors.
2. The processes observed in soft waters are acidification, eutrophication and water hardening. Which process dominates depends on the type of soft water.
3. Acidification as well as eutrophication of water bodies may ultimately result in the total disappearance of all aquatic macrophytes, with the exception of the floating-leafed nymphaeids *Nymphaea alba* (L.) and *Nuphar lutea* (L.) Sm. Observed successional stages are described and summarized.

Arzul, G. and P. Gentien (1990) **Chemical typology of coastal sediments in relation to red tides.** In: E. Granéli, B. Sundström, L. Edler and D. M. Anderson (ed.) *Toxic Marine Phytoplankton*. Elsevier, New York.
{red tide; phytoplankton; bloom; organic matter; sediments; copper; nutrients; nitrogen; phosphorus; *Alexandrium*}

The study of different chemical parameters characterizing the coastal sediments showed possible relationships between high levels of organic matter and total copper concentrations, and "red tide" occurrences. Sediment extracts had toxic effects on the growth of *Alexandrium tamarensis* in April, however, it was not observed in sediment elutriated in July.

Aubert, M. (1992) **Sanitary consequences of eutrophication and related ecological disequilibria in the marine environment.** In: R. A. Vollenweider, Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication*. Elsevier, Amsterdam.
{nuisance bloom, dinoflagelate, *Dinophysis*}

Considering the rates and dynamics of marine primary productivity it appears quite clear that besides the essential factors such as nutrient pools and inputs of energy, the function of growth-promoting or inhibitory telemediators (exocrines) present a very important control mechanism, in particular as far as the species compositions and periodic successions of phytoplankton are concerned. However, this mechanism also ultimately influences the overall equilibria. We must take into account many facts which show the importance of this last factor.

Such massive, semi-monospecies dinolflagellate blooms are, almost without exception, environmentally harmful, many of them also leading to the toxicity of sea food and relevant human pathology. However, in specific cases, such as the DSP intoxications induced by a number of species of Dinophysis, even the slight increase in population densities, e.g. >200 cells dm-3, may cause quite dramatic pathology among shellfish consumers and, of course, also important economic losses for mariculture activities.

Austen, M. C., R. M. Warwick, and M. C. Rosado (1989) **Meiobenthic and macrobenthic community structure along a putative pollution gradient in Southern Portugal.** *Marine Pollution Bulletin* **20**:398-405.
{benthos; Portugal; community; diversity; abundance; sewage}

Macro- and meiobenthos were sampled from Ria Formosa, Portugal along putative sewage pollution gradients in summer 1987 and winter 1988. The status of the benthos was assessed using multidimensional scaling ordination, ABC plots, and a variety of univariate indices of community structure. Meiobenthos in both seasons and macrobenthos in winter appeared to respond to sewage enrichment only in the immediate vicinity of the sewage outfalls and channels but ABC plots indicated that macrobenthic communities were moderately stressed throughout the area in summer. In the summer, human digging for shellfish results in considerable sediment turnover. Since meiofauna may be less affected by physical sediment disturbance than macrofauna this may explain why the macrofauna communities were apparently disturbed relative to the meiofauna even beyond the influence of the sewage. Sampling meiofauna with the macrofauna significantly increased our understanding of mans impact in this area. There was little correlation between macro- and meiobenthos in diversity, abundances, number of taxa and biomass and these idices gave no indication of a organic enrichment gradient.

Axelard, D. M., G. C. B. Poore, G. H. Arnott, J. Bauld, V. Brown, R. R. C. Edwards, and N. J. Hickman (1981) **The effects of treated sewage discharge on the biota of Port Philip Bay, Vitoria, Australia.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients*. Humana Press, Clifton, New Jersey.

{bacteria; nitrification; denitrification; sewage; microalgae; macrophytes; macrobenthos; zooplankton; phytoplankton; Australia; diversity; fish}

The Werribee sewage-treatment farm contributes more than half of the total nitrogen and phosphorus input to Port Philip Bay. This study attempted to determine the fate of these nutrients and their effect on the biota of the Bay. This was addressed by comparing community composition, biomass, productivity, or process rates in the Werribee area of the Bay with that in Bay areas more remote from nutrient discharge.

Rates of bacterial nitrification and denitrification were greatest in sediments closest to the sewage discharge point. Up to 15 percent of the inorganic nitrogen discharge may be lost via sequential nitrification-denitrification in a 4 km^2 area. Epibenthic microalgal biomass and productivity were found to be five times greater at Werribee than at a control station. The Werribee macrophyte community showed reduced species diversity, dominance of fast growing opportunistic species, loss of large brown algal species, and occasional algal blooms, as compared to communities in nutrient-poor areas of the Bay. Classification analysis revealed offshore and nearshore groups of macrobenthos in a 2 km^2 area near Werribee; species diversity was greatest offshore. The Werribee offshore macrofauna was typical of that along the whole northwestern coast of the Bay. In summer, fish biomass at Werribee was equal to that found at stations remote from sewage discharge, however, community composition differed. At Werribee, the nearshore fish community was dominated by juveniles and small species, while offshore older and larger fish were more abundant. Phytoplankton productivity decreased with increasing distance from sewage outfalls only during summer. Nitrogen is probably the nutrient critical to phytoplankton biomass production in the Bay but light and/or temperature may limit productivity over much of the non-summer period. Baywide phytoplankton productivity was similar to that of non-eutrophic coastal marine waters. Zooplankton standing crop was low compared to that for many estuaries and marine embayments. Densities of zooplankton in the Werribee area were highly variable, and crustacean species found at Werribee were also distributed throughout the Bay.

These findings suggest that sewage discharge had affected benthic more than planktonic communities, but that the measurable impact of the discharge is limited to a few hundred meters around the outfalls.

Baden, S. P., L. O. Loo, L. Pihl, and R. Rosenberg (1990) **Effects of eutrophication on benthic communities including fish: Swedish west coast.** *Ambio* **19**:113-122.

{oxygen; hypoxia; seaweeds; macroalgae; increase; decrease; macrofauna; lobster; fish; floating; mortality}

The southern Kattegat is susceptible to eutrophication due to shallow mean depth (23m) and a strong halocline which reduces intrusion of oxygen to bottom waters. The effects of eutrophication were first observed in the area in the autumn of 1980. Since then investigations on primary producers, fish, lobsters, and benthic infauna have been conducted to document the effects of eutrophication. Above the halocline in the Laholm Bay a change in the macrophyte species from *Fucus* spp. to filamentous green algae has been observed. Mortality of benthic macrofauna, mainly bivalves, has been observed in most years and seasons. The recruitment of flatfish has not been negatively affected. Around the halocline the benthic infauna were seriously affected by oxygen deficiency. Below the halocline, fish disappeared and lobsters emerged from burrows when oxygen saturation declined below 40%. When oxygen saturation decreased below 15% Norway lobsters were immobilized and their blood-pigment concentration decreased. Benthic infaunal species emerged from the sediment. Lobsters died when saturation dropped to 10%, while many infaunal species tolerated levels of 7-5% for some weeks. Analysis of stomach content indicated that neither fish nor lobsters died from lack of food, but from hypoxia. Subsequent to the reoxygenation of the bottom water during winter, flatfish and benthic infauna recovered whereas cod and lobster population did not.

Beatty, L. L. (1991) ***The response of benthic suspension feeders and their grazing impact on phytoplankton in eutrophied coastal ecosystems.*** Dissertation for Ph.D., The University of Rhode Island.

{benthos; MERL; nutrient; composition; abundance; biomass}

The eutrophication of coastal waters from land-derived nutrients affects all biological aspects of the estuarine ecosytem. Changes to the benthic community can be pronounced. Not only do benthic species respond to nutrient-induced phytoplankton blooms, but these animals may have a subsequent impact on the system.

A sixteen-month study was conducted with daily nutrient loading. One of the nutrient levels included enhanced silicon to promote diatom growth and potentially lead to a healthier food chain. Cores were taken monthly to follow changes in benthic species composition. Laboratory experiments were performed on five occasions from March to October to determined the role of benthic grazing in control versus nutrient-enriched systems. Cores were taken from mesocosms and removal rates of natural assemblages of phytoplankton were determined.

A two to five-fold increase in abundance and biomass was observed in enriched over control mesocosms. A shift in species composition included the rapid response of facultative suspension-feeding spinoid polychaetes, *Polydora ligni* and *Streblospio benedicti*, and amphipod, *Ampleisca abdita* and *Corophium* sp., to phytoplankton compared to the other nutrient systems, although differences were not statistically significant by the second summer. Zooplankton initially responded to phytoplankton blooms but adult benthic suspension feeders dominated the grazer biomass within three months of nutrient additions.

Benthic grazers could remove up to 75% of water column phytoplankton per day. Rates were higher in nutrient-enriched systems where animal biomass was greater than in control closures. Phytoplankton >10 um and water temperatures over 15°C were also significant factors in observed feeding rates. Benthic species successfully competed with zooplankton for food resources; alttough their weight-specific feeding rates are lower than those for copepods, opportunistic characteristics of spinoid polychaetes and amphipods and their ability to deposit feed when water column phytoplankton is depleted contribute to their success.

The results of this study are most applicable to shallow, well-mixed coastal areas. As water column depths decrease and/or food is more accessible to the benthos, benthic-pelagic coupling increases in importance.

Beauchamp, S. T. and J. Kerekes (1989) **Effects of acidity and DOC on phytoplankton community structure and production in three acid lakes (Nova Scotia).** *Water, Air, and Soil Pollution* **46**:323-333.
{acidity; lakes; phytoplankton; assemblage}

Phytoplankton community structure varied between the three lakes and between years within lakes. The Beaverskin Lake phytoplankton community was dominated by cyanophytes and chlorophytes in the summer and chrysophytes in the winter. Kejimkujik Lake was dominated by bacillariophytes in the summer of 1979 but no single group dominant in 1980 or 1981. Pebbleoggitch Lake phytoplankton consisted mainly of chlorophytes in 1979 but low biomass and no dominant groups characterized this lake during the growth season of 1980. Daily integral planktonic primary production measured simultaneously in the three lakes showed that in both years annual planktonic primary production was highest in the clear water lake, Beaverskin Lake, which also had lower dissolved organic carbon (DOC) concentration compared to the two dystrophic lakes. In the clear water lake annual production was similar between years but in the two colored lakes annual production was 40% higher in the second year. The observed increases in annual production between years in the colored lakes were largely due to changes in euphotic depth resulting from variations in hydrology and DOC export from the lake catchments. Lower discharges in the colored lakes in 1980 were accompanied by lower DOC concentration in the clear water lake did not produce significant changes in water color, light extinction coefficient nor annual production between year. Rates of primary production at light optimum (P-max) were consistently higher in the most colored, acidic lake indicating that relatively high rates of autotrophic production will occur under acidic conditions if nutrient supply is maintained.

Becker, D. S., N. L. Gerrish, and K. K. Chew (1981-1982) **Influence of organic enrichment on demersal fishes.** *Coastal Ocean Pollution Assessment News* **1**:50-52.
{fish; organic enrichment; demersal; Puget Sound}
No abstract

Bell, P. F. (1991) **Status of eutrophication in the Great Barrier Reef lagoon.** *Marine Pollution Bulletin* **23**:89-93.
{lagoon; phytoplankton; nutrients}

Historical data on the levels of nutrients and phytoplankton in the GBR lagoon are reviewed. The results indicate that background levels of P-PO_4 and phytoplankton have increased significantly over the past 50-60 years and that the levels appear be at or above the eutrophication threshold level for coral reef waters. Other data indicate that river discharge probability has a major impact on the nutrient status of the GBR lagoon, but other factors such the nitrogen-fixing blue-green alga, *Trichodesmium*, could also be important. *Trichodesmium* has the ability to introduce large amounts of new nitrogen and it appears that the increased phosphorus levels could be driving its growth. To-date little effort has been made to assess the impact of eutrophication on the coral reef communities. Because the background nutrient levels are relatively high both run-off and sewage discharges could have serious impacts on nearby coral reef communities. Tertiary treatment (i.e. nutrient removal) of sewage should be required for all discharges in the vicinity of coral reefs and special precautions need to be exercised when designing run-off drainage systems.

Berman, T. and Z. Dubinsky (1985) **The autoecology of *Peridinium cinctum* fa. *westii* from Lake Kinneret.** *Verhandiunsen der Internationalen Verlaasbuchhandlune* **22**:2850-2854.
{autoecology; *Peridinium*; pH; temperature; dinoflagellate; Lake Kinneret; freshwater}
No abstract

Berounsky, V. M. and S. W. Nixon (1985) **Eutrophication and the rate of net nitrification in a coastal marine ecosystem.** *Estuarine, Coastal and Shelf Science* **20**:773-781.
{nitrification; estuaries; nitrogen; nutrients}

Rates of nitrification were calculated for four large (13 m^3) estuarine-based microcosms that had been subjected to inorganic nutrient enrichment. Calculated rates were based on two years of weekly nitrate and nitrite measurements and ranged from a maximum of 0-55 umol NO^-_{2+3} produced $l^{-1}day^{-1}$ in the control tank (no enrichment) to over 13 umol NO^-_{2+3} produced $l^{-1}day^{-1}$ in the most enriched tank (receiving 18.6 umol NH_4 $l^{-1}day^{-1}$). Almost all NO^-_{2+3} production was pelagic, little was benthic. Net NO^-_3 production or net NO^-_2 production dominated the net nitrification rates during different seasons. Good correlations were found between various oxidation rates and substrate concentrations. The calculated net nitrite production rates were 10 to 1000 times higher than previously reported rates for open ocean systems, demonstrating the potential importance of nitrification to estuarine systems.

Beukema, J. J. (1990) **Long-term and recent changes in the benthic macrofauna living on tidal flat in the western part of the Wadden Sea.** Proceedings of the 7th International Wadden Sea Symposium, Ameland, The Netherlands.
{benthic; macrofauna; tidal flat; Wadden Sea; species abundance; biomass}

The bottom fauna living on tidal flats in the westernmost part of the Wadden Sea were followed quantitatively by biannual sampling at 15 fixed stations throughout the 1970-1990 period. During this period, the following long-term changes were observed;
1. biomass doubled and numerical abundance more than doubled; as a consequence the size of a 'mean' macrobenthic animal declined;
2. the abundance of more than half of the species studied increased significantly;
3. among these species, small deposit-feeding worms were over-represented and some species increased more than other species.

The above changes are attributed to the recent eutrophication of the area (CADÉE 1992). A favorable effect is the enhanced stock and productivity of the benthos. Detrimental effects (caused by prolonged periods of oxygen depletion) occurred incidentally and locally. recent (1988-1990) changes include a marked increase in the species which are known to be sensitive to low winter temperatures and are ascribed to the mild character of the last three winter. The stock of mussels declined during 1990 to unprecedently low levels. All intertidal mussel beds were completely destroyed by commercial fishermen to stock their subtidal plots. It is recommended that extensive tidal-flat areas should be closed for such fishery activities.

Beukema, J. J. (1991) **Changes in composition of bottom fauna of a tidal-flat area during a period of eutrophication.** *Marine Biology* **111**:293-301.
{benthos; faunal composition; tidal-flat; Dutch Wadden Sea; production; abundance; biomass}

During the last 20 yr the western half of the Dutch Wadden Sea has undergone significant eutrophication: concentrations of P and N compounds and planktonic algae have roughly doubled, as has primary production. Though oxygen levels are often low in summer, anoxic areas are small and rare due to strong tidal mixing. During the 1970 and 1990 period, macrozoobenthos was sampled annually at 15 stations at Balgzand, a 50-km^2 tidal-flat area in the westernmost part of the Wadden Sea. Not only did the estimates of total numbers, biomass, and production double during these two decades, but significant changes in the composition of the benthic community were observed, too: (1) the numerical proportion of polychaetes increased at the expense of molluscs and crustaceans, (2) the overall mean weight per individual of the macrozoobenthos decreased (numbers of individuals of small-size species increased more rapidly than those of large-sized species), and (3) though absolute numbers and biomass of all feeding types increased, the share of carnivores declined and that of deposit feeders increased; the proportion of suspension feeders showed little change. This study refers to true macrobenthos only (1-mm sieve) and further excludes two taxa (*Corophium* spp. and *Hydrobia ulvae*) which occasionaly exercised an undue influence on numbers. Mass mortalites caused by low oxygen concentrations were of a small-scale nature only. Total number of species fluctuated without a clear trend. As a consequence of the increasing numerical densities, trends in species numbers were slightly increasing when expressed per unit area and slightly decreasing when estimated per 100 individuals (by rerefaction).

Beukema, J. J. and G. C. Cadée (1986) **Zoobenthos responses to eutrophication of the Dutch Wadden Sea.** *Ophelia* **26**:55-64.
{benthos; Dutch Wadden Sea; biomass; secondary production; abundance}

During the last few decades nutrient concentrations in the Dutch coastal water have increased significantly. Values observed for rates of

primary production as well as for concentrations of chlo rophyll and for particulate organic matter have been higher during recent years than estimates from earlier periods. Thus more food will have been available for herbivorous benthos during recent years.

Both biomass and annual production of the macrozoobenthos living on the tidal flats in the western part of the Wadden Sea doubled during the 1970 to 1984 period. More than half of the species contributed to this increase. In the species studied in most detail, *Macoma balthica*, both reproductive success and growth rate increased significantly during the 15-year period.

Though a causal relationship between simultaneous increases of nutrient levels, primary production and secondary production cannot be proved, such a relationship seems to be natural. So far, obvious detrimental effects such as mass mortalities from lack of oxygen appear to be rare in the well-mixed Wadden Sea.

Beukema, J. J. and G. C. Cadée (1991) **Growth rates of the bivalve *Macoma balthica* in the Wadden Sea during a period of eutrophication: relationships with concentrations of pelagic diatoms and flagellates.** *Marine Ecology Progress Series* **68**:249-256.
{phytoplankton; bloom; flagellates; Wadden Sea; diatom; bivalve; growth; Macoma; secondary production}

Probably as a consequence of eutrophication, both the length of the annual phytoplankton blooms and the mean concentrations of flagellates (dominated by *Phaeocystis pouchetii*) have increased in the western part of the Wadden Sea during the last decades. Planktonic diatoms, on the other hand, have hardly increased, but fluctuate heavily from year to year. Among the benthic tidal-flat fauna, which has increased in total numbers and biomass during the last decades, the bivalve *Macoma balthica* was studies in detail. The 15 year (1974 to 1989) patterns of its annual growth and condition were compared with abundance patterns in phytoplankton components (during the growing seasons of *M. balthica*). Fluctuations in *M. balthica* were found to parallel fluctuations of planktonic diatoms but not those of *P. pouchetii*. It is concluded that *M. balthica* responded by faster growth and higher condition to better feeding conditions in years of high diatom abundance. Diatoms rather than *P. pouchetii* or other flagellates will be the most important food source for *M. balthica*.

Biggs, R. B., T. B. DeMoss, M. M. Carter, and E. L. Beasley (1989) **Susceptibility of US estuaries to pollution.** *Review in Aquatic Sciences* **1**:189-207.
{estuary; classification; susceptibility}
No abstract

Birch, P. B. and J. O. Gabrielson (1984) ***Cladophora* growth in the Peel-Harvey estuarine system following blooms of the cyanobacterium *Nodularia spumigena*.** *Botanica Marina* **27**:17-21.
{bloom; cyanobacteria; estuary; macroalgae; *Cladophora*; *Nodularia*; seaweeds}

In recent years severe blooms of the nitrogen-fixing cyanobacterium *Nodularia spumigena* have occurred during spring and early summer in the eutrophic Peel-Harvey Estuary. Following decomposition of these blooms there are blooms of *Cladophora* and other macroalgae, and more recently of a benthic species of *Oscillatoria*. Data on nitrogen and phosphorus in estuary water and in *Cladophora* tissue, combined with a decomposition study of *Nodularia*, indicate that large amounts of nutrients are recycled from *Nodularia* to other algae. Control of *Nodularia* blooms is now of primary importance not only because of serious problems caused directly by it, but also because of the nutrients made available upon its decay for other nuisance algae and bacteria.

Birch, P. B., J. O. Gabrielson, and K. S. Hamel (1983) **Decomposition of *Cladophora*.** *Botanica Marina* **26**:165-171.
{algae; *Cladophora*; estuary; Australia; decomposition; nitrogen; phosphorus}

Cladophora aff. *albida* is a benthic alga which grows in nuisance proportions in the shallow (2m) Peel-Harvey estuarine system in Western Australia. It grows as small (1-3 cm) ball-like clumps in beds 1 - 10 cm deep, the lower self-shaded sections of which are in various stages of decomposition.

Samples of *Cladophora* (half of which were pre-killed by freezing) were buried in a bed in nylon mesh for up to one year. Initially live *Cladophora* was very resistant to decay; only after two months did significant decomposition begin, resulting in loss of 50-60% of dry weight, carbon and nitrogen losses were slower (20-30% in two weeks, 50% after three months).

It was estimated that up to 60% of the *Cladophora* pool of nitrogen and phosphorus could be available for recycling in one year. This reduces the dependence of *Cladophora* on external inputs to maintain production.

Blackburn, S. I. and Y. Oshima (1989) **Review of culture methods for *Pyrodinium bahamense*.** In: G. M. Hallegraeff and J. L. Maclean (ed.) *Biology, Epidermiology and Management of Pyrodinium Red Tides*. Fisheries Department, Ministry of Development, Manila.

The dinoflagellate *Pyrodinium bahamese*, both var. *bahamense* and var. *compressum*, has been

successfully cultured in seawater-based media by several workers. These cultures were sometimes kept for many years but all of them were eventually lost. This tropical dinoflagellate requires temperatures of 24-30°C, dilute nutrient media and soil extract, while a pH optimum of 8 has also been observed. Recommendations for renewed culture attempts are provided.

Boddeke, R. and P. Hagel (1991) **Eutrophication of the North Sea continental zone.** Netherlands Institute for Fisheries Research, E:7.
{North Sea; shellfish; fish}

North Sea landings of demersal fish rose after 1963 to more than 1 millions tons from a rather constant level of about 400,000 tons since 1909. Landings of bivalves from the Dutch coastal zone increased greatly after 1950. From the data presented, a structural change in productivity of the Southern and Central North Sea in the period 1950-1985 as the result of eutrophication of the continental coastal waters emerges as the most likely cause of the enhanced commercial production. Therefore, the continuing decrease of the discharge of phosphate to the southern North Sea since the beginning of the eighties, is likely to have negative effects on the production of fish and shellfish in the S-E North Sea.

Bodeanu, N. (1992) **Algal blooms and development of the main phytoplanktonic species at the Romanian Black Sea littoral in conditions of intensification of the eutrophication process.** In: R. A. Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication.* Elsevier, Amsterdam.
{species abundance, species composition, Black Sea}

The growth of mineral salts and organic matter in the western Black Sea, caused by intensification in the 1980s and 1990s of anthropic activity in the pontic basin, the Danube and other tributary rivers, determined the increase of the frequency and magnitude of algal blooms with their detrimental consequences for ecosystems. More than 20 monospecific algal blooms have occured in Romanian coastal waters between 1983 and 1988. Of the eight species responsible for the phenomenon, five achieved the greatest blooms ever known at the Romanian littoral.

With the exception of algae which produce monospecific blooms, remarkable development of numerous other species has been recorded. The number of species with high numerical densities (over 100,000 cells l^{-1}), increasing from one period to the next, reached 72 in 1983-1988, compared with 61 in 1971-1982 and only 38 in 1960-1970. Of the total mass species which developed between 1960-1988, almost 60% reached the greatest development during the years 1983-1988. The intensity of the blooms, the growth of the mass species number, and the increase in density induced high levels of global photplankton. Continually rising, the mean biomass for the Romanian Black Sea areas was ten ti;mes greated in 1983-1988 than in 1959-1963.

Boesch, D. F. (1983) **Implications of oxygen depletion on the continental shelf of the Northern Gulf of Mexico.** *Coastal Ocean Pollution Assessment News* **2**:26-28.
{oxygen; hypoxia; Gulf of Mexico; nutrient}
No abstract

Boni, L., E. Carpené, D. Wynne, and M. Reti (1989) **Alkaline phosphatase activity in *Protogonyaulax tamarensis*.** *Journal of Plankton Research* **11**:879-885.
{bloom; pH; alkaline phosphatase; indicator; dinoflagellates}

A non-toxic strain of the marine dinoflagellate *Protogonyaulax tamarensis* (= *Gonyaulaz tamarensis*) has been isolated from a bloom in the Adriatic Sea, off the Emilia-Romagna coast. Cultures of the cells were grown in the laboratory in enriched seawater at various initial ambient orthophosphate (P_i) concentrations, ranging from 0.3 to 40 uM. The growth rate varied from 0.3 to 0.8 divisions day^{-1}, depending on the P_i levels. From measurements of kinetic parameters, the binding of the artificial substrate *p*-nitrophenylphosphate to the *P. tamarensis* alkaline phosphatase was quite strong (K_m = 50 uM). Maximal activity was observed at pH 8.4, although the pH-activity curve was broad, in contrast to that of other alkaline phosphatases. *Protogonyaulax tamarensis* alkaline phosphatase, measured over a 24 h period, exhibited an apparent diurnal fluctuation in activity, in common with the enzyme from other dinoflagellates.

Boni, L., L. Mancini, A. Milandri, R. Poletti, M. Pompei, and R. Viviani (1992) **First cases of diarrhoetic shellfish poisoning in the Northern Adriatic Sea.** In: R. A. Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication.* Elsevier, Amsterdam.
{Adriatic Sea, toxicity}

Shellfish poisoning occurs when toxic photoplankton species are present in their environment. Because shellfish such as mussels are filter feeders they concentrate toxins. It is also well known that sometimes also small amounts of toxic algae can produce serious shellfish poisoning. In the Adriatic Sea, dinoflagellate red tides are a recurring phenomenon, but no shellfish poisoning

has been described despite the presence of potentially toxic species such as *Alexandrium* spp. (Protogonyaulax) and *Dinophysis* spp. In June 1989 several cases of food poisoning characterized by vomiting, abdominal pain and diarrhoea were recorded along the coast of Emilia-Romangna and Marche, facing the north-western Adriatic Sea. The poisoning was attributed to shellfish ingestion, mostly mussels. Microscopic investigations revealed the presence of *Dinophysis* spp. in seawater and mussel guts. *Mytilus galloprovincialis, Venus gallina, Tapes semidecussatus,* and *Venus verrucosa* have been monitored for toxin by mouse bioassay and diarrhoetic shellfish poisoning (DSP) was detected only in mussels. Shellfish samples from Friuli Venezia Giulia, Veneto, Emilia-Romagna and Marche were monitored for toxin and from June 22 a temporary prohibition on mussel fishing for the period of DSP was imposed.

Borum, J. (1985) **Development of epiphytic communities on eelgrass (*Zostera marina*) along a nutrient gradient in a Danish estuary.** *Marine Biology* **87**:211-218.
{eelgrass; epiphytes; community; estuary; biomass; phytoplankton; nutrients}

The effect of nutrient enrichment on epiphyte development was examined by following the seasonal development of epiphyte biomass on eelgrass (*Zostera marina* L.) at four localities along a nutrient gradient in Roskilde Fjord, Denmark between March and December 1982. In the most nutrient-poor area, epiphyte biomass followed a distinct bimodal seasonal pattern with maxima in spring and early fall. Low nutrient availability and a high rate of eelgrass leaf renewal kept epiphyte biomass at a low level throughout the summer period. Unlike phytoplankton, the epiphytic community was not stimulated by nutrient enrichment during spring, however from May though August, the biomass of both components increased exponentially with increasing concentrations of total N in the water. Along the nutrient gradient, phytoplankton biomass increased 5- to 10-fold, while epiphyte biomass increased 50- to 100-fold. Thus differences in nutrient conditions among study sites were more clearly reflected by epiphytes than phytoplankton.

Boynton, W. R., W. M. Kemp, and C. W. Keefe (1982) **A comparative analysis of nutrients and other factors influencing estuarine phytoplankton production.** In: V. S. Kennedy (ed.) *Estuarine Comparisons.* Academic Press, New York.
{phytoplankton; productivity; estuary; biomass; production; N/P ratio; nitrogen; phosphorus}

We reviewed data concerning phytoplankton production, chlorophyll *a*, and associated physical and chemical variables from 63 different estuarine systems. Data were analyzed statistically to test hypotheses regarding algal productivity and factors regulating temporal patterns. Prior to statistical analysis, estuarine systems were classified into four groups based on criteria of physical circulation and geomorphology. Analysis of grouped data indicated that algal production and biomass were consistently high in warm periods of the year in a broad spectrum of estuaries and that ratios of available nitrogen to phosphorus were low during periods of high production, except in highly eutrophic systems. In general, phytoplankton production and biomass exhibited weak correlations with a variety of physical and chemical state variables, perhaps indicating the significance of rate processes as opposed to standing stocks in regulating these important features of estuarine systems. A six-year time series of measurements of algal production and chlorophyll *a* at stations in middle Chesapeake Bay exhibited considerable year-to-year variability, with a three-fold range in peak values. Summertime maxima were strongly related to annual loadings of both nitrogen (N) and phosphorus (P) but annual production appeared to be sustained primarily on recycled nitrogen and phosphorus. To generalize from these findings, N and P loading rates were estimated for 14 different estuarine systems, and a significant positive relationship was obtained between phytoplankton production and nitrogen (but not phosphorus) inputs.

Brand, L. E., M. D. Gottfried, C. C. Baylon, and N. S. Romer (1991) **Spatial and temporal distribution of phytoplankton in Biscayne Bay, Florida.** *Bulletin of Marine Science* **49**:599-613.
{phytoplankton; abundance; distribution; Florida; pigments}

Biscayne Bay provides a study in contrasts. North Biscayne Bay has undergone substantial changes during the twenties century resulting from the development of the metropolis of Miami around it while south Biscayne Bay has been relatively little affected by the dramatic human population increase in South Florida.

The phytoplankton at 24 stations throughout Biscayne Bay were examined monthly for 1 year. Phytoplankton were found to be 5 to 10 times higher in abundance in the north bay compared to the south and even more abundant near canal mouth. Eutrophication from freshwater runoff is the likely cause of the higher abundance of phytoplankton in the north bay as well as the higher fluorescence response indices and chlorophyll to phaeopigment ratios in the phytoplankton in the north. Phytoplankton are most abundant in the north bay right after the first major rains of the rainy season, thought to be the result of the large amounts of nutrients flushed into

the bay at that time. Phytoplankton are least abundant at the end of the dry season after a long period of little runoff. Phytoplankton abundance shows virtually no seasonality in the south bay where land runoff is relatively insignificant. The south Biscayne Bay ecosystem remains dominated by benthic macrophytes while the north bay shifted to an ecosystem dominated by a relatively dense plankton community with a few macrophytes remaining.

Breuer, G. and W. Schramm (1988) **Changes in macroalgal vegetation of Kiel Bight (Western Baltic Sea) during the past 20 years.** *Kieler Meeresforschungen, Sonderheft* **6**:241-255.
{Baltic; Kiel Bight; *Furcellaria*; *Phyllophora*; *Phycodrys*; abundance; biomass; coverage}
A large scale quantitative survey of the benthic vegetation of the Kiel Bight (Western Baltic Sea) has been performed by analysis of underwater television observations and samples obtained by SCUBA diving during 1985-86. This investigation was compared to a semiquantitative survey carried out in 1962-64 by Schwenke (1964, 1964). For the total study (2571 km^2), distinct changes in biomass and species composition have been observed. There is an increase of biomass above the 12 m level (probably with exception of the 6 m level) and a decrease below 12 m. Extensive *Furcellaria lumbricalis* populations have disappeared. *Furcellaria lumbricalis* has been replaced by *Phyllophora truncata* and *phycodrys rubens* which are the predominant species at present. Among other possible causes for these changes, the role of commercial stone fishing and effects of increasing eutrophication in the Kiel Bight are discussed.

Brey, T. (1986) **Increase in macrozoobenthos above the halocline in Kiel Bay comparing the 1960s with the 1980s.** *Marine Ecology Progress Series* **28**:299-302.
{macrozoobenthos; Kiel Bay; biomass; mollusc}
The macrobenthos of sandy sediments in the 9 to 13 m water depth area of Kiel Bay was investigated. Data from 1961 to 1965 were compared with data from 1982/83. Biomass of total macrobenthos was significantly higher in 1982/83 (14.6 g ash-free dry weight m^{-2}) than in 1961 to 1965 (4.7 g AFDW m^{-2}). This increase is mainly caused by mollusc species. Eutrophication, changes in predation pressure and changes in physical disturbance are discussed as possible reasons.

Brockmann, U., G. Billen, and W. W. C. Gieskes (1988) **North Sea nutrients and eutrophication.** In: W. Salomons, B. L. Bayne, E. K. Duursma and U. Förstner (ed.) *Pollution of the North Sea. An Assesssment.* Springer-Verlag, Berlin.
{North Sea; nutrients; oxygen; effects; bloom; review}
No abstract

Brockmann, U. and E. Dahl (1990) **Distribution of organic compounds during a bloom of *Chrysochromulina polylepis* in the Skagerrak.** In: E. Granéli, B. Sundtröm, L. Edler and D. M. Anderson (ed.) *Toxic Marine Phytoplankton.* Elsevier, New York.
{bloom; *Chrysochromulina*; phytoplankton; inorganic nutrients; organic; Skagerrak; Kattegat}
Nutrient elements, bound in dissolved organic substances, can become a major controlling factor for algal growth when inorganic nutrients are depleted. During the late phase of the extended bloom of *Chrysochromulina polylepis* in the Skagerrak/Kattegat during spring 1988, concentrations of particulate and dissolved organic substances (C, N ,P) were estimated together with hydrographic measurements, and nutrient and phytoplankton analyses. Along a profile through the Skagerrak between Skagen and Hällö a stable and most biologically rich pycnocline at 7-25 m depth separated two distinct chemical regimes: (i) a surface layer where nitrate (<0.2 ug at N dm^{-3}) and phosphate (<0.02 ug at P dm^{-3}) were nearly depleted and dissolved organic compounds (DOM) reached maximum concentrations (>10 ug at N dm^{-3} and >0.05 ug at P dm^{-3}), (ii) lower layers with higher inorganic nutrients and lower DOM. As a result of this, the pycnocline exhibited a minimum concentration of total dissolved nitrogen (<10 ug at N dm^{-3}) together with maximum cell densities (>16X10^6 cells dm^{-3}) of *C. polylepis*. Because of these vertical nutrient profiles, the cells could utilize both inorganic and organic bound nutrient elements from the adjacent layers. The main N-source was however probably nitrate as seen from mixing curves. High concentrations of dissolved carbohydrates (>3 umol Glc-eq dm^{-3}) in the mixed layer, significantly negative correlated with salinity, indicate that the dominating source for DOM was the Baltic outflow.

Brockmann, U. H., E. Dahl, and K. Eberlein (1985) **Nutrient dynamics during a *Gyrodinium aureolum* bloom.** In: D. M. Anderson, A. W. White and D. G. Baden (ed.) *Toxic Dinoflagellates.* Elsevier, New York.
{nutrient; dinoflagellate; phytoplankton; bloom}
Monospecies cultures of *Gyrodinium aureolum* were investigated in two 16 and 20 m deep enclosures for 20 and 22 days respectively. Nutrients were added at the beginning and after 10 or 12 days, simulating coastal front mixing. In spite of nutrient exhaustion in the upper layer

(nitrate below 0.1 ug at N dm^{-3}) the cells did not migrate to the nutrient-sufficient lower layer. After two days of nutrient depletion, *G. aureolum* maintained its high cell number. However, the cells decreased in the second enclosure during 5 days of nutrient deficiency and did not increase following the addition of nutrients, so that other species become dominant, including diatoms.

Brown, J. R., R. J. Gowen, and D. S. McLusky (1987) **The effect of salmon farming on the benthos of a Scottish sea loch.** *Journal of Experimental Marine Biology and Ecology* **109**:39-51.
{benthos; abundance; biomass; fish farming; diversity}

The effects of waste from a salmon farm on the benthos of a fjordic sea loch on the western coast of Scotland have been studied. Within 3 m of the floating cages the sediments was highly reducing, and dissolved oxygen content of the water overlying the sediment ranged from 35 to 75% saturation. At ≥15 m from the cages the sediment was oxygenated, and the dissolved oxygen content of the water overlying the sediment was 50-80% saturation. Sedimentary redox potential and dissolved oxygen content of bottom water showed a seasonal variation. The benthic fauna showed marked changes in species number, species diversity, faunal abundance, and biomass in the region of the fish farm, with four zones of effect identified. Directly beneath, and up to the edge of the cages, there was an azoic zone. A highly enriched zone, dominated by *Capitella capitata* (Fabricius) and *Scolelepis fuliginosa* (Claparède), occurred from the edge of the cages out to ≈8 m. A slightly enriched "transitional" zone occurred at ≤25 m, and a "clean" zone at the distances >25 m. This study showed that salmon farming had similar effects on the benthos as other forms of organic enrichment, but the effects were limited to a small area in the immediate vicinity of the cages.

Buhl-Jensen, L. and J. H. Fosså (1991) **Hyperbenthic crustacean fauna of the Gullmarfjord area (western Sweden): species richness, seasonal variation and long-term changes.** *Marine Biology* **109**:245-258.
{benthic; fauna; change; amphipods; disappearance}

Distribution of 118 species of Amphipoda, Mysidacea and Decapoda, sampled in 1984 and 1985 with an epibenthic sledge along a transect from the Skagerrak to the inner Gullmarfjord (Sweden), is described. Amphipods were richest in species in the Skagerrak, while most mysid species were taken at the sill. Deca-impoverished and the Lilljeborgidae, earlier represented by three species, had disappeared since 1930s. The changes are most likely caused by eutrophication of the fjord and deep-basin samples; (III) sill samples; (IV) Skagerrak samples. Characteristic species of the groups were identified with a pseudo *F*-test. Detrended Correspondence Analysis indicated seasonal faunal changes at 42 and 72 m depths. At both depths a shift in numerical dominance from amphipods to mysids was found in winter. The most pronounced changes seemed to occur at 42 m. Changes in composition and abundance of species during a renewal of the bottom water indicated that mysids were influenced by presumed near-bottom currents, while amphipods and decapods were not. Comparisons of the present amphipod fauna with the fauna in 1933-37 revealed significant differences. The fauna in the deep basin was impoverished and the Lilljeborgidae, earlier represented by three species are most likely caused by eutrophication of the fjord.

Cadée, G. C. (1986) **Increased phytoplankton primary production in the Marsdiep area (Western Dutch Wadden Sea).** *Netherlands Journal of Sea Research* **20**:285-290.
{phytoplankton; primary production; Dutch Wadden Sea; phosphate; eutrophication}

Annual phytoplankton primary production in the Marsdiep tidal inlet increased from ca 150 g C m^{-2} in the period 1964 to 1976, to ca 300 g C m^{-2} in 1981/1982 and 1985. This increase is considerable, but comparable to that observed in the outer Ems estuary, eastern Wadden Sea, from 240 g C m^{-2} a^{-1} in 1972/1973 to 400-500 g C m^{-2} a^{-1} in 1976/1980. Although the increase is most probably due to eutrophication, as illustrated by the regular increase in phosphate in the Marsdiep area since 1950, it is difficult to explain why this affected primary production no earlier than the late seventies. Primary production has probably not increased in the more turbid inner parts of the Wadden Sea, where light is the limiting factor, and P values were already higher than in the inlet areas.

Cadée, G. C. (1986) **Recurrent and changing seasonal patterns in phytoplankton of the westernmost inlet of the Dutch Wadden Sea from 1969 to 1985.** *Marine Biology* **93**:281-289.
{phytoplankton; abundance; Dutch Wadden Sea; distoms; flagellates; turbidity}

Data for phytoplankton composition and abundance in the Marsdiep are presented for the period from 1969 to 1985 inclusive. Only a few species dominated the phytoplankton. A recurrent pattern was observed in the seasonal succession: in winter, total cell numbers were invariably low, but freshwater algae, sluiced into the Wadden Sea from IJssel Lake, showed highest densities in winter. A diatom spring peak was observed around mid-April, followed by a *Phaeocystis pouchetii* peak about

three weeks later. Later in summer usually two more diatom peaks followed by non-diatom peaks were present. The exact timing of the spring peak varied from year to year, with the extremes being late March and early May. A relatively late spring peak usually coincided with a relatively high turbidity in the preceding winter. An increase in total cell numbers was found over the 17-year observation period. Diatoms decreased from 1969 to 1974 but have increased since then, reaching values above those of 1969 during recent years. Flagellates showed a consistent increase over the entire observation period.

Cadée, G. C. (1990) **Increased bloom.** *Nature* **346**:418.
{phytoplankton; bloom; North Sea; *Phaeocystis*; nutrient}
No abstract

Cadée, G. C. (1992) **Trends in Marsdiep phytoplankton.** Proceedings of the 7th International Wadden Sea Symposium, {phytoplankton; Marsdiep; diatom; bloom; phosphorus; nitrogen; North Sea; primary production; composition; biomass}

Phytoplankton cell-counts indicate an almost continuous increase in non-diatom plankton since the early 1970s. Particularly *Phaeocystis* blooms increased in duration. Diatoms fluctuated more irregularly. Man-induced eutrophication - increased in phosphate and nitrogen, but not in silicate - can explain such trends. They are comparable to those found in Helgoland, but different from (climate-induced) trends observed in the open North Sea during the Continuous Plankton Recorder survey. Such climatic effects are apparently overruled by eutrophication effects in coastal waters. Historical data on *Phaeocystis* for the Marsdiep area confirm the changes observed; they indicate blooming periods lasting some 50 days in 1897 and 1899, before eutrophication started. This blooming period has tripled in the late 1980s.

Annual primary production was measured less regularly, but the first ^{14}C production data were collected in 1963-1965. Primary production has remained c. 150 g carbon (C) m^{-2} a^{-1} up to the early 1970s, but doubled in the early 1980s. Production in 1990 might be relatively low due to freshwater (including nutrient) discharge from the IJsselmeer.

Chlorophyll-a showed an increase parallel with the primary production increase in the late 1970s, but the annual variation is large. Comparison with the 1951-1953 data is hampered because of differences in the methods used.

Cadée, G. C. and J. Hegeman (1991) **Historical phytoplankton data of the Marsdiep.** *Hydrobiological Bulletin* **24**:111-118.
{phytoplankton; trend; Marsdiep; Wadden Sea; *Phaeocystis*; bloom}

Published and unpublished data on phytoplankton of the Marsdiep tidal inlet were studied. Most older data going back to 1897, are based in net-phytoplankton only, the earliest quantitative (Utermöhl) data being from 1965. *Phaeocystis* sp. bloomed in the Marsdiep after a spring diatom peak, at least as long ago as 1897. Summer and autumn peaks of *Phaeocystis* sp., frequent now, were also observed in 1898 and 1899. The duration of the *Phaeocystis* blooms in 1897 to 1899 was shorter than observed after 1978, but longer than in the early 1970s. The recent (1987 to 1989) duration of *Phaeocystis* blooms is 2 to 3 times that of 1897-1899. The increase surpasses normal yearly variation and can be related to anthropogenically caused increase in nutrient concentrations. A number of diatom species, at present numerically dominant in the spring peak, are not mentioned as dominant in the earlier periods of observation. They are small and passed through the nets used. *Biddulphia sinensis*, at present often abundant, is an immigrant in the North Sea since 1903, and for that reason absent from the earliest Marsdiep observations. No clear trend in duration of diatom blooms is apparent during 1965 to 1989. Anthropogenic eutrophication did not affect diatom blooms. Marsdiep records in the literature of *Phaeocystis globosa, P. pouchetii* and *P.* sp. all refer to the same species.

Caldwell, J. W. (1985) ***Effects of elevated turbidity and nutrients on the net production of a tropical seagrass community.*** Dissertation for Ph.D., The University of Florida.
{turbidity; nutrients; seagrass; dredging; production; shading}

Dredging effects on seagrass communities in the Florida Keys were examined by (1) comparing impacts on net production resulting from dredging and natural weather events, (2) determining changes in community photosynthetic efficiency, (3) evaluating shading and nutrient effects on net production, and (4) developing a systems dynamics model.

Net community production was estimated during numerous meteorological and dredging events using the Odum-Hoskins oxygen technique in flow-though field microcosms. In other experiments, shading and nutrients (phosphorus, nitrate, and ammonia) were manipulated to simulate dredge plume conditions. The model examined the relationships between seagrass biomass, water column and sediment nutrients, detritus, and consumers.

The greatest depression in net community production resulted from severe thunderstorms and dredging events, respectively. Net community

production measured two years after dredging showed an approximate four-fold decreased.

In field microcosm experiments, significant interaction occurred between shading and nutrient concentration. Significant metabolic reduction occurred due to shading , even with higher nutrient conditions. All but the lowest concentration resulted in significantly increased production in the light. Qualitative comparison with a control showed an enhancement of production only in the light.

The model of seagrass production was most sensitive to changes in nutrient-seagrass relationships, seagrass production estimates, and seagrass-light interactions. Recovery of seagrass biomass following numerous dredging events (3.5 years) was longer than that from estimated total annual thunderstorms encountered (1 year) but shorter than recovery from hurricane events (4.1 years).

The effects of short-term dredging on net community production as shown by field experimentation and the model were less severe than some weather events because of differences in duration and intensity. Lowered post-dredging photosynthetic efficiency, as defined by unit biomass production per unit light, was a result of degraded system function possibly from sediment scour from the dredging cut. The major deleterious effect of dredging resulted from shading, although some production enhancement could occur from nutrient release. The model suggested that dredging effects were prolonged because of current scour from the dredging cut, that recovery time was comparable to hurricane events, and that more investigation is needed in seagrass-nutrient and light-production relationships.

Cambridge, M. L. and A. J. McComb (1984) **The loss of seagrass in Cockburn Sound, Western Australia. I. The time, course and magnitude of seagrass decline in relation to industrial development.** *Aquatic Botany* **20**:229-243.
{seagrass; effluents; Australia}

The areas of seagrass meadows in Cockburn Sound, a marine embayment in Western Australia, were estimated from historical aerial photographs supplemented by ground surveys, studies on meadows in adjoining areas, and coring for rhizome remains. Ten species of seagrass with different habitat tolerances are recorded for the area, with *Posidonia sinuos* Cambridge et Kuo forming the most extensive meadows. It is estimated that from 1954 to 1978 the meadow area was reduced from some 4200 to 900 ha., based on leaf detritus production from 23000 to 4000 t (dry wt.) y^{-1}. The major loss of seagrass occurred during a period of industrial development on the shore, and the discharge of effluents rich in plant nutrients.

Carpenter, E. J. (1970) ***Effects of phosphorus mining wastes on microorganisms of the Palmico River estuary, North Carolina.*** Dissertation for Ph.D., North Carolina State University at Raleigh.
{Palmico River estuary; blue-green algae; sewage; phosphorus; mining; photosynthesis}

To test the effects of phosphorus mining wastes (SPW) and domestic sewage on microorganisms of the Palmico River estuary, six 1400 m^3 artificial estuaries and eight 15.1 m^3 static pools were constructed. Concentration, excluding controls, of SPW in the pools was 1 percent in estuaries ranged from 1 percent to 51 percent of the total water volume. The present day concentration of SPW in the lower Palmico River is 0.7 percent (v/v) and is expected to rise as other companies begin mining operations. Three experiments were carried out, two (54 and 44 days long) in the estuaries and one (15 days long) in the plastic pools.

The experiments showed that the addition of SPW to estuarine water does not immediately increase the photosynthesis or biomass of phytoplankton. This is most likely because phosphorus does not limit the growth of phytoplankton in the river. As shown in a nutrient limitation study, nitrogen limits algal photosynthesis in the Palmico estuary. However, blue-green algae cell numbers (*Anabaena* sp. and *Spirulina* sp.) were 77.2 percent higher ($.010<p<.025$) than controls in estuaries containing approximately 13 percent SPW. Although cell numbers were 33.2 percent above controls in estuaries with 3 percent SPW, the difference was not significant at the 5 percent level. Also, blue-green algae (*Anabaena torulosa*) numbers were 404 percent higher ($.01<p<.025$) than controls in plastic pools with 1 percent SPW (v/v) and 295 percent above ($.010<p<.025$) controls with 1 percent SPW and 0.1 percent (v/v) artificial sewage. The growth of blue-green algae was probably stimulated by the addition of phosphorus in the SPW and their nitrogen fixing ability allowed then to obtain sufficient nitrogen in waters where this nutrient is limiting. This increase in blue-green algae may be potentially harmful to the estuary by changing the algal species composition and by adding fixed nitrogen to an estuary where photosynthesis is nitrogen limited.

An interaction occurred in the pools between SPW and the artificial sewage mix which resulted in photosynthesis 28.8 percent above the controls. The existence of this interaction shows the importance of sewage treatment facilities for towns in the Palmico River basin. Rate of phosphorus uptake by microorganisms was 23.1 percent higher ($p<0.005$) than controls in plastic pools with 1 percent SPW and 74.9 percent higher ($p<.005$) than controls in pools with both SPW and artificial sewage. This indicated that microorganisms are

taking up the added phosphorus in SPW. The uptake in pools with both SPW and sewage was 3.2 x that in the pools with SPW added alone. This uptake may reflect the primary productivity interaction which occurred in the pools. No changes in the V_{max} of glucose by bacteria was seen in the studies. This was probably because the rate of formation of glucose did not increase in an experiment of such short duration.

Carpenter, E. J. and D. G. Capone (ed.) (1983) ***Nitrogen in the Marine Environment.*** Academic Press, New York.
No abstract

Caspers, H. (1987) **Changes in the benthos at a sewage-sludge dumpsite in the Elbe Estuary.** In: J. M. Capuzzo and D. R. Kester (ed.) *Oceanic Processes in Marine Pollution. Vol.1. Biological Processes and Wastes in the Ocean.* Robert E. Krieger Publishing Company, Malabar, Florida.
{sewage; fauna; settlement; stability}

Twenty years of investigations on the benthos in the outer part of the Elbe Estuary, which includes a sewage-sludge dumpsite, show that the community structure was highly unstable. Some changes were brought about by hydrological factors and the variable pattern of sedimentation. Most of the changes, however, resulted primarily from biological factors, such as the predominance of one or two species, the availability of physical space, predation, and the life span of the species. The continual arrival of larvae, belonging to various taxa, caused a more rapid fluctuation in the benthic community structure than is usually encountered in freshwater habitats. Communities in the coastal marine area of the Elbe Estuary might best be designated as astatic and characterized as unstable but highly resilient.

Cederwall, H. and R. Elmgren (1980) **Biomass increase of benthic macrofauna demonstrates eutrophication of the Baltic Sea.** *Ophelia, Supplementum* **1**:287-304.
{abundance; macrofauna; benthic; Baltic}

Twenty-eight stations around the Baltic islands of Öland and Gotland, sampled by Hessle in 1920 and 1923 were revisited in 1976-1977. Using methods similar to those of Hessle, we demonstrate a statistically highly significant increase in macrofauna biomass above the halocline (median over 4 times higher, based on 23 stations) over the intervening 55 years. Neither differences in methods, nor interannual fluctuations can explain the large increase, which is considered to represent a real long-term change, apparent over the entire Baltic Sea. The only plausible cause is eutrophication of the Baltic, leading to higher food supplies for the benthic fauna. These results constitute the first statistically confirmed biological evidence of this eutrophication, and demonstrate that eutrophication is a major process affecting the entire Baltic Sea, and not just restricted coastal areas.

Cederwall, H. and R. Elmgren (1990) **Biological effects of eutrophication in the Baltic Sea, particularly the coastal zone.** *Ambio* **19**:109-112.
{Baltic; review}

The reported biological effects of the increased nutrient load on the Baltic Sea are summarized, with some comparisons with the Kattegat and Skagerrak. Interest is focused on the coastal zone, where effects are more obvious than in offshore areas, but from which results have not often been published internationally. Reports demonstrate environmental degradation over extensive coastal areas of the Baltic Sea. Recorded effects include increased nutrient levels; increased algal blooms, chlorophyll *a* concentrations, and primary productivity; decreased water transparency and decreased depth penetration of *Fucus vesculosus*; increased deposition of organic matter on the bottom and increased frequency and severity of oxygen deficency in bottom waters; and reduction of bottom fauna. It is concluded that for most Baltic countries efforts to reduce local eutrophication are likely to have important positive effects, even when reductions in discharges of nutrients are relatively insignificant in comparison to the total nutrient load on the Baltic Sea.

Cerco, C. F. (1981) **Nitrification in the upper tidal James River.** In: B. J. Neilson and C. E. Cronin (ed.) *Estuaries and Nutrients.* Humana Press, Clifton, New Jersey.
{bacteria; nitrification; ammonia; model}

A field and model study of the nitrification process in the upper tidal portion of the James River, Virginia, has been completed. Attention was devoted to the enumeration of nitrifying bacteria and to the determination of the fate of constituents involved in the nitrification process. Ammonia and nitrite oxidizers are present in the James River water column in concentrations of 10^{-1} - 10 mpm/ml and in the bottom sediments in concentrations of 10^2 - 10^5 mpm/ml. Elevated populations are observed in the vicinity of waste discharges suggesting that nitrification of these wastes begins immediately upon discharge. Examination of three sets of field data supports the hypotheses that nitrification occurs. Of particular interest is the observation, during two instances, of nitrate removal concurrent with nitrification.

Cheney, D. P. (1992) **Project development to harvest the beach-fouling alga Pilayella littoralis in Nahant Bay, MA.** 31st Annual

Symposium of the Northeast Algal Society, Woods Hole.
{seaweeds; beach; fouling; *Pilayella*; Nahant Bay}

The beaches of Nahant Bay, located on the north shore of Massachusetts, have been perturbated for many years by an unusual, presumably mutant, free-living form of the brown alga *Pilayella littoralis*. Normally, *P. littoralis* grows as a small filamentous plant attached to larger algae in the littoral zone during late winter and spring months. However, ever since at least 1903, large masses of free-living, perennial form of *P. littoralis* have been fouling Nahant Bay beaches, often accumulating at low tide in amounts of hundreds of tons. In recent years, there have been sightings of large casts of *P. littoralis* on beaches south of Nahant Bay, raising concerns that the distribution of the free-living form may be spreading. Recently, my laboratory in collaboration with a fisheries engineer at MIT has embarked upon a project aimed at developing the necessary harvesting equipment and strategy for effecting a solution to Nahant's beach-fouling problem. This project will examine the problem from a population biology as well as engineering viewpoint. The current distribution, quantity and *in situ* growth rate of *Pilayella* will be evaluated, in order to determine if harvesting will prove economically-practical. Molecular techniques will be used to determine the genetic relationship between presumed mutant and attached forms. A prototype harvesting system has already been developed and is being evaluated.

Cho, C.-H. (1991) **Mariculture and eutrophication in Jinhae Bay, Korea.** *Marine Pollution Bulletin* **23**:275-279.
{red tide; mortality; diatom; flagellates}

The contents of organic matters and sulfide in the superficial bottom muds, and mass mortality of shellfish mainly due to red tides in the Jinhae Bay are reviewed. COD, ignition loss, and sulfide contents increased for the last decade from 1972 to 1982. Causative organisms of red tides also changed from diatom to flagellates. A decrease of shellfish production or mass mortalities of this area would be caused by a high level of eutrophication, which resulted from both waste discharge from an industrial complex and organic deposits from the aquaculture.

Colombo, G., I. Ferrari, V. U. Ceccherelli, and R. Rossi (ed.) (1992) ***Marine Eutrophication and Population Dynamics.*** Olsen & Olsen, Fredensborg.

Contains eighteen papers on various aspects of eutrophication.

Conolly, N. J. and E. A. Drew (1985) **Physiology of *Laminaria*. III. Effects of a coastal eutrophication gradient on seasonal patterns of growth and tissue composition in *L. digitata* Lamour and *L. saccharina* (L.) Lamour.** *Marine Ecology* **6**:181-195.
{seaweeds; growth; nutrient; *Laminaria*}

Dissolved nitrate, nitrite, ammonium and phosphate were monitored for 2.5 years along a coastal eutrophication gradient originating at the St. Andrews sewer outfall. Linear growth rates and tissue composition (phosphorus, various nitrogen fractions and storage carbohydrates) were monitored at the same stations in lamina tissue of *Laminaria digitata* and *L. saccharina*. Growth rates were considerably enhanced at the eutrophicated stations both in spring, when exogenous nutrients were at peak values at all stations, and during the summer when exogenous nutrients were very low at all stations. Enhanced summer growth rates were correlated with the increased reserves of N and P accumulated during winter and spring, and particularly with soluble organic nitrogen reserves. Accumulation of storage carbohydrates was inversely correlated with growth rate and tissue N and P reserves, presumably because fixed carbon could be incorporated into new protein and thence new tissue only if internal non-protein N reserves were available.

Copeland, B. J. and D. E. Washlschlag (1968) **Biological responses to nutrients - eutrophication: Saline water considerations.** Advances in water quality improvement. Water Resources Symposium, Austin, Texas.
{ecosystem; nutrient; production; zooplankton; community; fish}

1) The addition of a known nutrient source to a marine community resulted in alteration of the metabolic patterns of the ecosystem. An increase in the amount of nutrient material caused an increase in photosynthetic production. 2) Species diversity of zooplankton is reduced in marine environments receiving various types of organic wastes, which indicates an interruption of normal community structure by the addition of new nutrient materials. 3) A theoretical case was presented to demonstrate that slight toxic effects are pronounced although not detectable by conventional means of measurement. With just a slight increase in mortality rate the biomass of the fishes affected would be decreased greatly. 4) Experiments on the metabolic rate of fishes revealed that slight pollution stresses tend to lower the metabolic rates considerably. The depression was greatest when the fish were already subjected to regular environmental stress, such as low temperature. 5) Most of the effects of waste materials in the marine environment are subtle. It appears that the community approach rather than the organismic approach will be more fruitful in evaluating the

impact of man-made changes in inland saline water ecosystems, notwithstanding the fact that the effects of stresses on individual populations can be physically quantifiable.

Correll, D. L. (1981) **Eutrophication trends in the water quality of the Rhode River (1971-1978).** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients*. Humana Press, Clifton, New Jersey.
{nutrient; phosphorus}

Five to eight-year data sets on turbidity and a series of nutrient parameters have been taken in the Rhode River, a small tidal river tributary to Chesapeake Bay. Trends of change at headwater stations indicate changes due primarily to local watershed runoff, while changes at stations near the river's mouth are indicative of changes in Chesapeake Bay.

The data have been analyzed first by summarizing monthly and seasonal means and variances, then by looking for year-to-year trends. Thus, for example, linear regressions of summer and fall turbidity versus time for 1971-1978 had very low slopes and low coefficients of determination. An interesting finding was the pattern or total phosphorus in surface waters. At the mouth of Rhode River, seasonal mean concentrations increased steadily for each season each year from the fall of 1971 to the fall of 1976. The most dramatic increases (four-fold) were observed in the summer and fall. A much smaller increase occurred in winter and spring values. In contrast, year-to-year concentrations of total phosphorus in surface waters in upstream stations over the same time period showed less clear-cut trends. Also, phosphorus loadings from local watershed runoff fluctuated widely, but had no steady rapid rise with time. Although total phosphorus increased dramatically at the mouth of Rhode River, dissolved orthophosphate, nitrate, and dissolved ammonia remained essentially constant, especially in the summer and fall. These data could indicate an increasing impact of summertime anoxic bottom waters on the phosphorus dynamics of the upper western shore of the Bay.

Cosper, E. M., V. M. Bricelj, and E. J. Carpenter (ed.) (1989) ***Novel Phytoplankton Blooms: Causes and Impacts of Recurrent Brown Tides and other Unusual Blooms (Papers from a conference at Stony Brook, NY, 27-28 October, 1988).*** Springer-Verlag, Berlin.
No abstract

Cosper, E. M., W. Dennison, A. Milligan, E. J. Carpenter, C. Lee, J. Holzapfel, and L. Milanese (1989) **An examination of the environmental factors important to initiating and sustaining "brown tide" blooms.** In: E. M. Cosper, V. M. Bricelj and E. J. Carpenter (ed.) *Novel Phytoplankton Blooms, Causes and Impacts of Recurrent Brown Tides and other UnusualBlooms*. Springer-Verlag, Berlin.
{brown tide; bloom; Narragansett Bay; Long Island}
No abstract

Cosper, E. M., C. Lee, and E. J. Carpenter (1990) **Novel "brown tide" blooms in Long Island embayments: A search for the causes.** In: E. Granéli, B. Sunström, L. Edler and D. M. Anderson (ed.) *Toxic Marine Phytoplankton*. Elsevier, New York.
{*Aurococcus*; brown tide; bloom; phytoplankton; Long Island; organic; micronutrients; nutrients; precipitation; heterotrophic uptake}

Unusual blooms of a previously unidentified chrysophyte, *Aureococcus anophaefferens*; have occurred in several coastal embayments along the northeast coast of the USA. The monospecific blooms were termed the "brown tide" due to the resulting water color. The first appearance of the "brown tide" occurred early in the summer of 1985 over a wide geographic range in non-contiguous bodies of water. The bloom did not return to some bays but, on Long Island, New York they recurred during the summer of 1986 and in diminishing densities during the summers of 1987 and 1988. Historically, a diverse group of small microalgal species dominate the phytoplankton biomass and productivity in Long Island bays during the summer. The continued dominance through several months at high cell densities ($> 10^9$ cells l^{-1}) of *A. anophaefferens* was the distinctive feature of consequence during these blooms.

Environmental variables which may contribute to the occurrence of the "brown tide" include elevated salinities due to drought conditions, pulses or rainfall delivering organic and/or micronutrients to bay waters, reduced grazing and restricted flushing of bays. The "brown tide" species appears to be closely related to an open ocean chrysophyte, *Pelagococcus subviridis*, and possibly was seeded into northeast coastal bays from offshore when conditions during 1985 were particularly favorable for its growth. The ability of this species to maintain at least minimal populations during the winter months seems to allow for its recurrence during subsequent summers. Culture studies have shown thatt his species has growth requirements for trace elements, chelators and organic nutrients some of which are different from many common estuarine and coastal phytoplankton species. The competitive advantage of *A. anophaefferens* over other potentially co-occurring species probably related to its heterotrophic and photoadaptive capabilities.

Costa, J. E. (1988) ***Eelgrass (Zostera marina L.) in Buzzards Bay: Distribution,***

production, and historical changes in abundance. Dissertation for Ph.D., Boston University.
{eelgrass; periphyton; abundance; growth; recolonization; Buzzard Bay}

The past and present-day distribution of eelgrass (*Zostera marina* L.) was documented using aerial photographs, field surveys, nautical charts, sediment cores, and first-had accounts. Eelgrass growth correlates with local temperature and insolation, and annual production is ≈350 g C $m^{-2}yr^{-1}$. In Buzzards Bay, eelgrass beds cover 41 km^2 of substrate and account for 12% of primary production; in shallow bays, eelgrass equals 40% of production.

Prior to the "wasting disease" of 1931-32, eelgrass populations equaled or exceeded present-day abundance. Six to 10 years after the disease, eelgrass covered less than 10% of the present-day habitat area. The process of recolonization was similar in many areas: new beds initially appeared on bare substrates, beds expanded, new beds appeared, and some beds were removed by disturbance. A computer simulation modeled these events, and showed that rapid recolonization of eelgrass populations is highly dependent on new bed recruitment, which in nature depends on seed dispersal. High disturbance rates slow eelgrass colonization and lower peak cover.

Local changes in eelgrass abundance are driven by anthropogenic and natural disturbances which are superimposed on the regional pattern of catastrophic decline and gradual recovery. Hurricanes, ice scour, and freezing periodically destroyed eelgrass beds in some areas. Eelgrass populations in poorly flushed, developed bays, with declining water quality, never recovered from the wasting disease or showed new declines in recent years.

The distribution of eelgrass is light limited, and eelgrass beds may disappear in enriched areas because of increases in algal epiphytes and phytoplankton. To identify what levels of nutrient loading cause these changes, concentrations and inputs of dissolved inorganic nitrogen (DIN) in Buttermilk Bay were measured. Periphyton on eelgrass leaves and plastic screen strips on floats correlated well to mean DIN. Experimental floats released nutrients and demonstrated that small increases in DIN significantly increased periphyton abundance. The depth of eelgrass growth in Buttermilk Bay decreased by 9 cm for every 1 uM increase in DIN. Periphyton abundance is more important than phytoplankton concentrations in limiting eelgrass growth in Buttermilk Bay, because water in this bay has short residence time, and phytoplankton gradients are less important.

Crema, R., A. Castelli, and D. Prevedelli (1991) **Long term eutrophication effects on macrofaunal communities in northern Adriatic Sea.** *Marine Pollution Bulletin* **22**:503-508.
{Adriatic Sea; macrobenthos; Po River; community structure; dystrophic; Italy}

The macrozoobenthic community in the northern Adriatic Sea, south of the Po river, along the Emilia-Romagna region coast, was sampled in 1985. Sampling site was central to a highly eutrophicated area with greatly increased intensity and frequency of dystrophic events over recent decades. The sampled community differs from all those described in the same area in a period (1934-1936) previous to the actual degree of eutrophication. Large abundances of species indicative of unstable bottoms, such as the bivalve *Corbula gibba* and the polychaete *Lumbrineris latreilli* were recorded. Moreover, the community structural features indicate a state of immaturity, such as in early successional stage communities. The increased frequency of acute dytrophic events and consequent shortening of the time between successive disturbances is proposed as the cause of bicenosis modification and its current structure and composition.

Crowder, A. and D. S. Painter (1991) **Submerged macrophytes in Lake Ontario: Current knowledge, importance, threats to stability, and needed studies.** *Canadian Journal of Fisheries and Aquatic Science* **48**:1539-1545.
{submerged vegetation; stability; shading; Lake Ontario}

The submerged limnetic community in Lake Ontario includes algae, bryophytes, and about 30 species of angiosperms. Their distribution is accurately known in some areas but not lake-wide, and a whole-lake survey is recommended. In nutrient cycling, submerged vegetation acts as a sinks during the summer; metals and metalloids occur in high concentrations in tissues from some areas. Known herbivores include invertebrates, fish, and waterfowl. Stands are necessary for many fish taxa as breeding or nursery habitats, and for waterfowl, but may be damaged by carp (*Cyprinus carpio*). Stability has been affected by water levels, sedimentation, wave and ice movement, invasive species, herbivory, eutrophication and turbidity, and contaminants. Recovery after control of P loading has occurred in Irondequoit Bay but is delayed by turbidity in the Bay of Quinte.

Cruz, A. A. d. l., C. T. Hackney, and J.P.Stout (1981) **Aboveground net primary productivity of three Gulf Coast marsh macrophytes in artificially fertilized plots.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients*. Humana Press, Clifton, New Jersey.

{nitrogen; enrichment; tidal marsh; macrophytes}

Plots (100 m^2) of four tidal marsh communities (*Juncus roemerianus* and *Spartina alterniflora* in Alabama, *J. roemerianus* and *Spartina cynosuroides* in Mississippi) common in the Gulf Coast were enriched with commercial NH_4NO_3 (23 percent N). The fertilizer was applied once at the beginning of 1978 growing season to stimulate a farm-plantation operation at a dosage (136 g/m^2) estimated to return to the soil approximately the same amount of nitrogen contained in the plants. Six 0.25 m^2 quadrants were harvested monthly from each community from April to November. The annual net productivity was estimated with a maximum minus minimum standing crop technique based on a predictive periodic model (PPM). A correction for plant mortality during the sampling period is provided in the PPM technique. Annual aboveground net primary productivity increased by 59 percent in the Alabama *J. roemerianus*, 84 percent in the Mississippi *J. roemerianus*, 82 percent in the *S. alterniflora* and 26 percent in the *S. cynosuroides*. It appears that short form or high marsh macrophytes responded more to nitrogen enrichment than tall form or low marsh plant.

Cruz-Kaegi, M. E. and G. T. Rowe (1992) **Benthic biomass gradients on the Texas-Louisiana shelf.** In: (ed.) *Nutrient Enhanced Coastal Ocean Productivity, NECOP Workshop Proceedings, October 1991*. Texas A&M University Sea Grant Program, TAMU-SG-92-109, {benthic abundance}

Macrofauna and bacterial biomass were studied in relation to depth, distance from the Mississippi River, primary productivity, and concentration of organic carbon in sediments. Preliminary results suggest that combined benthic biomass was relatively low in the Gulf of Mexico compared to that off New England. Low benthic biomass is thought to be a function of sediment load, unpredictable hypoxic events and trawling pressure, counteracting the positive effects of high primary productivity, fine grain size and relatively high concentrations of organic matter in the sediments.

Darnell, R. M. and T. M. Soniat (1981) **Nutrient enrichment and estuarine health.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients*. Hamana Press, Clifton, New Jersey.

{nutrient; estuary; cycle; ecosystem health}

Ecosystem health may be defined in terms of system norms or in terms of human utility. It is here defined as that state in which the components and processes remain well within specified limits of system integrity selected to assure that there is no diminution in the capacity of the system to render its basic services to society throughout the indefinite future. Knowledge of nutrient enrichment in freshwater systems is reviewed as a point of departure for understanding the response of estuaries to enrichment. Mixed and stratified estuaries respond in somewhat different fashions. Major changes associated with enrichment are changes in species succession and oxygen depletion in areas of organic accumulation, low mixing, and poor flushing. If of temporary and local chronic nature or of widespread occurrence, they could lead to irreversible loss of species and genetic stocks. Measures of ecosystem health are discussed, and pertinent management recommendations are put forth. Of especial importance are the needs to establish local species reserves, to manage total system integrity, and to develop better lines of communication between scientists and managers.

Dauer, D. M. and W. G. Conner (1980) **Effects of moderate sewage input on benthic polychaete populations.** *Estuarine and Coastal Marine Science* **10**:335-346.

{benthic; sewage; polychaete; abundance; biomass; productivity}

The polychaete fauna of a sandy intertidal habitat receiving effluent from a sewage treatment plant was compared to that of a control site. The total number of individuals, total biomass, and average species numbers were significantly greater at the sewage-affected site. The response of individual species to nutrient enrichment varied. Some species showed significantly greater numbers of individuals at the sewage-affected site while other species' densities showed no difference. All species maintained greater biomass at the enriched site, most biomass differences were significant. Those species which did not show density differences between sites tended to have the greater difference in average weight per individual. In general, species with either benthic development or some form of brooding behavior were best able to exploit the enriched condition by increased densities, or greater average biomass per individual. It was concluded that for moderate increasee in nutrient concentrations, benthic productivity will be most enhanced in those sediments with very low concentrations of fine sized particles.

Dauvin, J. C. and F. Gentil (1989) **Long-term changes in populations of subtidal bivalves (*Abra alba* and *A. prismatica*) from the Bay of Morlax (Western English Channel).** *Marine Biology* **103**:63-73.

{*Abra*; bivalve; organic; population; reproduction; growth; abundance; life history}

Two populations of *Abra alba* (Wood) and one of *A. prismatica* (Montagu) (Mollusca: Bivalvia) were studied over a 10 year period (1977-1987) in two muddy fine-sand subtidal communities of the Bay of Morlax, France. The survey provided an example

of long-term changes in the three *Abra* spp. populations, which displayed synchronized changes, with a regular annual cycle and increasing densities during 1979-1980 related to the higher concentration of organic matter resulting from the "Amoco Cadiz" oil spill in March 1978. *A. alba* rapidly adapts its demographic strategy to eutrophic conditions by increasing its reproductive potential, growth, and abundance. During times of eutrophication, *A. alba* has three spawning periods and two recruitments per year as opposed to two spawning periods and two recruitments per year during oligotrophic conditions. Growth of the juveniles of this species is insignificant until spring for individuals recruited in the autumn, whereas individuals which settle during spring or summer display immediate rapid growth. *A. prismatica* has a low capacity to adapt to eutrophic conditions. It has one annual period of sexual maturation at the end of the summer, with spawning in September-October and settlement beginning in mid-November. Growth of the juveniles after settlement is also insignificant until April. These results enable comparison of the demographic strategies of these two sympatric species.

DeBoer, J. A., H. J. Guigli, T. L. Israel, and C. F. D'Elia (1978) **Nutritional studies of two red algae. I. Growth rate as a function of nitrogen source and concentration.** *Journal of Phycology* **14**:261-266.
{red algae; growth; nitrogen; culture}

Gracilaria foliifera (Forsskal) Borgesen and *Neoagardhiella baileyi* (Harvey ex Kützing) Wynne & Taylor were grown in continuous-flow culture under controlled environmental conditions in 15 liter experimental chambers. Growth rate was related to the source and concentration of nitrogen enrichment supplied to the plants. Growth rate appeared to follow saturation-type nutrient uptake kinetics for plants receiving ammonium, nitrate, urea or sewage effluent enrichments. Ammonium enrichment produced higher growth rates than nitrate or sewage enrichment. The lowest growth rates occurred in the chambers receiving unenriched seawater or urea. Half saturation controls (K) for growth were in the range of 0.2 - 0.4 uM N for all N enrichments examined. The low estimated values of K compared closely with those found for microalgae and indicate that both species posses the ability to utilize very low concentrations of N.

Degobbis, D. (1989) **Increased eutrophication of the Northern Adriatic Sea.** *Marine Pollution Bulletin* **20**:452-457.
{phytoplankton; Adriatic Sea; oxygen; mucous aggregates}

Very calm and warm weather in late spring and early summer 1988 supported intense non-seasonal phytoplankton blooms in the western part of the northern Adriatic which is under direct influence of Po River discharge. Surface salinity decreased to 16 X 10^{-3}, and concentration of chlorophyll *a* increased up to 17 mg m^{-3}, with oxygen supersaturation up to 17 203 X 10^{-2}. Nanoplankton dominated the blooms (up to 76 X 10^{9} cells m^{-3}, but diatoms, particularly *Chaetoceros* spp. (up to 17 X 10^{9} cells m^{-3}), also occurred in large numbers. Large 'organic' aggregates were formed in the water column with dimensions (up to 2 m long) and in quantities never previously observed. During late summer and early fall aggregates were distributed over the entire region, and a general contamination of the coasts occurred. Oxygen concentration was dramatically reduced in the bottom layer of the entire region, an event not observed to such a degree since 1977. During that year, in contrast to 1988, large quantities of freshwater spread over the entire northern Adriatic causing extended phytoplankton blooms. In 1988 extremely low horizontal advection (current velocities usually below 20 cm s^{-1}) primarily favoured an accumulation and high aggregation of detritus, and greatly reduced oxygen concentration in the bottom layer.

DeGroodt, E. G., H. F. J. Los, T. A. Nauta, A. A. Markus, and I. deVries (1992) **Modelling cause-effect relationships in eutrophication of marine systems: an integral approach.** In: G. Colombo, I. Ferrari, V. U. Ceccherelli and R. Rossi (ed.) *Marine Eutrophication and Population Dynamics*. Olsen & Olsen, Fredensborg.
{modelling; nutrients; phytoplankton species composition; North Sea}

There is evidence that the elevated anthropogenic nutrient input into the North Sea is related to observed changes in primary production, phytoplankton biomass as well as species composition. Mathematical modelling techniques were used in order to analyze the influence of these inputs. The overall partitioning of gaines and losses has been simulated with a dynamic global model. The model simulates the spatial and temporal concentrations of nutrients and phytoplankton in the entire North Sea.

A general, more detailed ecological model has been developed for the representation of vertical inhomogeneities of nutrients and phytoplankton species composition. Nutrient and phytoplankton levels were computed for different nutrient inputs and varying meterological conditions. The model results show an interdependence of phytoplankton species composition and nutrient input. However, there is little effect of nutrient inputs on the calculated chlorophyll-a concentrations at deep (stratified) areas. These results indicate that

phytoplankton species composition may be more sensitive to changes in the nutrient inputs than the chlorophyll-a concentration.

Dennis, L. and H. H. Seliger (ed.) (1979) ***Toxic Dinoflagellate Blooms (Proceedings of the Second International Conference on Toxic Dinoflagellate Blooms, Key Biscayne, Florida, 31 October - 5 November, 1978).*** Elsevier, North Holland.
No abstract

Dethlefsen, V. and H. V. Westernhagen (1983) **Oxygen deficiency and effects on bottom fauna in the eastern German Bight in 1982.** *Meeresforschung* **30**:42-53.
{benthos; fish; oxygen}

In August and September 1982 two cruises were carried out to investigate the extent and effects of O_2-deficiencies in German and Danish coastal bottom waters. In two thirds of the more than 15 000 km^2 covered by the survey O_2-content was less than 4 ml/l (60% saturation); lowest values were near 1 ml/l.

In bottom waters with low O_2-contents, pH values were generally low (7.7). During the first cruise water in the area investigated was stratified, a thermocline was between 10-15 m above the bottom. In O_2-deficiency areas (O_2-saturation around 10%) fish catches were low containing dead *Agonus cataphractus, Pleuronectes platessa* and *Limanda limanda*. When operating underwater TV dead fish (*Agonus cataphractus, Callionymus lara, Ammodytes* sp. and flatfish) were detected lying dead on the bottom.

Evaluation of underwater photography revealed the occurrence of dead benthic organisms in areas with low oxygen. The species were *Ophiura albida* and *Venus stritula* (paired empty valves). Possible causes for the occurrence of oxygen deficiencies are discussed and it is concluded that eutrophication processes in combinations have triggered low oxygen conditions in bottom waters.

Doering, P. H., C. A. Oviatt, L. L. Beatty, V. F. Banzon, R. Rice, S. P. Kelly, B. K. Sullivan, and J. B. Frithsen (1989) **Structure and function in a model coastal ecosystem: silicon, the benthos and eutrophication.** *Marine Ecology Progress Series* **52**:287-299.

Lowering the N:Si ratio (14:1 to 1:1) in nutrient (N, P, Si) additions to large (13 m^3) outdoor mesocosms with and without an intact benthic community generally resulted in higher standing stocks of diatoms. An enriched diatom flora during the year-long experiment was not accompanied by a concomitant reduction in the extent of eutrophication caused by nutrient loading, as judged by oxygen concentration and metabolism or by chlorophyll *a* biomass. Enhanced growth of Atlantic menhaden *Brevoortia tyrannus* in the low N:Si ration treatment suggested that diatoms promote transfer of energy to higher trophic levels. Removal of the benthic community and associated sediments had a dramatic effect on pelagic community structure. Zooplankton were holoplanktonic in character and higher trophic levels were dominated by ctenophores, medusae, chaetognaths and fish. In the presence of an intact benthos the zooplankton had a larger meroplanktonic component and higher trophic levels were dominated by larvae of benthic adults (anemones, shrimp) or temporary planktonic adults (mysids).

Doi, T. and A. Nitta (1991) **Ecological modelling at Osaka Bay related to long-term eutrophication.** *Marine Pollution Bulletin* **23**:247-252.
{modelling; biomass; fauna}

Based upon the ecological model presented by Anderson & Ursin (1977), we constructed an adequate model which will quantitatively evaluate the overall impact of industrial large-scale development on fisheries at Osaka Bay. It is expected that the patterns of changes in biomass of dominant species, which caused by eutrophication, will be explained by the model we have established. The simulated results for two years, 1956-57, are as a whole comparable to the actual variations. However, the results for several species, including sea bass, flat fish, crab, mantis shrimp, and cuttlefish, differ significantly from observed data. It was attributed to the lack of accurate parameters of anabolism and catabolism for younger-aged stages of these species.

Dortch, Q., D. Milstead, N. N. Rabalais, S. E. Lohrenz, D. G. Redalje, M. J. Dagg, M. E. Turner, and T. E. Whitledge (1992) **Role of silicate availablilty in phytoplankton species composition and the fate of carbon.** In: (ed.) *Nutrient Enhanced Coastal Ocean Productivity, NECOP Workshop Proceedings, October 1991.* Texas A&M University Sea Grant Program, TAMU-SG-92-109, {composition, nutrient ratios, silicate, hypoxia}

It has been hypothesized that hypoxia and the fate of carbon are determined in part by pytoplankton size and species composition, which are influenced by many environmental factors, but especially by the supply of N and Si. In particular when N and Si concentrations are high, the predominant algal species are large, heavily to moderately silicified diatoms. While these may be grazed at rapid rates and fuel productivity at higher pelagic trophic levels, a large portion either sinks below the pycnocline directly or in fecal pellets, perhaps leading to hypoxia. When N concentrations are not

limiting and Si concentrations are low, as often happens on the Louisiana continental shelf, either lightly silicified diatoms or non-diatoms, usually small, flagellated algal species, predominate. These organisms yield less vertical flux of organic matter to the bottom, because most sinking phytoplankton is made up of only a few heavily or moderately silicified diatom species. Thus, silicate availability determines the vertical flux of directly sinking phytoplankton and influences the severity and extent of hypoxia. Any changes in riverine silicate input will affect hypoxia by this mechanism.

Dortch, Q. and T. E. Whitledge (1992) **Does nitrogen or silicon limit phytoplankton production in the Mississippi River Plume and nearby regions?** *Continental Shelf Research* **12**:12293-1309.
{nutrient limitation}

The Mississippi River carries very high concentrations of nutrients into the otherwise oligotrophic Gulf of Mexico, resulting in high primary production and hypoxia along the Louisiana continental shelf. The hypothesis that nitrogen availability controls and ultimately limits phytoplankton production ont he shelf was tested by measuring an indicator of nitrogen deficiency, the ratio of intracellular free amino acids/particulate protien (AA/Pr) in the area of the Mississippi River plume on a spring ans summer cruise. Neither AA/Pr ratios or nutrients in the water showed nitrogen limitation to be widespread. Ammonium concentrations were generally quite high, so the lack of phytoplankton nitrogen deficiency can be explained by rapid regeneration rates. Nitrogen limitation was most likely in the summer at high salinities. However, ratios of dissolved nutrient concentrations suggested that silicate was as likely, or sometimes more likely, to be limiting than nitrogen. Although silicate depletion may not cause a decrease in productivity, it could result in major changes in phytoplanakton size and species composition, and ultimately influence tropodynamics, regeneration, the fate of carbon, and severity and extent of hypoxia.

Doucette, G. J. (1989) ***Aspects of iron and nitrogen nutrition in two red tide dinoflagellates,* Gymnodinium sanguineum *Hirasaka and* Protogonnyaulax tamarensis *(Lebour) Taylor.*** Dissertation for Ph.D., The Univeristy of British Columbia.
{red tide; iron; nitrogen; dinoflagellate; phytoplankton; ultrastructure}

Iron stress-mediated effects on growth, biogeochemical composition, iron and nitrogen uptake, and ultrastructure have been examined in the red tide dinoflagellates *Gymnodinium sanguineum* Hirasaka and *Protogonnyaulax tamarensis* (Lebour) Taylor. The influence of nitrogen source (i.e. NO_3 or NH_4) on certain iron stress-mediated effects was studied, and in some comparisons were made with nitrogen stress-mediated changes in biogeochemical composition. The half-saturation constant for iron-limited growth (K_u = $1.7 \cdot 10^{-20}$ M) of *G. sanguineum* was estimated to be 10-1000 times greater than for other neritic species investigated previously. Also, the iron requirement of this dinoflagellate, in terms of Fe/C ratios, exceeded those of certain coastal diatoms by one to two orders of magnitude. Fe/N ratios demonstrated a larger (1.5-fold) minimum iron content of NO_3- than NH_4-grown cells, likely reflecting the iron content of NO_3 assimilatory enzymes. Acquisition of nitrogen by Fe-deplete, NO_3-grown cells was sufficiently inhibited to yield symptoms of N deficiency, revealed by decreased (ca. 1.4-fold) N quotas and free amino acid/protein ratios compared to Fe-deplete, NH_4-grown cells. Reductions in chlorophyll a (chl a) quotas (Q_{chl}) and photosynthetic electron transport (PET) efficiency (as measured by *in vivo* fluorescence indices) occurred under Fe depletion, and are consistent with the essential role of iron and chl a and PET component (i.e.) cytochrome and Fe-S proteins) biosynthesis. Nitrogen depletion affected Q_{chl} similarly, but altered PET efficiency to a markedly lesser extent than did Fe depletion. Iron-depleted *G. sanguineum* exhibited an enhanced iron transport capacity, which failed to be manifested following a transition from NH_4 to NO_3 nutrition. This suppression may result from concurrent iron and nitrogen stress, due to the inability of Fe-deplete, NH_4-grown cells to rapidly assimilate NO_3. The complete initial inhibition of NO_3 uptake when Fe-deplete, NH_4-grown cells were given saturating iron additions supports this idea. Iron stress caused reductions in chloroplast number and some degeneration of lamellar organization in this species. For *P. tamarensis*, iron limitation induced the formation of temporary (=pellicle) and resting (=hypnozygotes) cysts. Degenerative changes in organelle (i.e. chloroplasts, mitochondira and chromosomes) ultrastructure were largely restricted to pellicular cysts., consistent with their hypothesized role of maintaining variability over brief, rather than extended (c.f. hypozygotes) exposure to adverse conditions.

Dougherrty, J. E. and M. D. Morgan (1991) **Benthic community response (primarily Chironomidae) to nutrient enrichment and alkalinization in shallow, soft water humic lakes.** *Hydrobiologia* **215**:73-82.
{benthic; community; nutrients; lake; pH; chironomonids}

A comparison of the benthic fauna found in two shallow lakes in the New Jersey Pinelands (USA) illustrated the impact of elevated pH and nutrients caused by residential and agricultural disturbance on a naturally acidic, poorly buffered aquatic environment. Detailed community analysis suggested that change in community composition was a better indicator of response to disturbance than biological diversity indices. Chironomonidae (insecta) were the predominant components of the benthic macroinvertebrate assemblage of both undisturbed Oswego Lake (low pH, low nutrients) and Nescochague Lake (fluctuating pH, elevated nutrients). The genera *Procladius, Tribelos*, and *Pagastiella* dominated Oswego Lake, where as *Zalutschia zalutschicola, Procladius, Dicrotendipes*, and *Tanytarsus* dominated Nescochague Lake. *Glyptotendipes* was a common and unique member of the Nescochague Lake assemblage. Cluster analysis indicated that the chemical differences between lakes were the most important community determinants, although, within each lake, depth and substrate affected the local communities. Oswego Lake exhibited a departure nonchironomonid benthic fauna typical of low nutrient, acid lakes. In turn, Nescochague Lake exhibited an enriched nonchironomonid fauna including mollusks and planaria which were not found in Oswego Lake.

Dzurica, S., C. Lee, E. M. Cosper, and E. J. Carpenter (1989) **Role of environmental variables, specifically organic compounds and micronutrients on the growth of the chrysophyte *Aureococcus anophagefferens*.** In: E. M. Cosper, V. M. Bricelj and E. J. Carpenter (ed.) *Novel Phytoplankton Blooms, Causes and Impacts of Recurrent Brown Tides and other Unusual Blooms.* Springer-Verlag, Berlin.
{brown tide; bloom; growth}
No abstract

Eadie, B. J., J. A. Robins, P. Blackwelder, S. Metz, J. H. Trefy, B. McKee, and T. A. Nelson (1992) **A retrospective analysis of nutrient enhanced coastal ocean productivity in sediments from the Louisiana continental shelf.** In: (ed.) *Nutrient Enhanced Coastal Ocean Productivity, NECOP Workshop Proceedings, October 1991.* Texas A&M University Sea Grant Program, TAMU-SG-92-109, {production, sediments}

Sediments have been collected and analyzed to obtain evidence in support of the argument that anthropogenic nutrient loading has led to changes in coastal water quality and increased productivity. Cores representing approximately 100 years of input show unmistakable signs of increased accumulation of organic carbon beginning early in the 1900s. Organic tracers show that virtually all of this increase appears to be of marine origin. At two sites within the plume/hypoxia region, preliminary estimates are that 50 to 70 percent more organic carbon is presently accumulating than at the turn of the century. These preliminary interpretations provide strong support for the central themes of the NECOP program. Analysis and interpretation of further supporting information is continuing.

Edgar, R. K. (1970) ***The effect of nitrogen and phosphorus eutrophication on diatom community structure.*** Dissertation for Ph.D., Rutgers University, The State University.
{diatom; community; nitrogen; phosphorus; bacteria; phytoplankton}

An experimental, field test of the hypothesis that diatom community structure changes with changes in water quality was conducted by partitioning a brook with Plexiglass cylinders and maintaining in each different concentrations of nitrate (0.1, 1.0 and 10.0 mg NO_3/l) and phosphate (0.3 and 3.0 mg PO_4/l) for 18 days. The conclusive stability with respect to treatments of all community structural parameters - biotic composition, density, species diversity (H) and redundancy - strongly suggests that this enrichment had no significant effect upon the functional interactions occurring among the species composing the community. It is suggested that diatom communities are not as sensitive functions of water quality as they are purported to be in that their sensitivity is conditional upon the probabilities of environmental changes affecting the functional status of the community and our ability to detect such changes. Additionally, the results indirectly support the idea that products of bacterial metabolism other than nitrates and phosphates may exert a controlling influence over algal communities.

El-Sayed, M. K. (1982) **Effect of sewage effluent on the sediment of Northåsvatnet (a land-locked fjord), Norway.** *Marine Pollution Bulletin* **13**:85-88.
{sewage; fjord; Norway; sediments}

Nordåsvanet is a land-locked anoxic fjord along the west coast of Norway which is used as a natural recipient of untreated domestic sewage. The study of four core sediments collected from the heavily polluted basin of the fjord reflects the enrichment of surface sediments by Fe, Mn, Cu, Zn and organic matter. This surface enrichment is entirely attributed to anthropogenic input.

Elkins, J. W., S. C. Wofsy, M. B. McElroy, and W. A. Kaplan (1981) **Nitrification and production of N_2O in the Potomac: evidence for variability.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients.* Humana Press, Clifton, New Jersey.

{nitrification; ammonia; sewage}

Extensive measurements were carried out during the summer of 1977 and 1978 to define concentrations of inorganic nitrogen, O_2 and N_2O in the Potomac River. The chemistry of the river varied significantly between 1977 and 1978, with nitrification rates slower near the city of Washington D.C. by more than a factor of 10 in 1978. The nitrification rate was inversely correlated with the rate of fresh water flow into the estuary. It appears that production of N_2O in 1978 occurred mainly as a by-product of nitrification. The quantity of N_2O released to the atmosphere represented approximately 0.3 percent of sewage nitrogen. Conversion was more efficient in the summer of 1977, about 1-5 percent, reflecting either additional mechanisms for production of N_2O or larger yields for gas production in nitrification.

Elmgren, R. (1989) **Man's impact on the ecosystem of the Baltic Sea: Energy flows today and at the turn of the century.** *Ambio* **18**:326-332.

{energy flow; eutrophication; phytoplankton; benthic; primary; secondary; fish; production; ecosystem}

The impact of man on the Baltic ecosystem in the 20th century is summarized by estimating changes in major energy flows, expressed as organic carbon. Recent eutrophication has increased pelagic primary production by an estimated 30-70% and sedimentation of organic carbon by 70-190%. Above the primary halocline, biomass and production of benthos have increased, while in the deep waters of the Baltic proper, oxygen deficiency has led to the loss of formerly important food chains over nearly 100 000 km^3 of bottom. The net result is an approximate doubling of macrobenthic production, but little increase in meiobenthic production. Zooplankton production is thought to have increased less than primary production, perhaps by about a quarter. Fish catches in the Baltic have increased more than tenfold, but this is considered to be due only partly to increased fishing effort and the near extermination of fish-eating Baltic seals, though hunting and pollution, are likely to be about equally important. Today, the Baltic fishery requires about 10% of the primary production in the Baltic to produce its catches, whereas the remnant seal population needs less than 0.1%. At the beginning of this century the fishery required about 1% and the marine mammals an estimated 5% of the primary production.

Emara, H. I., M. A. Shriadah, T. H. Moustafa, and M. S. El-Deek (1992) **Effects of sewage and industrial wastes on the chemical characteristics of the Eastern Harbour and El-Mex Bay waters of Alexandria, Egypt.** In: R. A. Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication*. Elsevier, Amsterdam.

{oxygen, chlorophyll}

Sea water samples were collected from the Eastern Harbour and El-Mex Bay during the period from November 1987 to January 1989. The concentrations of dissolved oxygen, hydrogen sulphide, inorganic phosphae, nitrate, nitrite, ammonia, chlorophyll a and oxidizable organic matter are scattered in the ranges (0.00-5.11 ml l^{-1}), (0.00-2.94 mg l^{-1}), (0.35-17.6 ug at l^{-1}) (0.00-103.5 ug at l^{-1}), (0.00-21.6 ug at l^{-1}), (0.10-88.0 ug at l^{-1}), (0.00-5.56 mg m^{-3}) and (0.10-13.8 mg O_2 l^{-1}) respectively.

In general, El-Mex Bay exhibited higher concentrations of nutrients and oxidizable organic matter, which reveal higher eutrophication levels than the Eastern Harbour. Chlorophyll values were low and similar for the surface water of both areas, while the bottom water of El-Mex Bay reflected slightly higher levels. Hydrogen sulphide concentrations showed wide variations, reflecting higher values for the Eastern Harbour (1.33 mg l^{-1}) compared with El-Mex Bay (0.98 mg l^{-1}). Hydrogren sulphide-ammonia concentrations showed an impressive relationship, with estimated ratios of H_2S/NHc of 1.7 and 1.03 for the surface water of the Eastern Harbour and El-Mex Bay respectively.

The N/P ratio reflects higher values for the surface and bottom waters of El-Mex Bay (10.2, 13.2) in comparison with the Eastern Harbour (7.0, 7.4), and the majority of the investigated areas seems to be P-limited. The estimated amount of oxygen present after complete oxidation of organic matter ranged from 50 to 55% throughout 1988, which is about 14% lower than the values recorded during the last ten years in El-Mex Bay.

Eng, C. T., J. N. Paw, and F. Y. Guarin (1989) **The environmental impact of aquaculture and the effects of pollution on coastal aquaculture development in Southeast Asia.** *Marine Pollution Bulletin* **20**:335-343.

{aquaculture; Asia}

Coastal aquaculture is a traditional practice in Southeast Asia. Accelerated development in the last three decades has created negative environmental impacts, such as extensive mangrove conversion to ponds, changes in hydrologic regimes in enclosed waters due to proliferation of aquaculture structures, and discharge of high levels of organic matter into coastal waters. Similarly, the increasing deterioration of coastal water quality resulting from the discharge of domestic, agricultural and industrial wastes into coastal waters has affected aquaculture production and profitability. Furthermore, the

increased frequency of red tides in the region has posed serious threats to coastal aquaculture, especially to mollusc cultivation. The introduction of management measures to mitigate deteriorating coastal water quality and the adverse environmental impacts of aquaculture development has now become a matter of urgency to the region.

Fabrikant, R. (1984) **The effect of sewage effluent on the population density and size of the clam *Parvilucina tenuisculpta*.** *Marine Pollution Bulletin* **15**:249-253.
{sewage; density; size; bivalves; *Parvilucina*; sediments; nitrogen; California}

Changes in the population density and size of the clam *Parvilucina tenuisculpta* were related to municipal waste effluent (in particular, organic nitrogen concentration) off the coast of Palos Verdes, California. Average clam size increased as sediment organic nitrogen concentration increased, but population density increased until organic nitrogen concentration reached a critical level when population density decreased dramatically. These effects were explained in terms of increased available nutrition (in the form of sediment organic nitrogen pollutants) enhancing both population and individual size growth. However, when a critical concentration of organic decomposition products was reached, population density decreased due to the toxicity of the released compounds. It is suggested that *Parvilucina tenuisculpta* would make a good bioindicator of organic enrichment pollution.

Faganeli, J. (1982) **Nutrient dynamics in the seawater column in the vicinity of Piran submarine sewage outfall.** *Marine Pollution Bulletin* **13**:61-66.
{nutrient; sewage; Adriatic; nitrogen; phosphorus}

Variations of nitrogen and phosphorus concentrations in the vicinity of Piran (North Adriatic) submarine sewage outfall were studies as well as the treatment plant operation. On the basis of the data it was concluded that the influence of the outfall to the nutrient level in that area is negligible. In comparison the data from the shallow organically polluted water in the inner part of the Bay of Kopper are reported.

Fanuko, N. (1984) **The influence of experimental sewage pollution on lagoon phytoplankton.** *Marine Pollution Bulletin* **15**:195-198.
{sewage; Yugoslavia; lagoon; phytoplankton; abundance; Adriatic; bloom}

In a sewage pollution experiment in the lagoon system at Strunjan, Yugoslavia, an artificially polluted lagoon showed significantly lower chlorophyll a biomass and cell density, and the relationship between these two variables was altered.

Faust, M. A. and R. J. Chrost (1981) **Phytosynthesis, extracellular release, and heterotrophy of dissolved organic matter in Rhode River estuarine plankton.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients*. Humana Press, Clifton, New Jersey.
{excretion; DOM; phytoplankton; primary production; bacteria}

Rates of phytoplankton photosynthesis, extracellular release of dissolved organic matter (DOM), and the assimilation of DOM by bacterioplankton during *in situ* incubation were measured in the Rhode River estuary. Phytoplankton photosynthesis was in the range of 3 to 147 ug C l^{-1} h^{-1}. The release of DOM appeared to be inversely related to the photosynthetic activity of phytoplankton. A large percentage of the total carbon (C) fixed was released as ^{14}C-DOM, ranging from 4 to 66 percent of the total. Ultrafiltration was used to fractionate the ^{14}C-DOM into size classes from less than 500 to 300,000 molecular weight (MW). Bacterioplankton readily assimilated a wide range of ^{14}C-DOM MW size fractions. Both photosynthesis and phosphorus uptake were higher in nanoplankton. A positive linear relationship existed between log surface to volume ratio and log phosphorus uptake per biomass of phytoplankton. Bacterioplankton assimilated phosphorus more rapidly than phytoplankton. The species composition of plankton populations also constantly changed. The ^{14}C-DOM represented only 0.4 to 2.3 percent of the total DOM in the Rhode River. Its quantity and quality appear to be determined by the changing phytoplantkon population with produces it, and the changing bacterioplankton population which uses it. Preliminary data such as these may yield important insight into changes occurring in metabolic patterns of brackish ecosystems due to biological enrichment with nutrients.

Ferraro, S. P., R. C. Swartz, F. A. Cole, and D. W. Schults (1991) **Temporal changes in the benthos along a pollution gradient: Discriminating the effects of natural phenomena from sewage-industrial wastewater effects.** *Estuarine, Coastal and Shelf Science* **33**:383-407.
{benthos; pollution; sewage; toxic; California; wastewater; sediment}

As pollution from the Los Angeles County Sanitation Districts (LACSD) outfalls decreased between 1980 and 1983, the macrobenthic community partially recovered and surficial (0-2 cm deep) sediment contamination and toxicity decreased at 60 m water depth along a pollution gradient from

the outfalls. Pollution from the LACSD outfalls continued to decrease but macrobenthic conditions and surficial sediment quality deteriorated 1 km, was unchanged 3 km, and improved 5-15 km from the LACSD outfalls between 1983 and 1986. The net effect of natural phenomena is indicated when ecosystem changes occur in the opposite directions. Our data suggest that the net effect of natural phenomena (e.g. winter storms, El Niño) on the benthos was greater than LACSD wastewater effects 1 km, about equal to LACSD wastewater effect 3 km, and less than the LASCD wastewater effects 5-15 km from the outfalls at the LASCD 1983-86 mass emission rate. Surficial sediment samples collected beyond the 1 km station from the LASCD outfalls probably represented » 3 years of natural+effluent particulates accumulation, and they were, therefore, better suited for detecting long-term trends than for testing short-term temporal variability in surficial sediments significantly increased between 1983 and 1986, probably primarily reflecting renewed wastewater effects near the outfalls and the effect of natural phenomena (e.g. storm-induced sediment transport or erosion) further from the outfalls. Since natural phenomena may have an effect on the benthos ≥ 3 years of LASCD wastewater effects, short-term benthic changes must be interpreted cautiously at the study site.

Fiedler, P. C. (1982) **Zooplankton avoidance and reduced grazing responses to *Gymnodinium splendens* (Dinophyceae).** *Limnology and Oceanography* **27**:961-965.
{zooplankton; red tide; production; grazing}

A dense subsurface layer of *Gymnodinium splendens*, a feature often observed in coastal waters off southern California was actively avoided by macrozooplankton. Filtration rates, measured by uptake of trace amounts of radiocarbon-labeled diatoms, and ingestion rates, measured by gut fullness, of some herbivorous species were significantly reduced within the layer. These behavioral responses may help explain the formation and persistence of dinoflagellate blooms such as red tides in coastal waters often dominated by diatoms with higher maximum growth rates.

Fleischer, S., S. Hamrin, T. Kindt, L. Rydberg, and L. Stibe (1987) **Coastal eutrophication in Sweden: Reducing nitrogen in land runoff.** *Ambio* **16**:246-251.
{nitrogen; Sweden; runoff}

Eutrophication caused by excess nitrogen and the resulting plankton blooms in Kattegat have led to oxygen deficits in the bottom waters. Regional input of nitrogen affects southern Kattegat. The interdisciplinary project "Land Use-Water Quality" has identified the main source and transport routes of nitrogen in the drainage basin (10 100 km^2) of Laholm Bay. Possible measures to decrease nitrogen loading in the coastal waters, such as increased cultivation of catch crops and increased spreading of manure in the springtime, are presented. A holistic approach includes measures that may also prove beneficial to a number of related agricultural problems, e.g. monotonous landscape (very few types of crops, decreasing grass- and wet-land areas), sensitivity to environmental catastrophes (atmospheric loading by radioactive materials or by chemicals), surplus production, and the threat to almost 200 wild plant species. In addition to direct agricultural measures, restoration of wetlands and streams is also necessary to reduce nitrogen losses to the coastal environment.

Fletcher, R. L., V. Cuomo, and I. Palomba (1990) **The "Green Tide" problem, with particular reference to the Venice Lagoon.** *British Phycological Journal* **25**:87.
{green tide; macroalgae; Venice Lagoon; sewage; nutrient}

The excessive growth of macroalgae is a well known consequence of the nutrient enrichment of coastal waters by increased levels of sewage discharge and agricultural "run-off". These growths are characteristically dominated by green algae, in particular species of *Enteromorpha* and *Ulva*, and are appropriately termed "Green Tides". Such growth weas particularly evident during the warm summer of 1989 in the shallow, muddy harbours of the Solent (south coast of England). Problems caused by these algal growths include the fouling of nets and dredges, changes in the community structure of sediment dwelling invertebrates and the excessive deposits of rotting driftweed on amenity beaches, requiring removal and disposal by local Councils. Nowhere is the problem of "Green Tides" more dramatically illustrated than in the Venice Lagoon, Northern Adriatic. The present paper considers the causes and consequences of these luxuriant macroalgal growths in the Lagoon, the biological characteristics of the dominant contributors and the presently used methods of removal, treatment and utilization.

Foster, P. (1984) **Nutrient distributions in the winter regime of the Northern Irish Sea.** *Marine Environmental Research* **13**:81-95.
{nutrient; Irish Sea; nitrogen}

Quasi-synoptic distribution of salinity and the concentrations of dissolved inorganic nutrients in the winter regime of the Northern Irish Sea are presented. Salinity to nutrient regression analyses and the distributions of nutrient ratios show that the characteristics of Atlantic water are variously modified during their northward passage through the Irish Sea. Inherently different chemical characteristics of the fresh water sources discharging

into the Northern Irish Sea generate a conglomeration of water types in the area. Marine waters along the Irish coast are relatively enriched in silicon, while waters adjacent to the eastern coastal boundary are relatively enriched by anthropogenic nitrogen sources. Possible implications of the spatial dichotomy in nutrient status for the seasonal production cycle in the northern Irish Sea are considered.

Fransz, H. G. and J. H. G. Verhagen (1985) **Modelling research on the production cycle of phytoplankton in the southern bight of the North Sea in relation to riverborne nutrient loads.** *Netherlands Journal of Sea Research* **19**:241-250.
{modelling; phytoplankton; production; nutrient; North Sea}

The physio-chemical and biological composition of North Sea water off the Dutch coast is influenced by various factors including meteorological conditions, wind and tide induced flows and mixing, river pollution loads, waste loads and various physical, chemical and biological processes. The long term variations (> ~ 1 month) of the biological composition are mainly caused by fluctuations in meteorological conditions and concentrations of nutrients for algae.

The loads of phosphorus and nitrogen compounds on the North Sea have increased significantly since the early 20th century. Especially the discharge of phosphorus (P) and nitrogen (N) transported by the river Rhine has increased about sixfold since 1930. The nutrient rich river water originating from the rivers Scheldt, Meuse and Rhine, mixes with sea water in such a way that 50% of the river discharge is transported in a 15 km wide strip along the Dutch and Belgian coast. Especially in this coastal area, the increase in nutrient loads has had a marked influence on the nutrient concentrations. In fact, the increase in N and P and the essentially constant discharge of reactive silicate (Si) caused a change in nutrient, first depleted by phytoplankton, from N or P some 50 years ago to Si nowadays.

The question, to what extent the increase in nutrient enrichment has given rise to enhanced phytoplankton growth, or to changes in species composition, is difficult to answer because of a lack of reliable data from the past. Nevertheless it is conceivable that at present primary productivity may occasionally be higher than in the past. The upper limit to the recurrent diatom blooms in Dutch coastal waters is set by the amount of available silicate. An increase in the upper limit is not to be expected due to the constancy of the Si-load during the last 50 years. Some flagellate species, however, appear to be phosphorus limited in spring and locally dominate diatoms. Nitrogen compounds maintain low concentrations throughout the summer. Therefore, it is conceivable that the abundance of the specific flagellate species is closely related to the riverborne P- and N-loads.

The research as described in this paper intends to simulate the phytoplankton biomass and composition in relation to meteorological and hydrophysical conditions, nutrient loads and zooplankton biomass. It can be considered as a theoretical contribution towards a better understanding of the production and eutrophication processes in this polluted and exploited part of North Sea.

Fraser, T. H. and W. H. Wilcox (1981) **Enrichment of a subtropical estuary with nitrogen, phosphorus and silica.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients*. Humana Press, Clifton, New Jersey.
{enrichment; nitrogen; phosphorus; silica; estuary; phytoplankton}

Seasonal pulses of nutrients are delivered to Charlotte Harbor from the Peace River and other tributaries. Greatest loads occur during the summer wet season. Phosphate and nitrate values are much higher in the Peace River than in adjacent tributaries while ammonium and silica are similar among the streams.

Phosphate dilution curves in the estuary suggest that changing concentrations along the chloride gradient are the result of mixing processes. Inorganic nitrogen and silica dilution curves suggest non-conservative processes are occurring, since their concentrations decrease faster along the chloride gradient than can be explained by dilution alone. Thus, both inorganic nitrogen and silica could become limiting factors in different parts of Charlotte Harbor during portions of the annual cycle, while phosphorus is always abundant.

Phytoplankton populations respond positively to seasonal pulses of nutrients with higher productivity occurring during or just after high river flow. Productivity increases from the lower harbor to near the river mouth in all seasons. General population levels and productivity are similar to other Florida estuaries, with diatoms dominating the phytoplankton (blue-green algae less than 1 percent) community even with the increased nutrient levels.

Frid, C. L. J. and T. S. Mercer (1989) **Environmental monitoring of caged fish farming in macrotidal environments.** *Marine Pollution Bulletin* **20**:379-383.
{fish farming; benthos; sedimentation}

Recent years have seen considerable expansion in fish farming using cages. These have until recently been located in the sheltered and low current environments of sea lochs and fjords. Significant benthic enrichment is known to occur at these sites, but the effects are highly localized. Fish farm

development is now occurring in areas with strong tidal flows. The sitting of caged fish farming in macro-tidal environments may reduce the environmental impact of the industry on benthic communities at the farm site. However there exists the potential for accumulation of farm wastes in nearby sedimentary sinks. Additionally the longer residence time of the wastes in the water column has the potential, especially in regions with already high nutrient loadings and/or long flushing times, to lead to stimulation of phytoplankton blooms. Environmental monitoring of such developments therefore needs to consider these addition effects.

Friligos, N. (1981) **Enrichment by inorganic nutrients and oxygen utilization rates in Elefsis Bay (1973-1976).** *Marine Pollution Bulletin* **12**:431-436.
{nutrients; oxygen; Elefsis Bay; anoxic}

This paper concerns the enrichment by nutrients and the oxygen utilization rates of an intermittently anoxic basin. The concentration of nutrients and dissolved oxygen have been determined during seasonal surveys of water characteristics. The oxygen utilization rates ranged between 1.3 and 1.8 ml l^{-1} $month^{-1}$ from March to June and were considerably higher than those reported for oceanic waters. The nutrients enrichment appears to be considerably influenced by eutrophication and human activity. During anoxic conditions in summer, the mineralization of organic matter was associated with consequent accumulation of enormous amounts of nitrogen (ammonia), phosphates and silicates. Nutrient ratios underwent great fluctuation mainly due to anoxic conditions.

Friligos, N. (1982) **Enrichment of inorganic nutrients in the inner Saronikos Gulf (1973-1976).** *Marine Pollution Bulletin* **13**:154-158.
{nutrients; Saronikos Gulf; Greece; nitrogen; phosphorus}

This paper is concerned with the enrichment of inorganic nutrients in the Inner Saronikos Gulf near the Athens sewage outfall. This Inner Gulf tends to accumulate nutrients above the background level, expecially ammonia which was about four times more than the background value. Comparison of nutrient enrichment was made between the Inner Gulf and Elefsis Bay. It was found that Elefsis Bay contained considerably more nutrients than the Inner Gulf. This was mainly due to the different sources of nutrients as well as morphology of each area and the circulation of the waters.

Friligos, N. (1985) **Compensation effect of phytoplankton on nutrients from a sewage outfall in summer.** *Hydrobiologia* **126**:53-58.
{sewage; nutrients; phytoplankton; abundance}

This paper investigates the relationship between nutrients, chlorophyll *a* and physical variables in the upper Saronikos Gulf, an oligotrophic marine environment south of the Greater Athens Metropolitan Area. Phosphate, silicate, ammonia, nitrite, nitrate, salinity and dissolved oxygen were determined at eight stations on 9 occasions during summer 1982. A thermocline led to the stratification of the water column and the pycnocline was related to the thermocline. The values of oxygen were more or less normal. The eutrophication of seawater in the vicinity of the sewage outfall was demonstrated by surface levels of chlorophyll *a* being forty to two hundred times above background. This parameter provides evidence for a high phytoplankton standing stock. However, there were no appreciable differences between the nutrients in the outfall area and those in the background. This suggests rapid uptake of nutrients and/or effective dispersal from the outfall.

Friligos, N. (1985) **Impact on phytoplankton populations of sewage discharges in the Saronikos Gulf (West Aegean).** *Water Research* **19**:1107-1118.
{sewage; nutrients; phytoplankton; standing stock}

Temperature, salinity and concentrations of dissolved oxygen, nutrients, chlorophyll *a*, particulate carbon and nitrogen concentrations in sea water near the Keratsini sewage outfall are reported. Suggestions are made on the proposed length of the outfall diffuse and the extent of the sewage treatment. Eutrophication in the area around the outfall is demonstrated by enhanced chlorophyll *a*, particulate carbon and particulate nitrogen concentrations, for they provided evidence for high phytoplantkon standing stock. However no appreciable differences in the inorganic nutrient levels between the outfall area and the normal background were observed. This suggests rapid uptake of nutrients and/or effective dispersal from the outfall. The study indicates that in the case of oligotrophic waters and in the absence of the dissolved oxygen depletion, primary treatment may be preferable to secondary treatment.

Friligos, N. (1989) **Nutrient status on a silled embayment in the Ionian Sea (Gulf of Patras).** *Toxicological and Environmental Chemistry* **20-21**:21-27.
{nutrient; Gulf of Patras; Mediterranean; nitrate; silicate}

This paper is concerned with the enrichment of inorganic nutrients in the Patraikos Fulg. The Gulf of Patras is a silled embayment opening into the Ionian Sea on the west, and through the straits of Rio onto the Gulf of Corinth, on the east. The latter communicates though the Corinth canal with the Aegean Sea. Results of the Patraikos Gulf show only slighter greater concentrations of

nutrients than background, in particular nitrate and silicate. Also a comparison is made with the nutrient concentrations in polluted coastal gulfs of the Aegean. The different nutrient levels are due to the different sources of nutrients as well as the morphology and the circulation of the waters.

Gast, V. (1985) **Bacteria as a food source for microzooplankton in the Schlei Fjord and Baltic Sea with special reference to ciliates.** *Marine Ecology Progress Series* **22**:107-120.
{bacteria; microzooplankton; Baltic; ciliates; *Uronema*}

In situ vestigations revealed that number and biomass of microzooplankton increased with eutrophication along the length of the Schlei Fjord (FRG). The same observation was made for total bacterial numbers and biomass. Microzooplankton of the Schlei and total bacterial numbers showed a minimum in winter and major periods of development in late summer/autumn and spring. Usually the microzooplankton biomass in the Schlei was greater than the bacterial biomass. In contrast, the bacterial biomass for 5 of 6 stations in the Baltic Sea surpassed that of the microzooplankton during the summer. Number and biomass of microzooplankton in both bodies of water can mostly be attributed to protozoans of the 3 to 30 um fraction. Determined with the aid of radioactivity labeled bacterial cultures, the filtration rate of 'natural' microzooplankton populations exhibited a distinct dependency on microzooplanktonic biomass and water temperature. In March 1982 microzooplankton populations in the eutrophic Schlei Fjord filtered 5 to 58 % of the water per day. In the central Baltic Sea in August 1982 the rate was 70 % d^{-1} during the late stage of a decaying blue-green algae bloom. Laboratory experiments with *Uronema marinum* clearly showed that bacteria concentration exert a considerable imjluence on the development of ciliates. Only when a limiting concentration of about 1 x 10^6 bacteria ml^{-1} is attained does a proliferation of ciliates commence. Hence, bacteria can represent an important food source for microzooplankton, especially in biotopes with a high bacterial number and biomass.

Gerlach, S. A. (1988) **Eutrophication of Kieler Bucht.** *Kieler Meeresforschungen, Sonderheft* **6**:54-63.
{Baltic; nitrogen; phosphorus; nutrients}

Prior to 1975, average winter water nutrient concentrations at station Bokniseck in Kieler Bucht (Western Baltic) were 1.23 $mmol/m^3$ total phosphorus and 12.7 $mmol/m^3$ dissolved inorganic nitrogen. Nitrogen concentrations did not change until 1984. The mean of a few total phosphorus data from 1980-1984 is 1.94 $mmol/m^3$. Mean nutrient concentrations in the area between the southern entrance of the Great Belt and Darss Sill increased between 1975 and 1984 from 0.8 to 1.6 $mmol/m^3$ total phosphorus and from about 6 to 10 $mmol/m^3$ inorganic nitrogen. Comparatively higher nutrient concentrations at Bokniseck station are correlated to higher salinity. However, no data are available on nutrient imports into Kieler Bucht with saline deep water. Unchanged nutrient concentrations at Bokniseck prior to 1975 are an argument against any dominant influence of anthropogenic inputs which until 1974 increased to annually 1500 t of total phosphorus and 12 700 t of total nitrogen, plus 5000 t of nitrogen from the atmosphere. Higher phosphorus concentrations 1980-1984 are correlated to severe oxygen deficiency in the deep water. Mobilization of phosphorus from sediments becoming anoxic could be the reason. Biota could be such sources and sinks of nutrients that influence the nutrient balance of Kieler Bucht. To sum up, there are several processes besides anthropogenic inputs that influence nutrient concentrations in water. An assessment of winter water nutrient concentrations alone is no adequate tool for the evaluation of the effects of anthropogenic nutrient inputs via rivers, sewage, land runoff, groundwater and from the atmosphere.

Gerlach, S. A. (1990) **Nitrogen, phosphorus, plankton and oxygen deficiency in the German Bight and in the Kiel Bay.** *Kieler Meeresforschungen, Sonderheft* **7**:1-341.
{German Bight; Kiel Bay; Baltic; phosphate; nitrate; nitrite; ammonium; nitrogen; phosphorus; nutrients; oxygen; hydrogen sulphide; bloom; phytoplankton; biomass; abundance; sediments; turbidity; atmosphere; review; assemblage}
No abstract

Giesen, W. B. J. T., M. M. v. Katwijk, and C. d. Hartog (1990) **Eelgrass condition and turbidity in the Dutch Wadden Sea.** *Aquatic Botany* **37**:71-85.
{eelgrass; *Zostera*; Dutch Wadden Sea; turbidity; submerged vegetation; light}

Populations of eelgrass (*Zostera marina* L.) in the Dutch Wadden Sea have witnessed two major phases of decline this century. The first was the total disappearance of sublittoral beds during the wasting disease epidemic of the early 1930s, and their subsequent failure to recover. The second was the gradual disappearace of littoral eelgrass after the mid-1960s. It is argued here that both the lack of recovery of the sublittoral beds, and the disappearance of the littoral population, may have been effected, to a large extent, by changes in turbidity. The increasing turbidity can be linked

with progressively increasing eutrophication as well as deposit extracting and dredging activities.

Gieskes, W. W. C. and G. W. Kraay (1977) **Continuous plankton records: Changes in the plankton of the North Sea and its eutrophic southern bight from 1948 to 1975.** *Netherlands Journal of Sea Research* **11**:334-364.
{plankton; eutrophication}
No abstract

Gilmartin, M. and N. Revelante (1980) **Nutrient input and the summer nanoplankton bloom in the Northern Adriatic Sea.** *P.S.Z.N.I: Marine Ecology* **1**:169-180.
{nutrient; phytoplankton; nanoplankton; microplankton; eutrophicated}

A four-year oceanographic data set from the Northern Adriatic Sea identified the factors favoring development of the nanoplankton or microplankton components of the phytoplankton crop. Latitudinally atypical summer nanoplankton blooms, perhaps of recent origin, develop under vertically stratified conditions in the presence of high nutrient concentrations (including silicates). Including the summer blooms, the nanoplankton were responsible for more than half the total phytoplankton production about 90% of the time. No single mechanism governed phytoplankton cell size or size succession, but rather a number of mechanisms which were not mutually exclusive.

Giovanardi, F. and E. Tromellini (1992) **Statistical assessment of trophic conditions. Application of the OECD methodology to the marine environment.** In: R. A. Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication*. Elsevier, Amsterdam.
{chlorophyll, phosphorus, Adriatic Sea}

In order to study the time-space variability of the Po-Adriatic system, a multivariate statistical method has been used. This approach allows the determination of the source of variability and the parameters that mainly maintain the system in a perturbed state. The OECD classification of trophic state for inland waters has therefore been applied to the marine environment. This trophic classification criterion has been interpreted in terms of probability of assignment to the different trophic categories. Functional inter-relationships between total phosphorus (TP) and trophic indicators (chlorophyll and peak chlorophyll) have been determined. Based on the regression of TP versus chlorophyll and on the log-normal distribution of the chlorophyll data, an empirical model (Monte Carlo method) has been developed, thus determing the probabilities associated with the trophic level in the Emilia-Romagna coastal waters. The application of this model is quite useful for testing the environmental consequences depending on different interventions for phosphorus loading reductions.

Goldman, C. R. (1988) **Primary productivity, nutrients, and transparency during the early onset of eutrophication in ultra-oligotrophic Lake Tahoe, California-Nevada.** *Limnology and Oceanography* **33**:1321-1333.
{primary productivity; transparency; turbidity}

For more than half a century, the trophic status of water bodies has been of interest to limnologists and oceanographers alike. This report demonstrates the close, inverse relationship between ^{14}C-estimated primary productivity and transparency during the earliest stages of cultural eutrophication. As the population in the Tahoe basin has rapidly increased, Lake Tahoe has been characterized by an increase in primary productivity that has averaged 5.6% yr^{-1} for the last 28 yr. There has been a concomitant decline in transparency of 0.37 m yr^{-1}. During winter months when transparency is highest, the average annual loss has been slightly greater (0.40 m yr^{-1}). The average annual Secchi depth has decreased by 7 m during the last 19 yr of intensive monitoring. There has also been a significant increase in the light extinction coefficient. Photosynthetic efficiency has increased while there has been a gradual shrinkage of the euphotic zone. During the same period the total NO_3^--N content of the lake has increased significantly, but total P content has not. Lake Tahoe primary production has become increasingly P sensitive during the last decade as N has accumulated in the system. A gradual increase in the N:P may prove to be a general evolutionary characteristic of oligotrophic lakes during the earliest stages of eutrophication. The importance of variability is particularly evident from this study.

Goldman, J. C. (1976) **Identification of nitrogen as a growth-limiting nutrient in wastewaters and coastal marine waters through continuous culture algal assays.** *Water Research* **10**:97-104.
{wastewater; nitrogen; nutrients; phytoplankton; assay; N/P ratio}

Two series of continuous culture algal assays conducted in 1973 and 1974, totaling 63 experiments, were performed on mixtures of seawater and wastewater - both treated and untreated - from five locations along the coasts of MA and RI. The results conclusively show that nitrogen was the growth-limiting nutrient in these wastewaters and in coastal marine environments receiving such wastes. There was a linear relationship between total inorganic nitrogen (ΣN)

in the influent and particulate nitrogen (PN) representing algal biomass up to a ΣN concentration of about 10 mg l^{-1}. In addition, the N:P ratios in the test alga, *Phaeodactylum tricornutum*, varied between 10 and 20 (by atoms), whereas the N:P ratios in the wastewater-seawter mixtures were between 4 and 12, thus providing additional evidence that nitrogen was limiting. Enrichment with nitrogen and/or phosphorus to span a range of N:P ratios from 3.9 to 20 resulted in a linear response in PN concentration to (sum)N additions. Additions of P had no effect on algal growth. Removal of detergent-P in communities practicing marine waste disposal will hence have little impact on the control of eutrophication in coastal waters.

Goldman, J. C., Y. Azov, C. B. Riley, and M. D. Dennett (1982) **The effect of pH in intensive microalgal cultures. I. Biomass regulation.** *Journal of Experimental Marine Biology and Ecology* **57**:1-13.
{pH; phytoplankton; biomass; *Phaeodactylum*; *Dunaliella*; carbon}

Two freshwater and two marine algal species were grown in intensive continuous cultures at a fixed dilution rate of 0.5 day^{-1}, but a varying pH levels in the range 7.6 to 10.6. Both freshwater species *Scenedesmus obliquus* (Turp.) Kutz. and *Chlorella vulgaris* Beij., grew up in pH 10.6 although *C. vulgaris* was more adversely affected by alkaline pH than was *Scenedesmus obliquus* . Of the marine species, *Phaeodactylum tricornutum* (TFX-1) Bohlin was hardly affected by varying pH up to its maximum tolerable level of 10.3, whereas growth of *Dunaliella tertiolecta* (Dun) Butcher was adversely affected by increasing pH and ceased when the pH exceeded 9.3. These results are consistent with the general observations that many marine species cannot tolerate alkaline pH values much above 9.5. Moreover, the unique ability of *Phaeodactylum tricornutum* to grow at pH > 10 probably is a major factor contributing to its well documented success in large-scale outdoor cultures that are poorly buffered. It is difficult to separate metabolic from purely chemical factors that influence the pH tolerance limits of the individual species. The lower pH limits were, however, distinctly controlled by the production of alkalinity concomitant with NO_3^- uptake, whereas the upper pH limits in the case of *Scenedesmus obliquus* and *Phaeodactylum tricornutum* seemed to be regulated primarily by metabolic control. In no case was the availability of inorganic carbon an influencing factor in setting the maximum attained pH.

Goldman, J. C., C. B. Riley, and M. R. Dennett (1982) **The effect of pH in intensive microalgal cultures. II. Species competition.** *Journal of Experimental Marine Biology and Ecology* **57**:15-24.
{pH; compsitition; *Phaeodactylum*; *Dunaliella*; phytoplankton}

The results of a series of competition experiments between the chlorophyte *Dunaliella tertiolecta* (Dun) Butcher and the diatom *Phaeodactylum tricornutum* (TFX-1) Bohlin demonstrate conclusively that *Phaeodactylum tricornutum* dominates in intensive marine cultures when the pH rises above ≈10. This dominance results because of the diatom's unique ability among marine species to tolerate alkaline conditions. When the pH is regulated both freshwater and marine algae, once firmly established in culture at their respective pH optima, can resist invasion from competing species. Hence, pH control may be a method for maintaining species other than *P. tricornutum* in mass culture. When *Dunaliella tertiolecta*, however, is grown under even slight pH stress it becomes susceptible to invasion by *Phaeodactylum tricornutum*. This susceptibility to takeover by *P. tricornutum* increases with increasing pH. In contrast, the freshwater chlorophyte *Chlorella vulgaris* Beji., which also is sensitive to increasing pH, is capable of remaining dominant at any pH within its tolerance range when invaded by the pH-insensitive chlorophyte, *Scenedesmus obliquus* (Turp.) Kurz. Although allelopathic interactions may be responsible for the success of *Chlorella vulgaris* under seemingly stressful conditions, the success of *Phaeodactylum tricornutum* at increasingly higher pH seems to be related primarily to the alga's pH tolerance characteristics and not to any chemical interactions with competing species.

Gowen, R. J. and N. B. Bradbury (1987) **The ecological impact of salmonid farming in coastal waters: A review.** *Oceanography and Marine Biology: Annual Review* **25**:563-575.
{fish farming; organic enrichment; sediments; review}
No abstract

Goldman, C. R. (1988) **Primary productivity, nutrients, and transparency during the early onset of eutrophication in ultra-oligotrophic Lake Tahoe, California-Nevada.** *Limnology and Oceanography* **33**:1321-1333.
{primary productivity; transparency; turbidity}

For more than half a century, the trophic status of water bodies has been of interest to limnologists and oceanographers alike. This report demonstrates the close, inverse relationship between ^{14}C-estimated primary productivity and transparency during the earliest stages of cultural eutrophication. As the population in the Tahoe basin has rapidly increased, Lake Tahoe has been characterized by an

increase in primary productivity that has averaged 5.6% yr^{-1} for the last 28 yr. There has been a concomitant decline in transparency of 0.37 m yr^{-1}. During winter months when transparency is highest, the average annual loss has been slightly greater (0.40 m yr^{-1}). The average annual Secchi depth has decreased by 7 m during the last 19 yr of intensive monitoring. There has also been a significant increase in the light extinction coefficient. Photosynthetic efficiency has increased while there has been a gradual shrinkage of the euphotic zone. During the same period the total NO_3^--N content of the lake has increased significantly, but total P content has not. Lake Tahoe primary production has become increasingly P sensitive during the last decade as N has accumulated in the system. A gradual increase in the N:P may prove to be a general evolutionary characteristic of oligotrophic lakes during the earliest stages of eutrophication. The importance of variability is particularly evident from this study.

Gowen, R. J., P. Tett, and K. J. Jones (1992) **Predicting marine eutrophication: the yield of chlorophyll from nitrogen in Scottish coastal waters.** *Marine Ecology Progress Series* **85**:153-161.
{phytoplankton; chlorophyll; prediction; model; Scottish water; nitrogen; nitrite; nitrate}

There is perceived to be a problem of eutrophication in European marine coastal waters and hence a need to predict the response in terms of enhanced biomass of phytoplankton resulting from the input of anthropogenic nitrogen. This response was investigated indirectly by studying the relationship between nitrate and phytoplankton chlorophyll concentrations in waters of the Scottish west coast. Two-thirds of the 60 data sets analyzed gave significant inverse regression of chlorophyll on nitrate concentration. This result is explained by interpreting synoptic data as representing variation in time, with nitrate decreasing as a result of its assimilation by phytoplankton and conversion into chlorophyll-containing biomass. Thus the absolute value of the slope of each significant regression estimates the yield (q) of chlorophyll from nitrate and, indeed, from any form of nitrogen assimilable by microalgae. The median value for q was 1.05 mg chl $(\text{mmol N})^{-1}$; the range from 0.25 to 4.4 encompassed 95% of values. Some, but not all, of the variation in q could be explained by error in individual estimates due to chemical-analytical and sampling errors or to inhomogeneities in each sampled phytoplankton population. The remaining variation in q included a seasonal trend, which might have resulted from changes in phytoplankton species composition, nutrient limitation status, or the balance between anthropogenic and heterotrophic partitioning of nitrogen. It is suggested that an appropriate value of q can be used to predict the potential maximum increase in phytoplankton which would result from a given anthropogenic nitrogen discharge. The sensitivity of such predictions to error in determination of q is discussed, and the values obtained for q compared with observations in algal culture and mesocosms.

Granéli, E. (1981) **Bioassay experiments in the Falsterbo Channel- nutrients added daily.** *Kieler Meeresforschungen, Sonderheft* **5**:82-90.
{bioassay; Baltic; nutrients; phytoplankton; primary production; composition}

In situ enrichment bioassays were performed during the summers of 1978 and 1979 in the Falsterbo Channel, south Baltic Sea. Phosphorus and/or nitrogen was added daily for up to two weeks to 200 l polyethylene bags with unfiltered surface water. Additions of nitrogen or nitrogen plus phosphorus invariably increased the biomass and ^{14}C fixation of phytoplankton. Phosphorus additions had no such effects. Phytoplankton species which reacted most strongly to the enrichment were *Aphanotheca* sp., *Nodularia spumigena*, *Skeletonema costatum*, *Nitzschia closterium*, *Chaetoceros wighami* and *Oocystis* sp. The mean C/Chl a quotient was around 70 for chlorophyll a values below 6 mg m^{-3} but decreased to about 30 for chlorophyll a values above 10.

Granéli, E., P. Carlsson, P. Olsson, B. Sundström, W. Granéli, and O. Lindahl (1989) **From anoxia to fish poisoning: The last ten years of phytoplankton blooms in Swedish marine waters.** In: E. M. Cosper, V. M. Bricelj and E. J. Carpenter (ed.) *Novel Phytoplankton Blooms; Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms.* Springer-Verlag, Berlin.
{phytoplankton; bloom; Sweden; effects}
No abtract

Granéli, E., W. Graneli, and L. Rydberg (1986) **Nutrient limitation at the ecosystem and the phytoplankton community level in the Laholm Bay, south-east Kattegat.** *Ophelia* **26**:181-194.
{nutrient; phytoplankton; abundance; nitrogen; phosphorus}

Nutrient enrichment experiments in the laboratory with surface waters from the Laholm Bay, indicate that phytoplankton is nitrogen-limited. Phosphorus addition to phytoplankton samples rarely caused a biomass increase in aggreement with negligible alkaline phosphatases activity. Usually the inorganic-N/P quotient in surface waters was also below the Redfield ratio (16:1, by atoms), indicating potential nitrogen limitation. The supply ratio (runoff and deep water) of inorganic nutrients

to the surface water of the bay was 23N: 1P for March-October and thus indicates a mean shortage of phosphate. During summer when river runoff is small, the low N/P-ratio in the deep water (10:1) which is mixed into surface water suggests nitrogen limitation, in aggreement with the enrichment experiments. Benthic denitrification and the low N/P-ratio of zooplankton excretion may make regenerated primary production nitrogen-limited. The recent suggestion by Smith (1984), that marine ecosystems, like lakes, are phosphorus-limited because any nitrogen shortage is alleviated through nitrogen fixation, does not apply to the bay itself, where water exchange is too rapid to allow for an adjustment of the N/P-supply quotient.

Granéli, E., H. Persson, and L. Edler (1986) **Connection between trace metals, chelators and red tide blooms in the Laholm Bay, SE Kattegat - An experimental approach.** *Marine Environmental Research* **18**:61 - 78.
{copper; dinoflagellates; species composition}

The influence of the trace metals, copper, aluminum and iron, and of the strong complexing agents, EDTA and NTA, on phytoplankton growth in water from a brackish water bay was investigated through bioassay experiments. A diatom (*Skeletonema costatum* (Grev.) Clev) and a dinoflagellate (*Prorocentrum minimum* (Pav.) J. Schiller) were used as test organisms. The growth of both phytoplankton species was strongly inhibited by copper. This inhibition was generally inhibited by EDTA and NTA. Both phytoplankton species were considerably less inhibited by aluminum than by copper at the same metal concentration. While *S. costatum* responded to copper and chelator additions in the same way in sea water samples from different seasons, the growth of *P. minimum* exhibited pronounced seasonal variation. Other parameters than the values of pCu must be considered in order to account for the experimental results. This work supports the theory that alterations in contents of trace metals and natural chelators in seawater are important factors behind shifts in phytoplankton species composition.

Granéli, E., S. Schulz, U. Schiewer, D. Gedziorwska, W. Kaiser, and M. Plinski (1988) **Is the same nutrient limiting potential phytoplankton biomass formation in different coastal areas of the Southern Baltic?** *Kieler Meeresforschungen, Sonderheft* **6**:191-202.
{phytoplankton; biomass; Baltic; nutrients; chlorophyll}

During the winter 1984 and summer 1985, a series of limiting nutrient experiments (enrichment tests) were performed with coastal Baltic water by scientists from the German Democratic Republic, Poland and Sweden. The water used for the experiments was collected outside Warnemünde (GDR); Rostock (GDR), Sopot (P) and Falsterbo (S). The bioassays were performed under similar laboratory conditions. Nitrogen was the potentially most limiting nutrient for phytoplankton biomass formation in coastal water from Rostock, Sopot and Falsterbo. During winter, before the spring phytoplankton bloom had started, phosphorus was the "most limiting" nutrient in the Rostock area. For the Warnemünde area, no clear limiting nutrient was found, except during July 1984, when nitrogen addition doubled the phytoplankton biomass. The lowest algal standing stocks were found for Warnemünde and Flasterbo, followed by Sopot. Extremely high chlorophyll-*a* values were found outside Rostock. Our results show that these coastal areas in the southern Baltic do not differ essentially from each other with respect to the most limiting nutrient (*sensu* Liebig), although their nutrient levels are quite different. Nutrient limitation experiments are discussed in the context of assumed eutrophication of the Baltic.

Granéli, E. and K. Sundbäck (1985) **The response of planktonic and microbenthic algal assemblages to nutrient enrichment in shallow coastal waters, Southwest Sweden.** *Journal of Experimental Marine Biology and Ecology* **85**:253-268.
{nutrient; nitrogen; phosphorus; microalgae; phytoplankton; production; biomass}

Field and laboratory nutrient (nitrogen and phosphorus) enrichment studies were performed among natural phytoplankton and microphytobenthic assemblages from the brackish water Öresund, S.W. Sweden. The response of algae from a low-nutrient area (Falsterbo Canal) was compared to that of algae from a polluted, nutrient-rich area (Lomma Bay).

The biomass (measured as chlorophyll *a*) of both phytoplankton and microphytobenthos from the Falsterbo Canal increased after the addition of nitrogen. Phytoplankton growth was stimulated by the addition of phosphorus to the nitrogen-rich water of the polluted Lomma Bay. Sediment chlorophyll *a* showed no significant increase after the addition of nutrients in the Lomma Bay. In containers without sediment, phytoplankton uptake was calculated to account for ≈ 90 % of the disappearance of inorganic fixed nitrogen from the water. In the sediment containers the microphytobenthos was estimated to account for ≈ 20% of the nitrogen uptake. The rest was presumably lost mainly through denitrification.

When containers with microphytobenthos from Lomma Bay were kept in the dark, phosphorus was released at a rate of up to ≈ 180 uM m^{-2} day^{-1}. We suggest that by producing oxygen microbenthic

algae keep the sediment surface oxygenated thereby decreasing phosphorus transport from the sediment to the overlying water.

Granéli, E., B. Sundström, L. Edler, and D. M. Anderson (ed.) (1990) ***Toxic Marine Phytoplankton (Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton, Lund, Sweden, 26-30 June, 1989).*** Elsevier, New York.
No abstract

Granéli, E., K. Wallström, U. Larsson, W. Granéli, and R. Elmgren (1990) **Nutrient limitation of primary production in the Baltic Sea area.** *Ambio* **19**:142-151.
{Baltic; enrichment; primary production; nitrogen; phosphorus; nutrient; limitation}

In the Baltic Sea area, including the Kattegat, the external N/P loading ratios are generally well above the 16:1 Redfield ratio for all subareas (the Bothnian Bay, The Bothnian Sea, the Baltic proper and the Kattegat). During winter, the inorganic N/P ratio in surface waters varies. Appreciably higher values than the loading ratio are found for the northernmost basin, the low-saline Bothnian Bay, while lower values than the loading ratio are found for the Baltic proper and the Kattegat. Nutrient enrichment tests indicate general N limitation in the Baltic proper and the Kattegat, although stimulation of algal growth after P enrichment has been found in the Baltic proper during summer blooms of blue-green algae. Blooms of blue-green algae are common in the Baltic proper but hardly ever occur in the Bothnian Bay and the Kattegat. This has been the case for the last century, indicating natural summer N limitation. Full-scale experimental manipulation of the external N/P loading ratio has been carried out in the Himmerfjärdan basin, south of Stockholm. Results suggest nitrogen as the most limiting nutrient in coastal areas of Baltic proper, uninfluenced by direct nutrient discharges. The knowledge of the effects of altered external nutrient supplies for nutrient limitation in the Baltic Sea system as a whole is too limited to allow for reliable predictions. However, the Baltic Sea may have developed towards a more pronounced N limitation due to a twofold historic increase in P supply relative to N supply. At present, the situation may be reversed as N supply is probably increasing more rapidly than P supply. Management of the Baltic Sea area cannot be based on removal of either N or P in sewage, but must take both elements into consideration, as well as differences between sub-basin and between polluted and offshore areas.

Grassle, J. F., J. P. Grassle, L. S. Brown-Leger, R. F. Petrecca, and N. J. Copley (1985) **Subtidal macrobenthos of Narragansett Bay. Field and mesocosm studies of the effects of eutrophication and organic input on benthic population.** In: J. S. Gray and M. E. Christiansen (ed.) *Marine Biology of Polar Regions and Effects of Stress on Marine Organisms*. John Wiley & Sons, New York.
{MERL; benthic; macrofauna; Narragansett Bay; organic; eutrophication; population}

Benthic macrofaunal population in Narragansett Bay and replicate mesocosms representative of portions of Narragansett Bay respond rapidly to variation in food supply. During five years of sampling sharp increases in August mortalities occur when estimated carbon demands for benthic respiration exceed the amount of organic carbon reaching the bottom. Rapid recovery following these periods of high mortality indicate a very resilient community. Benthic population densities in mesocosms rapidly increase in response to external additions of plant material, and to within system increases in productivity from nutrient additions. Larval immigration and predation are also important in determining population densities in the experimental systems but these variables are less easy to control and the effects are less obvious.

Grassle, J. P. and J. F. Grassle (1984) **The utility of studying the effects of pollutants on single species populations in benthos of mesocosms and coastal ecosystems.** In: H. H. White (ed.) *Concepts in Marine Pollution Measurements*. Maryland Sea Grant, College Park.
{polychaete; bivalve; amphipod; nutrients; abundance; Mediomastus ambiseta; Nucula annulata; Polydora ligni; Ampelisca abdita}
No abstract

Gray, J. S. (1979) **Pollution-induced changes in populations.** *Philosophical of the Transactions of the Royal Society of London, Part B* **286**:545-561.
{population; community; pollution; organic matter; abundance; benthic fauna; strategy; log-normal; indicator}

The effects of pollution by organic matter, oil or industrial waste on marine communities are remarkably similar. Diversity values fall, biomass and numbers of organism initially rise and then fall as the pollution load is increased. Diversity indices are, however, insensitive to pollution-induced changes and have to be assessed subjectively. Departure from a log-normal distribution of individuals among species offers a sensitive and objective method of assessing perturbation effects on communities.

Under severe pollution stress, the dominant species are those which have a flexible life-history ranging from direct development to a planktonic larva and the ability to undergo short-term genetic

selection. Species having a somewhat less flexible life-history strategy show increased abundance under conditions of slight pollution. The increase in abundance of seven or eight neither rare nor common species, which gives the departure from log-normal distribution, is suggested as being the most significant and the earliest detectable change caused by pollution in a community. Thus the presence of a species in a polluted area may be more a question of life-history strategy than the tolerance of adverse environmental conditions. If this hypothesis is correct, considerable doubt must be placed on the ecological relevance of data from toxicity tests.

Gray, J. S. (1992) **Eutrophication in the sea.** In: G. Colombo, I. Ferrari, V. U. Ceccherelli and R. Rossi (ed.) *Marine Eutrophication and Population Dynamics.* Olsen & Olsen, Fredensborg.
{review; benthic communities; general model; remedial action; research needs}

Eutrophication begins with incresed growth rates of a range of organisms from phytoplankton and macroalgae to benthic animals and fish. This is followed by a change in the species composition of communities and then by a reduction in number of species as oxygen concentrationns of water begin to fall. Finally, anoxia ensues and few organisms survive and only bacterial mats remain.

Most data show only correlative relationships between nutrient input and effects on biological organisms. For Example, there is no established relationship between nutrient inputs and primary production; nor has a quantative relationship between organic enrichment and changes in benthic communities been established.

The Vollenweider nutrient loading concept has been widely applied to the management of freshwater lakes. It is shown that the parameters of the model cannot be estimated in marine contexts. In the marine environment the most widely remedial action for eutrophication is for areas that are suspected to be affected to prepare budgets of external nutrient loadings and then to find cost-effective ways of reducing the amounts of nutrients. Yet examples from Norway show that such budgets can be widely inaccurate and costly political decisions can be taken based on extremly poor data.

In a research context, for benthic communities subject to eutrophication, two models are proposed; one for responses to oxygen saturation and the other, a more speculative one for changes in C?N in sediments. It is suggested that, if verified, the latter will allow quantative dose-response predictions to be made, rather than the present state-of-the-art of simply simply making correlations between nutrient loads and various properties of benthic communities.

Gray, J. S. and E. Paasche (1988) **On marine eutrophication.** *Marine Pollution Bulletin* **19**:349-350.
{coast; review}
No abstract

Griggs, G. B. and T. S. Hopkins (1976) **The delineation and growth of a sludge field.** *Water Research* **10**:501 to 506.
{sewage; organic carbon; methane; oxygen; sediment; anoxic}

The color, odor, organic carbon, and acoustic reflection properties of bottom sediment can be used to delineate the area affected by the Athens sewage outfall. Both color and organic carbon content clearly define the region of high organic buildup around the discharge point. Maximum organic carbon values of over 6% were determined compared to normal regional values of less than 0.5%. The bottom area covered by black anaerobic sediments has increased 7 fold to nearly 9 km^2 in the past 2.5 yr. A smaller core area around the outfall can be easily distinguished by its strong seismic reflection characteristics believed to coincide with the production of methane gas.

Haas, L. W., S. J. Hastings, and K. L. Webb (1981) **Phytoplankton response to a stratification-mixing cycle in the York River estuary during late summer.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients.* Humana Press, Clifton, New Jersey.
{phytoplankton; hydrographic dynamics; nuisance bloom}

As part of a larger multidisciplinary study of the lower York River estuary, phytoplankton response to a tidally related cycle of stratification-destratification was examined during August 1978. A "red water bloom" dominated by the dinoflagellate *Cocchlodinium heterolobatum`* initially observed in the lower York River coincident with the spring tide-induced water column destratifiction event. It is proposed that the dinoflagellates initiating the red tide were advected into the estuary in deep water during the preceding period of stratification or were derived from cysts in the sediments and that destratification provided access to the surface waters. The extent of the red water increased during the ensuing restratified period in the York River, and several lines of evidence indicated that *C. heterolobatum* migrated diurnally between ammonium enriched waters below the halocline (8-10 m) and the relatively nutrient-poor surface waters. Other estuarine systems in which phytoplankton blooms associated with alternating periods of stratification-destratification have been observed are noted. The results illustrate the close relationship between phytoplankton and hydrographic dynamics in this estuarine system and emphasize the necessity to include the study of

hydrographic processes in the study of phytoplankton dynamics.

Hagmeier, E. (1978) **Variations in phytoplankton near Helgoland.** *Rappots et Procès-verbaux des Réunions Counseil International pour L'Exploration de la Mer* **172**:361-363.
{phytoplankton; abundance; nutrients; phosphate}
A summary is given of the observations on Helgoland Roads between 1962 and 1974. There was a tendency of phytoplankton stocks to increase during this period, although this was not statistically significant. The increase was probably related to the significantly rising amounts of nutrients available.

Hallegraeff, G. M. (1993) **A review of harmful algal blooms and their apparent global increase.** *Phycologia* **32**:79-99.
{red tides; nuisance blooms; review}
no abstract

Hallegraeff, M. and J. L. Maclean (ed.) (1989) ***Biology Epidemology and Management of Pyrodinium Red Tides (Proceedings of the Management and Training Workshop, Bandar Seri Begawan, Brunei Darussalam, Philippines, 23-30 May, 1989).*** Fisheries Department, Ministry of Development, Manila.
No abstract

Han, M.-S., K. Furuya, and T. Nemoto (1992) **Species-specific productivity of *Skeletonema costatum* (Bacillariophyceae) in the inner part of Tokyo Bay.** *Marine Ecology Progress Series* **79**:267-273.
{phytoplankton; productivity; *Skeletonema*; Tokyo Bay; photosynthetic rate}
The composition of red tides in Tokyo Bay varied with season; those during summer 1986 and 1987 were comprised almost entirely of *Skeletonema costatum*. Primary productivity by *S. costatum* ranged from 5.2 to 70.4 % of the total productivity; on an annual basis, its contribution was 18.8 %, as revealed by species-specific photosynthetic rate (SSP), determined by the micromanipulation of ^{14}C-labelled cells under simulated *in situ* conditions. SSP of *S. costatum* normalized with cell volume, and indicator of growth activity, showed temporal variations as the species composition of the red tides changed. The volume-specific SSP was high in the initial phase of the bloom. However, the high volume-specific SSP was rather short-lived.

Hansson, S. and L. G. Rudstam (1990) **Eutrophication and Baltic Sea fish communities.** *Ambio* **19**:123-125.
{fish; Baltic;increase; decrease}
The discharge of nutrients to the Baltic Sea has increased considerably during the 20th century. There are several indications that this eutrophication has affected the fish community. Changes in species composition has been reported from coastal areas, e.g. local increases in the abundance of pikeperch and decreased in whitefish. Total fish catches, dominated by herring, sprat, and cod, have increased tenfold in the past fifty years and doubled in the last twenty-five years. This increase is mainly due to intensified fishing, but possibly also to eutrophication and decreased fish predation by seals.

Hardy, J. T. and Z. Zubayli (1976) **Phytoplankton standing crop and sewage nutrient enrichment along the central coast of Lebanon.** *Environmental Pollution* **11**:195-202.
{phytoplankton; Lebanon; nutrients; chlorophyll a; sewage}
Surface nearshore water samples from seven stations along the central coast of Lebanon were analyzed at different seasons for concentrations for nitrate, nitrite, ammonia, phosphate and chlorophyll-*a* standing crop.
Concentrations of nutrients and chlorophyll-*a* are higher within 10 km along coastal zone south of Beirut and increase with decreasing distance from two major untreated sewage outfall. In some cases, chlorophyll-*a* standing crop near outfalls (e.g. 2.18 mg m^{-3}) are about 10 times greater than unenriched stations further south or than values reported from elsewhere in the eastern Mediterranean. Near outfalls, concentrations of phosphate, ammonia and chlorophyll-*a* tend to be greatest in summer, while nitrate is greatest in winter.
Preliminary measurements by carbon-14 assimilation indicate that the enriched coastal region has a higher rate of primary production than the unenriched area more than 10 km south of Beriut.

Harlin, M. M. and B. Throne-Miller (1981) **Nutrient enrichment of seagrass beds in a Rhode Island coastal lagoon.** *Marine Biology* **65**:221-229.
{lagoon; seagrass; vegetation; algae; seaweeds; nutrients; growth}
Seagrass and algal beds showed a variety of responses when the water column was treated with low level additions of ammonium, nitrate and phosphate. The nutrients were added separately to 3 uniform seagrass beds of a temperate coastal lagoon during 1979 and 1980. (1) Ammonium caused the production of dense mats of free-floating green algae *Enteromorpha plumosa* and *Ulva lactuca*. It also stimulated growth in both the leaf and root-rhizome fractions of *Zostera marina*. This growth

response in *Z. marina* was greater in the area where current reached 12 cm s^{-1} than in the area with little or no current. The concentration of nitrogen in the tissue did not change. In contrast, where current was lacking, *Z. marina* growth increase with ammonium was small, but the concentration of nitrogen in the tissue doubled over that in control plots. The growth of *Ruppia maritima* was inversely related to the growth of green algae in the same plots. The red alga *Gracilaria tilvahiae* did not grow better in ammonium, but its tissue reddened. (2) Nitrate additions enhanced the growth of the green seaweeds *Enteromorpha* spp. and *U. lactuca*, but not *Z. marina* or *R. maritima*. *G. tilvahiae*, when fertilized in isolation from other plants, showed a marginal response to this nutrient, and the tissue always reddened. (3) Phosphate enhanced growth in *Z. marina* and *R. maritima* exposed to moderate current. *G. tilvahiae* growing alone showed a small growth response to phosphate. The phosphate made no difference in the growth of the green seaweeds. (4) None of the nutrient supplements noticeably altered the species composition of either epiphytic or planktonic algae associated with the beds, although we did detect small increases in their numbers. The rapid and dense growth of green algae in nitrogen-enriched water probably limited growth of adjacent seagrasses and red algae. Because these seaweeds did not use the phosphate, it became available to other plant components. The overall floral response to nutrient addition in seagrass communities depends, therefore, upon the particular nutrient supplied, the ability of alterate species in the area to compete for that nutrient and the velocity of current in the specific area.

Hartig, J. H., J. F. Kitchell, D. Scavia, and S. B. Brandt (1991) **Rehabilitation of Lake Ontario: The role of nutrient reduction and food wed dynamics.** *Canadian Journal of Fisheries and Aquatic Science* **48**:1574-1580.
{Lake Ontario; nutrient; food web; ecosystem}

The Laurentian Lakes have a complex history of changes due to eutrophication, invasion of exotic species, and fisheries and phosphorus management practices. Remedial actions have reduced nutrient loadings and enhanced the role of food web interactions in improving water quality. Workshops sponsored through the United States - Canada International Joint Commission have addressed the relative importance of nutrient abatement and/or food web manipulation in affecting water quality trends. Both controls have combined to enhance water clarity in Lake Michigan. Lake Ontario has already exhibited the effects of nutrient controls and may be on the verge of manifesting food web controls. Research and monitoring recommendations to elucidate the effects of nutrient and food web controls include the following: (1) water quality and fisheries agencies must coordinate monitoring activities, standardize techniques, and establish and maintain long-term data sets to evaluate the effects of water quality and fisheries programs separately and together; (2) controlled, mesoscale, whole system experiments should be performed to quantify rates (e.g. growth, predation, etc.) of food web interactions; and (3) the scientific community should promote research which quantifies the impact of changes in food web dynamics on changes in toxic substance levels in Great Lakes fishes.

Heinänen, A. P. (1991) **Bacterial numbers, biomass and productivity in the Baltic Sea: A cruise study.** *Marine Ecology Progress Series* **70**:283-290.
{bacteria; abundance; biomass; Baltic; productivity}

Bacterial numbers, biomass and productivity were studied during 2 cruises in the Baltic Proper, Gulf of Finland and the Bothanian Sea. Bacterial population in the open sea area had longer turnover times and lower productivity than in coastal areas, comparable to those found in the open ocean, but their biomass and abundance were as high as in the coastal areas of the Baltic Sea. High bacterial productivity in the aphotic water layer in the Gulf of Finland is suggested to indicate eutrophication of this area.

Herbland, A., A. L. Bouteiller, and P. Raimbault (1987) **Does the nutrient enrichment of the equatorial upwelling influence the size structure of phytoplankton in the Atlantic Ocean?** *Oceanologica Acta* **Special Volume No. 6**:115-120.
{nutrients; phytoplankton; size structure; upwelling}

A study of the size structure of chlorophyll *a* (Chl*a*) covering the major part of the equatorial Atlantic Ocean from 5∞N to 5∞S leads to the conclusion that seasonal nutrient enrichment in the open Eastern equatorial Atlantic does not drastically affect the size distribution of the primary producers: 90% of the total Chl*a* is everywhere contained in the <10um fraction on the average. In the coastal upwelling near Dakar, this percentage is less than 60%, for the same range of Chl*a* concentrations. In the equatorial region the percentage of <1 um Chl*a* is the same in the deep chlorophyll maximum located at the top of the nitracline during the warm season and in the subsuperficial maximum of the upwelling. Therefore, from an ecological point of view, the term "upwelling" is misleading: the seasonal equatorial upwelling seems to be nothing other than the movement towards the surface of the deep chlorophyll maximum, with no appreciable increase of its value and some slight modification of its trophic organization.

Herdendorf, C. E. (1986) **Rebirth of Lake Erie: Recovering from phosphorus enrichment.** Ohio Sea Grant, Ohio Sea Grant Series, OHSU-RS-51.
{lake; Erie; phosphorus; recovery; algae; phytoplankton; oxygen; benthos; fish}
No abstract

Hesse, K., U. Hentschke, and U. Brockman (1992) **A synoptic study of nutrient and phytoplankton characteristics in the German Wadden Sea with respect to coastal eutrophication.** In: G. Colombo, I. Ferrari, V. U. Ceccherelli and R. Rossi (ed.) *Marine Eutrophication and Population Dynamics.* Olsen & Olsen, Fredensborg.
{phytoplankton; nutrients; Wadden Sea}

For the first time seasonal patterns of nutrient and phytoplankton distribution were evaluated in an interdisciplinary synoptic study covering the whole area (2,500 km^2) of the northern German Wadden Sea. Besides the large impact of the river Elbe, nutrient patterns revealed the importance of local sewage plumes originating from agricultural drainage and coastal purification plants. N to P ratios were relatively high over all the area in the winter and spring, indicating potential phosphorus limitation for phytoplankton growth. During the spring bloom of *Phaeocystis globosa*, which culminated in biomass concentrationsof 0.5 mg C per liter, phosphorus levels decreased to limiting concentrations in some of the outer regions of the Wadden Sea. In general, however, nutrient stocks were never exhausted, emphasizing the importance of turbidity as a major factor controlling primary production in this area.

In summer high levels of inorganic phosphate and low N/P ratios were observed, reflecting rapid remineralization of organic phosphorus constituents. It is suggested that the bulk of inorganic phosphate in summer results from the breakdown of allochthonous phytoplankton blooms being advected into the region from sites of intense growth such as the frontal region of the Ebe river plume and semi-enclosed coastal basins. Red tides of decomposing *Noctiluca scintillans* were observed in the Wadden Sea and massive blooms of *Glenodinium foliaceum* in the lagoons, amounting to concentrations of 13 mg C per liter and 19 mg C per liter, respectively. Mass occurrences of toxic forms were not recorded, although several species of *Dinophysis* as well as *Alexandrium* sp. occurred in low cell numbers in spring and summer. Allochthonus POC input was estimated to be approximately 85 g C per m^2 per year, equalling an excess remineralization of about 13 tons of inorganic phosphate per day for the whole area. Owing to inadequate light conditions in the Wadden Sea water, it is assumed that this high amount of phosphate cannot be recycled in the Wadden Sea itself, but is rather transported out of the system, thereby enhancing again bloom formation at the frontal region of the Elbe River.

Hesthagen, I. H. (1977) **Migrations, breeding, and growth in *Pomatoschistus minitus* (Pallas) (Pisces, Gobiidae) in Oslofjorden, Norway.** *Sarsia* **63**:17-26.
{growth; sand goby; *Pomatoschistus*; Oslofjord; length}

Aspects of the biology of the sand goby were studied over a period of 21 months. The goby is common in the littoral from April (at temperatures above 3°C) to July, when breeding takes place, and from September to December, when the somatic growth occurs. At temperatures above 19°C and below 4-5°C the goby is rare in the littoral.

The growth is very rapid, the 0-group fish reaching almost the length of the 1-group fish during their first growing season. Growth is faster than in other populations from similar latitudes, suggested to be due to eutrophication. Spawning occurs even in less than 1 m depth. There is an indication that light intensity, together with temperature, is important for breeding to start.

The food consists of any organism of appropriate size and texture. Polychaetes are a conspicuous component. Feeding occurs intensively all through the stay in the littoral, but its lower during the breeding season. Various features of the biology of the sand goby in Oslofjorden appear to be simple and more clearcut when compared to other populations studied, probably due to the stable and predictable environmental conditions.

Hinga, K. R. (1990) **Alteration of phosphorus dynamics during experimental eutrophication of enclosed marine ecosystems.** *Marine Pollution Bulletin* **21**:275-280.
{phosphorus; MERL}

A 28 month eutrophication experiment was conducted in marine mesocosms at Marine Ecosystems Research Laboratory of the University of Rhode Island. Each mesocosm contained 13 m^3 of seawater and a layer of benthic sediments transferred from adjacent Narragansett Bay. Nitrogen, phosphorus, and silica were added daily to the mesocosms.

The paper examines net exchange of phosphorus between benthic sediments and water column during the experiment. At low loading rates the regular annual pattern of phosphate concentrations is still evident but the amplitude of the pattern is magnified. At higher loading rates the annual pattern is lost and the effectiveness of the sediments to act as a 'buffer' to water column concentrations is reduced. In some cases the nutrient loading caused a release of phosphorus from the sediments.

Hinga, K. R. (1992) **Co-occurrence of dinoflagellate blooms and high pH in marine enclosures.** *Marine Ecology Progress Series* **86**:181-187.
{dinoflagellates; diatoms; blooms; pH; phytoplankton}

High abundances of dinoflagellates in mixed phytoplankton populations in marine enclosures were strongly correlated with high pH during 23 enclosure-years of weekly samples. Diatom blooms were not similarly correlated with high pH. The correlation with high pH was not the result of dinoflagellate blooms themselves drawing down the CO_2 and driving up the seawater pH. Examination of individual blooms of >500 cells ml^{-1} indicates that dinoflagellate cell counts increased only after the pH was driven high (i.e. >8.5). High pH occurred either by natural processes (diatom blooms) or, in one case, by an artificial manipulation of the pH in the enclosure. There were 9 periods in which the seawater pH exceeded 8.5. Dinoflagellate blooms occurred during 7 of those events. A high pH affinity for dinoflagellates could help explain reported successional sequences of diatom blooms followed by dinoflagellate blooms and the association of dinoflagellate blooms with eutrophication. Seawater pH should probably be included with other environmental factors in studies of the mechanisms that control the occurrence of field dinoflagellate blooms.

Ho, Y. B. (1987) ***Ulva Lactuca* (Chlorophyta, Ulvales) in Hong Kong intertidal waters - Its nitrogen and phosphorus contents and its use as a bioindicator of eutrophication.** *Asian Marine Biology* **4**:97-102.
{green algae; Ulva; sewage; nutrients; tissue; nitrogen; phosphorus; bioindicator; Hong Kong}

The cosmopolitan green alga *Ulva lactuca* L. is often found growing in areas contaminated by domestic sewage thus reflecting its ability to thrive under such conditions. In order to study the effects of eutrophic waters on the nutrient content of the alga and its potential as an indicator species, both seawater and *Ulva* samples were collected from 10 rural and 11 urban intertidal sites around the Hong Kong Island over a period of two years. Analysis of the water samples showed that the mean dissolved inorganic nitrogen (NO_3 and NH_4) and phosphate (PO_4) levels in the rural sites were respectively 49.7 ug N l^{-1} and 6.7 ug P l^{-1}. Water samples from the urban sites contained very high mean levels of ammonia (222.4 ug N l^{-1}) and phosphate (45.3 ug P l^{-1}) reflecting the extent of sewage contamination. The amount of tissue nitrogen and phosphorus in *Ulva* from urban areas were respectively 71 and 93% more than those in rural sites. Close correlation was found between the logarithmic concentration of seawater inorganic nitrogen and that of tissue nitrogen (r = 0.949). This also applied to seawater phosphate and tissue phosphorus (r = 0.927). It is conclude that *Ulva* is a good bioindicator of seawater eutrophication.

Hobbie, J. E. and J. J. Cole (1984) **Response of a detrital foodweb to eutrophication.** *Bulletin of Marine Science* **35**:357-363.
{bacteria; abundance; activity}

The response off planktonic bacteria and micro-protozoa to an experimental eutrophication gradient in coastal marine waters was investigated. Bacterial and microflagellate numbers, as well as glutamic acid mineralization and ^{3}H-thymidine incorporation, were measured in a series of 13 m^3 mesocosms for 6 months. The systems received a daily addition of sea water (3.7% of total) and nutrients so that the nutrients added were 0, 2, 4, 16 and 32 times the anthropogenic nitrogen, phosphorus and silica loading of Narragansett Bay, Rhode Island.

Both the biomass and primary production of the planktonic algae increased in direct response to nutrient loading through the 16X treatment; the response in the 32X treatment equaled that of the 16X treatment. In general, bacterial numbers and growth (calculated from thymidine uptake) were higher in the more eutrophic tanks but there were lags in the microbial response to the peaks and valleys of the algal growth. These lags caused poor correlation between instantaneous measurements of microbial and algal parameters such as numbers of bacteria and algal production. However, when daily production was summed for the entire 6 months of the study there was excellent correlation between the total algal production and the total bacterial production (r=0.89) for six tanks. It is difficult to convert from ^{3}H-thymidine incorporation to absolute quantities of bacterial production. We used a conservative conversion factor derived from laboratory values for the thtmidine content of bacterial cells to calculate bacterial production. Bacterial production (respiration plus growth) was nearly a constant fraction of planktonic primary production at all levels of eutrophication and averaged 31%. Our results are in good agreement with other estimates of the carbon flux through the detrital component of pelagic ecosystems.

Hodgkiss, I. J. and B. S. S. Chan (1987) **Phytoplankton dynamics in Tolo Harbour.** *Asian Marine Biology* **4**:103-112.
{Tolo harbour; phytoplankton; density; abundance; composition; nutrients; nitrogen; phosphorus; red tide; diversity}

An intensive study of the Tolo Harbour phytoplankton was carried out between January 1983 and February 1985. The results presented in

this paper refer to the dynamics of the total phytoplankton population at two stations, one in the inner harbour and the other in the outer harbour, for comparative purposes.

Results are presented in terms of the total phytoplankton cell density in the entire water column at each station; the abundance of the 5 major species of Bacillariophyceae and Dinophyceae at each station; and the relative contributions of the 6 classes of phytoplankton at each station in 1983 and 1984.

Increases in total phytoplankton standing crop and changes in the percentage composition of the component species are related to increasing nutrient levels in Tolo Harbour. The increased contribution of the Dinophyceae (also reflected in the increase in red tide incidents) is particularly stressed, because of the implications which such algal blooms have for the Tolo Harbour ecosystem.

Hognestad, P. T. (1987) **Assessment of the environmental conditions in the Skagerrak and Kattegat.** ICES, ICES Cooperative Research Report, {nitrogen; phosphorus; Kattegat; Skagerrak; priamry production; oxygen}
No abstract

Hosie, D. A., R. F. Uglow, L. Hagerman, T. Sondergaard, and W. Weile (1991) **Some effects of hypoxia and medium ammonia enrichment on efflux rates and circulating levels of ammonia in *Nephrops norvegicus*.** *Marine Biology* **110**:273-279.
{hypoxia; ammonia; Kattegat; Skagerrak; decapod; *Nephrops norvegicus*}

Eutrophication has been reported for autumn months in regions of the Kattegat/Skagerrak, causing stress to bottom-living organisms. The present studies, undertaken in April (1989), investigated the effects of hypoxia and high ammonia levels in the burrowing decapod *Nephrops norvegicus* (L.). The net ammonia efflux rates and circulating ammonia levels at 6 and 12 °C, at normoxia [partial] pressure of O_2 in the water (torr), P_wO_2 = 155 torr)] and hypoxia P_wO_2 = 24 torr) in normal seawater and ammonia-enriched (300 umol ammonia l^{-1}) seawater were examined. The hourly weight-specific efflux rates were very variable and in all groups included some individuals which showed periods of no net efflux, or even a net uptake of ammonia. At each temperature, net efflux-rate differences due to treatments were not significant (P>0.05; ANOVA, in all cases) and only the differences between the net efflux rates of the normoxic groups were significantly affected by temperature (P<0.05; ANOVA). Circulating ammonia levels were also variable, and at 6°C the ammonia-enriched groups had significantly higher weight-specific blood ammonia content values than the normoxic group (P<0.05 in both cases). A net uptake of ammonia occurred in ammonia-enriched conditions - probably along a reversed NH_4^+ gradient, as downhill pNH_3 gradients were maintained in all groups - and may represent the only means by which some brachial efflux of ammonia could proceed.

Howells, G. P. (1972) **The estuary of the Hudson River, U.S.A.** *Proceedings of the Royal Society of London, Part B* **180**:521-534.
{Hudson River estuary; phytoplankton; nutrients; bloom}

The Hudson River is a major waterway of the eastern seaboard of the United States. Its two major tributaries, the Mohawk and Hudson, combine to form the long narrow estuary of the Lower Hudson. The area is populated and industrially developed, and it is predicted that both domestic and industrial demands for water will increase, as well as the demand for waste disposal and for the maintanence of its recreational resources.

Recent studies of the ecology of the Estuary, survey of the levels of pollutants in water, and their distribution between water, muds and the biota indicate that water quality may need control if problems of maintenance of fisheries, eutrophication, and drinking water quality are to be avoided. There is clearly a case for relevant research into the processes and pathways of pollutants within this aquatic ecosystem, and for the study of effects of pollutants on biological communities in relation to concentration and time of exposure.

Estuaries are areas of great natural variations in environmental conditions and their flora and fauna is selected and restricted in its variety by the need to tolerate or regulate in the variable conditions. For this reason, the capacity of estuaries to accept pollutants which enhance natural variations is relatively great. The limit of environmental acceptance need to be determined by achieving the best reconciliation between industrial development and the maintenance of amenity.

Hull, S. C. (1987) **Macroalgal mats and species abundance: A field experiment.** *Estuarine, Coastal and Shelf Science* **25**:519-532.
{macroalgae; mats; benthos; infauna; abundance; Ythan estuary}

A field experiment was carried out whereby the density of macroalgae (*Enteromorpha* spp.) was manipulated and the resultant changes in sediment infaunal density were monitored. Four densities of *Enteromorpha* spp. were used: 0, 0.3, 1 and 3 kg FW m^{-2}, corresponding to control, low-, medium-, and high-density plots. The experiment ran from May to October 1985 and was sampled on three occasions. By July, the density of *Corophium volutator* was reduced at all weed levels when

compared to control plots, whereas densities of *Hydrobia ulvae, Macoma balthica, Nereis diversicolor,* and *Capitella capitata,* all increased. Samples taken in October when the weed mats were buried in the sediment showed fewer differences than in July. *Macoma, Nereis,* and *Capitella* were still significantly more abundant at medium and high weed densities. Corophuim showed no significant treatment effect. There was, however, a highly significant difference in population size structure for *Corophium.* Measurements of sediment redox potential and silt content under medium- and high-density plots revealed rapid anoxia with a significant increase in siltation.

Hungspreugs, M., W. Utoomprkporn, S. Dharmvanij, and P. Sompongchaiyakul (1989) **The present status of the aquatic environment of Thailand.** *Marine Pollution Bulletin* **20**:327-3332.
{Thailand; bloom; red tide}

The rapidly increasing population and developing agro-industrial activities in Thailand exert considerable stress on the aquatic environment. Untreated municipal wastes are discharged directly or indirectly to canals and rivers, causing high BOD_5 values and bacterial contamination close to populated areas. Improvements in domestic sewage treatment are likely to be prohibitively expensive in the near term at least. Eutrophication of coastal waters is an emerging problem. By contrast, few problems have been documented from trace metals discharged by industries, and the public health threat from seafood contamination does not appear to be significant. Uses of chlorinated hydrocarbon pesticides are declining sharply, these being replaced by organophosphate compounds which degrade rapidly in aquatic environments. Oil pollution has not been a problem, although fears of a major spill exists.

Imai, I., S. Itakura, and K. Itoh (1991) **Life cycle strategies of the red tide causing flagellates *Chattonella* (Raphidophyceae) in the Seto Inland Sea.** *Marine Pollution Bulletin* **23**:165-170.
{red tide; flagellates; cyst; life cycle; bloom}

Chattonella antiqua (Hada) Ono and *Chattonella marina* (Subrahmanyan) Hara et Chihara are the most noxious red tide flagellates which cause serious damage to fish farming, especially to yellowtail culture, in Japanese coastal waters such as the Seto Inland Sea during summer. Cysts of *Chattonella* were identified from sediments of the Seto Inland Sea. These cysts overwinter in sea bottom and play an important role in initiating the summer red tides. Most of the cysts adhere to solid surfaces such as diatom frustules and sand grains, which may aid in keeping the cyst populations within seed beds for red tides. Temperature is a principal factor affecting the physiology of cysts of *Chattonella.* No cysts germinate at 10 ∞C. Optimum temperature range is between 20 and 25 ∞C for germination. For maturation (acquisition of germinability) of the cysts, low storage temperature of 11 ∞C or below for more than four months is essential, whereas no significant maturation is observed at 20 ∞C or more. In freshly collected sediments, marked seasonality of germinability was confirmed in Suo-Nada. The cysts have germinability between spring and early summer. The cysts spend a period of spontaneous dormancy between autumn and the next spring, and they mature during the winter season. The life cycle of *Chattonella* is therefore well adapted to seasonal temperature fluctuation in the Seto Inland Sea. And further, alteration between benthic and planktonic stage is presumably unconstrained by virtue of shallowness of the Seto Inland Sea. The life cycle of *Chattonella* can be regarded as superior strategies in conclusion for the occurrences of the red tides in temperate waters such as the Seto Inland Sea.

Jaworski, N. A. (1981) **Sources of nutrients and the scale of eutrophication problems in estuaries.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients.* Humana Press, Clifton, New Jersey.
{estuary, freshwater, nutrient, budget, comparison}

A comprehensive analysis of external sources of nutrients is presented including an impact, comparison of external loadings, and the resulting scale of eutrophication. The major emphasis of the analysis is on nitrogen and phosphorus.

The relative contribution of various external sources for five major ecosystems is delineated. Discussion of seasonal and long-term trends of external sources is presented. The impact of external sources on the eutrophication process is evaluated. A scale of eutrophication for estuarine ecosystem is suggested for comparing the impact of nutrient enrichment.

Comparisons of external nutrient loadings and the scale of eutrophication for 13 estuarine and freshwater ecosystems are made. A detailed comparison of the five estuaries of the Chesapeake Bay is presented from which relationships between external nutrient loadings ($g/m^2/yr$) and eutrophic conditions are suggested.

Analysis of the relationship between external nutrient loadings, nitrogen/phosphorus ratio, and eutrophic state suggests that, for the East Coast estuarine ecosystems, if the phosphorus loading is 1.0 $g/m^2/yr$ or less, excessive eutrophic conditions can be prevented. The favorable response of the Potomac estuary to phosphorus control demonstrates that excessive eutrophic conditions may be alleviated with advanced wastewater treatment, depending on many factors including nutrient loadings.

Jaworski, N. A. and J. O.Villa (1981) **A suggested approach for developing estuarine water quality criteria for management of eutrophication.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients*. Humana Press, Clifton, New Jersey.
{criteria; management; framework}

A conceptual approach for developing water quality criteria for eutrophication management is suggested. The three basic components of the framework include source ambient relationships, effects, and impact analyses. The approach focuses on a conceptual method for developing decision-making criteria as opposed to the classical water quality criteria for a single value of limitation. The approach to developing framework of response relationships which can be readily incorporated into water quality standard-setting processes that include environmental considerations and technological and economic factors.

Jingzhong, Z., D. Liping, and Q. Baoping (1985) **Preliminary studies on eutrophication and red tide problems in Bohai Bay.** *Hydrobiologia* **127**:27-30.
{red tide; Bohai Bay; nutrients; phytoplantkon; community; composition; productivity; sewage; trophic state index}

A study was carried out in 1978-1981 on the relationship between eutrophication and the occurrence of red tides in Bohai Bay.

An assessment method using a single parameter as well as the multiparameter trophic State Index was adopted. DIN, DIP, COD loading and concentrations and phytoplankton community (species composition, diversity index, standing crop, chlorophyll a and primary productivity) were used as parameters. The western part of the bay and two sewage outfall sites showed the highest values of chlorophyll a, nitrate, phosphate, standing crop, primary productivity and the greatest population instability. Therefore, Bohai Bay, can be regarded as mesotrophic, but its estuary eutrophic. Anthropogenic factors are mainly responsible for its eutrophication. A relationship between environmental factors and red tide species was found. *Noctiluca miliaris, Prorocentrum minimum* and *Skeletonema coastatum* have their bloom periods from July to September and are the most significant species.

Jochem, F. and B. Babenerd (1989) **Naked *Dictyocha speculum* - a new type of phytoplankton bloom in the Western Baltic.** *Marine Biology* **103**:373-379.
{*Dictyocha*; phytoplankton; bloom; silicoflagellate; Baltic}

We report on the bloom incidence of a curious new type of phytoplankton organism: the naked form of the silicoflagellate *Dictyocha speculum*. This special form does not develop the siliceous skeletons which normally characterize the genus *Dictyocha*, its growth is apparently independent of the availability of dissolved silicate. The first massive bloom of this organism was observed in the Kiel Bight area, FRG, in May 1983. We suggest that the occurrence of this new type of bloom is related to changes in nutrient conditions due to increased eutrophication.

Johansson, J. O. R. and I. R.R. Lewis (1992) **Recent improvements of water quality and biological indicators in Hillsborough Bay, a highly impacted subdivision of Tampa Bay, Florida, USA.** In: R. A. Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication*. Elsevier, Amsterdam.
{chlorophyll, seagrass, blue-green algae, transparency}

Hillsborough Bay, the eastern uppermost section of the Tampa Bay system, is surrounded by a large metropolitan complex, supports extensive industrial activity, and serves as a major shipping port of fertilizer products. The Bay was determined to be highly eutrophic during the late 1960's. The City of Tampa's primary sewage treatment plant and runoff from fertilizer industry activities were considered as the major sources of excessive nutrient loading. Loadings from both these sources have been reduced during the last 10 years, which has probably been the leading cause of improved water quality parameters such as water clarity, dissolved oxygen, and chlorophyll. The improvements recorded in these parameters may, in part, be related to large biomass reductions of a planktonic blue-green alga, which used to dominate the fall and early winter phytoplankton population. Coincidental with improved water quality, seagrass and an attached macro-alga have vegetated shallow areas around the bay, which had been barren of attached vegetation for several decades.

Jones, R. A. and G. F. Lee (1986) **Eutrophication modeling for water quality management: An update of the Vollenweider OECD model.** *Water Quality Bulletin* **11**:118-.
{model; fish; yield; phosphorus; biomass; production}
No abstract

Jonge, V. N. d. and H. Postma (1974) **Phosphorus compounds in the Dutch Wadden Sea.** *Netherlands Journal of Sea Research* **8**:139-153.
{phosphorus; Dutch Wadden Sea; Rhine}

During the period of July 1970 to July 1971 phosphorus concentrations (phosphate, dissolved

organic phosphorus and particulate phosphorus) have been measured over the whole Dutch Wadden Sea including the Ems-Dollard area and the northern part of the IJsselmeer.

Phosphate values were in general higher than in the North Sea. Highest concentrations occur in summer in the inner parts as a result of accumulation and mineralization of organic material. In this way steep gradients are built up between these inner parts and the tidal inlets, with maxima of 2.5 ugst P/l. In winter differences are small and the phosphate distribution is more homogeneous. Very low phosphate values were only found in spring and summer in the tidal inlet between the islands Vlieland and Terschelling where phosphorus probably becomes limiting for plankton growth.

Since 1950 phosphate concentrations increased three times (0.5 to 1.7 ugat P/l average). Over the same period the river Rhine shows a similar increase. However, particulate phosphorus concentrations only doubled in the Wadden Sea (2.4 to 5.1 ugat P/100 mg carbonate-free suspended matter, on the average). It has been assumed that the difference between the two factors is due to a considerable increase in microbial activity.

Josefson, A. B. (1987) **Large-scale patterns of dynamics in subtidal macrozoobenthic assemblages in the Skagerrak: Effects of a production-related factor.** *Marine Ecology Progress Series* **38**:13-23.
{macrobenthos; assemblage; organic; sediment; abundance}

Macrobenthic infauna at water depths between 10 and 300 m was monitored over 5 yr in an 80 km wide area off the Swedish west coast. Year-to-year variations in number of individuals were analyzed for total fauna, trophic and reproductive groups and dominating species. Results demonstrated significant variations in total abundance synchronized between stations suggesting the importance of some extrinsic factor. Relative positions of dominants seemed largely unaltered, suggesting a similar response among species to the common factor. Much of the variability was accounted for by short-lived predatory and surface-deposit-feeding polychaetes and surface-deposit-feeding cumaceans. A comparison of the variability between species with planktotrophic and lecithotrophic larval development showed no difference between the categories, suggesting that the common factor operated on the bottom. Temperature and salinity data suggest only small differences between years. It is argued that the major cause of the common variability pattern is a factor related to production in the sea such as sedimentation of organic matter, which affects either of, or a combination of, settlement, somatic growth and survival of the bottom. Sediment organic matter over 3 yr changed in a way that would be predicted from the faunal changes and consistent with the hypothesis that sedimentation had caused the variation. Increased abundance were accompanied by increased organic content.

Josefson, A. B. and R. Rosenberg (1988) **Long-term soft-bottom faunal changes in three shallow fjords, West Sweden.** *Netherlands Journal of Sea Research* **22**:149-159.
{benthic; fauna; abundance; biomass; composition; diversity}

Three West Swedish fjords were investigated at the same 14 stations in 1976 and 1986, and 8 of these had been investigated in the 1920's. The stations are situated at 7 to 27 m water depths in protected areas without any significant local pollution input, but now with organically enriched sediments. Comparisons of benthic fauna between 1976 and 1986 showed the following significant reductions: in total mean abundance and biomass (excluding some large and rare species); in abundance and biomass of molluscs; in abundance of suspension feeders and carnivores. Similarity indices gave significant differences between 1976 and 1986. The greatest changes had occurred in the two fjords with the most restricted water circulation. Although these faunal changes may be attributed to several factors, recently increased periods of hypoxia in the bottom water, which could be a result of large-scale eutrophication, are suggested as the main impact on the benthos.

Justi'c, D. (1987) **Long-term eutrophication of the Northern Adriatic Sea.** *Marine Pollution Bulletin* **18**:281-284.
{Adriatic Sea; anoxia; oxygen; primary production; nutrients}

In the Northern Adriatic Sea, the occurrence of anoxic events near the bottom has considerably increased in frequency during the last 15 years. Although it has been suggested that increasing nutrient inflow from land-based sources has caused the phenomenon, there has been no direct evidence for this. An analysis of the oxygen distribution in the Northern Adriatic Sea between 1911 and 1982 clearly demonstrates that the probability of anoxic events near the bottom has increased in time. This process is related to the increasing primary production near the surface. There is strong evidence that the long-term nutrient enrichment of the Northern Adriatic Sea forces the above changes.

Justi'c, D. (1988) **Trend in the transparency of the Northern Adriatic Sea 1911-1982.** *Marine Pollution Bulletin* **19**:32-35.
{transparency; Adriatic; primary production; nutrients}

In the northern Adriatic Sea, the Secchi disk has been used in oceanographic studies since 1911. An

analysis of the data collected during summers between 1911 and 1982 demonstrates that, on the average, the Secchi disk depth has decreased in time. It is likely that a decrease in light penetration has reduced the benthic primary production and thus has increased the probability of an occurrence of anoxic events near the bottom. The long-term nutrient enrichment of the freshwaters discharging into the northern Adriatic Sea appears to be the main factor which has caused the above changes.

Justi´c, D. (1991) **Hypoxic conditions in the northern Adriatic Sea: Historical development and ecological significance.** In: R. V. Tyson and T. H. Pearson (ed.) *Modern and Ancient Continental Shelf Anoxia.* The Geological Society, London.
{oxygen; Adriatic; Po River; nitrogen; phosphorus; hydromedusae; meroplankton}

In the northern Adriatic Sea the occurrence of anoxic events and related benthic mortalities has considerably increased in frequency during the past 15 years. This paper summarizes recent findings and presents new evidence on the causes and consequences of this phenomenon. Trends in the oxygen content 1911-1984, trends in the Secchi disk depth 1911-1982 and long-term changes in the communities of benthos and meroplankton are described. The relative importance of a set of factors which create favorable conditions for the development of hypoxia is discussed.

Kaiser, W., A. Irmisch, D. Nehring, F. Georgi, and G. Bruel (1990) **Ecological investigation in the onshore pelagic zone near Warnemünde from March 1985 to March 1986.** *Limnologica* **20**:33-36.
{nutrients; chlorophyll; pelagic}

From March 1985 to March 1986 ecological investigations were carried out in the pelagic zone near Warnemünde with the aim of analyzing the annual variations in some oceanological parameters and ascertaining the productivity and eutrophication of this region. Main results are as follows:

- All parameters studied show annual variations, which are greatest for temperature, nutrients and biological parameters.
- Short term variations (few days) were strong, except in the case of temperature.
- Close connections exist between the biological and chemical parameters.
- The influence of the discharge from the River Warnow on the ecological conditions could not be clarified.
- As comparisons of chlorophyll and seston concentrations with those of the Arkona Basin and the Lübeck Bay show, the area studied can be characterized as a slightly eutrophic region of the Mecklenburg Bay.

Kat, M. (1987) **Toxic and non-toxic dinoflagellate blooms on the Dutch coast.** In: T. Okaichi, D. M. Anderson and T. Nemoto (ed.) *Red Tides: Biology, Environmental Science, and Toxicology.* Elsevier, New York.
{bloom; dino; abundance; toxic}

The water of the Dutch coastal area is a mixture of water entering the North Sea in the south through the Straits of Dover, fresh water from the rivers Rhine, Meuse and Scheldt and British coastal water (figure 2.). The seasonal occurrence and year-to-year frequency for the period 1973-1984 will be described of 9 dinoflagellates occurring in a 70 km wide area along the coast. Special attention has been paid to the presence of toxin producing dinoflagellates and the results of this program for 1986 and 1987.

Kautsky, N., H. Kautsky, U. Kautsky, and M. Waern (1986) **Decreased depth penetration of *Fucus vesiculosus* (L.) since the 1940's indicates eutrophication of the Baltic Sea.** *Marine Ecology Progress Series* **28**:1-8.
{light; depth penetration; seaweeds; chlorophyll; Baltic}

Although nutrient inputs to the Baltic Sea have increased drastically since the end of the last century, there is still little hard biological evidence of a general eutrophication of the Baltic Sea outside locally polluted areas. A revisit after 40 yr to some well-documented diving stations in the outer archipelago of the Åland Sea gave us an opportunity to register any changes in benthic vegetation that could be linked to eutrophication. By mapping the vertical distribution in coverage of bladder wrack *Fucus vesiculosus* (L.) at 11 stations we observed that the lower limit of this alga had moved upwards at 10 stations from maximally 11.5 m in 1943/44 to 8.5 m in 1984. Also the depth of maximum development had withdrawn from 5 to 6 m in 1943/44 to 3 to 4 m in 1984, while coverage at these depths was about the same: 58% and 51 % respectively. The deeper specimens today at 8.5 m had the same dwarfed appearance as those found at 11.5 m in the 1940's; at that time growth at 8.5 m was luxuriant. During both studies the decrease in *F.vesiculosus* coverage with depth towards the lower limit could be approximately fitted to an exponentially decreasing light attenuation curve. Since the structure of Baltic hardbottom communities is almost totally governed by abiotic factors, the changes in depth penetration are probably caused by decreased transparency of the water column due to eutrophication. Results indicate that the decreased water transparency arises from a 40 to 50% increase in summer values of chlorophyll *a* and nutrients in the offshore surface water of the Baltic Sea since the 1940's.

Keller, A. A. (1988) **An empirical model of primary productivity (^{14}C) using mesocosm data along a nutrient gradient.** *Journal of Plankton Research* **10**:813-834.
{primary production; MERL}

The two parameters of the hyperbolic tangent equation, P_m and a, were estimated from *in situ* vertical profiles of primary production using mesocosm data along a nutrient gradient. The parameters, derived from 4-h (around noon) ^{14}C incubations, were used together with the photosynthesis-light curve and hourly solar radiation data to calculate daily primary production rates (P_d). Approximately 40% of the daily production occurred in the 4h around noon. Considering parameter uncertainty, there was no indication of an increase in variation in production with increased nutrient loading, nor did biomass-specific *P-I* parameters increase. Annual production ranged from 82 to 901 gCm^{-2} $year^{-1}$ and was highest in the highest nutrient treatment tank. Daily productivity ranged from 0.02 to 9.1 $gCm^{-2}day^{-1}$ and was significantly correlated, in all treatments, with a composite parameter BI_0/k (where B is phytoplankton biomass; I_0 is daily radiation and k is the extinction coefficient). Linear regression of P_d against BI_0/k indicated that much of the variability (86%) in productivity was explained by light availability and phytoplankton biomass. Two approaches for predicting productivity were compared: (i) predicting production directly from environmental variables (i.e. BI_0/k) and (ii) predicting the parameter of the *P-I* curve from environmental variables and using these to calculate daily production.

Keller, A. A. (1989) **Modeling the effects of temperature, light, and nutrients on primary productivity: An empirical and a mechanistic approach compared.** *Limnology and Oceanography* **43**:82-95.
{chl a; ^{14}C production; primary productivity; MERL}

The prospect of reliably predicting production from environmental variables in heterogeneous estuarine environments offers clear logistic advantages over measurement with the ^{14}C technique, particularly if detailed coverage (in space and time) is desired. To that end, two different techniques for predicting phytoplankton production were tested and compared using data from Narragansett Bay, R.I., and experimental estuarine ecosystems. Primary productivity was first estimated via an empirical technique (principal component regression), which incorporated temperature, light, and nutrients as independent variables. This approach was compared with a traditional mechanistic formulation which included the same environmental variables as the major limiting factors. Both models provided good fits to the data (explaining 77-82% of the total variance). The predictive ability of the mechanistic model was significantly greater ($p<0.05$) than the principal component regression when tested on two independent data sets. Predictive ability between the two models was statistically compared by F - tests on the residual variability from each method.

Keller, A. A., P. H. Doering, S. P. Kelly, and B. K. Sullivan (1990) **Growth of juvenile Atlantic menhaden, *Brevoortia tyrannus* (Pisces: Clupeidae) in MERL mesocosms: Effects of eutrophication.** *Limnology and Oceanography* **35**:109-122.
{secondary production; growth; Atlantic menhaden; nutrient; MERL}

Growth and mortality of recently hatched Atlantic menhaden (*Brevoortia tyrannus*) were examined for 7 months under two levels of nutrient enrichment (with and without silicate enhancement) and control conditions in experimental marine mesocosms (13 m^3). Results from six plankton-dominated systems confirmed the often hypothesized but rarely demonstrated link between nutrient loading, food quantity, and growth in marine fish. Weekly abundance and mortality were not significantly different ($P \geq 0.05$) between controls and treatment mesocosms. On the other hand, von Bertalanffy's growth coefficients and mean asymptotic sizes of juvenile Atlantic menhaden were significantly different ($P < 0.05$) and positively correlated ($r^2 = 0.98$) with mean food availability (measured as the sum of phytoplankton plus zooplankton carbon), which in turn was significantly ($P < 0.05$) and positively correlated ($r^2 = 0.94$) with nutrient loading (measured as the input of N+P+Si).

Keller, A. A. and R. L. Rice (1989) **Effects of nutrient enrichment on natural populations of the brown tide phytoplankton *Aureococcus anophagefferens* (Chrysophyceae).** *Journal of Phycology* **25**:636-646.
{brown tide bloom; nutrient; picoalgae; MERL}

The brown tide picoalgae *Aureococcus anophagefferens* Hargraves et Sieburth was present in approximately equal numbers in 12 large scale (13000 L) mesocosms at the start of a nutrient addition experiment in June 1985. Increases in abundance in untreated systems mimicked the pattern of bloom development in Narragansett Bay, Rhode Island, the seawater source for the experiment. *Aureococcus* increased to maximal values of 2.6×10^9 cells L^{-1} and persisted at high numbers (>10^8 cells L^{-1}) for 7-8 weeks. In nutrient addition tanks, the picoalgae bloomed briefly (1-3 weeks) but rapidly declined to the usual level (~10^7

cells L^{-1} for eukaryotic algae in Narragansett Bay). The decline in picoalgae abundance was followed by an increase in total diatoms in all nutrient treated tanks. Mean picoalgae abundance in the mesocosms and the bay was significantly ($P<0.05$) and inversely correlated ($r=-0.93$) with mean concentration of dissolved inorganic nitrogen. The persistence of the brown tide species in control mesocosms and Narragansett Bay appears related to its ability to grow at very low concentrations of dissolved inorganic nitrogen, levels previously shown to limit diatom growth.

Keller, A. A. and R. L. Rice (1990) **Variation in DCMU-enhanced fluorescence relative to chlorophyll *a* : Correlation with the brown tide bloom.** *Journal of Phycology* **26**:202-205.
{brown tide blooms; fluorescence; nutrients; MERL}

DCMU-enhanced fluorescence and extracted chlorophyll *a* were simultaneously measured in Narragansett Bay, Rhode Island and the MERL (Marine Ecosystems Research Laboratory) mesocosms during the 1985 brown tide bloom. Marked differences in the relationship between these variables were observed as the phytoplankton community shifted from dominance by picoalgae to diatoms. The fluorescence to chlorophyll *a* ration was significantly ($P<0.05$) higher in the mesocosms and the bay when the brown tide species (*Aureococcus anophagefferens* Hargraves et Sieburth) dominated the phytoplankton community compared with other taxa. Although several factors could have affected the relationship we believe the high ratios are related to the pigment composition and / or small size of the brown tide organisms.

Kelly, J. R., V. M. Berounsky, S. W. Nixon, and C. A. Oviatt (1985) **Benthic-pelagic coupling and nutrient cycling across an experimental eutrophication gradient.** *Marine Ecology Progress Series* **26**:207-219.
{nutrient; flux; benthic; pelagic; nitrogen; phosphorus; MERL}

Sediment-water exchange rates of dissoloved inorganic nitrogen (NH_4^+, NO_3^-, NO_2^-) and phosphorus (PO_4^{3-}), water column concentrations of both dissolved and particulate forms of N and P, and net primary production (^{14}C) were measured during a summer period in large (13 m^3) experimental mesocosms that had been subjected to continuous daily nutrient additions (N, P, Si) for over 1 yr. The concentrations of combined dissolved inorganic plus particulate nutrient forms (N, P) were linearly related to the nutrient input rate across a loading range from 596 to 34100 mmols N m^{-2} yr^{-1}. Benthic nutrient regeneration generally increased, although not uniformly, with loading. Average summer fluxes for treatments ranged from about 150 to 1200 umols NH_4^+ m^{-2} h^{-1}, with highest rates being recorded at the 2 highest loading levels. Benthic nutrient regeneration did not increase in direct proportion to loading, but appeared strongly related to net primary production rates across the enrichment gradient. Comparison, across the experimental gradient, of the external nutrient supply rate with the benthic feedback of dissolved nutrients to the water column indicated that beyond a loading of about 2000 to 5000 mmols N m^{-2} yr^{-1} the water column nutrient dynamics became dominated by the external supply. Results suggest that the importance of benthic-pelagic interactions to biogeochemical and ecological cycles of coastal areas may decrease markedly with nutrient enrichments which exceed the needs of the autotrophic components of the ecosystem.

Kelly, M. and M. Naguib (1984) **Eutrophication in Coastal Marine Areas and Lagoons: A Case Study of 'Lac de Tuins'.** UNESCO, UNESCO reports in marine science, 29.
{coast; lagoon; review; concept; processes}

During the period from September 6 through 18, 1982 a workshop was conducted in Tunis, Tunisia to discuss and teach about problems of eutrophication in coastal marine areas. The history of the concept of eutrophication, as developed for north-temperate lakes, was discussed. The major processes involved, including nutrient enrichment, excess algal growth, oxygen depletion, and the microbial processes in anaerobic environments were described. Participants described eutrophic conditions found in coastal areas of their respective coUntries (all bordering the Mediterranean). The eutrophication of Lac de Tuins, perhaps the most eutrophic embayments in the world, was discussed and presented as a case study. During the workshop we realized that the concepts of cultural eutrophication as originally described for north-temperate lakes apply imperFectly to the marine environment. But the processes in both environments are similar, with the addition of large quantities of nutrients, excessive algal growth, depletion of oxygen with consequent microbial and chemical changes, and the death of large numbers of animals and complete change of ecosystem structure.

Kemp, W. M., R. R. Twilley, J. C. Stevenson, W. R. Boynton, and J. C. Means (1983) **The decline of submerged vascular plants in the upper Chesapeake Bay: Summary of results concerning possible causes.** *Marine Technology Society Journal* **17**:78-89.

{vascular plants; submerged; Chesapeake Bay; vegeation; nutrient; epiphytic; phytoplankton; algae; biomass}

This paper provides a summary and synthesis of research conducted to investigate possible causes of the decline in abundance of submerged aquatic vegetation (SAV) in the upper Chesapeake Bay beginning in the late 1960s. Three factors were emphasized in this study; runoff of agricultural herbicides; erosional inputs of fine-grain sediments; nutrient enrichment and associated algal growth. Widespread use of herbicides in the estuarine watershed occurred contemporaneous with the SAV loss; however, extensive sampling of estuarine water and sediments during 1980-81 revealed that typical bay concentrations of herbicides (primarily atrazine) rarely exceeded 2 ppb. On two occasions relatively high values (20-45 ppb) were observed for brief (2-4 h) periods in a small cove following runoff events. Short (2-6 h) and long (4-6 wk) term experiments indicated that ephemeral phytoxic effects would be expected in response to these highest herbicide concentrations followed by rapid recovery. However, normal concentrations (<5 ppb) had little measurable effects on plants. Historical increases in turbidity have been documented for some bay tributaries since the 1940s. During our study light (PAR) attenuated by suspended fine-grain sediments contributed more to total turbidity in bay shallows (< 1.5 m) than did phytoplankton chlorophyll *a*. Diel cycles of PAR available in SAV beds indicated that plant photosynthesis was light-limited for much of the day, and PAR often fell below the compensation level (I_c) needed for minimal plant growth. Although some SAV species exhibited considerable ability to adapt to reduce light by such mechanisms as increased pigmentation and stem elongation, increased turbidity has probably reduced overall depth distribution of SAV markedly. Effects of the continual increase in nutrient enrichment of the bay (documented since 1930) were tested by experimentally fertilizing pond mesocosms at levels common to the upper estuary. Moderate to high nutrient loadings resulted in significant increases in growth of epiphytic and planktonic algae and decreases in SAV production, as well as premature seasonal senescence of fertilized plant populations. Direct measurements demonstrated the inhibitory effect of epiphytic growth on SAV photosynthesis, due largely to light attenuation. The results of these various experiments were synthesized into an ecosystem simulation model which demonstrated the relative potential contributions of the 3 factors to SAV declines, where nutrients > sediments > herbicides. Other factors and mechanisms are also discussed along with possible resource management options.

Kennedy, V. S. (ed.) (1984) ***The Estuary as a Filter.*** Academic Press, Orlando.
No abstract

Kerr, S. R. and R. A. Ryder (1992) **Effects of cultural eutrophication on coastal marine fisheries: a comparative approach.** In: R. A. Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication.* Elsevier, Amsterdam, London, New York, Tokyo.
{fish yield}

Several generalities are common to the effects of cultural eutrhopication on fisheries in a variety of marine and freshwater ecosystems. Foremost is the absence of definitive diagnostic features to permit discrimination between direct eutrophication effects, and those engendered by other factors, often associated with anthropogenic change. It is also clear that euthrophication may profoundly modify the structure, function and species composition of fish production systems, with attendant consequences for both ecosystem function and the economic value of the yield. Eutrophication and its associated effects fall into one of four categories: direct effects on essential environmental factors; diminished suitability of the habitat factors necessary to sustain fisheries yeirld; transmission of effects accelerated by the rapid transfer of inimical biota among affected ecosystems; potential for elaboration of fisheries yield in terms of products that are not acceptable for human comsumption. Taken together, the patterns of change accompanying cultural euthrophication of fish production systems are generally recognizable, but are not always amenable to differentiation from the effects of associated factors, or to precise quantification.

Köhler, A. and F. Hölzel (1980) **Investigation on health conditions of flounder and smelt in the Elbe estuary.** *Helgoländer Meeresuntersuchungen* **33**:401-414.
{disease; health; flounder; smelt; River Elbe; North Sea; oxygen; nitrite}

Since 1958 the occurrence of flounder (*Platichthys flesus* L.) and smelt (*Osmerus eperlanus* L.) in the lower River Elbe has shifted gradually toward the mouth of the river into the North Sea: this may be due to periodical deprivation of oxygen and fluctuating peaks of toxic nitrite concentrations. The interior organs of both fish species caught in the Elbe estuary were examined. Macroscopic inspections revealed discolouring of the liver to be most pronounced in specimens 2-3 years of age. Cross-sections of the liver demonstrated histopathological symptoms of oedematous degeneration in smelt, and extreme lipoid vacuolation in flounder increasing with size and age of the fishes. The intestine of both species investigated showed massive desquamation defects

of the mucosa, occurring in smelts shortly after hatching, and in flounders after immigration into the estuary. The observations made suggest the influence of toxic compounds distribution in the aquatic environment on the health of both species.

Kononen, K. and Å. Niemi (1984) **Long-term variation of the phytoplankton composition at the entrance to the Gulf of Finland.** *Ophelia, supplementum* **3**:101-110.
{phytoplankton abundance; assemblage; composition; blue-green algae; N/P ratio}

Quantitative data on the phytoplankton in the sea zone off Tvärminne in 1968-1981 have been analyzed. The area is characterized by strong maxima of diatoms and dinoflagellates in spring and occasional maxima of blue-green algae in late summer. Rapid changes in hydrography, including interactions of different water masses, are frequent in the area. The year-to-year fluctuations of different phytoplankton species and groups are discussed against the background of the hydrographical and chemical changes in the Baltic Proper in the 1970s. Rises in the surface salinity and nutrient level were reflected by the increased total biomass, especially in summer, during the late seventies, and heterocystic blue-green algae became more abundant. The vernal marine diatoms were also more abundant in the late seventies than in the late sixties, but this was partly caused by variations in weather conditions in spring. *Diatoma elongatum*, which favours low salinity, was more abundant in the late sixties. However, many dominant marine species showed considerable year-to-year fluctuation not directly connected with the changes observed in the environment during the study period.

Kröncke, I. (1990) **Macrofauna standing stock of the Dogger Bank. A comparison: II. 1951-1952 versus 1985-1987 Are changes in the community of the northeastern part of the Dogger Bank due to environmental changes?** *Netherlands Journal of Sea Research* **25**:189-198.
{macrofauna; benthic; opportunistic; polychaetes; bivalves; species composition; abundance; biomass; Dogger Bank}

During April/May 1985-87 some of Ursin's (Ursin, 1960) stations on the Dogger Bank from April/May 1951-52 were revisited. This paper concentrates on results from the 'Tail End', the northeastern part of the Dogger Bank. The polychaete species *Ophelia borealis* and *Goniada maculata*, which were dominant species in 1951-52, showed similar distributions in 1985-87 on the whole of the Dogger Bank. Changes in the macrofauna distribution are obvious in the increase of opportunistic small polychaete species like *Spiophanes bombyx, Scoloplos armiger* and *Magelona* spp. In 1985-87 these species occurred in high individual numbers per m^2 all over the Dogger Bank in contrast to 1951-52, when they were found only in few individuals. Extensive patches of the bivalve species *Spisula subtruncata* discovered at the northeastern border of the Dogger Bank in the fifties were not found. Only small, fast-growing species like *Abra prismatica, Tellina fabula* and *Montacuta bidentata* occurred in high individual numbers per m^2. In 1987 the total biomass shows a reduction of about 30% in the area compared with 1950-54.

Some hypotheses are given to explain the changes in macrofauna distribution on the Dogger Bank between 1950-1954 and 1985-1987, taking into account the increasing eutrophication and pollution.

Lam, C. W. Y. and K. C. Ho (1987) **Red tides in Tolo Harbour, Hong Kong.** In: T. Okaichi, D. M. Anderson and T. Nemoto (ed.) *Red Tides: Biology, Environmental Science and Toxicology*. Elsevier, New York.
{red tide; oxygen}

Tolo harbour, a 15 km long landlocked inlet in the northeastern part of Hong Kong, has been severely affected by red tides over recent years. The frequency of occurences has markedly increased since 1980 with 69 incidents recorded from 1980-1986. A corresponding increase in dinoflagellate numbers in the inlet was found. More than twenty causative organisms were identified. Prorocentrum tridtinum, P. dentatum, P. sigmoides, Gymnodinium sp., Noctiluca scintillans and a variety of small flagellates occurred most frequently. Red tides were found throughout the whole year with peak occurrence in spring and autumn. The water quality, oceanography and meteorological conditions characterizing red tide occurrence during the period from 1976-1986 were analyzed and reported. The increasing red tides are a consequence of accelerated eutrophication in Tolo Harbour following intensive urban development in the catchment. The nutrient loadings of nitrogen and phosphorus have increased more than two-fold in the past decade. Concurrent increase in the nutrient levels in the inlet water has been found. The major impact of red tides at present is causing fishkills by anoxia.

Lara, R. J., E. A. Gomez, and A. E. Pucci (1985) **Organic matter, sediment particle size and nutrient distributions in a sewage affected shallow channel.** *Marine Pollution Bulletin* **16**:360-364.
{nitrogen; phosphorus; Blanca Bay; sediment; protein}

Sediment and seawater samples were taken in a sewage affected channel in Blanca Bay, Argentina. Protein content, 'humic substances' and silt-clay percentage were evaluated in the sediments; NH_4^+,

PO_4^{3+} and 'dissolved organic matter' in seawater. A highly significant correlation (r=0.747, n=59) was obtained for the relation between protein and % silt-clay. The 'humic substances' distribution depends more on the distance from the outfall than does the protein content, probably because of the important relation of the latter with the sediment particle size. The dissolved components showed a dilution pattern similar to that of a contamination plume in a moving water mass, reaching normal values at 1700 m from the outfall.

Larsson, U., R. Elmgren, and F. Wulff (1985) **Eutrophication and the Baltic Sea: Causes and consequences.** *Ambio* **14**:9-14.
{nitrogen; Phosphorus; Baltic}

New estimates of the total nutrient (N and P) load to the Baltic Sea are considerably higher than earlier calculations. Estimated total nitrogen load is 1.2 X 10^6 tons/year, total phosphorus load 77 X 10^3 tons/year. These figures may still be too low. The load may have increased about 4x for total nitrogen and about 8x for total phosphorus, due to man's activities.

Available data indicate that phosphorus is deposited in large amounts in the sediment, and that nitrogen is lost from the sediment through denitrification.

Larsson, U. and Å. Hagström (1982) **Fractionated phytoplankton primary production, exudate release and bacterial production in a Baltic eutrophication gradient.** *Marine Biology* **67**:57-70.
{phytoplankton; primary production; bacteria; Baltic}

The distribution of phytoplankton primary production into four size fractions (>10um, 10-3um, 3-0.2 um and <0.2 um), the utilization of algal exudates by bacteria and the bacterial production were studied in a eutrophication gradient in the northern Baltic proper. The polluted area exhibits substantially increased nutrient, especially nitrogen, levels while only minor differences occur in salinity and temperature regimes. Total primary production was 160 g C m^{-2} yr^{-1} at the control station and about 275 g C m^{-2} yr^{-1} at the eutrophicated stations. The estimated total exudate release was 16% of the totally fixed $^{14}CO_2$ in the control area and 12% in the eutrophicated area (including the estimated bacterial uptake of exudates). The difference in $^{14}CO_2$ uptake rates between incubation of previously filtered water (<3, <2, <1 um) and unfiltered water was used to estimated bacterial uptake of phytoplankton exudated which were found to contribute about half of the estimated bacterial carbon requirement in both areas. Bacterial production was estimated by the frequency of dividing cells (FDC) method as being 38 g C m^{-2} yr^{-1} at the control station and 50 g C m^{-2} yr^{-1} at the eutrophication stations. To estimate the mean *in situ* bacterial cell volume a correlation between FDC and cell volume was used. The increased annual primary production in the eutrophicated area was due mainly to higher production during spring and autumn, largely by phytoplankton cells (mainly diatoms) retaind by a 10 um filter. Primary production during summer was similar in the two areas, as was the distribution on different size fractions. This could possibly explain the similar bacterial production in the trophic layers at all stations since the bulk of bacterial production occurs during summer. It was demonstrated that selective filtration does not quantitatively separate photoautotrophs and bacteria. A substantial fraction of the primary production occurs in the size fraction <3um. The primary production encountered in the 3-0.2 um fraction was due to abundant picoplankton (0.5 to $8X10^7$ ind l^{-1}), easily passing 3 um filter. The picoplankton was estimated to constitute up to 25% of the total phytoplankton biomass in the control area and up to 10% in the eutrophication area.

Laws, E. A. (1983) **Man's impact on the marine nitrogen cycle.** In: E. J. Carpenter and D. G. Capone (ed.) *Nitrogen in the Marine Environment.* Academic Press, New York.
{nitrogen; cycle; budget; New York Bight; sewage; Kanaohe Bay}
No abstract

Laws, E. A. and D. G. Redalje (1979) **Effect of sewage enrichment on the phytoplankton population of a subtropical estuary.** *Pacific Science* **33**:129-148.
{sewage; phytoplankton; estuary; primary production; Kanaeohe Bay; chlorophyll a; biomass; nutrients; light; growth rate}

Phytoplankton primary production; concentrations of chlorophyll *a*, particulate carbon and nitrogen, adenosine triphosphate, inorganic nitrogen and phosphorus; and secchi depths were measured at four stations in Kanaeohe Bay, Oahu, on a biweekly basis for 20 months prior to diversion of sewage discharges from the bay. Nutrient enrichment experiments designed to determine biomass limitation indicated that phytoplankton biomass, as measured by chlorophyll *a*, was nitrogen-limited in all parts of the bay, and that phosphorus was simultaneously limiting in the sector of the bay furthest from the sewer outfalls. Mean light-saturated productivity indices in all parts of the bay were about 11-12 mg C mg^{-1} chl *a* hr^{-1}, values close to the maximum reported for phytoplankton in eutrophic marine environments.

Based on the results of dawn-to dusk C-14 incubations and an estimated phytoplankton C: chl *a* ratio of 50 by weight, phytoplankton growth rates were estimated to fall in the range of 4-6 percent per hour in all parts of the bay. Such growth rates are close to the maximum growth rates reported for marine phytoplankton grown on light-dark cycles in continuous culture, suggesting that phytoplankton growth rates (as opposed to biomass) were limited primarily by suboptimal or supraoptimal light intensities rather than by nutrients. Based on these growth rates and an assumed phytoplankton C:N ratio of 5.68 by weight, nitrogen recycling was estimated to account for 80 percent of phytoplankton nitrogen uptake in the part of the bay receiving direct sewage inputs, and for over 90 percent of phytoplankton nitrogen uptake in the other sectors of the bay. Estimates of living and detrital particulate carbon were made based on an assumed C: ATP ratio in living organisms of 285 by weight. From this partitioning, living carbon was found to vary by a factor of 3-4 between the sewage-enriched and unenriched sectors of the bay. However, estimated detrital carbon concentrations were uniform throughout the bay, as were the measured concentrations of inorganic nitrogen. These results are consistent with the interpretation that the population of microorganisms, both bacteria and phytoplankton, are substrate-limited in all sectors of the bay.

Laws, E. A. and D. G. Redalje (1982) **Sewage diversion effects on the water column of a subtropical estuary.** *Marine Environmental Research* **6**:265-279.
{phytoplankton; Kaneohe Bay; sewage; estuary; growth}

A study of the phytoplankton community and water column chemistry in Kaneohe Bay, Oahu, Hawaii, before and after the diversion of secondary treated sewage from the bay has shown that changes in total nutrient concentrations in the water column cannot be accurately predicted without taking into account water column-benthos interactions. During the first year after sewage diversion, the decomposition of about 400 tonnes of benthic organisms, primarily filter feeders, resulted in water column dissolved organic nitrogen and phosphorus concentrations roughly an order of magnitude higher than those expected in the absence of such interactions. The biomass of phytoplankton appears to have been N limited both before and after sewage diversion, with internal nutrient recycling accounting for 70-99% of phytoplankton nutrient uptake. Both the biomass and growth rate of the phytoplankton declined as a result of the sewage diversion, with post-diversion growth rates evidently well below nutrient-saturated values. Since the principal stresses on the bay's coral reef community as a result of the sewage discharges appear to have resulted from the elevated concentrations of plankton in the water, various measures of seston concentration appear to be the most ecologically significant indicators of nutrient enrichment in the system.

Lee, G. F. and R. A. Jones (1981) **Application of the OECD eutrophication modeling approach to estuaries.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients*. Humana Press, Clifton, New Jersey.
{modeling; lake; estuary}

Approximately five years ago, the Organization for Economic Cooperation and Development (OECD) initiated a 22 country, 200 lake and impoundment study of nutrient load-eutrophication response relationships. Emphasis in the study is being given to the evaluation of the Vollenweider models for correlating nutrients load with eutrophication response. The U.S. part of this study included the investigation of about 40 waterbodies or parts thereof. The results of the U.S. and the other studies all show a strong correlation between the phosphorus load to a water body as normalized by mean depth and hydraulic residence time, and the planktonic algal chlorophyll, Secchi depth (water clarity), and the hypolimnetic oxygen depletion rate. These relationships have been developed to a sufficient degree of sophistication so that they are the method of choice for estimating the impact of altering the phosphorus load to a P-limited waterbody on eutrophication-related water quality.

While the U.S. OECD waterbodies were primarily lakes and impoundments, included as part of the data base upon which the statistical correlataions were made were three parts of the Potomac estuary. It appears that in general, the OECD eutrophication modeling approach is applicable to estuarine systems as well as lakes and impoundments. In addition to reviewing the U.S. OECD study results, this paper presents a discussion of the modifications that may need to be made in the OECD-Vollenweider eutrophication modeling approach in order to apply it to some estuarine systems.

Lee, V. and S. Olsen (1985) **Eutrophication and management initiatives for the control of nutrient inputs to Rhode Island coastal lagoons.** *Estuaries* **8**:191-202.
{lagoon; management; macroalgae; nutrient; salt pond; seaweeds; macroalgae}

An assessment of developing eutrophic conditions in small temperate lagoons along the coast of Rhode Island suggests that in such shallow, macrophyte based systems the response to nutrient enrichment differs from that described for planktonic based systems. The nitrogen loadings

per unit area of the salt ponds are 240-770 mmol N per m^2 per year. Instead of the high nutrient concentrations, increased phytoplankton biomass and turbidity, leading to eventual loss of benthic macrophytes described for such systems as the Chesapeake, Patuxent and Appalachicola Bay, nutrient enrichment of the Rhode Island lagoons has led to increased growth of marine macroalgae. The increased macroalgal growth appears to alter the benthic habitat and a shift from a grazing to detrital food chain appears to be impacting important shellfisheries. As more extensive areas of organic sediments develop, geochemical cycling changes, resulting in higher rates of nitrogen re mineralization and accelerated eutrophication. The major sources of nitrogen inputs to the salt ponds have been identified and a series of management initiatives have been designed to limit inputs from present and potential development within the watersheds of the lagoons.

Lenzi, M. (1992) **Experiences for the management of Orbetello Lagoon: eutrophication and fishing.** In: R. A. Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication*. Elsevier, Amsterdam.
{seaweeds, fish yield}

The development of human activity has caused hypertrophic conditions in Orbetello Lagoon. Decisions are based on increasing water circulation and on removal of part of the seaweed biomass. Consequently, important changes in the trophic structure of the ecosystem have taken place, with a significant increase in animal bomass. This fact has persuaded us that management of a lagoon environment with high production is possible.

Leppäkoski, E. (1980) **Man's impact on the Baltic ecosystem.** *Ambio* **9**:174-181.
{Baltic; oxygen; review; benthos; abundance; composition}

The drainage from about 250 river systems and the municipal and industrial wastes of some 17 million people sooner or later end up in the Baltic, which has been described as one of the most severely polluted sea areas in the world. Human activities have caused excessive eutrophication and resulted in damaging oil spills, and the chronic discharge of heavy metals and other toxic substances like PCBs which are seriously affecting the biomass of the Baltic. Even though the Baltic is one of the most thoroughly studied seas, much remains to be done and the author concludes that we will probably never fully understand it as a "natural and man-influenced system".

Levin, L. A. (1986) **Effects of enrichment on reproduction in the opportunistic polychaete *Streblospio benedicti* (Webster): A mesocosm study.** *Biological Bulletin* **171**:143-160.
{nutrients; reproduction; polychaete; MERL}

The influence of organic enrichment on growth and planktontrophic development of the spinoid polychaete *Streblospio benedicti* Webster was examined in two mesocosm experiments conducted at the MERL facility, University of Rhode Island. Specimens of *S. benedicti* were collected and their reproductive traits monitored near the conclusion of a two-year eutrophication experiment. Nutrient (N, P, and Si) enrichment at 8X and 32X the average aerial input into Narragansett Bay, Rhode Island, resulted in increases in body length, segment number, and length per segment, and a doubling of brood size in *S. benedicti* females. These increases were substantially higher during May (12°C) than August (20°C). Enrichment effects were stronger in the 8X than 32X nutrient treatment. In the sewage sludge experiment body size increased 20% over control values at the highest (8X) sludge treatment level (nitrogen loading equivalent to the 8X nutrient treatment) but no significant increase was noted at the 4X sludge level, which received half as much nitrogen as the 8X sludge treatment. Mean brood size increased by a factor of 4.6 over controls in the 8X sludge treatment and by a factor of 2.3 in the 4X sludge treatment. Within the range of adult body sizes observed, brood size enhancement occurred independent of increased length or segment in both nutrient and sludge enrichment treatments. The ability to translate elevated food supply directly into increased reproductive output may underly opportunistic dynamics in macrobenthos. Brood size enhancement of the magnitude observed probably contributes to the high *S. benedicti* densities found in polluted or organically enriched settings.

Liaci, L. S. (1980) **Pollution effects on marine biota.** *Memorie di Biologie Marina e di Oceanographia* **Suppl.10**:85-94.
{organic; colored tides; dinoflagellates}

Effects of organic substance pollution on marine organisms have been studied and related to eutrophication. The study refers effects of coloured tides due to Dinoflagellates on mollusca and fishes. The pattern of uptake and accumulation of some heavy metals was taken into consideration.

In fact, some specimens clearly showed that their uptake was directly proportional to the concentration of the heavy metal in the sea. Other factor such as salinity, temperature etc. and their role on uptake, accumulation and elimination of the metal are reported. Furthermore, the effects of pesticide pollution has been examined with special reference to the episode occurring in the harbour of Brindsi where methaldehyde was spilt.

As a consequence of pollution, skeletal and gill deformities, as also defects of reproduction, growth,

number of eggs and epidermal papillomas and hepatic tumors were observed. Alteration of the biocenosis and involutions of ecological series due to organic slimes have been noted.

Likens, G. E. (ed.) (1972) ***Nutrients and Eutrophication: The Limiting Nutrient Controversy (Proceedings of the Symposium on Nutrients and Eutrophication: The Limiting Nutrient Controversy, W.K. Kellog Biological Station, Michigan State University, 11-12 February, 1971).*** American Society of Limnology and Oceanography and the Allen Press, Lawrence, Kansas.
No abstract

LISS (1990) **Status report and interim actions for hypoxia management.** Long Island Sound Study, U.S. Environmental Protection Agency, {oxygen; hypoxia; modeling; impacts; sewage; runoff; management; nitrogen; Long Island Sound}
No abstract

Littler, M. M., D. S. Littler, and B. E. Lapointe (1986) **Baseline studies of herbivory and eutrophication on dominant reef communities of Looe Key National Marine Sanctuary.** NOAA, NOAA Technical Memorandum, NOS MEMD 1.
{algae; community; nutrient; limitation}
Presently, only limited knowledge is available regarding the dominant algal assemblages at Looe Key National Marine Sanctuary and the effects of herbivory and nutrient limitation in controlling the structure of these communities. The goals of this research are to: (1) provide a preliminary inventory and general distributional assessment of dominant algal communities, (2) initiate pilot studies of the effects of nutrient enrichment and grazing on structure of the reef communities and (3) contrast findings with other reef habitats for which comparable data are available. This research accomplishes these goals. Increases our understanding of ecological processes that influence dominant reef communities and provides data of use in management decisions directed towards preserving Looe Key National Marine Sanctuary in a natural state.

LoCicero, V. R. (ed.) (1975) ***Toxic Dinoflagellate Blooms (Proceedings of the First International Conference on Toxic Dinoflagellate Blooms, Boston, 4-6 November, 1974) (MIT Sea Grant Report MITSG 75-8).*** Massachusetts Science & Technology Foundation, Wakefield, Massachusetts.
No abstract

Lucht, F. and M. Gillbricht (1978) **Long-term observations on nutrient content near Helgoland in relation to nutrient input of the River Elbe.** *Rappots et Procès-verbaux des Réunions*
Counseil International pour L'Exploration de la Mer **172**:358-360.
{nutrients; Helgoland; River Elbe; phosphate; nitrogen; discharge; freshwater}
No abstract

Maclean, J. L. (1984) **Indo-Pacific toxic red-tide occurrences, 1972-1984.** In: A. W. White, M. Anraku and K.-K. Hooi (ed.) *Toxic Red Tides and Shellfish Toxicity in Southeast Asia.* Southeast Asian Fisheries Development Center and the International Development Research Center,
{toxic; red tide; bloom}
No abstract

Maclean, J. L. (1989) **Indo-Pacific red tides, 1958-1988.** *Marine Pollution Bulletin* **20**:304-310.
{red tides; Indo-Pacific; dinoflagellate; bloom}
A summary of recent toxic red tides in the southwestern Pacific region is given, showing that the dinoflagellate *Pytodinium bahamense* var. *compressa* remains the major causative organism of paralytic shellfish poisoning and is apparently continuing to spread around the region. *Noticluca scintillans* blooms occur in some countries and have been associated with mass mortality of fish. The raphidophyte *Chattonella* (=*Hornellia*) has been implicated in both fish and shrimp kills. A relationship with El Nino-Southern Oscillation (ENSO) events and some similarities with recent plagues of the crown-of-thorns starfish (*Acanthaster planci*) are discussed.

Maestrini, S. Y. and E. Granéli (1991) **Environmental conditions and ecophysiological mechanisms which led to the 1988 *Chrysochromulina polyepis* bloom: An hypothesis.** *Oceanologica Acta* **14**:397-413.
{bloom; nuisance; nitrogen; Scandinavian}
Information available on the 1988 *Chrysochromulina polyepis* bloom in Scandinavian coastal waters is evaluated. Special attention is paid to the early bloom stage and the sequence of both environmental and physiological mechanisms leading to the bloom, and a tentative, integrated scheme is given of causes which led to the observed events.
Environmental conditions favourable for *Chrysochromulina polyepis* are considered to have resulted from: a) an exceptionally high runoff of nitrogen-rich water in winter and early spring; b) strong mixing of the water column, immediately

followed by a long period of vertical stability and stratification; c) a diatom bloom 30% larger than usual, peaking around 20 March; and d) a second diatom bloom in mid April, largely dominated by *Skeletonema costatum*. These events combined to cause the euphotic layer to become silicate-exhausted, phosphorus-poor and fairly nitrogen-rich. The lack of silicate prevented diatom growth. Weak turbulence and strong stratification favoured growth of non-siliceous, motile nanoplankton.

C. polyepis is believed to have outcompeted co-existing algal species by producing a toxin acting first as a grazer repellent, while its cell density was still below 10^4 individuals l^{-1}. At the conjectured location of first appearance of the bloom (or at one of several locations), in the Skagerrak near Gullmar Fjord, the grazing repellent forced a shift of grazing to other algae around the latter part of April. With increased population density of *C. polyepis* (10^6 cells l^{-1}), the toxin then became sufficiently concentrated to affect directly not only by grazers, but all other organisms. From late April, the *C. polyepis* population increased free from grazing and other losses. In conditions of light and nutrient sufficiency, a high growth rate (corresponding to 0.8 div. d^{-1}) was achieved. Actively growing cells were buoyant and remained in the upper part of the water column.

With increasing population density (10^7 cells l^{-1}), nutrient became exhausted and self-shading decreased available light. By mid May, the growth rate had decreased to zero, and the population started to become senescent. *C. polyepis* deteriorated in physiological state, perhaps party because of self-poisoning, and this led to sinking. No further growth occurred, but cell densities showed higher values (several 10^7 cells l^{-1}, with maximum density between 5 and 10 m) because distribution became patchy both horizontally and vertically. At the end of May a significant part of the population had died, and cell leakage produced an increase in dissolved organic matter. The resultant lower turbidity and regenerated nutrients then allowed other flagellates and some diatoms to resume growth. The remaining *C. polyepis* cells sunk to the pycnocline (15-20 m), which acted as a barrier and greatly retarded this sinking, by which means the cells became concentrated, and produced the highest reported cell densities at the pycnocline. It is assumed that the bloom later sedimented.

Since relevant environmental conditions for the initiation of the bloom occurred over a very large area (75.10^3 km^2) and the dominant currents were not altogether consistent with the spreading of the bloom, polygenesis of the bloom should be considered a possibility.

To what extent long-term global change and eutrophication might have contributed to this exceptional bloom remains unclear. Since the production of the toxin seems to be favoured by phosphorus deficiency, however, a large input of nitrogen in combination with a reduction in the phosphorus loading is believed to have contributed indirectly to the bloom, by changing the nutrient status of the coastal waters from being nitrogen- to phosphorus-limited.

Mäkinen, A., I. Haahtela, H. Ilvessalo, and J. Lehto (1984) **Changes in the littoral rocky shore vegetation in the Seili area, SW Archipelago of Finland.** *Ophelia* **Suppl. 3**:157-166.
{macroalgae; seaweeds; species composition; rocky shore; Archipelago}

The littoral macrophyte communities were studied in 1968-69 by Ravanko at 23 rocky shores around Seili, SW archipelago of Finland. Four of these shores were revisited in 1981-82. The most noticeable finding was the altered species composition in the area. The number of green algae and phanerograms had increased and the number of brown and red algae decreased. The macrophyte biomass (fresh and dry weight m^{-2}) had drastically decreased because of the total lack of *Fucus vesiculosus*.

Mäkinen, A., J. Kääriä, and M. Rajasilta (1988) **Factors controlling the occurrence of *Furcellaria lumbricalis* (Huds.) Lamour and *Phyllophora truncata* (Pallas) Zinova in the upper littoral of the Archipelago of SW Finland.** *Kieler Meeresforschungen, Sonderheft* **6**:140-146.
{red algae; *Furcellaria*; *Phyllophora*; plankton; light; *Mytilus*; archipelago}

The influence of eutrophication on the occurrence of the red algae *Furcellaria lumbricalis* and *Phyllophora truncata* was studied in the sea area of Turku. Due to increased sediment load and planktonic production, light penetration in the water has decreased in the northern parts of the study area. Furthermore, the quality of the sea bottom has changed. Plots of 1 m^2 (N=100) in the upper littoral zone (0.5-6m) were studied by SCUBA diving, in order to investigate the factors controlling in the occurrence of the red algae. Two transects were situated in the eutrophicated area, and two in the reference area. In the plots, the percentage cover of each plant species and of *Mytilus edulis* was documented, and the Secchi disc visibility and depth was measured.

The numerical data were analyzed by correlation analysis and stepwise multiple regression analysis (BMDP2R). In the eutrophicated area, abiotic factors (percentage cover of plain bottom and bottom quality) explained 81.28% of the variation of red algae cover. In the reference area, the biotic factors (total number of species and *Mytilus* cover

in %) were the most important factors, explaining 66.4% of red algae cover.

Malone, T. C. (1984) **Anthropogenic nitrogen loading and assimilation capacity of the Hudson River estuarine system, USA.** In: V. S. Kennedy (ed.) *The Estuary as a Filter.* Academic Press, Orlando.
{nitrogen; phytoplankton; production; regeneration; Hudson River; sewage; capacity}

The coastal plume of the Hudson River estuary receives inputs of new nitrogen of sewage origin from the lower estuary and of offshore origin from adjacent coastal water. As a consequence of these inputs, the plume is one of the most productive coastal systems in the world's ocean. The extent to which such high production reflects the input of sewage-nitrogen depends on the capacity of phytoplankton to assimilate new nitrogen input to the plume and on the magnitude of sewage-nitrogen input relative to coastal inputs, i.e., on the capacity of the plume to "filter" inputs of new nitrogen.

The importance of new nitrogen varies seasonally relative to nitrogen recycled within the plume. Regenerated production increases from 10% of total phytoplankton production during winter to a maximum of 80% during summer. Sewage-nitrogen supports an average of 54% of new production during the spring bloom period (March-May) compared to 121% during the subsequent period of stratification (June-October) and 221% during winter (November-February). On an annual basis, these estimates indicate that phytoplankton production has increased by ca. 30% in response to the input of sewage-nitrogen.

These patterns have important implications in terms of cross-shelf transport and exchange. The supply of new nitrogen from offshore is highest during March-May and, along with sewage-nitrogen, appears to support a large seaward export of nitrogen in the form of phytoplankton biomass. In contrast, most new nitrogen is exported via plankton fraction of phytoplankton food webs during summer. Consequently, a relatively small fraction of phytoplankton production is available to fuel oxygen demand below the pycnocline during summer when assimilation capacity is greatest.

Malone, T. C. (1991) **River flow, phytoplankton production and oxygen depletion in Chesapeake Bay.** In: R. V. Tyson and T. H. Pearson (ed.) *Modern and Ancient Continental Shelf Anoxia.* The Geological Society, London, England.
{oxygen; phytoplankton; Chesapeake Bay; climate; anoxia}

Oxygen depletion leading to a summer anoxia in subpycnocline waters of the mesohaline reach of Chesapeake Bay has been a annual event for at least five decades. It is generally assumed that the spatial and temporal extent of bottom water anoxia has increased in response to higher phytoplankton productivity due to anthropogenic nutrient loading. However, synoptic observations of environmental conditions (river flow, temperature, salinity, dissolved oxygen, and nutrients) and phytoplankton from 1984 to 1988 indicate that oxygen depletion is not related to phytoplankton productivity on seasonal to interannual scales. Rather, nutrient loading is linked to oxygen depletion and summer anoxia via the spring accumulation of phytoplankton biomass which is more than sufficient to fuel oxygen depletion. Thus, interannual variability in the magnitude of summer anoxia is primarily driven by climate factors which govern vertical density stratification (mixing).

Mambeke, F. v., M. A. Bianchi, and G. Cahet (1984) **Short-term bacterial reactivity of nitrogen-enriched seawater of a eutrophic lagoon.** *Estuarine, Coastal and Shelf Science* **19**:291-301.
{bacteria; nitrogen; lagoon; growth; respiration}

We carried out, in September, a 24 h experiment to determine the potential reactivity of bacterial communities found in the sea water in Arcachon Basin (France). To create eutrophic systems, batches of seawater were enriched with 30 mg l^{-1} of either ammonium chloride or amino acids. Samples were taken every 3 h. Quantitative measurements were made of direct counts (AODC), biomass and ATP content. The heterotrophic bacterial communities were defined in terms of their catabolic potentialities and 'specific' diversity. Bacterial heterotrophic activity was established by measuring heterotrophic uptake and the mineralization percentage of labelled glucose or amino acids. From these data, ratios of AMP/ATP and P/B were calculated where P is the uptake of labelled substrate and B is the biomass.

After the nitrogen enrichment an increase of the respiration was seen at first. After 6 h, a biomass peak appeared associated with a continuous increase in the number of cells. Bacterial growth was concurrent with a qualitative modification of the community: UAI increased, and diversity dropped. A less diversified community resulted suggesting an immature ecological state (zymogenous bacteria). Low values of respiration percentage (20%) characterized high growth yields.

Marchetti, R. (1992) **The problems of the Emilia Romagna coastal waters: facts and interpretations.** In: R. A. Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication.* Elsevier, Amsterdam.
{gels, Adraitic Sea}

In this work, the two main problems concerning the upper Adriatic coastal waters are examined: the so-called algal blooms and the gels or excretions.

The former comprises the uncontrolled reporduction of microalgae causing an enormous mass of living matter which is incompatible with bathing, the decomposition of which causes oxygenc consuption and the death of the animals living on the sea bottom. This phenomenon is not new and is strongly connected with the polluting loads from the Po and other minor rivers along the coast. The latter - in respect to the upper Adriatic coatal waters during the summers of 1988 and 1989 - is due to the excretion of products which are normally emitted by algal cells with various functions and which, under circumstances still not completely understood, can reach enormous amounts as occurred in the summer of 1989. In the July of that year, it was calculated that about 10,000 km^2 of sea were covered by a layer of gel. The nature of the compounds of which the gel is formed hs been individuated in polysaccharides forming a structure incorporating 98-99% of water and which is completely harmless for humans. The most probable cause of the formation of these gels has been identified with the strong meteorological and climatic anomalies which characterized that period, traces of which have not been found in the data of the preceding 100 years.

The conclusions of this analysis are that, although for the first of the two events adequate action on the sources of contamination would have some probability of success, for the second there is no reasonable counter-action to be proposed at present.

Matsuoka, K. (1989) **Morphological features of the cyst of *Pyrodinium bahamense* var. *compressum*.** In: G. M. Hallegraeff and J. L. Maclean (ed.) *Biology, Epidemology and Management of Pyrodinium Red Tides*. Fisheries Department, Ministry of Development, Manila.
{dino; Pyrodinium; cyst}

Cysts of *Pyrodinium bahamense* var. *compressum* and several similar species are compared with special attention to differences in process characters. Keys to these species with and without references to archeophyle features are provided.

Mattson, J. and O. Lindén (1983) **Benthic macrofauna succession under mussels, *Mytilus edulis* L. (Bivalvia), cultured on hanging long-lines.** *Sarsia* **68**:97-102.
{benthic; macrofauna; succession; culture; sediments; *Capitella*; *Nucula*; opportunistic; abundance; biomass}

Cultures of the mussel *Mytilus edulis* produce accumulations of feces as well as mussels on the sea floor below the cultures. Changes in the sediment composition and benthic community structure under such cultures were studied over a three-year period on the Swedish west coast. Deposition of organic matter created several centimeters of sediment each year, resulting in production of H_2S in the uppermost layer. Originally, the benthic fauna was dominated (as per numbers of individuals) by *Nucula nitidosa* and (as per biomass) by *Echinocardium cordatum* and *Ophiura* spp. After 6-15 months of mussel culturing these and other species disappeared and were replaced by opportunistic polychaetes (*Capitella capitata, Sclelepis fuliginosa*, and *Microphthalmus sczelkowskii*). The abundance of these species fluctuated due to changes in the position of the redoxcline and their annual life cycle. The anaerobic sediments and mass occurrence of opportunistic polychaetes were localized to a zone under and 5-20m around the cultures. After harvesting of the mussels only limited recovery was observed after one and a half year.

McComb, A. J., R. P. Atkins, P. B. Birch, D. M. Gordon, and R. J. Lukatelich (1981) **Eutrophication in the Peel-Harvey estuarine system, Western Australia.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients*. Humana Press, Clifton, New Jersey.
{green algae; Cladophora; phytoplankton; nutrient; Australia}

The most obvious symptom of eutrophication in this estuarine system is a green alga, *Cladophora*, which was sparse in 1966 but now accumulates and rots on the shores. The work is part of a continuing study designed to asses the relationships between nutrient input and the growth of *Cladophora* and phytoplankton.

The system consists of two shallow basins, interconnected and linked to the ocean by a narrow channel. It is fed by three rivers; 90 percent of river flow occurs during four winter months.

Phytoplankton and water nutrient levels are low in summer, but high during and after an input of river nutrients in winter. Nitrogen:phosphorus ratios, regression analyses, and nutrient limitation assays suggest that nitrogen is potentially limiting in summer and autumn, phosphorus in winter and spring. The Harvey typically supports higher phytoplankton levels that the Peel. Diatom populations may be replaced by blue-green in summer in the Harvey.

Cladophora forms detached sphere of branched filaments and is only prominent in the Peel. Changes in biomass and growth of confined populations in the field, together with laboratory experiments, show that growth occurs when temperatures and light intensities are high, not in winter when water column nutrient levels are high. Water from between the algal spheres has increased levels of phosphorus compared with the water column above, emphasizing the possible importance of nutrient release from decaying material below. It is suggested that phytoplankton are important in trapping water-column nutrients

during and after river nutrient input, and that subsequent *Cladophora* and phytoplankton growth depends on nutrient recycling.

McErlean, A. J. and G. Reed (1981) **Indicators and indices of estuarine overenrichment.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients*. Humana Press, Clifton, New Jersey. {indicator; index; estuary; eutrophication}

Indicators and indices of nutrient overenrichment, which might be applied to the problems of estuarine overenrichment, are reviewed from the literature from the time of the national symposium on eutrophication (1968) to the present. While many existing methods have been applied to estuarine work and some new ones have been developed, there do not appear to be a large number of usable techniques for estuarine investigation.

McLusky, D. S., M. Teare, and P. Phizacklea (1980) **Effects of domestic and industrial pollution on distribution and abundance of aquatic oligochaetes in the Forth estuary.** *Helgoländer Meeresuntersuchungen* **33**:384-392.
{distribution; abundance; Oligochaetes; Forth estuary; macrofauna; diversity}

The Forth estuary is a major estuary on the east coast of Scotland; it receives effluents from domestic and industrial (petro-chemical and distilling) sources. Following a study on the distribution of macrofauna of the intertidal areas in relation to pollution (McLusky et al., 1978), this paper is concerned with the distribution and abundance of aquatic oligochaetes and the small polychaete *Manayunkia aestuarina* in relation to estuarine salinity, organic enrichment, and industrial effluent. In the most polluted parts of the estuary oligochaetes are the sole inhabitants of the mudflats; in other less polluted flats they are very abundant. In the least polluted parts the numbers of oligochaetes diminish as the numbers and diversity of macrofauna increases. Estimates of the production of oligochaetes are given.

Menesguen, A. (1992) **Modelling coastal eutrophication: the case of French *Ulva* mass blooms.** In: R.A.Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication*. Elsevier, Amsterdam.
{*Ulva*, macroalgae}

During the last decade, the excessive proliferation of *Ulva* sp. (Chlorophyceae) during spring and summer has been detrimental to recreational use of several beaches of Brittany (France). These worldwide mass blooms are well known in eutrophicated lagoons (e.g. Venice, Tunis), but are paradoxical along open beaches with a large tidal range and low terrestrial nutrient inputs. Numerical modelling of the coupled physical and biological aspects clearly explains the Ulva mass blooms by the dynamic trapping of water masses in bays where tidal residual drift vanishes, and shows the main responsibility to be the increase of nitrogen inputs (from agricultural sources) in triggering the recent magnification of a natural phenomenon.

Messner, U. and J.-A. v. Oertzen (1990) **Recent changes in the phytal zone of Greifswald Bay.** *Limnologica* **20**:183-186.
{Greifswald Bay; submerged vegetation; coverage; plankton; light; red algae}

The phytal zone of Greifswald Bay, a coastal water in the northeast of the GDR was studied from spring to autumn in 1985. The submersal vegetation was mapped, and it was found that the coverage of the bottom had decreased from 90% (Seifert, 1938) to about 10%. The authors consider increasing plankton production and the deterioration of light conditions at the bottom owing to eutrophication are the main causes of this decline. Quantitative studies of the macrofauna of the phytal zone show that the zone covered by red algae [mainly *Furcellaria fastigiata* (L.) Lamour in the investigation area] is populated by a large number of species in various growth stages. The fauna inhabiting the less ramified *Potamogeton pectinatus* L. and *Zostera marina* L. stands was less diversified. It can be assumed that the decline of the red algae stocks to insignificant remains has led to major changes in the food web and energy flow. Although no quantitative data can yet be offered, it must be feared that loss of this habitat threatens the continued existence of a herring population there. The dense bluegreen blooms in mid-summer may restrict the use of these waters by holiday makers for bathing. The changes that have taken place thus seem to jeopardize many of the uses to which Greifwald Bay has been put.

Millner, R. S. (1980) **Pulp and paper mill waste pollution in the Swale, a tidal channel on the east coast of England.** *Helgoländer Meeresuntersuchungen* **33**:366-376.
{pulp; paper; oxygen; benthos; abundance}

The effect of pulp and paper mill waste discharges in the Swale, a tidal channel on the southeast coast of England, has been studied. A pulsing tidal movement in the Swale results in effluent being trapped within the estuary for up to 20 days. This has resulted in adverse effects on the quality of the water and sediment along a substantial part of the estuary with the greatest effect occurring east of the mill in the direction of the residual current. A reduction in the dissolved oxygen concentration occurred along a 13-km stretch of the estuary with mean values falling to 53% saturation near the mill. High levels of organic matter in the sediment reflect the deposition of material from the mill effluent stream and loss on ignition values of up to

12 % were found east of the mill, falling to 5 % within 4 km northwest of the mill. The macrofauna of the intertidal mudflats was typical of a stressed environment with a low number of species and with a few being represented by large numbers of individuals. The dominant species was the sabellid polychaete *Manayunkina aestuarina* which reached peak numbers of over 1.5 million m-2 1.5 km east of the mill. An increase in the total biomass near the mill is thought to be associated with organic enrichment from the mill wastes.

Mills, C. A., S. I. Heaney, C. Butterwick, J. E. Corry, and J. M. Elliott (1990) **Lake enrichment and the status of Windermere charr, *Salvelinus alpinus* (L.).** *Journal of Fish Biology* **37 (Supplement A)**:167-174.
{fish; lake; trophic status; nutrient; enrichment; deoxygenation; feeding}

All English population of Artic charr, *Salvelinus alpinus* (L.), are found in the Lake District (northwest England). There are at least four races of charr in Windermere, the largest lake in England; the North and South basins of the lake each contain two distinct races that spawn in autumn and spring respectively. The spring spawners in both basins probably represent less than 15% of the total population in the lake.

Changes in the population density of charr in the lake are described briefly and examined in relation to the trophic status of the lake. Other factors that could possibly affect the charr population are reviewed, especially the influence of climate change.

Mingazzini, M., A. Rinaldi, and G. Montanari (1992) **Multi-level nutrient enrichment bioassays on Northern Adriatic coastal waters.** In: R. A. Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication.* Elsevier, Amsterdam.
{species abundance, nutrient enrichment, Adriatic Sea, limitation}

In order to evaluate the role of nutrients on phytoplankton growth in Northern Adriatic coastal waters, nutrient enrichment bioassays at three different complexity levels of the experimental system were undertaken. The algal growth responses both to inorganic (P and N) and to organic (group B vitamins) added nutrients were measured on *Skeletonema costatum* and *Prorocentrum micans*, which are considereed the most representative species in local blooms within the two groups of diatoms and dinoflagellates, respectively. The results obtained from the simplest experimental level, in which the cultured algae were added to filtered sea water, are compared with the superior levels in which the same species were naturally abundance in phytoplankton communities of tested samples. A good agreement has been found in data sets, indicating phosphorus as the primary stimulating algal growth nutrient while, from a compositional point of view, diatoms always accounted for most of the phytoplankton increase. A similar effect of diatom dominance has also been observed in autumn assays conducted on a differently shaped community (represented by *Chaetoceros* spp. and *Gymnodinium* sp.) while nitrogen and phosphorus together stimulated phytoplankton growth.

Montgomery, R. T., B. F. McPherson, and E. E. Emmons (1991) **Effects of nitrogen and phosphorus additions on phytoplankton productivity and chlorophyll *a* in a subtropical estuary, Charlotte Harbor, Florida.** U.S. Geological Survey, Water-Resources Investigations Report 91-4077.
{nitrogen; phosphorus; phytoplankton; productivity; estuary; Charlotte Harbor}

The response of natural phytoplankton assemblages in a subtropical coastal plain estuary, Charlotte Harbor, Florida, to inorganic nitrogen and phosphorus additions was determined from measurements of relative changes in both the uptake of carbon-14 and concentrations of chlorophyll *a*. The effects of nitrate plus nitrite nitrogen, ammonia nitrogen, and orthophorus additions over a series of concentrations were evaluate through *in situ* experiments conducted during periods of seasonally low and high river inflows. The responses to nutrient additions were evaluated for three different size fractions of phytoplankton. Relative changes of phytoplankton carbon uptake and chlorophyll-*a* concentrations were highly variable with regard to season, location, nutrient, and size fractions.

Within areas of the estuary characterized by lower salinities, phytoplankton exhibited a distinct seasonal pattern to additions of inorganic nitrogen. Under seasonally high freshwater inflow, phytoplankton show little response to inorganic nitrogen additions, whereas under seasonally low inflow, phytoplankton responded to the inorganic nitrogen additions. The seasonally high freshwater inflow increased ambient inorganic nitrogen concentrations and water color. The high water color greatly reduced light penetration in the water column and limited phytoplankton productivity. The effect of nutrient additions in the higher salinity reaches of the estuary indicates that, under normal conditions, these areas are continually nitrogen limited. During periods of high freshwater inflow during the summer months, the estuary can be divided conceptually into a low-salinity zone where phytoplankton production is mediated by light availability, as determined by high water color, abd a high-salinity zone where phytoplankton production is nitrogen limited. Seasonal nutrient concentration data and

comparisons among inorganic nitrogen inputs and observed phytoplankton productivity support the experimental bioassay results. Each of these lines of evidence indicates that, exclusive of seasonal riverine influences that affect light penetration of the water column, nitrogen availability normally limits phytoplankton production within the Charlotte Harbor estuarine system.

Moore, C. G. and T. H. Pearson (1984) **Response of a marine benthic copepod assemblage to organic enrichment.** Proceedings of the Second International Conference on Copepod, Ottawa, Canada.
{benthic; copepods; assemblage; sewage; Scottish coast; density}
No abstract

Mori, K. (1979) **Effects of artificial eutrophication on the metabolism of the Japanese oyster Crassostrea gigas.** *Marine Biology* **53**:361-369.
{oyster; *Crassostrea*; gonads; development; spawning; fats; mortality; Matsushima Bay; Japan; growth}
Matsushima Bay, one of the richest oyster-culture areas in Japan, is subject to heavy artificial eutrophication, mainly from the inflow of city and factory sewages. The physiological activity in the oyster *Crassostrea gigas* in hanging cultures (i.e. suspended in wire-mesh cages) in this embayment declined markedly with progressive development of the gonads; this decline in activity coincides with eutrophication-induced accumulation of fatty material in the epithelia of the digestive respiratory substrates in order to maintain its increased physiological needs. However, the fats are inefficient energy sources for the oyster and hence, during each spawning season, 50% mortality occurs. In addition, such phenomena as overmaturation of the gonad and disturbance of the lipid and steroid metabolism seem to accelerate this mass mortality. On the basis of the results, the author has compiled a schematic diagram which illustrates the possible causes of mass mortality among *C. gigas* in an eutrophic environment such as Matsushima Bay.

Morton, B. (1989) **Pollution of the coastal waters of Hong Kong.** *Marine Pollution Bulletin* **20**:310-318.
{Hong Kong; Victoria Harbour; Tolo Harbour; oxygen; phytoplankton; algae; *Ulva*; red tides; benthos; abundance; benthos; fish}
This paper reviews the available literature on Hong Kong's marine coastal pollution. The highly urbanized and industrial cities of Victoria and Kowloon pollute Victoria Harbour with untreated domestic sewage and industrial effluents. The development of new cities, Shatin and Tai Po, on the shores of the partially enclosed Tolo Harbour have created Hong Kong's first critical marine environmental problem, secondary sewage treatment schemes having been inadequate to prevent this. Agricultural wastes (notably pig manure) compound the problem in Tolo Harbour, but virtually everywhere in the New Territories lowland water courses are polluted from this source leading to the degradation of most enclosed bays. Sufficient evidence is at hand to understand local long-term trends in environmental degradation. Hong Kong's coastal water are polluted generally; Tolo Harbour, grossly so. Concern exists regarding the safety of bathing beach water quality, contaminated sea food, and the overall quality of other enclosed bodies of water in Hong Kong.

Moshiri, G. A., N. G. Aumen, and W. G. Crumpton (1981) **Reversal of the eutrophication process: A case study.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients*. Humana Press, Clifton, New Jersey.
{bloom; dinoflagellates; fishkill}
Bayou Texar, Pensacola, Florida, is a bayou estuary which was advancing toward eutrophy, due to nutrient loadings from various sources. The occurrence of characteristic symptoms of eutrophication, coupled with the closing of the bayou for water contact recreation, led to the initiation of an intensive seven-year study. Initial results indicated that Carpenter's Creek is a prime source of most nitrogen species and that an exchange exists between dissolved phosphates and those adsorbed onto sediments. Carbon fixation rates varied, with the stations closest to Carpenters Creek exhibiting the most productivity. It also appeared that nitrates may be more important in controlling rates of carbon fixation than phosphates. An ensuing study directed at phosphate exchange suggested that reducing conditions in the muds cause substantial release of iron-bound PO_4 from the sediment-water interface followed by adsorption onto particles in the aerobic flocculent layer above the interface. This mechanism could allow sufficiently rapid exchange of PO_4 between sediment and water resulting in a low, stable concentration in the water as observed. Other investigations involving bacterioplankton, dissolved glucose, and heterotrophic production indicated that algal primary productivity is the major source of dissolved glucose. A final study demonstrated a paucity of benthic macroinvertebrates, probably due to a graded suspension of particles at the sediment-water interface and the absence of a sharply defined bottom. The zooplankton community exhibited a low diversity while numbers of individual species were high. The phytoplankton community was composed primarily of dinoflagellates, with diatoms, cryptophytes, chlorophytes and

microflagellates occurring in lesser quantities. It was also suggested that the importance of toxins from algal blooms to fish kills may be greater than previously indicated. Specific recommendations made after the fourth year of study were implemented in most part and led to a substantial improvement of water quality and the subsequent opening of the bayou to the public for recreational use.

Murakami, A. (1973) **Red tide in the Seto Inland Sea.** *Information Bulletin on Planktology in Japan* **19**:131-132.
{Japan; nitrogen; phosphorus; red tide; bloom}

In the past 10 yr, a serious situation of red tide has developed in the Inland Sea. The probable cause is excessive eutrophication. In the Inland Sea, the concentrations of soluble inorganic N and P in seawater have increased greatly compared with concentrations found 20 yr ago. The only fundamental countermeasure of such red tide is to eliminate the source of excessive eutrophication.

Musayeva, E. I. (1985) **Mesoplankton near the Bulgarian Coast.** *Oceanology of the Academy of the Sciences of the USSR* **25**:647-652.
{zooplankton; biomass; mesoplankton}

The distribution of mesoplankton in Burgas Bay in 53 bottle samples taken in October-November 1982 is discussed. A drop in the total biomass of zooplankton from north to south can be traced on a northern meridianal section (Cape Krotiriya to Cape Kaliakra), probably resulting from a decrease in the eutrophication effect of the Danube in this direction. The plankton off the Bulgarian coast was in typical autumn condition. In the southern part of Burgas Bay, where there is a discharge current carrying eutrophicated sewage from the city of Burgas, various stages in the development of the community, from a young community in the inner end of the bay to a mature one at its outlet, were observed.

Myers, V. B. and R. I. Iverson (1981) **Phosphorus and nitrogen limited phytoplankton productivity in northeastern Gulf of Mexico coastal estuaries.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients*. Humana Press, Clifton, New Jersey.
{nitrogen; phosphorus; limitation; phytoplankton; productivity; nutrients}

An understanding of nutrient limitation of estuarine phytoplantkon growth is important in making environmentally sound decisions concerning watershed development and the use of aquatic environments for waste disposal. Experiments to determine nutrient limitation of phytoplankton productivity were conducted monthly during the summers of 1975 and 1976 in several shallow north Florida coastal and estuarine systems by inorganic carbon-14 uptake and phosphorus-32 bioassays. The results of these nutrient enrichments experiments suggest that phosphorus is frequently more important than nitrogen in limiting phytoplankton productivity in nearshore northern Gulf of Mexico. A multiple regression model was constructed to determine which combinations of environmental and nutrient variables could explain the most variation of phytoplankton productivity in these coastal systems. The final regression model was:

P.P. = 32.1 + 48.4 S.R.P. = 0.54 Salinity

where: P.P. is phytoplankton productivity in ugCl^{-} 1 hr^{-1}, S.R.P. is soluble reactive phosphate in ug-atom PO_4 l^{-1}, and salinity is part-per thousand. This model explained 64 percent of the variation in phytoplantkon productivity.

Nitrogen has been identified as the primary limiting nutrient for phytoplankton in coastal waters and it has been proposed that the removal of phosphorus from marine waste discharges will have little impact on the control of eutrophication. The observation that phosphorus is important in limiting phytoplankton productivity in these coastal and estuarine areas suggests that water quality planning for the coastal zone is best done on a regional basis, with consideration given to local nutrient cycling processes.

Nakanishi, H., M. Ukita, M. Sekine, M. Fukagawa, and S. Murakami (1992) **Eutrophication control in the Seto Inland Sea.** In: R. A. Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication.* Elsevier, Amsterdam.
{fish yield, Japan}

The Seto Inland Sea, surrounded by the four large islands of Honshu, Shikoku and Kyushu, is famous for its scienic beauty and coastal fishery. However, the beauty of this areas has been threatened by a high concentration of human population and industry which contribute to water pollution and euthrophication problems.

In this study, we examine the present water pollution problems of this area; we have studied the history of water pollution in the Seto Inland Sea, the influx of nutrients into all sections of this area and the relationship between euthrophic levels and fishery productions in each section of the Seto Inland Sea. We have also analyzed the secondary organic pollution which is a result of the primary photosynthesis production and the comprehensive eutrhopic situation of the sea and each of its sections, in comparison with other coastal seas in Japan.

From the results of this evaluation, we propose the following four strategies for eutrophication

control in the Seto Inland Sea: (1) Elimination of nitrogen (N) and phosphorus (P) discharging loads by means of controlled chemical fertilizer consumption and recycling of human and livestock excreta as fertilizer (as a conclusion of the budget of N and P in Japan); (2) Consolidation of treatment facilities for the point sources of pollutants such as domestic sewage and industrial waste water; (3) Diversion of the discharging N and P loads from the Seto Inland Sea into the adjacent open sea aras of Japan w;hich have a larger carrying capacity through the exclusion system such as a sewer system (through comparison with each adjacent sea area of Japan); (4) Dredging of sediments over the polluted zones.

Nalewajko, C. and M. A. O'Mahony (1989) **Photosynthesis of algal cultures and phytoplankton following an acid pH shock.** *Journal of Phycology* **25**:319-325.
{pH; acid; lake; phytoplankton; photosynthesis}

In acidifying lakes, pH decreases abruptly in response to acid precipitation events. We tested the hypothesis that in comparison to a circumneutral lake, phytoplankton photosynthesis in an acidifying lake is less sensitive to a rapid decrease in pH (acid pH shock).

Phytoplankton in Plastic Lake, which is undergoing acidification, was characterized by a predominance of Pyrrophyta, and phytoplankton photosynthesis decreased to a lesser extent in response to an acid pH shock than the photosynthesis of populations from St. Nora Lake, a circumneutral lake located nearby, in which Pyrrophyta were not abundant. Rates of phytoplankton photosynthesis in acid pH shock experiments were significantly correlated with hydrogen ion but not with dissolved inorganic carbon (DIC) concentrations.

Depression of photosynthesis following an acid pH shock occurred in axenic cultures of *Chlorella pyrenoidosa* Chick but was not observed in axenic cultures of the acidophilic alga *Chlorella saccharophila* (Krug.) Nadson or in three species isolated from Plastic Lake. However, the three isolates were not acidophilic during growth. We conclude that phytoplankton in acidifying lakes consists predominantly of species which are tolerant to acid pH for short periods (hours) but cannot grow at these pHs.

Nehring, D. (1981) **Phosphorus in the Baltic Sea.** *Marine Pollution Bulletin* **12**:194-198.
{Baltic Sea; phosphorus; Gotland Sea}
No abstract

Nehring, D. (1984) **The further development of the nutrient situation in the Baltic proper.** *Ophelia* **Suppl.3**:167-179.
{nitrogen; phophorus; nutrient; Baltic; hydrographic}

Long-term nutrient trends were studied in the deep water (in general 1958-1982) and in the winter surface layer (in general 1958-1983) of the Baltic proper. Phosphate accumulated in the deep water, on average, over the whole period under investigation, whereas nitrate has decreased significantly since 1979. The concentrations of these nutrients also increased in the winter surface layer. The highly significant overall trends in this layer correlated closely with an increase in salinity. The reasons for the long-term variations in nutrients and the consequences of the eutrophication observed are briefly discussed.

Nehring, D. (1992) **Eutrophication in the Baltic Sea.** In: R. A. Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication.* Elsevier, Amsterdam.
{nitrogen, phosphorus, oxygen, Baltic Sea}

Eutrophication is identified as one of the most serious problems in the Baltic Sea. Trend studies covering the period 1958-89 show increasing phosphate and nitrate concentrations in the surface layer in winter and in the deep water below the permanent halocline. Consequences of the eutrophication are discussed with respect to the biological productivity and the determination of the oxygen conditions in stagnant Baltic deep waters. Conditions for eutrophication in the Baltic Sea are compared with those in the Mediterranean Sea.

Nehring, D., S. Schulz, and W. Kaiser (1984) **Long-term phosphate and nitrate trends in the Baltic Proper and some biological consequences: A contribution to the discussion concerning the eutrophication of these waters.** *Rappots et Procès-verbaux des Réunions*
Counseil international pour L'Exploration de la Mer **183**:193-203.
{Baltic; nutrients; nitrogen; phosphorus; fish; oxygen; primary production; phytoplankton; zooplankton}

The phosphate and nitrate levels in the winter surface layers of the central Arkona, Bornholm, and southern Gotland Seas roughly tripled from 1969 to 1978 (phosphate: 0.2 to 0.6 umol l^{-1}; nitrate: 1.5 to 4.0 umol l^{-1}). In the deep water below the halocline, long-term accumulation of these nutrients was also found in the Gda´nsk, Gotland, Fårö, and Landsort Deeps. This process was most significant at a depth of 100 m in the Gotland Deep, where on average phosphate increased from about 1 to 2.5 umol l^{-1} between 1958 and 1978, and nitrate from about 4 to 8 umol l^{-1} between 1969 and 1978.

The biological effects of the nutrient increase on the pelagic system of the Baltic are obviously low and masked by inadequate observation frequency or by annual fluctuations. On the other hand the increasing yields of the Baltic fisheries do not seem to be the result of the growing fishing effort alone but are the consequence of higher biological production.

Neilson, B. J. and L. E. Cronin (ed.) (1981) ***Estuaries and Nutrients.*** Humana Press, Clifton, New Jersey.
No abstract

Nielsen, A. and G. Ærtebjerg (1984) **Plankton blooms in Danish waters.** *Ophelia, Supplementum* **3**:181-188.
{phytoplankton; primary production; nitrogen; bloom}

In the past fifteen years there seems to have been an increase in the occurrence of massive plankton blooms along the coast of the North Atlantic Ocean, including the North Sea, the Kattegat and the Belt Sea. Some of the plankton blooms have caused fish mortality, either directly by poisoning of the fish, or indirectly by suffocation due to oxygen deficiency. It is indicated in the paper that the increased pollution load on the coastal zone may play an important role in the development of massive plankton blooms in Danish waters.

Niemi, A. (1972) **Observations on phytoplankton in eutrophied and non-eutrophied archipelago waters of the southern coast of Finland.** *Memoranda Societatis pro. Fauna et Flora Fennica* **48**:63-74.
{phytoplankton; Finland; biomass; composition}

A comparison is made of the summer course of the biomass and the composition of the phytoplankton populations of 3 archipelago zones in clean and polluted conditions off the southern coast of Finland. In summer low phytoplankton biomass follow a vigorous spring bloom in the oligotrophic areas. Strongly eutrophic waters are characterized by high biomasses (primarily due to the blue-green alga *Oscillatoria agardhii*) persisting throughout the summer. In addition to phytoplankton biomass, the composition of phytoplankton and the occurrence of certain indicator group may be a good criteria of the quality and level of eutrophication.

Nienhuis, P. H. (1983) **Temporal and spatial patterns of eelgrass (*Zostera marina* L.) in a former estuary in the Netherlands, dominated by human activities.** *Marine Technology Society Journal* **17**:69-77.
{eelgrass; submerged vegetation; Netherlands}

A review is given of the temporal and spatial patterns of the eelgrass population in Grevelingen estuary, SW Netherlands, after it has been transformed into a salt-water lake. In summer 1978, after a development of 8 years of opportunistic colonization by seeds and rhizomes, all potential habitats in the lake were occupied and covered 44 km^2 of sheltered sediment areas with a water depth of 0-2.5 m. After man-induced changes in environmental conditions the eelgrass population dropped down in 1980 to about half the 1978 situation. The possible causes of this sudden decline have been discussed, *viz* seed production and germination, water temperature, wasting disease, transparency of the water and macro-algal competition. The most plausible explanation for mass decline of eelgrass in Lake Grevelingen in 1980 is associated with an increase in organic matter deposition on the bottom, following a change in nutrient loading of the lake, causing rapid deoxygenation and toxification of the sediments, and consequent die back of rhizomes and roots. Water temperature and salinity may have played a minor role in the eelgrass wax and wane.

Nilsson, P., B. Jönsson, I. L. Swanberg, and K. Sundbäck (1991) **Response of marine shallow-water sediment system to an increased load of inorganic nutrients.** *Marine Ecology Progress Series* **71**:275-290.
{sediment; nutrients; microflora; production; biomass; composition; productivity; meiofauna; bacteria; grazing; oxygen}

An outdoor experimental system was used to investigate the effect of an increased load of inorganic nitrogen and phosphorus on the lower trophic levels of the food web of a shallow-water sandy sediment. Estimates of structural changes were based on relationships between the biomass of autotrophs, heterotrophic bacteria and meiofauna and their qualitative composition. Effects on the functions of the sediment community were assessed by measuring primary and bacterial productivity and meiofaunal grazing rates using radiolabelling, as well as measuring changes in oxygen and nutrient fluxes and carbon pools. The sediment system responded within 2 to 3 wk to the nutrient enrichment. Meiofauna biomass increased, resulting in higher relative importance of oligochaetes and harpacticoid copepods. Primary productivity increased faster than meiofaunal grazing, resulting in an increase of microalgal biomass by a factor of 4. Diatom and filamentous cyanobacteria were favoured by the increased nutrient levels. The stimulated photosynthetic activity has a negative feedback on the producing sediment layer, which was lifted off by oxygen bubbles entrapped in the mucus-rich top most layer. Stimulated growth of the filamenous green alga *Enteromorpha clathrata* resulted in a biomass of ca 2 g C m^{-2} after 4 wk, which was more than 2 times the biomass of microautotrophs living in the sediment. Bacterial

productivity responded only weakly to the nutrient additions and the grazing pressure on bacteria was high during the whole 4 wk experiment. Meiofauna removed on average about 4 % of the microalgal biomass and 12 % of the bacterial biomass per day in treatments with increased nutrient levels. Although autotrophic organisms were more important carbon sources than bacteria for meiofauna, the impact of grazing on microautotrophs was small, whereas grazing may be important in regulating bacterial growth. Measurements of ammonium, nitrate, phosphate and silicate flux showed that shallow-water sediment with a high primary productivity in the top layer functions as a sink for inorganic nutrients. In terms of biomass, the addition of nutrients led to a dominance of meiofauna. However in terms of productivity, autotrophs predominated and thus, during the initial phase of increasing nutrient levels, the entire sediment system was dominated by autotrophic processes.

Nishijima, T. and Y. Hata (1991) **Growth potentials of red tide phytoplankters in coastal seawater by AGP assay.** *Marine Pollution Bulletin* **23**:175-179.
{red tide; algal bloom; growth potential; nutrients}

The method for the preparation of algal inocula for AGP (algal growth potential) assay was studied, and the growth potentials and growth limiting nutrients of red tide phytoplankters in coastal seawater were determined. The red tide phytoplankters *Heterosigma akashiwo*, and *Skeletonema costatum* were used as assay organisms. When using AGP assay the growth potentials were found to be dependent on the preparation of the algal inoculm. Accurate growth potentials were obtained only when sufficiently nutrient-starved cells were inoculated into the samples. Insufficient starvation of the cells resulted in an overestimation. Based from the results of the assay methods, the growth potentials of Osaka Bay water were about 10^4 cells/ml for *H. akashiwo* and about 10^5 cells/ml for *S. costatum*. Moreover, the water was found to have a potential to develop to the density of red tide for both organisms. The growth limiting nutrients of the water for both red tide organisms were determined to be nitrogen and phosphorus.

Nixon, S. W. (1980) **Between coastal marshes and coastal waters - A review of twenty years of speculation and research on the role of salt marshes in estuarine productivity and water chemistry.** In: P. Hamilton and K. B. MacDonald (ed.) *Estuarine and Wetland Processes*. Plenum Publishing Co., New York.
{marsh; estuary; nitrogen; phosphorus}
No abstract

Nixon, S. W. (1981) **Remineralization and nutrient cycling in coastal marine ecosystems.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients*. Humana Press, Clifton, New Jersey.
{nutrients; remineralization; cycling}

Our views of remineralization and nutrient cycling in coastal marine ecosystems have changed considerably over the last 30 years. The major trend has been an increasing appreciation for the complexity of processes involved, including some marked changes in our perception of the association between bacteria and particulate matter in the sea. Among the more recent development in this area is a growing awareness of the importance of the coupling between benthic and pelagic communities in coastal waters. There appears to be a strong linear correlation between the organic matter produced in the overlying water and the amount of organic matter consumed on the bottom in almost all of the coastal environment for which annual data are available. The large amount of organic matter consumed by the benthos (perhaps 25-50 percent of that produced) is associated with a large flux of inorganic nutrients from the sediments to the overlying water. The stoichiometry of net benthic nutrient regeneration differs from that of pelagic regeneration, however, and simple Redfield type models probably cannot be applied. The amount of fixed inorganic nitrogen returned to the water across the sediment-water interface appears to be about half of that expected on the basis of the flux of phosphorus. This behavior, along with the fact that an appreciable amount of organic matter in coastal waters gets remineralized on the bottom, contributes to the low N/P ratio that is characteristic of these areas and may be responsible for the observation that nitrogen is a direct measurements of the flux of dissolved N_2 across the sediment-water interface indicate that denitrification is probably responsible for the loss of fixed nitrogen during decomposition in the sediments. If this is a widespread phenomenon, estuaries, bays, and other coastal waters may be major sinks in the marine nitrogen cycle and important terms in the global nitrogen budget. However, the fact that eutrophication appears to be an increasing problem in many estuaries is dramatic warning that anthropogenic nutrient inputs can overwhelm the recycling and remineralization processes in coastal waters.

Nixon, S. W. (1982) **Nutrient dynamics, primary production and fisheries yields of lagoons.** *Oceanologica Acta Supplément* **4**:357-371.
{lagoon; primary production; fish yield; lake; nutrient}

There is a great range in many of the characteristics of the lagoons which make up 13% of the world coastline, including size (a few ha up to 800,000), shape, annual temperature range, fresh water input, exchange with the sea, anthropogenic inputs, and human uses. While these differences appear to have a marked influence on the species composition of lagoon ecosystems around the world, there are also some remarkable similarities in nutrient dynamics, the standing crop of phytoplankton, annual primary production, and fisheries yields of many lagoons. For example, in many of the systems reviewed, the annual phosphate cycle was similar in timing and magnitude, primary production amounted to some 200-400 g C m^{-2} yr^{-1}, and fisheries landings were on the order of 50-100 Kg ha^{-1} yr^{-1}. There appears to be an empirical correlation between primary production and fisheries yields in a great variety of marine systems which may be similar in slope to that found in large lakes. However, the yield of marine systems at any given level of primary production appears to be 10-20 times greater. The yield of lagoon fisheries per unit area is commonly as high or higher than that from the most productive coastal and offshore fisheries.

Nixon, S. W. (1987) **Chesapeake Bay nutrient budgets - a reassessment.** *Biogeochemistry* **4**:77-90.
{Chesapeake Bay; nutrient; budget; nitrogen; phosphorus; silicon; management}

Recently published annual mass balances or budgets for nitrogen, phosphorus, and silicon in Chesapeake Bay have pictured the estuary as retaining a very large fraction, perhaps all, of the nutrients that enter from land drainage, the atmosphere, and anthropogenic discharges. However, those budgets have been based on estimates of the net exchanges of nutrients at the mouth of the Bay or on the rates of accumulation of nutrients and sediments calculated from the distribution of various geochemical tracers in the sediments. While conceptually straightforward, the first approach is subject to large errors because it requires the determination of a small "signal" against a large background of tidal "noise". The second approach has led to overestimates of the nutrient trapping efficiency of the bay because tracer-derived sediment deposition rates have been multiplied by the surface area of the whole bay or various parts of the bay rather than by the smaller area of active sediment deposition. This approach is also incorrect because the average, long-term rates of sediment deposition measured by the geochemical tracers, including major floods, have been compared to shorter-term records of nutrient input.

The more appropriate calculation of nutrient retention based on contemporaneous measurements of nutrient and sediment input and the chemical composition of sediments accumulated in the estuary shows that Chesapeake Bay retains only some 3-6% of the nitrogen, 11-17% of the phosphorus and 33-38% of silicon brought into its waters during a year in which no major flood occurred.

This behavior suggests that current problems of estuarine eutrophication are more a consequence of present nutrient inputs than an inevitable or inescapable legacy of past enrichment. It also follows that the management or manipulation of nutrient loadings to estuaries may lead to a more rapid response in environmental quality than previously predicted.

Nixon, S. W. (1988) **Physical energy inputs and the comparative ecology of lake and marine ecosystems.** *Limnology and Oceanography* **33**:1005-1025.
{lake; estuary; physical energy; tide; nutrient}

Although freshwater and marine systems both receive light and heat energy from the sun and are mixed by the wind, only marine systems receive additional mechanical energy from the tide. This input is very small relative to the flux of solar energy but may exceed that from wind. Some obvious physical consequences of this additional energy input include the development of intertidal habitats, the presence of stronger currents, and more vigorous vertical mixing. It is argued that these (and perhaps other) consequences lead to coastal marine ecosystems which differ in a number of important ways from temperate lakes.

There is some evidence that coastal marine systems generally maintain a larger standing crop of benthic animals and that these fauna are more effective in mixing the bottom sediments. As a result of better sediment mixing (and perhaps warmer and better oxygenated bottom water), organic matter deposited on the bottom of coastal marine areas may be more completely metabolized and less C, N, and P retained than in lake sediments. Materials are more tightly bound to particles, like many metals, may behave similarly in lake and marine sediments. Although many lakes are strong sinks for nutrients and metals, marine bays and estuaries may be much less effective in retaining nutrients.

A major consequence of the input of tidal energy appears to be a more intensive yield of fish from marine systems compared with temperate lakes. The data suggest that this more intense yield is not due to the size or interconnection of marine areas or to higher primary production. Rather, the efficiency of transfer of primary production to fish appears to be greater. Tropical lakes appear more like marine systems in this regard, and this may be related to lower thermal stability and more effective wind

energy transfer because of a small Coriolis effect at low latitudes.

Nixon, S. W. (1989) **An extraordinary red tide and fish kill.** In: E. M. Cosper, V. M. Bricelj and E. J. Carpenter (ed.) *Novel Phytoplankton Blooms Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms.* Springer-Verlag, Berlin.
{Narragansett Bay; red tide; sewage}
No abstract

Nixon, S. W. (1990) **Quanifying the relationship between nitrogen input and the productivity of marine ecosystems.** Eighth Marine Technology Conference and International Symposium for Ecology, Tokyo, August 1990, and Shimane, September 1990, Japan.
{nutrients; productivity; relationship; estuary; nitrogen}

The concept that the input of dissolved inorganic nutrients, especially nitrogen, regulated the basic level of primary production and, hence, the yield of fish from marine ecosystems developed in Western Europe and Scandinavia about a century ago. This "agricultural model" of marine production was conceived only after quantitative biological sampling methods and analytical techniques for measuring nutrients in the sea became available during the late 1800s and early 1900s.

Verification of the model has been slow because of difficulties in measuring the rate of nutrient input to marine areas, problems in measuring primary production, lack of long-term comprehensive data, a system-specific view among researchers that discourages broad comparisons, and a reluctance to undertake ecosystem-level experiments in marine ecology. Widespread use of the ^{14}C technique after about 1950, recent efforts to develop nutrient budgets, and the completion of a long-term nutrient addition experiment using marine mesocosms, have now provided data used in this report to quantify the broad, general relationship between primary production and fisheries yields from the sea have only been assembled in the past few years, but the evidence is now compelling. Despite the great complexity of marine ecosystems, the simple first-order relationship between nutrient inputs and productivity that was first conceived a century ago seems generally correct.

Nixon, S. W. (1992) **Quantifying the relationship between nitrogen input and the productivity of marine ecosystems.** Advanced marine Technology Conference, No.5, Japan, The concept that the input of dissolved inorganic nutrients, especially nitrogen, regulated the basic level of primary production and, hence, the yield of fish form marine ecosystems developed in Western Europe and

Nixon, S. W. and V. M. Berounsky (1984) **The role of nitrification in contributing to low oxygen conditions in an urban waterway.** Rhode Island Water Resources Center, FY-1983.
{nitrification; oxygen; Providence River}
No abstract

Nixon, S. W., J. R. Kelly, B. N. Furnas, C. A. Oviatt, and S. S. Hale (1980) **Phosphorus regeneration and the metabolism of coastal marine bottom communities.** In: K. R. Tenore and B. C. Coull (ed.) *Marine Benthic Dynamics*. University of South Carolina Press, Columbia, South Carolina.
{phosphate; Narraganett Bay; flux; sediment}

In situ measurements of the exchange of phosphate between sediment and the overlying water at three stations in Narragansett Bay, Rhode Island, showed that there was almost always a net flux out of the sediments. The magnitude of the flux ranged from near zero in winter to almost 60 umols m^{-2} hr^{-1} in summer. The flux was strongly correlated with temperature during the spring warming and did not decrease with increasing phosphate concentrations in the overlying water. Calculations indicate that the phosphate cycle in coastal waters such as Narragansett Bay is dominated by sediment-water exchanges. Some 120 mg-at of inorganic P m^{-2} yr^{-1} were released annually to the overlying water, or enough phosphorus to support about 50% of the annual phytoplankton primary production. The flux of dissolved organic phosphorus was erratic and lower, and appreciable uptake as well as release was often observed.

Laboratory experiments using replicate cores collected from the bay at different times of year showed that oxygen uptake, carbon dioxide release, and phosphorus exchange by the sediments were also influenced by the availability of fresh organic matter. It was clear from the laboratory and field measurements that the regeneration of organic matter by the benthos results in a return of inorganic nutrients to the water column that is anomalously low in fixed nitrogen relative to phosphorus. This remarkable feature of benthic regeneration, along with the fact that a large amount of organic matter is decomposed on the bottom in shallow areas compared with the open sea, appears to be responsible for the characteristically low N/P ratio of coastal marine waters and for the importance of nitrogen rather than phosphorus as a major limiting nutrient in these areas.

Nixon, S. W., C. A. Oviatt, J. Frithsen, and B. Sullivan (1986) **Nutrients and the productivity of estuarine and coastal marine ecosystems.** *Journal of Limnological Society of Southern Africa* 12:43-71.
{nutrients; primary productivity; estuary; coastal; microheterotrophs; recycling; MERL}

Recent research on estuarine and coastal marine ecosystems has revealed two particularly interesting things about nutrient and productivity. First is the observation that these areas are among the most intensively fertilized environments on earth. Second is the common finding that much of the characteristically high primary productivity of these shallow waters is supported by nutrients released or recycled by pelagic and benthic microheterotrophs. Since nutrient inputs to coastal areas have probably been increasing and are likely to continue to do so, it is particularly important to understand the relationship between nutrient loading and nutrient cycling and the extent to which their interactions may set the levels of primary and secondary production in coastal systems.

That some direct relationship exists between the input of nutrients and the productivity of higher trophic levels has been a principle of marine ecology since the turn of the century. It is surprisingly difficult, however, to find quantitative evidence showing that estuaries, lagoons, or other coastal waters respond to eutrophication by producing a larger biomass of animals. Part of this difficulty arises because the amount of nitrogen or phosphorus incorporated in animal tissue is a very small term in the total nutrient budget of an estuary, and the accuracy and precision of ecological field measurements may not be adequate to the task. In addition, the response of natural systems to nutrient enrichment is compounded by changes in climate, hydrography, harvesting effort and technology, and pollution.

Attempts to avoid these problems by carrying out controlled nutrient addition experiments in the field or with mesocosms have been much rarer in marine ecology than limnology. The results that are available for such studies seem to suggest that there is a modest enhancement of primary production with nutrient addition, but that most of this extra organic matter is rapidly consumed, presumably by microheterotrophs. In other words, as nutrient inputs rise, so does the rate of nutrient recycling. Only a small fraction of the added nutrients appears as an increment in the production of higher trophic levels.

Nixon, S. W., C. A. Oviatt, J. Garber, and V. Lee (1976) **Diel metabolism and nutrient dynamics in a salt marsh embayment.** *Ecology* 57:740-750.
{diel; dissolved oxygen; metabolism; nitrogen; nutrients; phosphorus; salt marsh; silica; Narragansett Bay}

Simultaneous measurements of the diel patterns of dissolved O_2, pH-CO_2, dissolved organic nitrogen, ammonia, nitrite, nitrate, dissolved organic phosphorus, phosphate, and silicate were made on four occasions in a shallow salt marsh embayment (Bissel Cove, Narragansett Bay, Rhode Island, U.S.A.) that was closed to tidal water exchanges for 24-h periods. In spite of high rates of community photosynthesis and respiration, there appeared to be little diel exchange in dissolved nutrient concentrations, especially with respect to inorganic nitrogen. During summer and early fall, inorganic nutrients appeared to cycle within the sediment-detritus system of the embayment bottom, rather than being released to the overlying water. This suggest that there would be little export of inorganic nutrients from the marsh during tidal exchanges with the estuary. The behavior of this marsh embayment contrasts with reports from other marsh areas where large net imports or exports of nutrients have been observed. The concentrations of dissolved organic phosphorus and nitrogen were higher than inorganic forms, and showed substantial variation over each diel sampling period. The relationship between photosynthetic or respiratory gas exchange and nutrient cycling in waters influenced by benthic community metabolism is subtle and complex, and cannot be adequately approximated by simple models such as the Redfield ratio.

Nixon, S. W. and M. E. Q. Pilson (1983) **Nitrogen in estuarine and coastal marine ecosystems.** In: E. J. Carpenter and D. G. Capone (ed.) *Nitrogen in the Marine Environment.* Academic Press, New York.
{nitrogen; estuary; budget; distribution}
No abstract

Nixon, S. W. and M. E. Q. Pilson (1984) **Estuarine total system metabolism and organic exchange calculated from nutrient ratios: An example from Narragansett Bay.** In: V. S. Kennedy (ed.) *The Estuary as a Filter.* Academic Press, Orlando.
{Narragansett Bay; estuary; nutrient; denitrification; net ecosystem metabolism; phosphorus; budget}

The average ratio of the concentration of dissolved inorganic nitrogen (DIN) to phosphorus (DIP) found in many estuaries differs from that in the rivers, sewage, rain, and offshore waters that contribute nutrients to these systems. These differences are largely the result of various biological processes which take place in the estuary, including denitrification, the net production of organic matter, and the consumption and remineralization of organic matter carried into the

estuary. Net production in this case represents the total amount exported, harvested, and removed through long-term burial that is in excess of the amount imported and consumed within the estuary. It is not the same as the commonly reported net production by the autotrophic components of the system. Together with physical mixing and chemical exchange processes which take place in the system, these biological transformations provide a dynamic "filter" which often makes the quantity and form of nutrients exported from an estuary quite different from those it imports. These changes can themselves provide insight into the internal processes of the estuary.

For Narragansett Bay (RI, USA) we have combined measurements of the annual nutrient input with the ratio of the annual time and volume-weighted mean concentrations of DIN and DIP found in the Bay, measurements of the annual rate of denitrification, and data on the chemical composition of the plankton to calculate the total system metabolism of the Bay. The result suggests that the system is autotrophic, with net production exceeding consumption by about 80 g C m^{-2} y^{-1}. Since only a small portion of this organic matter accumulates in the sediments (~ 6 g C m^{-2} y^{-1}) or is removed in the fishery (~ 1 g C m^{-2} y^{-1}), some 70-75 g C m^{-2} y^{-1} may be exported from the Bay, an amount equal to 22-24% of the reported production by the phytoplankton.

Nixon, S. W., M. E. Q. Pilson, C. A. Oviatt, P. Donaghay, B. Sullivan, S. Seitzinger, D. Rudnick, and J. Frithsen (1984) **Eutrophication of a coastal marine ecosystem - An experimental study using the MERL microcosms.** In: M. J. R. Fasham (ed.) *Flows of Energy and Materials in Marine Ecosystems.* Plenum Publishing Co., New York.
{nutrients; phytoplankton assemblage; phytoplankton abundance; secondary production; MERL}
No abstract

NOAA (1990) **Estuaries of the United States**
Vital statistics of a national resource base. NOAA, A special NOAA 20th anniversary report, {estuary; resource; review}
No abstract

Nowicki, B. L. and S. W. Nixon (1985) **Benthic nutrient remineralization in a coastal lagoon ecosystem.** *Estuaries* **8**:182-190.
{ammonia; nitrate; nitrite; phosphate; phosphorus; lagoon; Narragansett Bay; flux; N/P ratio}

In situ measurements of the exchange of ammonia, nitrate plus nitrite, phosphate, and dissolved organic phosphorus between sediments and the overlying water column were made in a shallow coastal lagoon on the ocean coast of Rhode Island, U.S.A. The release of ammonia from mud sediments in the dark (20-440 umol per m^2 per h) averaged ten times higher than from a sandy tidal flat (0-60 umol per m^2 per h), and while mud sediments also released nitrate and phosphate, sandy sediments took up these nutrients. Fluxes of nutrients from mud sediments, but not from sandy areas, markedly increased with temperature. Ammonia release rates for mud sediments in the light (0-350 umol per m^2 per h) were lower than those in the dark and it is estimated that some 25% of the ammonia released to the water column on an annual basis may be intercepted by the benthic microfloral community. Estimates of the annual net exchange of nutrients across the sediment-water interface, weighted by sediment type for the lagoon as a whole, showed a release of 450 mmol per m^2 of ammonia, 5 mmol per m^2 of phosphate, 5 mmol per m^2 of dissolved organic phosphorus, and an uptake of 80 mmol per m^2 of nitrate. Although rates of ammonia and nitrate exchange were comparable to those described for the deeper heterotrophic bottom communities of nearby Narragansett Bay, rates of benthic phosphate release were significantly lower. On an annual basis the Bay benthos released approximately 20 times more inorganic phosphate per unit area than did the lagoon benthos. As a result, the N/P ratio for the flux from the sediments was 74:1 in the lagoon, compared with 16:1 in "average" marine plankton and 8:1 for the benthic flux from Narragansett Bay. The lack of remineralized phosphate in the lagoon is reflected in water column phosphate concentrations (always <1um) and water column N/P ratios (anual N/P = 27) and suggests that the lagoon may show phosphate limitation rather than the nitrogen limitation commonly associated with marine systems.

O'Connor, D. J. (1981) **Modeling of eutrophication in estuaries.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients.* Humana Press, Clifton, New Jersey.
{nutrient; model; phytoplankton; estuary}
No abstract

O'Reilly and D. A. Busch (1984) **Phytoplankton primary production on the northwestern Atlantic shelf.** *Rappots et Procès-verbaux des Réunions Counseil International pour L'Exploration de la Mer* **183**:255-268.
{Atlantic shelf; phytoplankton; primary production; sewage}

Phytoplankton production of particulate and dissolved organic carbon was measured using ^{14}C simulated *in situ* sunlight incubation method

during 23 survey of the Mid-Atlantic Bight, Georges Bank, and the Gulf of Maine. Annual phytoplankton production (particulate plus dissolved) ranged between 260 and 470 g C m^{-2} yr^{-1} in various regions, which places this continental shelf system among the most productive in the world. The highest rates of daily phytoplankton production were consistently found off the coast of New Jersey in the sewage-polluted apex of the New York Bight, followed by the shallow, well-mixed waters on Georges Bank. In general, high daily rates of primary production (1 g C m^{-2} yr^{-1}) were observed during most of the months sampled and were not limited to the 'spring bloom' period.

Available data indicate that microheterotrophs above the thermocline (not the seabed) supply most of the mineralized nutrients required by the productive summer phytoplankton communities. Size-fractionation of the ^{14}C-labeled particulate organic carbon revealed that netplankton (> 20 um) are major primary producers during the spring and fall blooms in the Mid-Atlantic Bight, on Georges Bank, and in the Gulf of Maine; however, the nanoplankton (< 20 um) are responsible for most of the annual photosynthesis of organic carbon. On the annual basis, the percentage of particulate carbon productivity by nanoplankton increased from the shallow to the deep water. Euphotic per cent extracellular release (PER) of dissolved organic carbon by phytoplankton ranged between 0 and 55 %, averaging 15 %, and increased from the shallow to the deep waters of the continental shelf. No well-defined seasonal cycle in euphotic PER was evident from our data.

Ochi, T. (1987) **The development of anoxic water and red tide associated with eutrophication in Hiuchi Nada Inland Sea, Japan.** In: T. Okaichi, D. M. Anderson and T. Nemoto (ed.) *Red Tides: Biology, Environmental Science, and Toxicology*. Elsevier, New York.
{red tides; oxygen}

The mechanism of anoxic water mass formation was investigated in the eastern part of Hiuchi-Nada. It was found that the oxygen consumption by the sediment was unexpectedly small and that the oxygen consumption by organic matter freshly deposited on the bottom from phytoplankton blooms, followed by frequent breakdown of the thermocline were important contributing factors in the formation of anoxic water masses in Hiuchi-Nada.

Officer, C. B. and J. H. Ryther (1980) **The possible importance of silicon in marine eutrophication.** *Marine Ecology Progress Series* **3**:83-91.
{silicon; nitrogen; phosphorus; evidence; phytoplankton; diatoms; flagellates}

Diatom phytoplankton populations are the usual food for zooplankton and filter feeding fishes and contribute in a direct way to the large fishable populations in coastal zones. Flagellates, on the other hand, are frequently poor foods for most grazers and can lead to undesirable eutrophication effects. Arguments are presented that silicon is often the controlling nutrient in altering a diatom to a flagellate community. The alteration is governed by the relative magnitudes of the natural fluxes of the nutrients nitrogen, phosphorus and silicon to the receiving water body and the recycled fluxes of nitrogen and phosphorus for oceanic, estuarine and inland water bodies.

Okaichi, T. (1987) **Red tide problems in the Seto Inland Sea, Japan.** In: T. Okaichi, D. M. Anderson and T. Nemoto (ed.) *Red Tides: Biology, Environmental Science, and Toxicology*. Elsevier, New York.
{red tides; blooms; oxygen; abundance}

With the development of industries along the coast of Seto Inland Sea, Japan, aquaculture of yellowtail, oyster and nori (laver) have been suffering from outbreaks of red tides. During these two decades 20 billion yellowtail worth about 20 billion yen were killed. Comprehensive surveys on the cause of outbreaks of red tides are carried out by workers at Universities and Prefectures. Countermeasures to avoid the fishkill are devised and the monitoring systems for red tides, PSP and DSP within Prefectures are organized by the Bureau of fisheries.

Okaichi, T., D. M. Anderson, and T. Nemoto (ed.) (1988) ***Red Tides: Biology, Environmental Science, and Toxicology (Proceedings of the International Symposium on Red Tides, Takamastu Perfecture, Japan, 10-14 November, 1987).*** Elsevier, New York.
No abstract

Olenin, S. N. (1990) **Benthic "desert" and transitional ecological zone at the bottom of the eastern part of the Baltic Sea.** *Oceanology of the Academy of Sciences of the USSR* **29**:751-753.
{benthic; desert; Baltic; transition; macrofauna}

As a result of studies performed during 1981-1987 on the slope and floor of the Gotland basin in the eastern Baltic Sea, a transitional ecological zone was distinguished between the benthic "desert", which is devoid of macrofauna and situated on the floor and slope of the basin below 110-120 m, and the upper sections of the benthic zone above 80-90 m, which has a comparatively rich and varied bottom populations. The zoobenthos of the transitional zone is extremely poor and is

characterized by a predominance of mobile invertebrate forms.

Olsen, P., M. Cohn, J. B. Mahoney, and E. Feerst (1984) ***Ganyaulax excavata* Monitoring in New Jersey.** *Coastal Ocean Pollution Assessment News* **3**:25-26.
{nuisance bloom; *Gonyaulax*; red tide; nutrient; New York Bay; New Jersey}
No abstract

Olsson, G. E., B. Sundström, and L. Edler (1987) ***In situ* studies of the effects of humic acids on dinoflagellates and diatoms.** In: T. Okichi, D. M. Anderson and T. Nemoto (ed.) *Red tides: Biology, Environmental Science, and Toxicology*. Elsevier, New York.
{blooms; humic}

Experiments with 160 l plastic bags were performed in September 1986 *in situ* on the west coast of Sweden. One series of bags were filled with water containing the natural phytoplankton community dominated by dinoflagellates (>80% of the total phytoplankton biomass). The other series was filled with 1 um filtered sea water inocculated with the diatom *Phaeodactylum tricornutum*. Phosphorus or nitrogen was added alone or together with commercially available humic acids to both series. Bags with no additions (C) or with only humic acids added (CH) were used as controls. *P. tricornutum* was stimulated by nitrogen addition, while no positive response was obtained by any nutrient addition to the dinoflagellate bags. Dinoflagellate biomass increased several fold when humic acids were added together with nitrogen. Also the alkaline biomass phosphatase activity (APA) increased drastically both in the CH and nitrogen + humic acid bags. Tentative conclusions are: 1) The dinoflagellates were inhibited by heavy metals and the humic acids alleviated this inhibition by working as chelating agents. 2) The diatom was not inhibited by heavy metals because it could still grow quite well without humic acids. 3) As APA increased in the dinoflagellate control bag with only humic acids we assume that nitrogen in the humic fraction to some extent was available for the dinoflagellates.

Oviatt, C. A., A. A. Keller, P. A. Sampou, and L. L. Beatty (1986) **Patterns of productivity during eutrophication: A mesocosm experiment.** *Marine Ecology - Progress Series* **28**:69-80.
{oxygen; net ecosystem production; MERL}

In a 28 months mesocosm experiment, levels and patterns of productivity and respiration were observed for a range of nutrient additions selected to provide a gradation from conditions in lower Narragansett Bay, Rhode Island, USA, to maximum impact for an urban estuary receiving present day levels of sewage effluents. For a 32-fold increase in nutrients, system apparent production increased by only a factor of 3.5. Seasonal patterns of autotrophy during the winter-spring diatom bloom and heterotrophy during summer and early fall occurred at all treatment levels. With the exception of the 8X treatment, all treatments above 2X had a greater respiratory demand in the water column than the benthos. The highest treatment mesocosm (32X) went briefly anoxic during the second summer of the experiment during a period when little productivity was occurring in the water column.

Oviatt, C. A., P. Lane, F. F. III, and P. Donaghay (1988) **Phytoplankton species and abundance in response to eutrophication in coastal marine mesocosms.** *Journal of Plankton Research* **11**:1223-1244.
{nutrient; species composition; phytoplankton; assemblage; abundance; MERL}

In a mesocosm nutrient enrichment experiment the species (or categories) and abundances of diatoms, dinoflagellates, flagellates, monads and ciliates were identified and counted over a 16 month period. Diatoms and ciliates increased with increasing nutrient treatment while monads and flagellates, less than 10 um, did not. In some instances grazing controlled abundances to low levels in nutrient enriched treatments. By contrast, in the field diatoms sometimes appeared to decrease while small phytoplankton less than 10 um appeared to increase under eutrophic conditions. While nuisance species were occasionally present in various nutrient treatments, the intensity and frequency of their presence did not tend to increase with nutrient treatment. Generally species (or categories) did not appear to change with nutrient treatment.

Oviatt, C. A., J. G. Quinn, J. T. Maughan, J. T. Ellis, B. K. Sullivan, J. N. Gearing, P. J. Gearing, C. D. Hunt, P. A. Sampou, and J. S. Latimer (1987) **Fate and effects of sewage sludge in the coastal marine environment: A mesocosm experiment.** *Marine Ecology Progress Series* **41**:187-203.
{production; respiration; fate; nutrients; sludge; oxygen; grazing; MERL}

A mesocosm experiment to assess the fate and effects of sewage sludge in the coastal marine environment was conducted over 4 mo. during the summer of 1984 with 9 different treatments of sewage sludge and nutrient additions. Evidence from settling rate studies, accumulations of carbon and pollutant organics and ratios of $\Delta^{13}C$ in the sediment indicated up to 83% of the sludge particulate inputs settled to the bottom and up to 51% accumulated there. While no toxicity due to organics or metals was apparent, prolonged hypoxia

and even anoxia occurred in upper treatment levels. At summer temperatures, sludge particulate inputs in excess of 1 g C m^{-2} d^{-1} caused these hypoxic conditions. In contrast to low primary production in low and medium sludge treatments during the last 2 mo. of the experiment, the highest sludge treatment had high production. We attribute these patterns to excessive grazing pressure from zooplankton and benthic fauna in the lower 2 treatments and hypoxia-retarded grazing in the upper treatment. In the upper treatments, peaks of production stimulated peaks of excessive respiration suggesting that respiration of sludge particulates was enhanced or co-metabolized with the production of fresh organic material.

Paerl, H. W. (1988) **Nuisance phytoplankton blooms in coastal, estuarine, and inland waters.** *Limnology and Oceanography* **33**:823-847.
{bloom; phytoplankton; marine; estuary; freshwater; cyanobacteria; dinoflagellates; review}

Multiple interacting physical, chemical, and biotic factors, in proper combinations lead to the development and persistence of nuisance algal blooms. Upon examining combinations of environmental conditions most likely to elicit nuisance blooms, commonalities and analog situations become more apparent among coastal marine (dinoflagellate-dominated), estuarine(dinoflagellate- and cyanobacteria-dominated), and freshwater (cyanobacteria-dominated) ecosystem. A combination of the following hydrological, chemical, and biotic factors will most likely lead to bloom-sensitive waters: a horizontally distinct water mass; a vertically stratified water column; warm weather conditions, as typified by dry monsoon tropical climates and summer seasons in temperate zone; high incident photosynthetically active radiation (PAR); enhanced allochthonous organic matter loading (both as DOC and POC); enhanced allochthonous inorganic nutrient loading (nitrogen and/or phosphorus); adequate availability of essential metals, supplied by terrigenous inputs or upwelling; underlying sediments physically and nutritionally suitable as "seed beds" for resting cysts and alkinetes; algal-micrograzer (protists and rotifers) synergism, which also enhances nutrient cycling without consumption of filamentous and colonial nuisance taxa; and selective (for non-nuisance taxa) activities of macrograzers (crustacean zooplankton, larval fish).

Nuisance bloom taxa share numerous additional physiological and ecological characteristics, including limited heterotrophic capabilities, high degrees of motility, and toxicity. Given such a set of commonalities, it would appear useful and timely to identify and address generally applicable criteria for deeming a water body "bloom sensitive" and to incorporate such criteria into the design of water quality management strategies applicable to both coastal marine and freshwater habitats.

Pagou, K. and L. Ignatiades (1988) **Phytoplankton seasonality patterns in eutrophic marine coastal waters.** *Biological Oceanography* **5**:229-241.
{phytoplankton; seasonality; Aegean Sea}

Phytoplankton seasonality patterns were examined in an inshore eutrophic station fertilized continuously by domestic sewage. Data of certain physical (temperature), chemical ($P\text{-}PO_4$, $N\text{-}NO_3$, and $Si\text{-}SIO_2$ concentrations), and phytoplanktonic (chl *a*, total cell, diatom, and dinoflagellate concentrations) parameters were analyzed by time series analysis (autocorrelation, cross correlation). The phytoplanktonic and chemical parameters exhibited significant seasonal variability-in spite of the constant fertilization of the water-which was associated with the seasonal variability of temperature.

Parker, C. A. (1983) **Localized hypoxia recurs in the New York Bight.** *Coastal Ocean Pollution Assessment News* **3**:1-3.
{oxygen; New York Bight}
No abstract

Parker, C. A. and J. E. O'Reilly (1991) **Oxygen depletion in Long Island Sound: A historical perspective.** *Estuaries* **14**:248-264.
{oxygen; hypoxia; historical; Long Island Sound}

A retrospective analysis of available data was conducted to characterize the spatial distribution and temporal trends in dissolved oxygen (DO) concentrations in Long Island Sound (LIS) over the past four decades. A general east-west gradient of decreasing bottom DO was evident in all historical data examined. In our review of data from the 1950s , collected by Gordon Riley and colleagues, and from contemporary surveys, we found no evidence of hypoxia ($DO \leq 3.0$ mg l^{-1}) in the Eastern Basin; however, in the deeper waters of the Central Basin, there is some evidence for recent (1986) emergence of moderate hypoxia. The Western Basin experienced episodes of hypoxia during the 1970s which became more recurrent and possibly more severe in the late 1980s. The most severe, persistent and chronically recurrent hypoxia occurred throughout the water column of the East River and in bottom water of the Western Narrows. An unprecedented episode of anoxia was observed in both the Western and Eastern Narrows regions of LIS in 1987. Previously, anoxia occurred rarely, was short-lived, and was confined to the East River. Statistical trend analyses revealed a significant increase in the summer minimum bottom DO in the lower and middle reaches of the East River over the past 20 years. Beginning in 1981, however, DO

declined markedly in the adjacent Narrows bordering the Nassau County nearshore. The improvements in East River water quality over the previous 15-20 years appear to have been gained at the expense of poorer water quality in the western sound. Mechanisms potentially responsible for the recent decline the bottom DO in western LIS are suggested.

Pastorok, R. A. and G. R. Bilyard (1985) **Effects of sewage pollution on coral-reef communities.** *Marine Ecology Progress Series* **21**:175-189.
{sewage; coral reef; lagoon; species composition; abundance; benthic algae; primary production; nutrient; oxygen; Kaneohe Bay; turbidity; sedimentation}

Sewage pollution is an increasing problem in tropical marine environments. In this review we synthesize present knowledge of the effects of sewage pollution on coral-reef communities, and suggest directions for future research. A wide range of sewage impacts on coral-reef communities has been reported. Little or no impact has been observed on some reefs in well-flushed waters that receive small quantities of effluent, whereas large discharges of effluent into poorly-flushed lagoons and bays have caused major changes in species composition and abundance. The 3 components of sewage effluent most detrimental to coral communities are nutrients, sediments, and toxic substances. Nutrient enrichment by sewage effluent may enhance benthic algal biomass and primary production in the water column. Increased primary production in the water column favors benthic filter-feeding invertebrates which, with the benthic algae, may out-compete corals and other reef-building organisms. Anthropogenic inputs of dissolved nutrients and organic particulate matter may also depress oxygen levels. While heavy sediment loads on corals may be lethal, lesser quantities may inhibit growth, cause changes in the growth forms of colonies, decrease coral cover, alter species composition of reef-building organisms, and inhibit coral recruitment. Toxic substances may induce metabolic changes in corals, decrease rates of growth and reproduction, or reduce viability of corals. Although further research is needed on all three major components of sewage effluent, the most critical need is for comprehensive, long-term studies of sewage impacts. The combined effects of particulate and toxic substances are especially poorly documented at this time.

Pearson, T. H. (1975) **The benthic ecology of Loch Linnhe and Loch Eil, a sea-loch system on the west coast of Scotland. IV. Changes in the benthic fauna attributable to organic enrichment.** *Journal of Experimental Marine Biology and Ecology* **20**:1-41.
{sediments; benthic fauna; species; anoxic; effluent}

Changes are described in the benthic fauna of Lochs Linnhe and Eil in response to organic enrichment of the loch sediments, brought about by the input of effluent material from a pulp and paper mill. Fluctuations in the amount of effluent discharges are related to subsequent successional changes in the fauna. As organic enrichment proceeds, there is progressive elimination of species, accompanied by an increase in the numbers of the surviving species. Excessive organic deposition leading to anoxic conditions at the sediment/water interface results in the elimination of all but a few annelid species. The observed successional changes are discussed in the light of recent hypotheses concerning ecological changes in relation to environmental stress.

Pearson, T. H. (1980) **Marine pollution effects of pulp and paper industry wastes.** *Helgoländer Meerestuntersuchungen* **33**:340-365.
{pulp; paper; oxygen demand; benthic; abundance; sediment; composition}

The scale of waste discharges to the marine environment from the pulp and paper industry in various parts of the world is outlined and a brief description of the major characteristics of such wastes is given. The information available on the direct toxicity of these wastes to marine fauna and flora is assessed including both lethal and sublethal effects. The environmental impact of waste discharge and subsequent ecosystem modifications are considered in detail; the complex adjustments to the nutrient and carbon budgets of the water column and sediment involved in direct alterations to their oxygen balance and other indirect eutrophication effects are described. It is concluded that whereas the direct toxicity of these wastes has minimal effect in the marine environment the complex problems created by increasing the oxygen demand on the receiving waters can have considerable impact in inshore areas. Methods of minimizing the effect of such impacts and of forecasting their extent are outlined.

Pearson, T. H. (1987) **Benthic ecology in an accumulating sludge-disposal site.** In: J. M. Capuzzo and D. R. Kester (ed.) *Oceanic Processes in Marine Pollution. Vol.1. Biological Processes and Wastes in the Ocean.* Robert E. Krieger Publishing Company, Malaba, Florida.
{benthic; sludge; Eh; sediments; pH; abundance; biomass; species; annelids; nematods; deposit-feeder}

The distribution of benthic fauna in the area of the sludge-disposal site in the Firth of Clyde, Scotland, is related to the gradient of increasing organic

enrichment created by dumping. Faunal succession in relation to enrichment is related to changing productivity along the gradient. Community changes are ascribed to progressive maximization of carbon utilization as input levels increase; this involves responses at many levels of organization. It is concluded that the benthic ecosystem has fully adapted to the continuously high organic carbon input.

Pearson, T. H., A. B. Josefson, and R. Rosenberg (1985) **Petersen's benthic stations revisited. I. Is the Kattegat becoming eutrophic?** *Journal of Experimental Marine Biology and Ecology* **92**:157-206.
{benthic; macrofauna; abundance; biomass; increase; decrease; composition; Baltic}

The macrobenthic fauna present at the stations sampled by C.G.J. Petersen in 1911-1912 in the Kattegat were re-assessed in 1984 using equipment and techniques similar to those used in the original surveys. The total biomass of organisms present in 1984 was found to be significantly reduced in the north and west of the area and in areas shallower than 25 m. These changes were largely attributable to decreases in the populations of large echinoid, *Echinocardium*. When echinoids were excluded, significant increases in the biomass of other organisms present in 1984 were found to the east of the area and in areas deeper than 25 m. In general the majority of species were found to be smaller in individual size in 1984 when compared with the earlier surveys. Dominance comparisons based on biomass changes showed that deposit-feeders had decreased and suspension-feeders and carnivores had increased in dominance. Most notably *Echinocardium* had decreased and the ophiuroid *Amphiura filiformis* (Müller) had increased in dominance at over 70% of the stations sampled. In general ophiuroids and annelids had increased and echinoids and molluscs had decreased in dominance. Comparisons of similarity values indicated that community composition has changed markedly over the area, with only ≈30% similarity of species between 1911-1912 and 1984 at most stations.

The possible causes underlying these general changes are considered, amongst which changes in fish predation pressures, the direct effects of trawling and long-term temperature fluctuations are suggested. Whilst such factors may be partially responsible, the most probable causes is considered to be a general eutrophication of the area.

Pearson, T. H. and R. Rosenberg (1976) **A comparative study of the effects on the marine environment of wastes from cellulose industries in Scotland and Sweden.** *Ambio* **5**:77-79.
{benthos; abundance; diversity; indicator}

The influence of effluents from cellulose industries on the benthic faunas of comparable fjordic systems on the west coasts of Sweden and Scotland is assessed. Generalizations are made about sequential changes in the interrelationship of benthos and sedimentary structure. Estimates are made of the rates of such changes along a gradient of environmetal stress brought about by the organic enrichment of marine sediments and these can be used to assess the probable effect of large inputs of organic material to marine sediment. The advantages and disadvantages of using indicators species, comparing faunal groups, and using diversity indices in the description of ecological changes are briefly considered.

Pearson, T. H. and R. Rosenberg (1978) **Macrobenthic succession in relation to organic enrichment and pollution of the marine environment.** *Oceanography and Marine Biology: Annual Review* **16**:229-311.
{macrobenthos; benthic; organic enrichment; sediments; abundance; biomass; spatial; temporal; diversity; similarity; indicator; opportunistic}
No anstract

Pearson, T. H. and S. O. Stanley (1979) **Comparative measurement of the redox potential of marine sediments as a rapid means of assessing the effects of organic pollution.** *Marine Biology* **53**:371-379.
{sediments; redox potential; macrofauna; benthos; abundance; species; biomass}

A rapid method for measuring the redox potential (Eh) values of marine sediments is described. This method has been used to relate changes in the areas of highly reduced sediment in a sea loch system to the continuously fluctuation inputs of organic waste from a pulp and paper mill. Subsequent faunal changes in these areas can be related to changes in the measured sedimentary redox level. The method is suggested as a rapid means of assessing the potential impact of an additional organic input to a marine sediment.

Pease, B. C. (1977) ***The effect of organic enrichment from a salmon mariculture facility on the water quality and benthic community of Henderson Inlet, Washington.*** Dissertation for Ph.D., University of Washington.
{mariculture; benthos; infauna; epifauna; sediments}

The effect of fish excretion and respiration at a salmon mariculture facility on the local water quality was evaluated. In the immediate vincinitiy of the facility, dissolved oxygen concentrations were consistently depressed while ammonia concentrations were increased, but neither effect was significant based on accepted criteria. The

mariculture facility had no apparent effect on the local phytoplankton population. Major fluctuations in the local water quality were a result of natural hydrographic conditions and phytoplankton activity.

The effect of fish feces and excess fish food from the mariculture facility on the benthic environment was also evaluated. There was a definite accumulation of organic matter under and extending at least 15 m from the salmon pens. This organic accumulation caused significant changes in the structure of the benthic epifaunal and infaunal communities. Epibenthic mats of the sulfide-oxidizing bacterium, *Beggiatoa*, were observed under salmon pens along with an increased abundance of several large predatory species (*Cancer gracilis, Lepidopsetta bilineata,* and *Myoxocephalus polyacanthocephalus*). The benthic infauna community under the salmon pens declined in species richness and became numerically dominated by the polychaete worm, *Capitella capitata*, a well-known ubiquitous indicator of organic pollution. Therefore, the mariculture facility would have little or no effect on the marine environment if the settleable solids were collected and removed, or depressed in such a way that there was no accumulation in the underlying sediments.

Pekkari, S. (1973) **Effects of sewage water on benthic vegetation.** *O I K O S Supplymentum* **15**:185-188.
{seaweeds; sewage; benthic; abundance; abnormal}

The influence of sewage water on benthic vegetation was studied in the Stockholm Archipelago and in the Gulf of Bothnia. The most conspicuous effects of sewage effluents in the Gulf of Bothnia are the excalves of marine and freshwater vegetation distinctly differing from the vegetation in the vi cinity. Disappearance and abnormal shape of plants are conspicuous effects of sewage water in the inner part of the Stockholm Archipelago.

Perciasepe, R. (1992) **Progress Report of the Baywide Nutrient Reduction Reevaluation.** Chesapeake Bay Program,
{abundance; oxygen}

In 1987, the parties to the original Chesapeake Bay Agreement signed a new Chesapeake Bay agreement. The 1987 Chesapeake Bay Agreement set a specific goal-to achieve at least a 40 percent reduction of nitrogen and phosphorus entering the mainstem Chesapeake Bay by the year 2000. Although this progress report's fingdings are preliminary, trends and generalizations of nutrient loads, water quality, and hibatat improvements are becoming evident. Most of the background studies for the Nutrient Reduction Reevaluation have been drafted. To date, seven model runs have been completed for use in this report.

Perry, D. M., J. B. Hughes, and A. T. Herbert (1991) **Sublethal abnormalities in embryos of winter flounder, *Pseudopleuronectes americanus*, from Long Island Sound.** *Estuaries* **14**:306-317.
{abnormalities; winter flounder; disease; Long Island Sound; Boston Harbor}

Sublethal abnormalities were examined in developing embryos of the winter flounder, *Pseudopleuronectes americanus*, as part of a study of its early reproductive success in Long Island Sound and two sites in Boston Harbor. These sites represented varying levels of anthropogenic contamination that were possibly affecting reproduction, as ascertained by chromosomal abnormalities and lowered developmental rates in the embryos. Effort was focused on examination of blastula and tail-bud embryos from field-captured females spawned at the laboratory. Abnormalities observed included evidence of cytotoxicity and chromosome damage. Embryos of fish from New Haven were usually the most aberrant, while embryos from other sites, notably Hempstead, Shoreham, and both Boston Harb or stations, showed subtle indications of abnormality.

Persson, L.-E. (1987) **Baltic eutrophication: A contribution to the discussion.** *Ophelia* **27**:31-42.
{Baltic; macrozoobenthos; abundance; diversity}

Quantitative sampling of macrozoobenthos has been performed in the southern Baltic in the 1920s and the 1950s. Some of these stations (43) were revisited in 1982/83. The total abundance and biomass was significantly increased in 1982/83 compared to the 1950s. It is suggested that the main part of the biomass increase might be due to reduced stocks of predatory flatfishes in the 1920s and 1930s.

The most conspicuous difference in the comparisons is the widespread distribution of the polychaete *Capitella capitata* in 1982/83. This is attributed to increased trawling activities in recent decades and not to organic enrichment.

Phillips, D. J. H. and S. Tanabe (1989) **Aquatic pollution in the Far East.** *Marine Pollution Bulletin* **20**:297-303.
{Far East; algal blooms; oxygen; red tides}

An overview of the problems experienced in the Far East relating to aquatic pollution is presented, with emphasis on the quality of coastal waters. The pollution problems faced by developing and developed nations in the region tend to vary in type according to socioeconomic factors. The appropriate treatment and disposal of sewage remains a particular problem in the developing nations. Industrial and agricultural effluents also exert measurable effects on marine resources in many of these regions. The environmental impacts of major

engineering and development projects are also a cause for concern in certain areas. In the developed nations, the impacts of conservative contaminants (especially the highly persistent and toxic organochlorines) are considered to be the most significant problem at present. The region as a whole exhibited a great dependence on seafood as a primary or preferred source of protein, and the protection of coastal waters is therefore of vital concern. In addition, tourism provides much-needed foreign exchange in many countries of the region, and the tourist facilities are mostly situated on the coast. Additional regulatory initiatives are required in many areas, coupled to strong legislative action and robust monitoring of coastal pollution, if the vital marine resources are not to be irreversibly damaged.

Phoel, W. C., K. L. Webb, and C. F. D'Elia (1981) **Inorganic nitrogen regeneration and total oxygen consumption by the sediments at the mouth of the York River, Virginia.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients*. Humana Press, Clifton, New Jersey.
{nitrogen; regeneration; oxygen}

In situ measurements of inorganic nitrogen fluxes and riverbed oxygen consumption were made on sediments in 3, 9, and 16 m of water at the mouth of the York River during stratified and destratified water conditions. Ammonium was regenerated, the rate of which increased with depth and oxygen concentration in the overlying water. Nitrate and nitrite fluxes from the sediment were minimal or non-existent during stratification at the 16-m station but increased and the nutrients were taken up by the sediments under destratified conditions. At the 3-m station, which is above the halocline when developed, nitrate and nitrite appeared to be the major forms of nitrogen being released by the sediments. Oxygen consumption by the riverbed at the 16 and 9-m stations was higher during the increased oxygen tensions associated with vertical destratification. The 3-m stations maintained the higher rates of oxygen consumption throughout the sampling period. The in situ incubation of bottom water alone at all three stations indicated negligible rates of oxygen uptake.

Polak, J. and G. D. Haffner (1978) **Oxygen depletion of Hamilton Harbour.** *Water Research* **12**:205-215.
{oxygen; eutrophic; demand; sediment}

Processes involved in the oxygen cycles of the highly eutrophic Hamilton Harbour were studied. Sediment oxygen demand $k_s(O_2\ m^{-2}\ day^{-1})$ was measured by an *in situ* method and was determined to be dependent on oxygen concentration c (ml^{-1}) in the water phase. This dependence was expressed by the equation $k_s = 0.72 + 0.26c$. The water column oxygen demand of the harbour was determined experimentally and revealed a significant dependence on oxygen concentration. It was estimated that over 80% of the oxygen supplied to the harbour was used within the water column. The sediment oxygen consumed about 18% of the oxygen entering the harbour and was relatively most important in the early stages of stratification when the hypolimnetic dissolved oxygen concentrations were high. The main sources of oxygen were atmospheric reaeration (80%), lake-harbour exchange (10%) and photosynthesis (10%).

Portnoy, J. W. (1991) **Summer oxygen depletion in a diked New England estuary.** *Estuaries* **14**:122-129.
{oxygen; estuary; organic; fish kill; marsh}

The diked and freshened Herring River estuary (Wellfleet, Massachusetts) experiences regular summer hypoxia and one- to three-week period of main stream anoxia, often accompanied by fish kills. Stream hypoxia results from the temperature-dependent increase in oxygen demand of organic matter released by diked salt marsh deposits; periods of total anoxia are induced by heavy rains which increase the runoff of wetland organic matter. Historic reductions in tidal flushing have extended the low salinity region of the estuary normally characterized by high organic loads and minimal flushing. Recurrent main stream anoxia has depressed both migratory and resident aquatic fauna.

Porumb, F. (1992) **On the development of *Noctiluca scintillans* under eutrophication of Romanian Black Sea waters.** In: R. A. Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication*. Elsevier, Amsterdam.
{species, abundance, *noctiluca scintillans*, Black Sea}

This paper analyses the development of Noctiluca scintillans during the 1980s and 1990s as a consequence of the intense eutrophication of the Romanian waters of the Black Sea.

Price, K. S., D. A. Flemer, J. L. Taft, G. B. Mackiernan, W. Nehlsen, R. B. Biggs, N. H. Burger, and D. A. Blaylock (1985) **Nutrient enrichment of Chesapeake Bay and its impact on the habitat of striped bass: A speculative hypothesis.** *Transactions of the American Fisheries Society* **114**:97-106.
{Chesapeake Bay; fish; striped bass; oxygen; habitat; nitrogen; phosphorus; aquatic vegetation; chlorophyll}

Stocks of striped bass *Morone saxatilis* have declined in the Chesapeake Bay system over the last decade. We present evidence for the working hypothesis that the decline has resulted, in part,

from loss of deep-water habitat for adults, caused by limiting concentrations of dissolved oxygen that are related, in turn, to nutrient enrichment and greater planktonic production. A related hypothesis is that changes in the near-shore habitat for juvenile striped bass, involving severe declined in submerged aquatic vegetation due to nutrient-driven planktonic shading, also have contributed to the decline of striped bass. Nutrients (nitrogen and phosphorus) and in chlorophyll *a*, an indicator of phytoplankton biomass, have increased i many areas of the bay and tributaries over the past 20 to 30 years. These trends are qualitatively correlated with greater deoxygenation of the deep channel in the mid and upper bay. During the late 1970s, summer oxygen concentrations as low as 2 ml/liter approached to within 7-8 m of the surface, allowing water stressful to striped bass to intrude onto shoal areas of the bay. The volume of Chesapeake Bay bottom waters containing 0.5 mg O_2/liter or less was about 15 times greater in July 1980 than in July 1950. The combination of the expanding hypoxic pool and summer temperature above preferred levels for adult striped bass may contribute to and "oxygen-temperature squeeze" that forces adults onto shoal areas of the bay or out of the upper bay. Many of these shoal areas now lack suitable cover for juvenile striped bass and their prey. Strong intraspecific competition among striped bass may be occurring there.

Provini, A., G. Crosa, and R. Marchetti (1992) **Nutrient export from the Po and Adige river basins over the last 20 years.** In: R. A. Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication*. Elsevier, Amsterdam.
{phosphorus, nitrogen, Adriatic Sea}

Available data on nutrient concentration and flow of the Po and Adige river waters were analyzed in order to evaluate the nitrogen and phosphorus load carried into the Adriatic Sea, as well as the changes that have occurred since 1968. Load data results were highly correlated with the flow, following relations of the linear type. The yearly mean loads amount to 13,000 t of total P and 110,000 t of total mineral N for the Po, and 1200 t and 13,000 t respectively for the Adige. These values are more than two times higher than those evaluated in 1968. Nitrogen increased quite regularly, while the phosphorus load had already reached its maximum value at the end of the 1970s. Nutrient increase during 1968-88 can be explained by a higher production of detergents and fertilizers, and the constructions of numerous sewer networks in the Po and Adige basins.

Quinlan, A. V. (1982) **An Ecodynamic Analysis of Algal Blooms Fouling Nahant Bay Beaches.** MIT Sea Grant Program, MITSG 82-15.
{seaweeds}

Since the early 1900's the sandy beaches of Nahant Bay, Massachusetts have been chronically fouled by hundreds of tonnes of an abnormal form of the filamentous brown alga *Pilayella littoralis*. In warm weather, foul-smelling gaseous decomposition products sporadically cause great discomfort in the local residential and recreational populations. At the request of state and federal officials, a multidisciplinary research team was assembled to find out why this alga grows so abundantly in the surf zone and shallow sublittoral of the fouled beaches. The research team was specifically asked to evaluate the influence of effluents from a municipal sewage treatment plant outfall located on the bay's ocean boundary. The concentrations of algal nutrients were measured in the outfall boil and at fourteen other locations throughout the bay at seventeen monthly intervals. In addition, dyes, drift-cards, and computer simulations were used to estimate the trajectory of effluents released from the treatment outfall. All the available information consistently indicated that the effluent plume is completly dispersed long before reaching the algal drift community, and at most, only 1-2% of the macronutrients available to the alga come from the outfall. Tidal exchange with Massachusetts Bay was found to contribute roughly 74 times as much nitrogen, the macronutrient apparently limiting the alga's growth, as the outfall does on each tide. As a consequence, the municipal sewage effluents released into Nahant Bay were exonerated as a cause of the algal fouling problem there.

Quinn, H., J. P. Tolson, C. J. Klein, S. P. Orlando, and C. Alexander (1989) **Susceptibility and Status of Gulf of Mexico Estuaries to Nutrient Discharges.** NOAA National Ocean Service, {nutrients; nitrogen; phosphorus; estuary; susceptibility; N/P ratio; classification; review}
No abstract

Quinn, H., J. P. Tolson, C. J. Klein, S. P. Orlando, and C. Alexander (1989) **Susceptibility of East Coast Estuaries to Nutrient Discharges: Albemarie/Pamlico Sound to Biscayne Bay.** NOAA National Ocean Service, {nutrients; nitrogen; phosphorus; estuary; susceptibility; N/P ratio; classification; review}
No abstract

Quinn, H., J. P. Tolson, C. J. Klein, S. P. Orlando, and C. Alexander (1989) **Susceptibility of East Coast Estuaries to Nutrient Discharges: Passamaquoddy Bay**

to Chesapeake Bay. NOAA National Ocean Service, {nutrients; nitrogen; phosphorus; estuary; susceptibility; N/P ratio; classification; review}
No abstract

Quinn, H., J. P. Tolson, C. J. Klein, S. P. Orlando, and C. Alexander (1991) **Susceptibility of West Coast Estuaries to Nutrient Discharges: San Diego Bay to Puget Sound.** NOAA National Ocean Service, {nutrients; nitrogen; phosphorus; estuary; susceptibility; N/P ratio; classification; review}
No abstract

Rabalais, N. N. and D. F. Boesch (1986-1987) **Extensive depletion of oxygen in bottom waters of the Louisiana shelf during 1985.** *Coastal Ocean Pollution Assessment News* **3**:45-47.
{oxygen; Louisiana; Gulf of Mexico}
No abstract

Rabalais, N. N., R. E. Turner, J. W.J. Wiseman, and D. F. Boesch (1991) **A brief summary of hypoxia on the northern Gulf of Mexico continental shelf: 1985-1988.** In: R. V. Tyson and T. H. Pearson (ed.) *Modern and Ancient Continental Shelf Anoxia.* The Geological Society, London, England.
{oxygen; hypoxia; Gulf of Mexico; Louisiana; phytoplankton}
Oxygen-deficient conditions occur from April to October on the inner to middle continental shelf of the northern Gulf of Mexico and may cover up to 9500 km^2 during mid-summer off the Louisiana coast. Hypoxic bottom waters are found in 5-60 m water depth, 5-60 km offshore and extend up to 20 m above the bottom. Salient forcing functions contributing to hypoxic water formation, maintenance and break-up are presented. Stratification is directly correlated with hypoxia in time and space, suggesting that reaeration of bottom waters is controlled by physical processes that are influenced by regional wind fields, river discharge and continental shelf scale currents. Phytoplankton biomass reaches the bottom waters in the hypoxic zones in large amounts (>5 ug/l), fueling water column and benthic respiration rates, but to a currently unknown degree. Increased nutrient loadings in the two major rivers and changes in the proportion of those nutrient essential to phytoplankton growth have probably changed both the phytoplankton community species composition and community production. It is not yet clear whether the extent and severity of hypoxia on the Louisiana continental shelf have changed as a result of these riverine water quality changes.

Radziejewska, T. and I. Drzycimski (1988) **Meiobenthic communities of the Szczecin Lagoon.** *Kieler Meeresforschungen, Sonderheft* **6**:162-172.
{composition; distribution; meiobenthos; lagoon; Baltic; nematode; ostracod; copepods}
Based on data collected at 7 stations 4 times a year in 1985 and 1986, composition and distribution of meiobenthic communities in the Polish part of the Szczecin Lagoon, a eutrophic and polluted water body connected with the Baltic Sea, is presented. The data show a tendency to reduced total meiobenthic densities and diversity from the lower to upper reaches of the lagoon. The meiobenthic communities studied were dominated by nematodes, ostracods ranking second in numerical importance. Harpacticoid copepods were most abundant at the outer stations which are influenced by Baltic inflows. Most of the 10 harpacticoid species recorded in the lagoon were found at the outer stations (lower reached) as well. Similarity analysis allowed to separate three zones within the lagoon: (1) the outer zone, its stations showing most abundant and diverse meiobenthic communities; (2) the innermost zone (upper reaches) with the least abundant and qualitatively impoverished communities; and (3) the intermediate zone.

Raffaelli, D., J. Limia, S. Hull, and S. Pont (1991) **Interactions between the amphipod *Corophium volutator* and macroalgal mats on estuarine mudflats.** *Journal of the Marine Biological Association of the United Kingdom* **71**:899-908.
{macroalgae; seaweeds; mudflat; amphipod; *Corophium*; *Capitella*}
One of the most obvious effects of eutrophication in sheltered coastal areas and estuaries is enhanced growth of opportunistic macroalgae, which may form extensive mats over intertidal mudflats during the spring and summer. In the Ythan estuary, densities of the amphipod *Corophium volutator* (Pallas) in the sediment underlying weed mats were significantly lower than those in weed-free sediments, and are dominated by species characteristic of organically enriched, low oxygen environments such as *Capitella capitata.* Long-term data sets on *Corophuim* abundance in the Ythan suggest that this species has declined dramatically throughout those parts of the estuary affected by weed mats.

Two fields experiments have been carried out to assess the effects of weed mats on assemblages. In the first experiment, sediments subjected to a range of weed densities displayed faunal responses consistent with those observed by survey of weed-covered and weed-free areas. Under a high biomass of weed, the amphipod *Corophuim volutator* disappeared almost completely from the mudflat. The second experiment indicated that the physical

presence of weed filaments may be as important as the effects of weed on sediment chemistry in affecting the density of *Corophium*, probably through interference with the amphipod's normal feeding behavior. It is concluded that weed mats have a significant impact on *Corophium*, which is an important component of the diet of fish and shore-birds in the estuary.

Raffaelli, D. G. and C. F. Mason (1981) **Pollution monitoring with meiofauna, using the ratio of nematodes to copepods.** *Marine Pollution Bulletin* **12**:158-163.
{meiofauna; nematode; copepod; ratio; sandy beaches}

The ratio of nematodes to copepods was calculated for meiofauna samples from 17 beaches and additional values for intertidal and sublittoral sites were obtained from the literature. Intertidal ratios increased with decreasing particle size, but ratios from polluted sites were always extremely high. Sublittoral ratios increased with depth. It is suggested that this ratio has potential for monitoring organic pollution of sandy beaches.

Raman, A. V. and K. P. Prakash (1989) **Phytoplankton in relation to pollution in Visakhapatnam harbour, east coast of India.** *Indian Journal of Marine Sciences* **18**:33-36.
{phytoplankton; nutrients; Visakhapatnam harbour; sewage; abundance; diversity}

Sporadic outbursts of phytoplankton, notably diatoms and phytoflagellates, are observed from Visakhapatnam harbour waters subjected to pollution. The harbour waters are characterized by high proportions of inorganic nutrients attributable to sewage and industrial waste discharges. High phytoplankton standing crop and chlorophyll concentrations accompanied by low species diversity at the harbour locations indicate severe eutrophication of waters in this area as against near normal conditions in the open sea.

Reguera, B. and Y. Oshima (1990) **Response of *Gymnodinium catenatum* to increasing levels of nitrate: Growth patterns and toxicity.** In: E. Granéli, B. Sundström, L. Edler and D. M. Anderson (ed.) *Toxic Marine Phytoplankton*. Elsevier, New York.
{*Gymnodinium*; nitrate; phytoplankton; growth; red tides}

Gymnodinium catenatum, responsible for PSP outbreaks in NW Spain, was cultured in K media with increasing levels of nitrate. Growth rates were calculated from measurements of *in vivo* fluorescence and cell counts. Toxicity was determined by HPLC. Toxin concentrations per cell reached a peak with nitrate concentrations of 110-220 uM. Much of the increase in toxin concentration was due to a higher production rate of GXT 6, showing that the toxin profile is not a conservative property in this species.

Renk, H., J. Nakonieczny, and S. Ochocki (1988) **Primary production in the southern Baltic in 1985 and 1986 compared with long-term mean seasonal variation.** *Kieler Meeresforschungen, Sonderheft* **6**:203-209.
{primary production; Baltic; phytoplankton; Chlorophyll a}

On the basis of long-term investigations, the course of seasonal variations of mean daily primary production and mean chlorophyll-*a* concentration in the Southern Baltic waters are presented. The mean annual primary production of the Gda´nsk Deep, Borholm Deep and the Gotland Deep amounted to 12.4 gC m^{-2}, 88.8 gC m^{-2} and 107.2 gC m^{-2}, respectively. The primary production of the Southern Baltic in 1986 was higher than in 1985, and higher than the long-term mean value. The mean annual production for the Southern Baltic in 1986 amounted to 130 gC m^{-2}. On the basis of long-term observations of primary production and chlorophyll-*a* of the Southern Baltic, certain upward trends in phytoplankton production were observed.

Revelante, N. and M. Gilmartin (1976) **The effect of Po River discharge on phytoplankton dynamics in the Northern Adriatic Sea.** *Marine Biology* **34**:259-271.
{phytoplankton; Adriatic Sea; community; nutrients; density; primary production; nanoplankton; microplankton; bloom}

An oceanographic transect, extending from Yugoslavia across the Northern Adriatic Sea to the Po delta in Italy, was occupied during 1972 and 1973 to establish the effect of Po river discharge on the phytoplankton communities of the region. Density distribution showed distinct seasonal features: a winter-spring period of low stability throughout the water column, and a summer period of stratification. The total water-column plant nutrients (nitrate, nitrite, phosphate, silicate) showed a 1.3 to 4.5-fold decrease eastward, with semi-eutrophic conditions restricted to an area off the Po delta. Nanoplankton usually dominated the phytoplankton community, in terms of cell density, surface chlorophyll *a* concentrations, and surface primary production rates. However, all significant maxima in these characteristics resulted from increases in the microplankton component. Changes in the frequency of major microplankton groups characterized three periods of the annual cycle: September-December, neritic, temperate diatom flora with some littoral elements (e.g. *Nitschia seriata*); January-May, neritic, temperate diatom flora of different composition (e.g. *Lauderia borealis*, *Skeletonema costatum*); May-August, dinoflagellates (e.g. *Prorocentrum micans*) at

western stations and dinoflagellates plus neritic, warm-water diatoms at eastern stations. The seasonal cycle was characterized by spring and fall maxima tending to coincide with maximum Po river discharge and/or periods of low water-column stability and vertical mixing. The higher nutrient input at western stations was correlated with the co-dominance of only a few species of microplankton during bloom periods, suggesting that these species (*S. costatum, N. seriata*, and 5 others) can serve as indicators of eutrophic conditions in this region. Assimilation ratios of both the micro- and nanoplankton suggested borderline nutrient conditions. Phosphate was implicated as the limiting nutrient.

Revelante, N. and M. Gilmartin (1977) **The effects of Northern Italian rivers and Eastern Mediterranean ingressions on the phytoplankton of the Adriatic Sea.** *Hydrobiologia* **56**:229-240.
{phytoplankton; Mediterranean; Adriatic Sea; standing crop; diversity; chl. a; density; microplankton; nanoplankton; *Nitzschia seriata*; indicator; dinoflagellate; coccolithophores}

An analysis of the distribution of the phytoplankton standing crop during a period of high stability characterized by the relative influence of northern Italian rivers and Mediterranean waters on the Adriatic Sea. The region influenced by northern Italian rivers was marked by low community diversities, relatively high chlorophyll *a* standing crops and cell densities, high microplankton to nanoplankton community volume ratios, and the dominance of *Nitzschia seriata*. To the contrary, the region influenced by Mediterranean waters exhibited high community diversities with prominent oceanic and warm water elements, low chlorophyll *a* standing crops and microplankton cell densities, low microplankton to nanoplankton ratios, and a relatively conspicuous coccolithophore flora.

Nanoplankton populations remained relatively constant throughout the Adriatic. However eutrophication resulted in a marked increase in the microplankton component of the community, with the diatom *Nitzschia seriata* serving as a prime indicator of the process, even in regions several hundred kilometers downstream from nutrient sources.

Even under relatively low rates of river discharge, the influence of northern Italian rivers could be traced along the entire western side of the sea to the Otranto Strait, with low north to south and high west to east gradients resulting from the effect of a cyclonic surface circulation pattern on inflowing Mediterranean waters in the south and river discharge in the north.

Revelante, N. and M. Gilmartin (1980) **Microplankton diversity indices as indicators of eutrophication in the Northern Adriatic Sea.** *Hydrobiologia* **70**:277-286.
{phytoplankton; diversity; Adriatic Sea; Mediterranean; indicator; chl. a}

Phytoplankton community diversity indices are used to characterize 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.

Reys, E. and M. Merino (1991) **Diel dissolved oxygen dynamics and eutrophication in a shallow, well-mixed tropical lagoon.** *Estuaries* **14**:372-381.
{oxygen; dynamics; eutrophication; lagoon; Mexico; primary productivity}

Bojorquez Lagoon (BL), located on the Mexican Caribbean, has received sewage and dredging impacts as a result of tourism development. The lagoon supports a high diversity of primary producers compared to sheltered adjacent lagoons dominated by *Thalassia testudinum* communities. The Diurnal Curve Method (Odum and Hoskin, 1958) was used to measure community metabolism and asses eutrophication in BL by comparing it to the nonimpacted lagoons and to other systems studied with this method. Dissolved oxygen community input to the water column in BL ranged between 8.3 g O_2 m^{-2} d^{-1} and 41.5 g O_2 m^{-2} d^{-1} during 1985 and 1986, and averaged 17.1, whereas dissolved oxygen community consumption ranged from 6.4 g O_2 m^{-2} d^{-1} to 37.6 g O_2 m^{-2} d^{-1} and averaged 15.2. These values are higher than those found for the adjacent lagoons and similar coastal lagoons, and are similar to results from other lagoons with sewage or seafood waste discharge. Net flux of oxygen from the community to the water column averaged 1.9 g O_2 m^{-2} d^{-1} and ranged from -9.8 g O_2 m^{-2} d^{-1} to 8.1 g O_2 m^{-2} d^{-1}. These values are low compared to the adjacent lagoons, and close to zero, as in dystrophic environments. Primary productivity, as estimated by oxygen input, increased in BL during the period of study, indicating that eutrophication is proceeding, but the lagoon has not reached yet a level of "critical eutrophication" as defined by Mee (1988).

Riegman, R., A. Rowe, A. A. M. Noordeloos, and G. C. Cadée (1993) **Evidence for eutrophication induced *Phaeocystis* sp. blooms in the Marsdiep area**

(Netherlands). In: T. J. Smayda and Y. Shimizu (ed.) *Toxic Phytoplankton Blooms in the Sea.* Elsevier, Amsterdam.
{*Phaeocystis*; ammonium/nitrate ratio}

Recently, a global epidemic of novel and nuisance phytoplankton blooms has been suggested. Anthropogenic linkage is still questionable because the involved mechanisms are unclear. In all coastal areas of the European continent, anthropogenic enrichment of N and P (but not Si) has favoured non-diatom blooms during the nutrient controlled period (late spring-autumn). The colonial flagellate, *Phaeocystis* sp., regarded harmfull because of its massive foam production during the wane of the bloom, has increased in Dutch coastal waters. This increase coincides with a decrease of the average N/P ratio from 38 down to 13 dutring the nutrient controlled period (summer) as a consequence of altered nutrient discharges from Lake IJssel and the river Rhine. Competition experiments in continuous cultures showed that the *Phaeocystis* could become dominant at N/P ratios below 16. At higher N/P ratios *Phaeocystis* did not become dominant. In laboratory cultures, colony formation was absent under P-limitation. Under N-limitation, *Phaeocystis* formed only colonies when nitrate was the nitrogen source. Dutring growth on ammonium, no colonies were formed under limiting conditions. The importance of the ammonium/nitrate ratio for *Phaeocystis* colony formation under nutrient limiting conditions was illustrated in 1991 by a summer bloom which occurred in the Marsdiep area after the ammonium/nitrate ratio had dropped remarkably.

Riisgård, H. U. and E. Poulsen (1981) **Growth of *Mytilus eudulis* in net bags transferred to different localities in a eutrophicated Danish Fjord.** *Marine Pollution Bulletin* **12**:272-276.
{growth; bivalves; *Mytilus*; fjord; H2S; oxygen}

The growth rate has been measured in *Mytilus edulis* transferred in net bags to seven localities in the brackish Danish fjord, Limfjorden, in which certain areas are heavily eutrophicated. The increase in shell length, shell weight and flesh body weight was measured after growth periods of 14-18 days. The increase in, e.g., flesh dry weight ranged from twice the start weight to a four-fold increase of the start weight. The net growth efficiencies were estimated to be between 54 and 73%. Algal concentration was in no case the limiting growth factor, but low growth rates were observed in areas with seasonal oxygen depletion and release of toxic H_2S from the sediments. It is suggested that measurements of actual growth in *Mytilus edulis* can be a useful technique in the study of biological effects in marine recipients.

Ritz, D. A., M. E. Lewis, and M. Shen (1989) **Response to organic enrichment of infaunal macrobenthic communities under salmonid seacages.** *Marine Biology* **103**:211-214.
{macrobenthos; benthic; infauna; organic enrichment; abundance; biomass; diversity}

The response of infaunal macrobenthic communities beneath salmonid seacages to solid organic wastes (food pellets and fish excreta) was tested by means of the ABC-method (abundance, biomass comparison methods: Warwick 1986) on samples collected from the SAFCOL seafarm at Badger Cove, southeast Tasmania, from February to July 1988. The intermittent nature of the addition of organic waste allowed us to monitor decline and recovery of the macrofauna, i.e., harvesting of a cage permitted a period of recovery whilst restocking precipitated a decline. The ABC-method proved to be a sensitive indicator of community health. Under a normal feeding regime the macrofaunal community structure indicated a moderately disturbed condition. Only 7 wk after the cage was harvested, species richness had increased markedly and the community adopted an undisturbed condition. Further improvement was apparent 14 wk post-harvest. Similarly, a decline to a moderately disturbed condition was apparent 7 wk after restocking and species richness had declined. No such changes occurred under a cage which contained fish continuously over the same period.

Rosenberg, R. (1985) **Eutrophication-the future marine coastal nuisance?** *Marine Pollution Bulletin* **16**:227-231.
{oxygen; benthic fauna; fish; Sweden; bloom; review}

Increased inputs of nutrients to marine coastal areas over the last decades have created a basis for eutrophication of the waters surrounding Sweden. In combination with relatively low water exchange in these vertically stratified and almost non-tidal waters, local and regional effects of increased macro-algal biomass, and decreased oxygen concentrations in bottom water leading to mortalities of benthic animals and decreased fish catches have at times been observed. The effects were first noted in the Baltic, but are now obvious also in Swedish and Danish coastal areas in the Kattegat and the Belt Sea. Similar symptoms have recently also been recorded off the Danish North Sea coast. Other shallow coastal and shelf areas, where stratification occurs, can be regarded as potentially eutrophic risk areas.

Rosenberg, R. (1992) **Eutrophication-related marine ecosystem studies in western Sweden.** In: G. Colombo, I. Ferrari, V. U. Ceccherelli and R. Rossi (ed.) *Marine*

Eutrophication and Population Dynamics. Olsen & Olsen, Fredensborg.
{ecosystem; sediment transport; Kattegat}

A six year multidisciplinary programme in the Kattegat on the Swedish west coast is summarized. There are indications that primary production and sedimentation of organic material have increased lately due to eutrophication. Although primary production is not exceptional (annual mean 144 g C per square meter) the special geomorphological and hydrographical featurew of the southern Kattegat (shallow, semi-enclosed, no tide, strong halocline) promote development of periodic bottom-oxygen deficiency. The ecological importance of vertical sedimentation and of lateral transport of ephemeral blankets into areas of deposition is discussed. Several examples of rapidly occurring negative ecological effects caused by eutrophication are given.

Rosenberg, R., R. Elmgren, S. Fleischer, P. Jonsson, G. Persson, and H. Dahlin (1990) **Marine eutrophication case studies in Sweden.** *Ambio* **19**:102-108.
{review; Sweden; nutrient; effects}

This article summarizes the eutrophication of two sea areas: 1) the Baltic Sea and in particular a coastal area which is affected primarily by effluents from a tertiary sewage plant; and 2) the Kattegat and in particular the Laholm Bay, which is affected primarily by nutrient inputs from agriculture and forest land. During this decade, inputs of N and P to these large sea areas have increased by factors of approximately 4 to 6 and >8, respectively. Internal nutrient transport and atmospheric deposition is discussed. It is concluded that N availability generally limits primary production, except in Bothnian Bay, where P has this role. P is, however, the limiting factor at times in some coastal areas, and in the Baltic for N-fixing blue-green-algae, which bloom in warm summers when low N/P ratios prevail. Noted eutrophication effects are localized elevated primary production, decreased depth distribution and species richness of macroalgae. Eutrophication is most likely a stimulus to high benthic infaunal biomass and fish biomass in well ventilated sea areas. Other areas suffer today from almost permanant (the Baltic proper) or seasonal (the Kattegat) hypoxia with devastating effects on benthos and demersal fish. The N cycle and future possible consequences in relation to nutrient input are discussed. It is concluded that a reduction by at least half of external N and P to the Baltic sea, and N inputs to the Kattegat is needed to mitigate the negative effects of eutrophication.

Rosenberg, R., J. S. Gray, A. B. Josefson, and T. H. Pearson (1987) **Peterson's benthic stations revisited. II. Is the Oslofjord and eastern Skagerrak enriched?** *Journal of Experimental Marine Biology and Ecology* **105**:219-251.
{benthic; fauna; abundance; biomass; composition; organic enrichment}

In summer 1985, 23 of the stations established in 1914 by C.G.J. Petersen in the northern Skagerrak and the Oslofjord, were revisited to compare the present state of the macrobenthic assemblages with the previous condition. The methods used were similar to those of the original survey.

The total benthic biomass was significantly higher in 1985 by, on average, a factor of 1.8 over the whole area. Most of this change was due to a highly significant increase of worms, notably polychaetes, and a significant increase of ophiuroid and echinoid echinoderms. Similarity values in terms of biomass suggested that community composition had changed considerably over the 70-yr period, in particular in the inner and central Oslofjor (11% similarity) but also in the outer Oslofjord and the Skagerrak (33% similarity). There was no difference in the comparative size of individual organisms over the period.

The observed increase in biomass is greater than the increase along the Swedish Skagerrak coast observed in the late 1970s, and well beyond the observed limits of annual variability in such areas. Different causes for the observed changes are discussed and it is suggested that a general organic enrichment has taken place in the Oslofjord.

Rosenberg, R., B. Hellman, and B. Johansson (1991) **Hypoxic tolerance of marine benthic fauna.** *Marine Ecology Progress Series* **79**:127-131.
{hypoxia; oxygen; benthic; fauna; tolerance}

In stratified coastal marine waters hypoxia is a growing problem affecting bottom-dwelling animals. Earlier studies suggest oxygen concentrations of about 2 ml l^{-1} (Rosenberg, 1980) as the lower tolerance limit for many benthic species in coastal areas. We exposed several conspicuous infaunal species on the NE Atlantic continental shelf, contained within their sediment habitat, to gradually reduced oxygen concentrations. Tolerance to hypoxia for the 8 species examined was in the range of 0.5 to 1.0 ml l^{-1} (8 to 15% saturation), which they could tolerate for several days to weeks. The ophiuroid *Amphiura filiformis* left its protected position in the sediment at an oxygen concentration of 0.85 ml l^{-1} (13% sat.), whereas *A. chiajei* emerged from the sediment at 0.54 ml l^{-1} (8% sat.).

Rosenberg, R. and L.-O. Loo (1988) **Marine eutrophication induced oxygen deficiency: Effects on soft bottom fauna, western Sweden.** *Ophelia* **29**:213-225.

{oxygen; benthic; macrofauna; increase; mortality}

Marine eutrophication is studied in a multidisciplinary project in the Kattegat, western Sweden. Input of nutrients has increased several-fold during this century; nitrogen ≈ 6 times, phosphorus ≈ 10 times. This has caused elevated concentrations of nutrients in the water and increased primary production. Some adverse effects at the bottom have been noted annually from about August through October in the 1980's, e.g. fish catches have dropped and mortalities have been reported for fish and benthic animals including *Nephrops norvegicus*.

In this paper we evaluate the effects on benthic macrofauna which are suggested to be caused mainly by oxygen deficiency occurring especially around the depth of a strong halocline (≈ 15 m), but also along a bottom transect down to 57 m. At some sites the benthic communities were impoverished, and at others only some species seemed to be especially sensitive, e.g. the bivalve *Abra alba* and the brittle star *Amphiura filiformis*.

In shallow (< 10m) exposed waters an annually occurring mortality of molluscs was observed over large areas from 1980 onwards. Affected species were mainly the bivalves *Cardium edule* and *Mya arenaria*. The causes behind this mortality may also be oxygen deficiency occurring during calm weather periods.

Rydberg, L., L. Edler, S. Floderus, and W. Granéli (1990) **Interaction between supply of nutrients, primary production, sedimentation and oxygen consumption in SE Kattegat.** *Ambio* **19**:134-141.

{nutrients; nitrogen; phosphorus; oxygen; Baltic}

Intensive measurements of nutrient fluxes, carbon and nitrogen assimilation, sedimentation and oxygen consumption within the SE Kattegat are used in an effort to follow the coupling between increasing nutrient supply and decreasing deep-water oxygen concentration. The investigated area is a part of the strongly stratified Baltic estuary, with a hampered deep-water exchange and a large supply of nitrogen from nearby anthropogenic sources. Measurements were undertaken during 1981-1988. The results are discussed, mainly in terms of annual or seasonal mean values. The average primary production, 11.4 mol C m^{-2} (corresponding to 45 mmol C m^{-2} d^{-1} during the "productive season"; from March to October), was surprisingly well correlated with the uptake of inorganic nitrogen, which averaged 1.68 mol N m^{-2} (11.1 mol C m^{-2}, using the Redfield ratio). The oxygen consumption (deep water and benthic) which averaged 20 mol O_2 m^{-2} d^{-1}, was well correlated with the measured nitrate uptake and with the external supply of nitrate to the surface water. The consumption was twice as high as that in the open Kattegat.

Ryther, J. H. and W. M. Dunstan (1971) **Nitrogen, phosphorus, and eutrophication in the coastal marine environment.** *Science* **171**:1008-1013.

{nutrients; nitrogen; phosphorus; phytoplankton}

The distribution of inorganic nitrogen and phosphorus and bioassay experiments both show that nitrogen is the critical limiting factor to algal growth and eutrophication in coastal marine waters. About twice the amount of phosphate as can be used by the algae is normally present. This surplus results from the low nitrogen to phosphorus ratio in terrigenous contributions, including human waste, and from the fact that phosphorus regenerates more quickly than ammonia from decomposing organic matter. Removal of phosphate from detergents is therefore not likely to slow the eutrophication of coastal marine waters, and its replacement with nitrogen-containing nitrilotriacetic acid may worsen the situations.

Saad, M. A. H. and E. I. M. Hemeda (1992) **Effect of pollution on the Western Harbour of Alexandria. I. Environmental characteristics.** In: R. A. Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication*. Elsevier, Amsterdam.

{pH}

The Western Harbour of Alexandria has an area of about 1962 acres and a water depth ranging from 6-14 m. This harbour is protected by two water breaks and is divided into two areas; the inner and outer ports. The water quality of the harbour has deterioated due to the effects of various pollutants discharged from ships at anchor and sewage waste outfalls. Variations of some of the environmental conditions in the harbour were studied. Temperature measurements generally decreased with depth. The highest average water temperatures were recorded in July and August, whereas the lowest were in January and February. The Secchi disc readins showed remarkable variations: the minimum and maximum regional average Secchi values were accompanied by the highest and lowest regional averages of suspended matter (SM). The irregularity in the vertical distribution of SM possibly coincided with turbulence of the wsater column from navigation and the effect of pollution. Salinity values generally increased with depth. The discharge of sewage wastes from numerous ships and land-based sources decreased the surface salinity. The highest regional average salinity values were found at locations far from the direct effect of sewage pollution. The pH values generally decreased with depth: low pH values were found at locations directly affected by sewage wastes.

Sales, D., A. Gómez, and D. Cantero (1983) **Incidence of urban sewage disposal in the**

salt-ponds areas of the south of the Bay of Cadiz. *Marine Pollution Bulletin* **14**:447-452.
{Cadiz Bay; oxygen; salt pond}

The highest pollution indices in the marsh and tide-lands situated to the south of the Bay of Cadiz have been evaluated. At the present, the salt industry of this area is being transformed into mariculture installations. This study consisted of the systematic evaluation of different parameters at 26 sampling stations during the period 1976-1981. The results suggest that extensive zones are too seriously affected to make use of them as marine piscifactories.

Samanidou, V., K. Fytianos, and G. Vasilikiotis (1989) **Distribution of nutrients in the Thermaikos Gulf, Greece.** *Toxicological and Environmental Chemistry* **20-21**:29-37.
{nutrients; Greece; methods; nitrogen; phosphorus; distribution; sewage}

The distribution of nutrients (phosphate, nitrate, nitrite and ammonium) in water samples from eleven sampling stations in the Thermaikos Gulf was studied during a period of one year (1985-1986). Significant seasonal fluctuations were observed mainly for nitrate and ammonium, with a maximum during winter and a minimum in the summer. The obtained data showed that the nutrients are present at relatively high concentrations near the agricultural areas, in the harbour of Thessalonki and in the area where municipal sewages are discharged.

Sampou, P. and C. A. Oviatt (1991) **Seasonal patterns of sedimentary carbon and anaerobic respiration along a simulated eutrophication gradient.** *Marine Ecology Progress Series* **72**:271-282.
{organic carbon; oxygen uptake; sulfate reduction}

Concentrations of organic carbon and rates of dissimilative sulfate reduction in surface sediments of marine mesocosms were examined along an experimental eutrophication gradient. Phytoplankton biomass increased due to addition of inorganic nutrients (N, P, Si). This increase was especially pronounced during the winter-spring diatom blooms, which increased in magnitude and duration along the nutrient gradient. Net system production in winter and spring resulted in carbon deposition and accumulation in surface sediments (maximum net accumulation 17 mol C m^{-2}). Benthic remineralization of carbon exceeded depositional supply during summer and fall. Sediment carbon concentration approached background levels in December and February, suggesting very little annual accumulation of sediment carbon. Sediment oxygen consumption and sulfate reduction rates in organic enriched sediments were an order of magnitude higher than control and were correlated with temperature and carbon concentrations (r^2=0.85). Anaerobic metabolism was the dominant metabolic pathway in control and treated sediments, with 50 to 70% of annual carbon remineralization due to sulfate reduction.

Sampou, P. A. (1989) ***Effects of eutrophication on the biogeochemical cycling of carbon, oxygen, sulfur and energy in coastal marine ecosystems.*** Dissertation for Ph.D., University of Rhode Island.
{biogeochemical cycling; energy flow; MERL; sewage; nutrients; production; ecosystem; oxygen}

The effects of eutrophication on the biogeochemical cycling of the major elemental cycles, carbon, oxygen, and sulfur and on energy flow, were investigated in experimental marine ecosystems (mesocosms). Eutrophic environmental conditions were created within mesocosms by daily addition of varying amounts and sources of nutrients and sewage sludge. Inorganic nutrient loading resulted in an increase in the magnitude and duration of winter-spring phytoplankton populations and production with a correlated increase in sedimentation and accumulation of carbon in surface sediments. Net ecosystem production during the winter and spring was followed by net system heterotrophy during the summer and fall with a concomitant decrease in sedimentary carbon concentrations. Carbon sedimentation and accumulation (up to 19 mol C M^{-2}) in surface sediments stimulated sediment oxygen consumption and sulfate reduction metabolism. Sulfate reduction increased by an order of magnitude in carbon enriched sediments and was a dominant pathway for benthic carbon remineralization in all the mesocosms. However, the fraction of benthic metabolism using sulfate for a terminal electron acceptor did not increase along the nutrient addition gradient when annual integrated estimates of metabolism were compared.

Whole system carbon and oxygen budget showed the sediments to be an important and influential component in eutrophic marine ecosystems. A significant fraction of allochthonous sewage carbon was remineralized via sulfate reduction in the sediments. This led to the dissociation of carbon cycling from oxygen and energy flow in the system due to an increased role of sulfur biogeochemistry. Accumulation of solid sulfides in the sediments from sulfate reduction during the experiment explained the discrepancy between carbon dioxide and oxygen consumption at the sediment water interface (respiratory quotients > 2) and represented a large storage of energy originally contained in organic matter.

Oxygen dynamics in eutrophic marine systems were regulated by phytoplankton cycles and sulfur cycling in the sediments. Initiation of hypoxia

(oxygen less than 2 mg l^{-1}) was caused by rapidly declining phytoplankton populations and a large imbalance between day oxygen production and night oxygen consumption in the water column. However, high sulfate reduction rates and the accumulation of hydrogen sulfide in surface sediments was found to be influential in the demise of the macrofauna and the precipitation and maintenance of oxygen concentrations less than 1 mg l^{-1}.

Sand-Jensen, K. and J. Borum (1983) **Regulation of growth of eelgrass (*Zostera marina* L.) in Danish coastal waters.** *Marine Technology Society Journal* 17:15-21.
{submerged vegetation; eelgrass; growth; shading}

Eelgrass is the dominant macrophyte in coastal Danish waters. The productivity of eelgrass is at the same level as fertile terrestrial crops and it can be substantially higher than the phytoplankton production in open waters when compared per unit surface area. Eelgrass may contribute significantly to the total production of all autotrophic components in shallow coastal areas.

The above-ground biomass of eelgrass is more variable than the below-ground biomass due to a higher turnover rate and exposure to physical factors of the former. In shallow water, biomass of eelgrass increases rapidly from spring to early summer and stabilizes at a high level during late summer. Growth is continuous throughout the year although it occurs at a higher rate during spring and summer. Individual plants produce about 16 leaves and rhizome segments per year. During spring and summer each plant produces a new leaf every 9-15 days and their life span is about 2 months. The rapid turnover is important in keeping down the epiphytic load by producing new tissue. It also produces a continuous supply of senescing leaves which presumably leads to stabilized energy transformations within the detritus food web. Since the leaf biomass increases from spring to summer, the ratio of daily productivity to biomass (P/B) falls because of increased self-shading. Water temperature and availability of nutrients do not affect seasonal variation in leaf productivity. Nutrient availability may, however, affect the biomass as a yield limiting factor.

Eutrophication of coastal waters changes in the balance among different autotrophic components. Growth of phytoplankton, epiphytes and free-floating algae, which take up inorganic nutrient from the free water phase, is greatly stimulated. This will result in decreased growth rates, depth penetration and, eventually, survival of eelgrass though shading.
Biomass and growth measurements of epiphytic algae provide a convenient method for assessing the effect of inorganic nutrient loading in different parts of a receiving area. Eelgrass is suitable as an indicator of trace-metal pollution as it occurs over a widespread area and chemical analysis for trace metals is a relatively simple procedure. Due to the high growth potential of eelgrass leaves (about 5-6 cm leaf turion^{-1} day^{-1}), growth rates of leaves can be used as a very sensitive method of assessing the effects of industrial waste products both in the field and in laboratory tests.

Sandulli, R. and M. d. N. Giudici (1989) **Effects of organic enrichment on meiofauna: A laboratory study.** *Marine Pollution Bulletin* **20**:223-227.
{meiofauna; sewage; nematode; harpacticoid; copepod; ratio}

A 84 day laboratory experiment indicates the decline of intertidal meiofauna abundance may be directly related to treatment level and time of exposure to sewage sludge. The observed changes revealed a marked decrease of nematodes and total disappearance of mesobenthic harpacticoids while the non-interstitial copepod species were little affected. The possibility of a new interpretation of the Nematode/Copepod ratio as an index of organic pollution in sediments is discussed.

Schiewer, U., R. Börner, and N. Wasmund (1988) **Deterministic and stochastic influence of nutrients on phytoplankton function and structure in coastal waters.** *Kieler Meeresforschungen, Sonderheft* **6**:173-183.
{phytoplankton; nutrients; composition; abundance; chlorophyll a}

Knowledge of how phytoplankton responds to nutrient inputs is essential for water management and for minimizing eutrophication. Only processes that are deterministic, i.e. that can respond as algorithms, are controllable. The study area is the chain of inshore waters (so-called Bodden) south of the Darss-Zingst peninsula- shallow eutrophic waters of estuarine character in the Southern Baltic. Monitoring programmes and laboratory experiments have revealed an annual periodicity of the phytoplankton and of the physico-chemical factors influencing it. On the basis of these results, experiments were carried out in enclosures to study the effects of nutrient loading on phytoplankton. The purpose was to test the feasibility of influencing phytoplankton development under field conditions during the transition period from late spring to mid-summer.

This contribution presents results from the 1985 shallow water enclosure experiments (FLAK 85) which demonstrate that
- the scale of phytoplankton reactions and the species involved are stochastic in character and are governed by stochastic interactions between meteorological events and water exchange processes in the chain of Bodden;

- all processes affecting phytoplankton growth are deterministic in character, conforming to simple batch theories: simultaneous addition of nitrogen and phosphorus favours green algae, and in exceptional cases one algal species became dominant
- nutrient loadings do not affect the time of transition to the mid-summer phytoplankton population, the most important regulating factor obviously being temperature.

Schindler, D. W. (1981) **Studies of eutrophication in lakes and their relevance to the estuarine environment.** In: B. J. Neilson and L. E. Cronin (ed.) *Estuaries and Nutrients*. Humana Press, Clifton, New Jersey.
{lake; estuary; comparison; Vollenweider; nutrient; composition}
No abstract

Schlungbaum, G. and G. Nausch (1988) **Nutrient turnover at the sediment/water interface in shallow eutrophic coastal waters.** *Kieler Meeresforschungen, Sonderheft* **6**:184-190.
{sediment; interface; nutrient; phosphorus; phosphate; phytoplankton; primary production}

The nutrient situation in eutrophic shallow coastal water systems is characterized by particular features. In addition to water exchange with the open sea, interactions at the sediment/water interface play a significant role. With the help of investigation of phosphate sorption/desorption balances and on the denitrification capacity of shallow coastal waters, the following general conclusions can be made: The phosphate concentrations in the water are primarily determined by physico-chemical reactions with the sediment, and less by the rhythm of the phytoplankton primary production. Through intensive interactions between sediment and water, a phosphate "equilibrium" concentration which fluctuates very little is maintained over the whole year. High primary production rates are possible at these low equilibrium concentrations of phosphate sorption capacities. With the development of nearly anaerobic conditions, nitrate reduction can occur at a rate, when the appropriate amount of nitrate is made available to the reaction. Under optimal conditions for nitrate reduction, nitrate concentration is also not a parameter characterizing the nature of the water body.

Schramm, W., D. Abele, and G. Breuer (1988) **Nitrogen and phosphorus nutrition and productivity of two community forming seaweeds (*Fucus vesiculosus, Phycodrys rubens*) from the Western Baltic (Kiel Bight) in the light of eutrophication processes.** *Kieler Meeresforschungen, Sonderheft* **6**:221-240.
{nitrogen; phosphorus; seaweeds; productivity; *Fucus*; *Phycodrys*; Baltic}

Considerable amounts of nutrients enter, as a result of human activity, the Western Baltic Sea in the form of discharge of seepage from land or as atmospheric input. Benthic macrophytes which preferably inhabit the nutrient recipient shallow near-shore areas, and where they often constitute the major primary producers may thus play an important role in eutrophication processes by uptake and accumulation on nutrient elements, enhanced primary production and following degradation of the produced organic material. Nutrient uptake, binding capacity and illumination as well as nutrient dependent growth of the two community forming seaweeds *Phycodrys rubens* and *Fucus vesiculosus* have been investigated and related to the seasonal patterns of the nutrient conditions in their respective habitats. Nutrient concentrations, both phosphorus and nitrogen, in the algal beds are markedly higher than in the surface water of the open Kiel Bight. In general, the seaweeds seem not to be nutrient limited under natural conditions except for nitrogen in *Phycodrys* during summer. Nutrient tissue contents are saturated only for nitrogen during winter. The significance of these findings is discussed in view of the observed increasing nutrient levels and changes of the vegetation in the Kiel Bight.

Schultz, S., G. Ærtebjerg, G. Behrends, G. Breuel, P. Ciszewski, U. Horstmann, K. Kononen, E. Kostrichkina, J. Leppänen, F. Møhlenberg, O. Sandström, M. Viitasalo, and T. Willén (1992) **The present state of the Baltic Sea pelagic ecosystem - an assessment.** In: G. Colombo, I. Ferrari, V. U. Ceccherelli and R. Rossi (ed.) *Marine Eutrophication and Population Dynamics*. Olsen & Olsen, Fredensborg.
{Baltic Sea; assessment; pelagic biology; phytoplankton assemblage}

In recent years, the decrease of salinity as well as of the temperature and oxygen in the deep water has continued in the Baltic Sea. In addition, the content of phosphate and nitrate has declined in the winter surface water at least during the last two years. However, both the primary production capacity and the assimilation numbers have been increasing for most sub-areas of the Baltic Sea, indicating a higher phytoplankton activity. The stock of zooplankton increased in tha Arkona, Bornholm and Eastern Gotland Seas. Changes in the species composition or in the structure of the phytoplankton and zooplankton community have not been observed.

The present status of the Baltic Sea pelagic system reflects clear signs of eutrophication. The reasons for this are seen in the anthropogenic

impact in conjunction with the features of the Baltic Sea and a stagnation period lasting thirteen years.

Schulz, S. and G. Breuel (1981) **Response of plastic-bag enclosed summer phytoplankton to a nutrient input under in situ conditions in the Arkona Sea (Baltic Sea).** *Kieler Meeresforschungen, Sonderheft* **5**:91-100.
{phytoplankton; nutrients; Baltic; primary production; Arkona; biomass; composition}

In July 1878 several experiments with enclosed summer phytoplankton communities were carried out in the Arkona Sea using 25 l cylindrical bags made of 0.2 mm polyethylene film. These experiments concerned the response of phytoplankton to nutrient input. Phytoplankton biomass, primary production and chlorophyll content increased rapidly in enriched water, in contrast to the controls where changes were negligible. Nutrients were depleted to the same levels as in the controls after a few days. The μ-algae were the first to respond to nutrient input, followed later by diatoms and dinoflagellates. In the course of the experiments, however, the energy was stored to an increasing extent in the cyanophytes at the expense of other groups where energy content remained constant or decreased slightly.

Schulz, S., G. Breuel, and A. Irmisch (1988) **Simulated eutrophication in enclosure experiments in the Arkona Sea.** *Kieler Meeresforschungeb, Sonderheft* **6**:73-84.
{Arkona Sea; Baltic; plankton; nutrients; primary production; biomass; productivity}

In spring, summer and autumn enclosure experiments were performed in the central part of the Arkona Sea. The natural water with the plankton community was enriched by nutrients to about winter levels, and to the double of these concentrations.

In spring and summer, the phytoplankton responded with rapid uptake of nutrients and an increase in primary production and biomass. In autumn, the uptake of nutrients was also fast, whereas productivity did not increase, and biomass only in diatoms. Not only did the production increase with higher nutrient supply, but also the productive season was prolonged. This fact is important for the function of the pelagic system in the Baltic, because the biomass and nutrients remaining in the spring bloom determine to a great extent the productivity of the whole year.

Seiki, T., E. Date, and H. Izawa (1991) **Eutrophication in Hiroshima Bay.** *Marine Pollution Bulletin* **23**:95-99.
{nutrients; primary production; budget}

Several researches for eutrophication in the northern Hiroshima Bay were carried out to investigate nutrient budgets in aquatic circulation processes, i.e. primary production, settling flux of particulate organic matter (POM) and the benthic remineralization.

It became apparent from these investigations that primary production contributed more to the organic pollution in the northern bay than land based organic loadings by a factor of 10, that approx. 70-80% of the POM originating in phytoplankton were easily remineralized into inorganic nutrients during the settling process in water, and that approx. 60% of nitrogen and 70% of phosphorus in POM settled on the sediments might be returned to the water column by the release from benthic sediment.

Seitzinger, S. P. and S. W. Nixon (1985) **Eutrophication and the rate of denitrification and N_2O production in coastal marine sediments.** *Limnology and Oceanography* **30**:1332-1339.
{denitrification; N_2O production; nutrient; MERL}

Large (13 m^3, 5m deep) microcosms with coupled pelagic and benthic components were used to measure the effect of nutrient loading and eutrophication in coastal marine ecosystems on the rates of benthic denitrification (N_2) and N_2O production. After 3 months of daily nutrient additions, average denitrification rates ranged from about 300 umol N m^{-2} h^{-1} in the sediments of the control microcosm to 880 in the most enriched microcosm, which received 65 times the nutrient input of the control. Increases in the production of N_2O were more dramatic and increased by a factor of about 100, from 0.56 N m^{-2} h^{-1} in the control to 51 in the most enriched microcosm. Although there was a clear increase in the denitrification rate in the more eutrophic systems, the amount of fixed nitrogen removed was a constant or progressively smaller fraction of the nitrogen input. Even in the most enriched microcosm, at least 16% of the N input was removed by denitrification.

Seliger, H. H. (1989) **Mechanisms for red tides of *Pyrodinium bahamense* var. *compressum* in Papua New Guinea, Sabah and Brunei Darussalam.** In: G. M. Hallegraeff and J. L. Maclean (ed.) *Biology, Epidemology and Management of Pyrodinium red Tides*. Fisheries Department, Ministry of Development, Manila.
{red tides; blooms; abundance}

Mechanisms are proposed to explain the development of red tides of the toxic dinoflagellate *Pyrodinium bahamense* var. *compressum* along the northern and southern coasts of Papua New Guinea and along the northwest coast of Borneo, from

Sabah to Burnei Darussalam. The "spread" of red tides to areas not previously affected and the increased frequency of annual occurrences of paralytic shellfish poisoning in already colonized areas are suggested to be the result of coastal hypertrophication. Increased nutrients along coastlines permit sufficient reproduction of dinoflagellates in entrained surfaces patches to compensate dilution losses, enhancing emigration over longer distances.

Sellner, K. G. and M. M. Olson (1985) **Copepod grazing in red tide of Chesapeake Bay.** In: D. M. Anderson, A. W. White and D. G. Baden (ed.) *Toxic Dinoflagellates.* Elsevier, New York.
{secondary production; zooplankton; bloom; Chesapeake Bay; red tide; grazing; dinoflagellates}

Copepod grazing of dinoflagellate blooms in Chesapeake Bay and its tributaries was investigated using ^{14}C-labelling procedures. Grazing rates for *Eurytemora affinis*, the late winter - early spring dominant herbivore, on *Heterocapsa triquetra* were low with a mean rate of 0.011 +- 0.002 ml copepod^{-1}h^{-1}. However, at a cell density of 2.43 X 10^5 ml^{-1}, the ingestion rate corresponds to 1.88 ugC copepod^{-1}h^{-1}, or approximately one-third of the copepod's daily ration. Fecal pellet production every 6-9 min. Low grazing rates for the spring-fall dominant herbivore, *Acartia tonsa*, were also recorded where the copepod was feeding on blooms of *Gymnodinium* sp. and *Katodinium rotundatum.* Mean rates ranged from 0.005 - 0.048 ml copepod^{-1}h^{-1}, corresponding to estimated ingestion rates of 0.038 - 0.102 ugC copepod^{-1}h^{-1}, well below the rate recorded for *Eurytemora.* These data indicated that *A. tonsa* may not remove significant quantities of dinoflagellate carbon in Chesapeake Bay and its sub-estuaries.

Silva, E. S. (1985) **Ecological factors related to *Prorocentrum minimum* blooms in Obidos Lagoon (Portugal).** In: D. M. Anderson, A. W. White and D. G. Baden (ed.) *Toxic Dinoflagellates.* Elsevier, New York.
{red tide; bloom; environmental condition}

Prorocentrum minimum Schiller red waters have often been observed in Obidos Lagoon and have caused toxicity of bivalve there. Particular attention is given to two of those blooms, separated by about 10 years, in May-June 1973 and in January-February 1983. A comparative study of environmental conditions during the two red waters of *P. minimum* is presented.

Skjoldal, H. (1992)
Personal Communication.

Skjoldal, H. R. and I. Dundas (ed.) (1991) ***The Chrysochromulina polylepis bloom in the Skagerrak and the Kattegat in May-June 1988: Environmental conditions, possible causes, and effects.*** ICES, Copenhagen.
{bloom; *Chrysochromulina*; causes}
No abstract

Smayda, T. J. (1989) **Primary production and the global epidemic of phytoplankton blooms in the sea: A linkage?** In: E. M. Cosper, N. M. Bricelj and E. J. Carpenter (ed.) *Novel Phytoplankton Blooms; Causes and Impacts of Recurrent Brown Tides and Other Unusual Blooms.* Springer-Verlag, Berlin.
{primary production; phytoplankton bloom}
No abstract

Smayda, T. J. (1992) **A phantom of the ocean.** *Nature* **358**:374-375.
{dinoflagellate; red tides; foodweb}
No abstract

Smayda, T. J. and Y. Shimizu (ed.) (1993) ***Toxic Phytoplankton Blooms in the Sea (Proceedings of the Fifth International Conference on Toxic Marine Phytoplankton, Newport, Rhode Island, U.S.A., 28 October -1 November 1991).*** Elsevier, Amsterdam.
No abstract

Smayda, T. J. and A. W. White (1990) **Has there been a global expansion of algal bloom? If so, is there a connection with human activities?** In: E. Granéli, B. Sundström, L. Edler and D. M. Anderson (ed.) *Toxic Marine Phytoplankton.* Elsevier, New York.
{phytoplankton; algae; bloom; nutrient enrichment}
No abstract

Smith, D. W. (1984) ***Responses of aufwuchs, phytoplankton and macrophytes to municipal and industrial wastes in San Francisco Bay and bay analog systems.*** Dissertation for Ph.D., University of California, Berkeley.
{auhwuchs; phytoplankton; seaweeds; San Francisco Bay; method; mesocosm}

The use of aquatic organisms which colonize artificial substrates (aufwuchs) is currently being developed as a method of assessing localized effects of municipal and industrial discharges into San Francisco Bay, California by state regulatory agencies. The method is intended to provide an inexpensive and robust bioassay which will serve as an index of wastewater effects on the phytoplankton community, since the effects on

phytoplankton cannot be directly observed. In this study functional or physiological responses (photosynthesis, respiration, chlorophyll *a*, and biomass) were measured in the laboratory, in mesocosms and in the field to characterize the response of the aufwuchs community to wastewater and some of its individual stimulatory and toxic components. The mesocosm consisted of 12 outdoor 3000L tanks with a constant supply of baywater. The response of aufwuchs under experimental conditions confirmed and elucidated the causes of the stimulatory response of aufwuchs grown on substrates moored in dilution-fields in San Francisco Bay.

The effects of colloidal and microbial components of wastewater on earlier colonizing and later rapid growth phase of the auchwuchs community were determined to be unimportant with respect to the measurable differences caused by exposure to wastewater. Wastewater was found to stimulate growth of aufwuchs. Inorganic nitrogen was determined experimentally and deductively to be the causative stimulatory component of wastewater. Aufwuchs were also shown to be sensitive to toxic compounds found in the wastewater.

The stimulatory and toxic response of aufwuchs amplified the response of phytoplankton. Various aspects of the Bay's physical and chemical environment such as light turbulence and ambient nutrient concentration may result in this amplification by moderating factors. Aufwuchs, then, may serve as an early warning of potential effects of wastewater on phytoplankton.

Strategies of substrate deployment and harvest were also assessed. Increased biomass, facilitated by relatively long incubation intervals (7-14 days), was shown experimentally to maximize the precision of the technique. The precision of the method is adequate from a regulatory point of view to delineate the region where biota are influenced by wastewater.

Smith, S. V. (1981) **Responses of Kaneohe Bay, Hawaii, to relaxation of sewage stress.** In: B. J. Neilson and L. E. Eugene (ed.) *Estuaries and Nutrients*. Humana Press, Clifton, New Jersey.
{nitrogen; sewage; nutrient; cycling; Hawaii}

Kaneohe Bay is a subtropical coral reef/estuary complex which was subjected to increasing sewage loading; that sewage was diverted in 1977 and 1978. We have treated the loading and diversion as a controlled , total-ecosystem experiment to evaluate the chemical and biological responses to external subsidy of nutrients. We here consider the Bay's response to sewage loading and to its diversion largely in the context of a nitrogen budget.

Even the most heavily impacted portion of the Bay showed only modest increases in dissolved nitrogen levels within the water column. Particulate materials including plankton biomass, as well as dissolved inorganic phosphorus, were elevated substantially. The benthos showed increased biomass and metabolic rates, especially of heterotrophs responding to fallout of organic particulate materials. Nutrient recycling within the Bay was the major immediate source for the nutrients for the observed rapid metabolic activity.

Sewage accounted for approximately 80 percent of the inorganic nitrogen and 90 percent of the inorganic phosphorus delivery to Kaneohe Bay. Diversion lowered the land-derived inorganic nitrogen and phosphorus input to the Bay by 70-80 percent. Virtually all components of the system have responded to this diminished nutrient subsidy, but the water column nutrient washout and biological recovery are predictably occurring more rapidly than the benthos responses.

Snelgrove, P. V. R. and J. B. Lewis (1989) **Response of a coral-associated crustacean community to eutrophication.** *Marine Biology* **101**:249-257.
{crustacea; coral; *Madracis*; Barbados; composition; density}

Seventy-five samples of the crustacean fauna associated with the coral *Madracis mirabilis* (Duchassaing and Michelotii) were obtained at five sites along the west coast of Barbados in 1985. Samples were analyzed to determine whether any community response to eutrophication was evident. Ordination (multidimensional scaling) and classification (group average clustering) based on Bray-Curtis dissimilarity measures separated the fauna of highly eutrophied sites from those that were less eutrophied. Dominance plots based on relative abundance and log-normal plotting methods were ineffective in distinguishing the fauna of eutrophied sites. The crustacean fauna responded to cutrophication mainly by reduction of density of animals. No differences in species richness, number of site endemic species or rare species were observed between highly eutrophied and less eutrophied sites. Nine "indicator" species of eutrophy were identified on the basis of strong density differences between sites.

Soulsby, P. G., D. Lowthion, and M. Houston (1982) **Effects of macroalgal mats on the ecology of intertidal mudflats.** *Marine Pollution Bulletin* **13**:162-166.
{macroalgal mats; mudflat; benthos; abundance; biomass}

The standing biomass and distribution of the invertebrate fauna of mudflats covered by macroalgal mats has been determined and compared with that of mudflats unaffected by algae. The faunal biomass of algal-covered mud was consistently higher than uncovered mud, mainly

due to the presence of large populations of the snail *Hydrobia ulvae*. The structure of the faunal composition of algal-covered mud was altered and the numbers of at least one species of polychaete worm markedly reduced. The effects of these changes on the bird population exploiting the mudflats is discussed.

Soulsby, P. G., D. Lowthion, and H. A. C. Montgomery (1985) **The role of sewage effluent in the accumulation of macroalgal mats on intertidal mudflats in two basins in southern England.** *Netherlands Journal of Sea Research* **19**:257-263.
{macroalgae; nutrients}

Two intertidal basins in southern England, Portsmouth Harbour and Langstone Harbour, both support large crops of the macroalgae *Ulva* and *Enteromorpha* each summer. Both Harbours have received discharges of sewage but the discharge in Portsmouth has been removed. Data from surveys of algal distribution, standing biomass, tissue nutrient concentration and water column nutrient concentration have been evaluated in order to detemine the relationship between effluent discharge and macroalgal growth. No direct relationship between water column nutrient concentration and macroalgae biomass or area cover was found in the field. Concentrations of Nitrogen and Nitrogen:Phosphorus ratio in the tissues suggest that Nitrogen is stored in excess during the growing season. It is concluded that the evidence strongly indicates that further increases in sewage derived nutrient will not result in higher standing crops of algae than currently observed.

Spencer, C. P. (1985) **The use of plant micro-nutrient and chlorophyll records as indices of eutrophication in inshore waters.** *Netherlands Journal of Sea Research* **19**:269 -275.
{indices; chlorophyll; nutrients}

The records for 14 years of plant micro-nutrient concentrations and the quantities of chlorophyll in Liverpool Bay are reviewed. The complicated and varied hydrographical regimes which characterize the area preclude the use of the former variables as precise indicators of the extent of enrichment of the water. There is nonetheless evidence that the area can sometimes support high standing crops of phytoplankton. Advective dispersal processes and variations in their intensity are probably particularly important in controling the magnitude of these crops of phytoplankton. It is suggested that adequate long term records of the frequency and durations of such blooms are likely to be a more useful indication of the extent or eutrophication of the area and of any long term trends which might occur than are the hydrochemical data.

Stachowitsch, M. (1991) **Anoxia in the Northern Adriatic Sea: rapid death, slow recovery.** In: R. V. Tyson and T. H. Pearson (ed.) *Modern and Ancient Continental Shelf Anoxia.* The Geological Society, London, England.
{Adriatic; oxygen; benthos; anoxia; mortality}

The Northern Adriatic Sea is characterized by the full range of features associated with sensitive marine ecosystems. In the Gulf of Trieste, mortalities due to anoxia have been reported in 1974, 1983 and 1988. The anoxic event in September 1983 led to mass mortality in a highly developed and wide-ranging community in the Gulf. This destroyed over 50% of the epifaunal biomass in only two days, and over 90% within four days.

The increased frequency, severity, and range of recent oxygen deficiencies suggest that, in addition to meteorological and hydrographic factors, anthropogenic influences are a contributing or enhancing factor in the onset of anoxic conditions and associated mass mortalities. These anthropogenic influences may be subsumed under the heading eutrophication. If eutrophication only slightly increases the rate of oxygen decrease below the thermocline, it may advance the point at which critical oxygen levels are attained by several days. Since only a few days of anoxic conditions are required to destroy this benthic community (with an equally short time required for reoxygenation) the degree of eutrophication may determine whether an ecological catastrophe occurs or not.

The recolonization process between 1984 and 1987 has been slow: the total biomass and the relative contribution of the designating species have remained distinctly below previously recorded values. Additional anthropogenic influences (intensive dredging) may further impede recolonization. A further, small-scale mortality was registered in 1988.

Stambler, N., N. Popper, Z. Dubinsky, and J. Stimson (1991) **Effects of nutrient enrichment and water motion on the coral *Pocillopora damicornis*.** *Pacific Science* **45**:299-307.
{nutrient; coral; phosphorus; nitrogen; density; growth}

Exposure of the hermatypic coral *Pocillopora damicornis* (Linnaeus) to elevate levels of dissolved inorganic phosphorus did not affect the colony or the zooxanthellae. Exposure to elevated levels of dissolved inorganic nitrogen and inorganic nitrogen + phosphorus led to an increase in algal density, and as a result, to an increase in the chlorophyll concentration. These latter two experimental enrichments slowed skeletal growth rate of the corals, probably because of a decrease in the photosynthetic rate of the algae and perhaps a decrease in the translocation of photosynthetic products from the algae to the coral. The algae

probably used the photosynthetic energy for their own increased growth. Experimental manipulation of water motion used in these experiments did not affect the coral or the symbiotic algae.

Stockner, J. G. and D. D. Cliff (1979) **Phytoplankton ecology of Vancouver Harbor.** *Journal of the Fisheries Research Board of Canada* **36**:1-10.
{phytoplankton; Vancouver Harbor; primary production; sewage}

Phytoplankton production and distribution were examined over a 2-yr period in the Burrard Inlet system, which includes a true fjord (Indian Arm), a shallow blind inlet (Port Moody arm), and a turbulent narrows region that is contiguous to the Port of Vancouver. Greatest annual production occurred in Port Moody Arm with a mean of 532 g C m^{-2} yr^{-1} while the lowest values were in Indian Arm and the Narrows region, averaging about 260 g C m^{-2} yr^{-1}. Nitrate and zooplankton grazing were the main factors limiting phytoplankton production in Indian Arm, while flushing and poor light conditions influenced phytoplankton growth in the Narrows and outer Burrard Inlet. Most of the discharges of domestic and industrial wastes have been diverted to the Fraser River, and Vancouver Harbor can be considered relatively clean and pollution-free because of strong tidal mixing and seaward flushing. The only sign of eutrophication in the inlet is in Port Moody Arm where sufficient nutrients from sewage discharges and a relatively stable mixed-layer depth create near optimal conditions for phytoplankton growth. Daily production here is among the highest recorded in the literature for Pacific coastal marine waters.

Stockner, J. G., D. D. Cliff, and K. R. S. Shortreed (1979) **Phytoplankton ecology of the Strait of Georgia, British Columbia.** *Journal of the Fisheries Research Board of Canada* **36**:657-666.
{phytoplankton; primary production; chlorophyll a; Strait of Georgia}

Observations of phytoplankton production, abundance, and distribution were made at 16 stations in the Strait of Georgia from 1975 to 1977. The discharge of turbid Fraser River water exerts a strong influence on phytoplankton production and distribution in surface waters by rapid light attenuation and horizontal advection. At plume boundaries and back eddied where light conditions improve, very high production occurs (>4-5 g C m^{-2} d^{-1}), because of rapidly replenished nutrients supplied by the Fraser River. Advection, turbulence, zooplankton grazing, and summer nitrate depletion collectively impart a heterogeneous distribution pattern to phytoplankton in the surface waters of the Strait of Georgia. Mean annual production varies from lows of 150 g C m^{-2} in Fraser River plumes to highs over 500 g C m^{-2} in sheltered boundary waters of inlets. Recent increases in ammonia and nitrate from land drainage and domestic sewage, mainly through the Fraser River, are related to increases in phytoplankton standing stocks in the Strait.

Stockner, J. G. and K. S. Shortreed (1988) **Response of *Anabaena* and *Synechococcus* to manipulation of nitrogen: Phosphorus ratios in a lake fertilization experiment.** *Limnology and Oceanography* **33**:1348-1361.
{lake; nutrient addition; picoplankton; chlorophyll; N/P ratio; bacteria}

Additions of inorganic nitrogen and phosphorus to selected areas of oligotrophic Kennedy Lake began in 1978 and resulted in development of late-summer blooms of nitrogen-fixing cyanobacteria *Anabaena circinalis* in 1981 and 1982. In subsequent years the blooms were successfully eliminated by increasing the molar N:P ratio of added nutrients to 35:1. The nutrient additions also resulted in dramatic increases in both autotrophic (predominantly *Synechococcus* sp.) and heterotrophic (bacteria) picoplankton numbers, with respective maxima of 4.0 x 10^5 ml^{-1} and >4.0 x 10^6 ml^{-1}. Chlorophyll concentrations were generally <2 ug $liter^{-1}$ during untreated conditions and increased to as much as 50 ug $liter^{-1}$ during blooms. In years following the *Anabaena* blooms, hypolimnetic nitrate concentrations were significantly higher in the treated basin of the lake than they were in an untreated basin or than they were before the blooms. Development of nitrogen-fixing cyanobacteria blooms is dependent on both a low N:P supply ratio and a sufficient phosphorus supply.

Sukhanova, I. N., M. V. Flint, G. Hilbaum, V. Karamfilov, A. I. Kopylov, E. Matveea, T. N. Rat'kova, and A. F. Sazhin (1988) ***Exuviaella cordata* red tide in Bulgarian coastal waters (May to June 1986).** *Marine Biology* **99**:1-8.
{*Exuviaella*; red tide; bloom; Burgas Bay; phytoplankton; plankton; species composition}

The structure and some functional characteristics of the plankton community at the times of a *Exuviaella cordata* red tide were investigated in Burgas Bay, Bulgaria, in May and June 1986. Characteristics of main plankton components (phyto-, bacterio-, nanoheterotrophic plankton, ciliates and mesoplankton) in the bloom area are presented. Development of the *E.cordata* bloom was determined by abiotic conditions among which eutrophication and salinity decrease caused the patch character of its rapid development. Attainment of maximum red tide (ca. 1 x 10^9 cells l^{-1}; 1 x 10^3 g m^{-3}) from background (500 to 800 x 10^3 cells l^{-1};

600 g m^{-3}) took 3 to 7d. Growth rate (u) during that period was 1.2 to 2.2 doublings per day. A sharp bloom decline (3 to 4d) was caused by parasitic flagellates destroying the alga's chloroplast. Diel biomass losses due to grazing remained below 5%. Metabolites and degradation products of *E.cordata* revealed no pronounced toxic effects on the other components of the planktonic community. The rapid bloom degradation due to effects of parasitic flagellates indicates the high potential ecosystem "self-regulation".

Sullivan, B. K. and P. V. Banzon (1990) **Food limitation and benthic regulation of population of the copepod *Acartia hudsonica* Pinhey in nutrient-limited and nutrient-enriched systems.** *Limnology and Oceanography* **35**:1618-1631.
{secondary production; copepods}

Evidence that population size of copepods in coastal marine ecosystems can be both resource and predator limited was obtained from experimental enclosures with and without the sediment community in place. The novel finding was that meroplankton and attached benthos were apparently effective competitors and predators of planktonic copepods in both nutrient-limited and nutrient-enriched systems. During the spring period of increase *Acartia hudsonica*, as well as other abundant species of copepods, reached considerably higher numbers in four mesocosms without sediments than in four other mesocosms with the normal sediment community in place regardless of rate of nutrient input to the mesocosms. Measurements of population parameters of *A. hudsonica* indicated equivalent rates of reproduction, growth, and recruitment in nutrient enriched treatments, with and without sediments. Suppression of population growth in the presence of sediments was therefore not due to food limitation but, by inference, to higher rates of mortality associated with high abundances of potential predators of benthic origin. In unenriched control mesocosms, resource competition with the benthos may also have contributed to low population densities in tanks with sediments (reproductive rates were more food limited in enclosures with sediment). These results demonstrate important interactions between benthic and pelagic fauna that have often been overlooked but nevertheless may be important in regulating dynamics of pelagic copepod populations in shallow, well-mixed waters.

Sullivan, B. K., P. H. Doering, C. A. Oviatt, A. A. Keller, and J. B. Frithsen (1991) **Interactions with the benthos alter pelagic food web structure in coastal waters.** *Canadian Journal of Fisheries and Aquatic Science* **48**:2276-2284.
{benthos; food web; pelagic ecosystem}

Results from studies in experimental enclosures containing both water column and benthic communities show that the benthos has an important effect on the structure and productivity of pelagic food webs whether that change is nutrient enriched or nutrient limited. Research over a 10-yr period in 13m-3 mesocosms showed that changes in the pelagic food web were correlated with different sediment communities and with the presence or absence of a benthos. The abundance of copepods was inversely correlated with numbers of macrofauna. At both low and high nutrient levels, systems without benthos had greatly enhanced numbers of carnivorous holozooplankton including ctenophore, medusans, chaetognaths, and fish. Our observations indicate that the presence of the benthos shortens the pelagic food web and inhibits the response of pelagic fauna to nutrient enrichment in well-mixed coastal waters. The strength of benthic-pelagic coupling, which is controlled by the amount of turbulence in the water column, may be more important to food web structure than the rate of nutrient supply and could determine which subsystem responds to eutrophication.

Sullivan, B. K. and P. J. Ritacco (1985) **Ammonia toxicity to larval copepods in eutrophic marine ecosystems: A comparison of results from bioassays and enclosed experimental ecosystems.** *Aquatic Toxicology* 7:205-217.
{ammonia toxicity; copepods; eutrophic marine ecosystems; mortality;MERL}

In an experiment designed to simulate eutrophication of a shallow coastal ecosystem, nutrients were added to experimental ecosystems (MERL mesocosms) in six different treatment levels. We observed large reductions in the numbers of normally dominant copepods of the species *Acartic tonsa* and *A. hudsonica* associated with a high concentrations of unionized ammonia (NH_3) in the two most nutrient enriched treatments. Comparison of 48h LC_{50} values of 10-15 $uMl^{-1}NH_3$ obtained from laboratory bioassays with concentrations of NH_3 associated with increased mortality in the MERL tanks indicated that bioassay data correctly predicted trends of high and low mortality as well as fluctuations in the numbers of copepods in MERL tanks. Actual mortality rates of the mesocosm copepods was sometimes higher than predicted, however.

Sullivan, B. K. and P. J. Ritacco (1988) **Effects of nutrients and copper on copepod population dynamics: A mesocosm study.** In: M. S. Evans (ed.) *Toxic Contaminants and Ecosystem Health; A Great Lakes Focus.* John Wiley & Sons, Inc., New York.

{copepod; biomass; copper; survival; egg production; MERL}
No abstract

Swartz, R. C., F. A. Cole, D. W. Schults, and W. A. DeBen (1986) **Ecological changes in the Southern California Bight near a large sewage outfall: benthic conditions in 1980 and 1983.** *Marine Ecology Progress Series* **31**:1-13.
{sewage; species richness; biomass; density; macrobenthos; California}

The structure of the macrobenthic community, sediment toxicity, and sediment contamination changed greatly between 1980 and 1983 along a pollution gradient from the Los Angeles County Sanitation Districts (LACSD) sewage outfalls on the Palos Verdes Shelf, California, USA to a reference site in the northern Santa Monica Bay. Stimulation of the species richness, biomass, and density of the benthos along the 60 m contour 5 to 11 km from the outfalls was significantly reduced in 1983 when compared to 1980. The clam *Parvilucina tenuisculpta* and the polychaete *Tharyx* sp. A were the numerically dominant species in the area of benthic stimulation in both years. Stations 1 to 3 km from the outfalls in 1980 were occupied by a depauperate fauna strongly dominated by the opportunistic polychaete *Capitella* spp. In 1983 species richness and biomass significantly increased close to the outfalls, *Capitella* spp. was much less abundant, and the assemblage was dominated by ostracods of the genus *Euphilomenedes* that are characteristic of background conditions or areas only slightly affected by wastewater discharges. At the reference site in Santa Monica Bay there were no significant changes in species richness, biomass, or density between 1980 and 1983, and the brittlestar *Amphiodia urtica* remained the dominant species. Sediment contamination by most measured chemicals and parameters of organic enrichment decreased on the Palos Verdes Shelf, but not at the reference station, between 1980 and 1983. Sediments collected within 3 km of the outfalls in 1980 were acutely toxic to the phoxocephalid amphipod *Rhepooxynnius abronius.* There was no significant toxicity associated with any sediment from the shelf in 1983. These ecological changes correspond with the reduction in the mass emission of BOD and chemical contaminants from the LACSD outfalls between 1980 and 1983. Severe storms in the winter of 1982-1983 may also have contributed to improvements in sediment quality and the partial recovery of the macrobenthos.

Takahashi, M. and N. Fukazawa (1982) **A mechanism of "Red-Tide" formation. II. Effect of selective nutrient stimulation on the growth of different phytoplankton species in natural water.** *Marine Biology* **70**:267-273.
{red tide; nutrient; phytoplankton; growth; abundance; macronutrient; micronutrient; chlorophyll a}

Three semi-continuous culture experiments were conducted by using natural algal populations [dominants: *Skeletonema costatum, Thalassiosira* sp., *Gymnodinium* sp., *Heterosigma* sp. (formerly called *Olisthodiscus luteus*) and *Eutreptilla* sp.] collected from Tanigawa Harbor, Japan, where red-tides occurred occasionally. The effects of macro- and micro-nutrients on the growth of different species of algae were specially evaluated by a dialysis bag culture technique. Two types of responses for nutrients were clearly observed: macro- and micro-nutrient dependency. The former group includes *S. costatum, Thalassiosira* sp. and *Eutreptilla* sp. which mainly stimulated their growth by macro-nutrients. *Heterosigma* sp. was the latter group which was stimulated by micro-nutrients. *Gymnodinium* sp. showed an intermediate type. A red-tide of *Heterosigma* sp. formed during the experiment in the harbor and is discussed with the results of the present culture experiments and some field observations.

Takano, H. (1987) **Red-tides at the mouth of Sumida River, Tokyo, during the last eleven years, 1976-1986.** In: T. Okaichi, D. M. Anderson and T. Nemoto (ed.) *Red Tides: Biology, Environmental Science, and Toxicology.* Elsevier, New York.
{phytoplankton; abundance}

The quantities of chlorophyll a, including pheopigments, in the brackish water of Sumida River were measured at a fixed station near the laboratory at least once in ten days from January 1976 to December 1986. Values higher than 30 ug/l were obtained mainly from the middle of April to the end of September, and in February and October in some years. The highest value was 356 ug/l at the end of July 1977. The main growth areas of plankton were in Tokyo Harbour. Populations were swept to the sampling station by tidal currents.

Tamminen, T. (1982) **Effects of ammonium effluents on planktonic primary production and decomposition in a coastal brackish water environment. I. Nutrient balance of the water body and effluent tests.** *Netherlands Journal of Sea Research* **15**:455-464.
{ammonia; primary production; decomposition; nutrients; archipelago; Baltic; effluent}
No abstract

Tamminen, T. (1982) **Effects of ammonium effluents on planktonic primary**

production and decomposition in a coastal brackish water environment. II. Interrelations between abiotic and biotic components of the planktonic ecosystem. *Netherlands Journal of Sea Research* **15**:349-361.
{ammonia; phosphate; effluent; phytoplankton; primary production; decomposition; nutrients; archipelago; Baltic; abiotic}
No abstract

Tamminen, T. (1984) **Ammonium effluent tests with phytoplankton and bacterioplankton communities and with a test alga.** *Ecological Bulletins* **36**:120-124.
{ammonia; phytoplankton; bacterioplankton; primary production; effluent}

Stimulative and toxic effects of industrial effluents containing high concentrations of ammonium were assayed in natural brackish water communities of phytoplankton and bacterioplankton and with laboratory cultures of a test alga (*Chlorella* sp.). Acute effluent effects on planktonic communities were measured with short-term primary productivity and heterotrophic activity assays. Effects on *Chlorella* were determined as biomass increase during 14 d.

Activity of bacterioplankton was inhibited by the lowest effluent additions (corresponding approximately to 100 ug NH_4-N l^{-1}). Phytoplankton was stimulated over a wide range of effluent additions (5 to 1000 ug NH_4-N l^{-1}), and toxicity was observed with effluent additions over 1000 ug NH_4-N l^{-1}. *Chlorella* showed the largest stimulation (up to 1000% of the control), and inhibition occurred only with the highest effluent additions (over 6000 ug NH_4-N l^{-1}). The different responses of these organisms to effluent additions are discussed with regard to applying effluent tests to environmental monitoring and research. A coupling of test results and field data is considered to be a special advantage if the pollutant under study is significant in the cycles of matter in the environment.

Tamminen, T., S. Kaitala, K. Kivi, and J. Kuparinen (1985) **Response of a planktonic brackish water community to single and combined additions of ammonium and phosphate in a factorial mesocosm experiment.** In: J. S. Gray and M. E. Christiansen (ed.) *Marine Biology of Polar Regions and Effects of Stress on Marine Organisms*. John Weily & Son Ltd., New York.
{ammonia; phosphate; mesocosm; Finland; phytoplankton; primary productivity; model}

Effects of single and combined addition of ammonium (38 and 75 mg N m^{-3}) and phosphate (10 and 20 mg P^{-3}) on the structure and function of enclosed (220 l) planktonic communities were examined during a 12-day 3^2 factorial experiment on the southern coast of Finland, in early August, at the commencement of the annual blue-green algal bloom in the area. Particulate and excreted primary productivity, heterotrophic activity (^{3}H-glucose turnover rate), $^{33}PO_4$ assimilation, ^{14}C-methylamine (ammonium analogue) assimilation and chlorophyll *a* were measured on four dates (activity parameters in >3 um and <3 um size fractions). Nitrogen fixation (acetylene reduction method) was measured at the end of the experiment. Phytoplankton responded rapidly to the nutrient addition, with up to a 3-fold increase of chlorophyll *a* on the first date, when the single effect of ammonium was the most significant. Ammonium was the main limiting nutrient for phytoplankton production during the experiment, but also significant phosphate effects and combined effects of ammonium and phosphate were observed. Nitrogen-fixing blue-green algae were only phosphate-limited. The interaction of nitrogen and phosphorus cycles in the regulation of primary productivity demonstrates that the concept of the limiting nutrient cannot be rigorously applied at the community level. Hetertrophic activity was stimulated by both nutrients, and the results emphasized the functional role of <3 um picoplankton in both nutrient and carbon cycles. Mean percentages of the total particulate assimilation were 44% (CO_2), 69% (PO_4) and 68% (methylamine) in the < 3um fraction during the experiment (n=45-54). The result suggest that bacterioplankton would directly affect primary production through competition for inorganic nutrients.

Tamminen, T. (1990) ***Eutrophication and the Baltic Sea: Studies on phytoplankton, bacterioplankton, and pelagic nutrient cycles.*** Dissertation for Ph.D., University of Helsinki.
{Baltic; phytoplankton; bacterioplankton; nutrients; cycles; bloom; nitrogen; phosphorus; Finland}

Planktonic processes were studied at the SW coast of Finland, the Baltic Sea, in order to examine causal connections relevant to eutrophication in the ecosystem. The annual pattern of nutrient limitation was investigated by means of experiments on several system levels, and by analyzing *in situ* nutrient ratios. Nitrogen was shown to be the basic limiting nutrient throughout the growth seasons, and colimitation by phosphorus occurred in early summer.

The shift from new production of the spring bloom to regenerated production of the summer season was studied in terms of nitrogenous nutrition. Clear preference succession from nitrate

to ammonium was demonstrated, but nutrient availability overruled inherent preferences in nutrient assimilation. During regenerated production, utilization of organic nutrients was (organic N) uptake, while bacterial regeneration of organic P provided an important P sources also for phytoplankton.

Research strategies for the dynamically fluctuating pelagic environment were outlined with special emphasis on the interrelation between fluctuations in the physical environment and within the planktonic food web at different time scales. Continuous interaction between experimental food web fluctuations, and system modelling appears inevitable in order to understand nutrient cycle phenomena in the special conditions of the Baltic Sea.

Nitrogen discharge was shown to promote eutrophication in the Baltic Sea. Effective reduction of nitrogen loading is therefore of vital importance.

Taslakian, M. J. and J. T. Hardy (1976) **Sewage nutrient enrichment and phytoplankton ecology along the central coast of Lebanon.** *Marine Biology* **38**:315-325.
{sewage; phytoplankton; Lebanon; nutrients; abundance; diversity; dominance; blue-green algae; dinoflagellates; diatom; indicator}

The abundance and taxonomic diversity of phytoplankton has been studied in relation to sewage pollution (proximity to outfalls) south of Beirut, Lebanon. Surface-water samples were collected from a series of beach stations extending from the American University of Beirut to 20 km south from June, 1973 to July, 1974. Samples were preserved, concentrated by settling, and the concentration of each taxon of phytoplankton enumerated in an inverted microscope. Water samples from the vicinity of two major sewer outfalls (Carton and Khalde sewers) showed very high concentrations of NH_4^+, NO_2^-, NO_3^- and PO_4^{-3}, a greater total concentration of phytoplankton, and a lower taxonomic diversity than samples remote from outfalls. A considerable variation in the occurrence of species and dominance occurred along the pollution gradient. Blue-green algae and dinoflagellates were dominant in polluted waters, while diatoms dominated in cleaner water away from major sewage outflow. From the dominance and relative distribution of the taxa along the pollution gradient, certain taxa (*Oscillatoria* spp., *Spirulina* spp., *Phormidium* spp., *Synechococcus custos* and *S. elongatus*, *Gymnodinium* spp., and *Prorocentrum* spp.) emerge as indicator species of pollution. These changes correspond to a typical degradation of a complex community to a less mature state by the inflow of nutrient-rich sewage (eutrophication) along a coastal region about 10 km long.

Thompson, G. B. and J. Ho (1981) **Some effects of sewage discharge upon phytoplankton in Hong Kong.** *Marine Pollution Bulletin* **12**:168-173.
{sewage; phytoplankton; abundance; assemblage; diversity; Hong Kong}

The coastal waters of Hong Kong constitute a transition from estuarine conditions in the west to more oceanic conditions in the east, with a major discharge of untreated sewage located at the mid-point. Chlorophyll *a* was determined and net phytoplankton was sampled at 45 stations throughout this transition. Over a period of 20 months, Chlorophyll *a* values rarely exceeded 2 ug l^{-1} in unpolluted coastal waters. Estuarine waters generally contained 2-6 ug l^{-1} and, in waters influenced by sewage discharge, values sometimes exceeded 20 ug l^{-1}. There was no evidence of a reduction in taxonomic diversity in polluted areas except in summer, when the net phytoplankton was dominated by *Chaetoceros* spp. In the autumn and early winter, *Skeletonema costatum* was abundant in the central polluted areas.

Tolmazin, D. (1985) **Changing coastal oceanography of the Baltic Sea. I. Northwestern Shelf.** *Progress in Oceanography* **15**:217-276.
{Black Sea; environment; nutrient; nitrogen; oxygen; hypoxia; anoxia; mortality; benthos}

This article describes the hydrography of the Northwestern Shelf (NWS), of the Black Sea emphasizing the changes induced by water management in the Dnieper and Dniester river basins. The existing literature and previously unpublished data have been reviewed and synthesized to describe water property fields and transport mechanisms of NWS and the Dnieper and Dniester estuaries before the early 1960s, or the so-called precontrol period, when the effect of artificial river flow control upon the coastal waters was insignificant.

After the hydroenergy complexes and water withdrawal and disposal systems on the river became fully operational in the early 1970s (the so-called postcontrol period), the annual river discharge from the Dnieper and Dniester rivers had noticeably decreased and seasonal river flow patterns had been artificially modified. Instead of a powerful and short early spring flood, typical for the natural conditions in the Dnieper river, the hydrographs in the post control period exhibit two smaller peaks of river discharge of much longer period. One of them (winter-early spring) is caused by intense hydroenergy generation and weir discharge through the cascade of storage reservoirs. Another is associated with the spring flood, modified by intense water consumption and storage in this period. High average river discharge in late May-

early June strengthened the summer pycnocline which inhibits vertical mixing in the estuaries and coastal waters. Owing to a slow summer circulation, the rate of natural purification of the entire coastal system has been reduced. This coupled with the increased nutrient, organic and pollutant transports, decreased the dissolved-oxygen concentration and led to anoxic events and mass mortalities of marine organisms in the previously productive regions. These effects have primarily plagued the benthic communities along the entire western coast of the NWS since 1973.

Winter convective overturn in the Black Sea reaches its maximum depth at the southern boundary of the NWS. Thus, the NWS waters descend beneath the seasonal and main thermoclines in the open sea and are spread by the prevailing currents across the entire sea in the cold intermediate layer (CIL). By the dynamic mechanism the projected man-made modifications in the riverine-estuarine systems of the NWS will affect and change the large-scale thermocline structure and marine life of the Black Sea.

Tomascik, T. (1990) **Growth rates of two morphotypes of *Montastrea annularis* along a eutrophication gradient, Barbados, W.I.** *Marine Pollution Bulletin* **21**:376-381.
{coral; Barbados; growth rate; reef; growth form; morphotype}

Growth rates (skeletal linear extension) of columnar and lobate morphotypes of the reef-building coral *Montastrea annularis* were compared within and among seven fringing reefs along a previously described eutrophication gradient on the west coast of Barbados using X-ray radiography. Both morphotypes of *M. annularis* exhibit similar patterns of increasing average growth rates with improving environmental conditions. However, the average growth rates of the columnar morphotype are statistically higher ($P<0.001$) on all reefs in the study, when compared to the lobate morphotype. It is suggested that while environmental conditions exert a measurable effect on the growth rates of both morphotypes, the differences in the average growth rates between the two growth forms, under similar environmental conditions, may be related to genetic conditions.

Index master chronologies computed for a columnar morphotype of *M. annularis* indicate a general pattern of decreasing growth rates within the past 30 yr at each of the seven fringing reefs. It is postulated that this general pattern of decreasing growth rates may be directly related to the deterioration of water quality along the west coast of the island.

Tomascik, T. (1991) **Settlement patterns of Caribbean scleractinian corals on artificial substrate along a eutrophication gradient, Barbados, West Indies.** *Marine Ecology Progress Series* **77**:261-269.
{corals; Barbados; settlement; reef}

Artificial substrate settlement plates (terracotta tiles) were set out on 3 fringing reefs for a period of 12 mo to study settlement patterns of juvenile scleractinian corals along a eutrophication gradient on the west coast of Barbados, W.I. A total of 716 coral planulae settled on 120 experimental plates after 12 mo of exposure. Statistically higher ($p<0.05$) average number of juvenile corals per plate ($X = 9.2 +- 3.3$; $N = 40$) was recorded on a less eutrophic reef compared to 2 more eutrophic reefs ($X = 6.9 +- 3.1$; $N = 40$ and $X = 1.9 +- 1.3$; $N = 40$). Differences in juvenile coral settlement between reef zones, within each reef, were dependent on the reef's position along the eutrophication gradient. Statistically higher number of coral planulae ($X = 7.2 +- 4.5$; $N = 60$) successfully settled on vertical plates compared to horizontal plates ($X = 4.8 +- 3.3$; $N = 60$). Coral planulae did not settle on upper surfaces of horizontal plates. In terms of relative abundance, the most common coral species in the juvenile population on the experimental plates were *Poritea asteroides* Lamarck which accounted for 42% of the settled planulae, followed by *Agaricia* spp. (23%); and *P. asteroides* (Pallas) (19%). Juveniles of *Montastrea annularis* (Ellis & Solander), *Siderastrea* spp. and *Diploria* spp., while present at 2 northern reefs, were absent from the most eutrophic reef.

Tomascik, T. and F. Sander (1985) **Effects of eutrophication on reef-building corals. I. Growth rate of the reef-building coral *Montastrea annularis*.** *Marine Biology* **87**:143-155.
{coral; reef; growth; zooxanthellae; SPM}

Fourteen environmental variables were monitored at seven locations along the west coast of Barbados on a weekly basis over a one-year period, 1981 to 1982. The physicochemical and biological data indicate that an environmental gradient exists as a result of increased eutrophication of coastal waters. Growth rates (linear extension) of *Montastrea annularis* (Ellis and Solander), measured along the environmental gradient, exhibit high correlation with a number of water quality variables. Concentration of suspended particulate matter is the best univariate estimator of *M. annularis* skeletal extension rates ($r^2 = 0.79$, $P<0.0001$). The results suggest that suspended particulate matter may be an energy source for reef corals, increasing growth up to a certain maximum concentration. After this, reduction of growth occurs due to smothering, reduced light levels and reduced zooxanthellae photosynthesis.

Tomascik, T. and F. Sander (1987) **Effects of eutrophication on reef-building corals. II. Structure of scleractinian coral communities on fringing reefs, Barbados, West Indies.** *Marine Biology* **94**:53-75.
{corals; community; reef; species composition; zonation; diversity; sedimentation}

Seven fringing reef complexes were chosen along the leeward coast (west) of Barbados to study the effects of eutrophication processes upon the scleractinian coral assemblages. The structure of scleractinian coral communities was studied along a eutrophication gradient with a quantitative sampling method (line transect) in terms of species composition, zonation and diversity patterns. On the basis of these data the fringing reefs were divided into three ecological zones: back reef, reef flat, and spur and groove. Statistically discernible and biologically significant differences in scleractinian coral community structure, benthic algal cover and *Diadema antillarum* Philippi densities were recorded among the seven fringing reefs. High correlations between environmental variables and biotic patterns indicate that the effects of eutrophication processes (nutrient enrichment, sedimentation, turbidity, toxicity and bacterial activity) were directly and/or indirectly affecting the community structure of scleractinian coral assemblages. In general, species diversity was most sensitive in delineating among-reef, and among-zone, differences, which were attributed to intensification of eutrophication processes. *Porites asteroides* Lamarck, *P. porites* (Pallas), *Siderastrea radians* (Pallas), and *Agaricia agaricites* (Linnaeus) were the most abundant coral species in the polluted southern reefs. The absence and/or low abundance of coral species previously characterized as well adapted to high turbidity and sedimentation [i.e. *Montastrea cavernosa* Linnaeus, *Meandrina meandirtes* (Linnacus)] indicate that eutrophication processes may adversely affect these species. It is suggested that sediment rejection abilities, combined with feeding and reproductive strategies, are the primary biological processes of scleractinian corals through which eutrophication processes directly and/or indirectly affect the structure of coral communities.

Tomascik, T. and F. Sander (1987) **Effects of eutrophication on reef-building corals. III. Reproduction of the reef-building coral *Porites porites*.** *Marine Biology* **94**:77-94.
{reef; corals; reproduction; larval development; maturation; zooxanthellae; gonad index}

The sexual reproduction of *Porites porites* (Pallas), a shallow water hermatype coral, was studied over a one-year period (June, 1982 to June 1983) on three fringing reef complexes lying along an eutrophication gradient on the west coast of Barbados, West Indies. The data suggest that *P. porites* is a gonochoric species with a brooding mode of reproduction, but a low incidence (2.7%) of hermaphroditism was detected in a population sampled from a reef subjected to urban and industrial pollution. Gonadal development occurs within the mesenteries between the retractor muscles and the mesenterial filaments. Gametogenesis occurs during nine to ten months of the year, with the peak reproductive activity occurring predominantly in the fall and winter (November to January). Gametogenesis was therefore loosely synchronized between colonies; however, gonad in all stages of development were present within colonies throughout the reproductive season. The reproductive season of two *P. porites* populations sampled from two polluted reefs began one to two months earlier than that of a *P. porites* population sampled from a less polluted reef. The simultaneous presence of ova and larvae within a colony between November and April suggests that larvae may be released repeatedly during an extended breeding season. No correlation was found between the average number of gonads and polyp size. However, the gonad index (average number of gonads based on the sum of male and female gonads) showed an inverse relationship with a number of environmental variables. It is suggested that zooxanthellae photosynthesis through reduced light levels may significantly lower the energy available from photosynthates to the maturing ova and/or embryos, thus depressing larval development and maturation. Coral colonies samples from two polluted reefs contained lower numbers of larvae than colonies sampled from a less polluted reef. The 2:1 sex ratio observed in a *P. porites* population sampled from a polluted reef may result from rapid asexual reproduction (fragmentation), indicating that the mode of reproduction may be influenced by environmental conditions.

Topping, G. (1976) **Sewage and the sea.** In: R. Johnston (ed.) *Marine Pollution*. Academic Press, London, England.
{sewage; nutrients; benthos; review; oxygen; phytoplankton}
No abstract

Tracey, G. A. (1988) ***Effects of eutrophication on growth and bioenergetics of the blue mussel,* Mytilus edulis.** Dissertation for Ph.D., University of Rhode Island.
{mussel; growth; energetics; physiology; toxicity; Narragansett Bay; MERL; sewage; phytoplankton; food}
Eutrophication may be an important environmental problems in marine water receiving excess inorganic or organic nutrients from urban or agricultural activity. Nutrient-induced changes may

include both altered nutritional and toxicological environments. Shifts in food quality may occur by the mixture of sewage sludge with natural particulates of shifts in phytoplankton species composition to food organisms of lower nutritional value. In addition, the toxicity of environmental conditionsmay be adjusted by environmental conditions created by eutrophication. These aspects of eutrophication were examined in this research.

Growth and bioenergetics of the blue mussel, *Mytilus edulis*, was used to indicate ecosystem alteration caused by eutrophication. Bioenergetics measurements included the physiological responses of clearance rate, assimilation efficiency, respiration rate and ammonia excretion. Apparatus used in the development of the research included the use of experimental marine ecosystems (mesocosms). Mesocosms were amended daily with varying amounts and sources of nutrients, and mussels were exposed to the mesocosm waters. Additional research involved examination of effects on mussels caused by a dense algal bloom in Narragansett Bay. A portion of one study involved documentation of mortality in mussels along a transect in Narragansett Bay.

Mussels are sensitive to copper and toxicity is strongly dependent upon environmental conditions characteristic of a particular eutrophic state. Factors which influence the eutrophication-toxicity relationship include the rate of biological removal of Cu from the water column and the partitioning of Cu between dissolved and particulate phases. Sewage sludge does not serve as a potential food resource for mussels, and acts to dilute out available food. Food availability appears largely dependent upon plant biomass as indicated by chlorophyll *a* concentration. Mussels may be extremely sensitive to shifts in phytoplankton species composition, especially during the reproductive phase of the species. A picoplanktonic algal bloom caused reduced feeding in mussels when present in sufficient densities.

The results of the research indicate that eutrophication may profoundly effect the growth and physiological responses of mussels. Mechanisms of effects include alteration of food quality and modification of pollutant availability. Of all physiological measurements, clearance rates were generally most sensitive.

Tsutsumi, H., S. Fukunaga, N. Fujita, and M. Sumida (1990) **Relationship between growth of *Capitella* sp. and organic enrichment of the sediment.** *Marine Ecology Progress Series* **63**:157-162.
{*Capitella*; sediments; organic matter; growth; algae; opportunistic}

Laboratory colonies of *Capitella* sp., which is found densely distributed in organically enriched or polluted areas, were cultured in sediments with various levels of organic matter to examine the relationship between level of sediment organic matter and growth of individuals. Growth was independent of absolute levels of sediment organic matter, but was significantly correlated with increases in the levels of sediment organic matter on addition of algal powder to the sediment. These results indicate that *Capitalla* species predominating in organically enriched areas have a physiological requirement for organic materials discharged from sources of organic enrichment, e.g. abundant growth of algae, fish farming, industrial effluent, sewage, if they are to grow normally. Although association of some *Capitella* species with sediment organic enrichment has previously been recognized as a reflection of their opportunistic characteristics, a physiological requirement for organic materials discharged from sources of organic enrichment may be the single factor most responsible for the concentration of *Capitalla* species in organically enriched areas. However, it is unlikely that they can directly ingest and assimilate such organic materials. Since the additional organic materials are easily decomposed in the sediment, *Capitella* species may require either (1) some specific microorganisms, the levels of which increase with levels of the organic materials, or (2) certain substance(s) produced during decomposition of the organic materials.

Tsutsumi, H., T. Kikuchi, M. Tanaka, K. Imasaka, and M. Miyazaki (1991) **Benthic faunal succession in a cove organically polluted by fish farming.** *Marine Pollution Bulletin* **23**:233-238.
{benthic; fauna; succession; abundance; community}

In the past two decades, fish farming using net cages has developed in the coastal water throughout Japan. Such fish farming has allowed the production of large amounts of valuable fish and their supply to the markets in major cities on a regular basis. However, fish farming is often followed by serious organic pollution of the water and bottom sediments in the vicinity of the cages since approximately 90% of the food for the fishes results in organic discharge to the environment around the fish farm. Organic pollution of soft bottom sediment is apt to be accompanied by the development of reducing conditions in the sediment and deoxidization of the bottom water, as a results of the decomposition of abundant organic matter. The benthic communities in the organically polluted areas are subjected to catastrophic environmental disturbances. We have assessed the environmental conditions and abundance of benthic communities in a specific cove since 1966. The results of the present study clearly show the dramatic changes in fauna and the reduction in the abundance of members of the benthic communities

in the cove that have accompanied the progress of the organic pollution associated with fish farming.

Tubbs, C. R. and J. M. Tubbs (1983) **Macroalgal mats in Langstone Harbour, Hampshire, England.** *Marine Pollution Bulletin* **14**:148-149.
{green algae; seaweeds; sewage; bird}

The spread of green algae over mudflats in Langstone Harbour has been caused by increased discharges of both treated and untreated sewage effluent. The decline in some species of estuarine birds may be a secondary effect of the blanketing of the muds by algae, but Soulsby *et al.*, 1982 concluded that the evidence for a causal link was inconclusive. This note examines the points they put forward in support of this.

Turner, R. E. and N. N. Rabalais (1991) **Changes in Mississippi River water quality in this century.** *BioScience* **41**:140-147.
{nutrients, nutrient ratios}
No abstract

Turner, R. E. and N. N. Rabalais (1994) **Coastal eutrophication near the Mississippi River delta.** *Nature* **368**:619-621.
{nutrients}

Changes in delivery of river-borne nutrients such as dissolved phosphate, nitrate and silicate, owing to land-use changes and anthropogenic emissions, are known to result in eutrophication-enhanced phytoplankton blooms-and more severe hypoxic events in many enclosed bays and seas. Although similar ecological effects might be expected on continental shelves, the occurrence of such eutrophication has been unresolved. Here we present evidence of eutrophication of the continental shelf near the outflow of the Mississippi River, obtained by quantifying biologically bound silica (BSi) in diatom remnants within dated sediment cores. BSi accumulation rates are greatest in water depths of 20 to 50 m within 100 km of the river mouth, and have increased by as much as 100% this century. The increases were substantial by 1980, by which time riverine nitrogen loading had doubled relative to the beginning of the century, even though silica loading had declined by 50% over the same period. Thus changes in river-borne nutrient loadings can modify coastal coastal food webs and affect the amount and distribution of oxygen in bottom water on the scale of continental shelves.

Twilley, R. R., W. M. Kemp, K. W. Staver, J. C. Stevenson, and W. R. Boynton (1985) **Nutrient enrichment of estuarine submerged vascular plant communities. 1. Algal growth and effects on production of plants and associated communities.** *Marine Ecology Progress Series* **23**:179-191.
{submerged plants; community; growth; estuary; nutrients; estuarine ponds; epiphytes; biomass; light; mechanism}

Eight experimental ponds containing submerged vascular plants (predominantly *Potamogeton perfoliatus* and *Ruppia maritima*) were subjected in duplicate to 4 levels (including controls) of fertilization from June to August 1981. Seston and phytoplankton chlorophyll *a* increased with fertilization, and pronounced algal blooms were evident under high dosage. Of the total seston, phytoplankton exerted the greatest influence on attenuation of photosynthetically active radiation (PAR), such that there was insufficient light for submerged vasculat plant growth at the sediment surface during blooms. An extensive epiphytic community developed on plants in all nutrient-treated ponds at densities similar to those observed in nature on senescent plants. At high nutrient treatments the accumulation of epiphytic material resulted in >80% attenuation of the incident radiation at the leaf surface. Biomass of submerged macrophytes decreased significantly under high and medium nutrient treatments compared to control and low treatments within 60d following initial fertilization. Apparent production of vascular plants (based on oxygen production and ^{14}C-bicarbonate uptake) was reduced at the higher nutrient treatments for both *R. maritima* and *P. perfoliatus*. Most of this reduction in macrophyte photosynthesis could be explained by attenuation of PAR associated with epiphytic material. However, without PAR attenuance in the overlying water, observed levels of epiphytic growth would be insufficient to reduce light below compensation levels needed to sustain vascular plant growth. At the high fertilization rates, integrated primary production of pond communities was significantly reduced with the loss of vascular plants, even though phytoplankton and epiphytic growth were enhanced.

Tyson, R. V. and T. H. Pearson (ed.) (1991) ***Modern and Ancient Continental Shelf Anoxia. Special Publication No. 58 of The Geological Society.*** The Geolocical Society, London.
No abstract

Ursin, E. and K. P. Andersen (1978) **A model of the biological effects of eutrophication in the North Sea.** *Rappots et Procès-verbaux des Réunions Counseil International pour L'Exploration de la Mer* **172**:366-377.
{model; North Sea; nutrients; yield; fish}

In a model of the pathways of phosphorus through the North Sea ecosystem, first, a steady supply of nutrients from rivers etc. was simulated, and next, an increasing supply. With apparently realistic data for water exchange and nutrient supply the model predicted a slight increase in the yield of fish, far from sufficient to describe the observed yield increase over the period 1960-1970.

Valente, R. M., D. C. Rhoads, J. D. Germano, and V. J. Cabelli (1992) **Mapping of benthic enrichment patterns in Narragansett Bay, Rhode Island.** *Estuaries* **15**:1-17.
{sediments; redox potential; remote sensing; benthos; methods; stage; infauna; assemblage; bacteria; habitat; review; Narragansett Bay}

A synoptic reconnaissance survey was performed over a five-day period in August 1988 to assess benthic habitat quality throughout Narragansett Bay, Rhode Island, using REMOTS® analysis sediment-profile photography and analysis in combination with measurements of the levels of *Clostridium perfringens* spores (a fecal indicator) in sediments. Three main areas of degraded benthic habitat quality related to either excessive organic enrichment or physical disturbance were identified based solely on the REMOTS® analysis: the Providence River Reach, Greenwich Bay and its associated coves and harbors, and an area located along the southwest side of Prudence Island. Sediments at many stations in these areas exhibited shallow apparent redox-potential discontinuity (RPD) depths, high apparent oxygen demand, and low-order benthic successional stages. Elevated *Clostridium perfringens* spore counts in surface sediments were attributed to inputs from wastewater treatment facilities. The highest spore counts occurred at the head of the bay, where wastewater treatment discharges and associated combined sewer overflows are numerous. Using data from the REMOTS® analysis and the sediment inventory of *C. perfringens* spores a distinction was made between organic enrichment of the bottom from sewage, versus nonsewage enrichment or physical disturbance. The combination of techniques employed in this investigation could be used to design more efficient monitoring to assess eutrophication effects in estuaries and determine the effectiveness of regulatory or management initiatives to reduce organic overenrichment of benthic habitats.

Van Es, F. B., V. A. M.A., L. A. Bouwman, and H. G. J. Schröder (1980) **Influence of organic pollution on bacterial, macrobenthic and meiobenthic populations in intertidal flats of the Dollard.** *Netherlands Journal of Sea Research* **14**:288-304.
{oxygen; bacteria; benthos; biomass; diversity; Ems estuary; tidal flat; macrofauna; meiofauna}

Large amounts of organic waste-water are discharged into the Ems-Dollard estuary, mainly in autumn and early winter. In November 1975 and June 1975 a number of samples were taken from the sediment of the tidal flats and analyzed for bacterial numbers, organic carbon and mud content. Cores were taken to quantify macro- and meiofauna. Oxygen saturation was measured in the water column over the sediment.

In November the oxygen saturation was less than 20% in a considerable part of the Dollard. It is not clear to what extent the inward increase in organic matter content of the sediment was influenced by the waste-water discharge.

The correlation between the viable counts of aerobic heterotrophic bacteria and the organic matter content, as observed in the other parts of the estuary, was absent in the most polluted part of the Dollard. However, the differences between the numbers counted in November and June were not significant in that area.

Numbers of sulphate-reducing bacteria decreased sharply between November and June, indicating a dependency on the waste-water discharges. Numbers of sulphide-oxidizing bacteria decreased in summer concomitantly with the sulphate-reducing bacteria. These data suggest that, in contrast to the other parts of the estuary, in the Dollard obligate autotrophs play a predominant part in the populations of sulphide-oxidizing bacteria during the time of high waste discharges.

Population diversities of meio- and macrofauna of the tidal flats were strongly decreased in the vicinity of the outfall. Total biomass of macrofauna decreased to zero, whereas meiofauna biomass significantly increased. Some possible explanations for the effects on the benthic fauna are given.

Veer, H. W. v. d. (1989) **Eutrophication and mussel culture in the western Dutch Wadden Sea: Impact on the benthic ecosystem; A hypothesis.** *Helgoländer Meeresuntersuchungen* **43**:517-527.
{mussel; Dutch Wadden Sea; benthos; nutrient; macrofauna; biomass}

Since 1950, two large-scale changed have taken place in the western Dutch Wadden Sea, namely the eutrophication of the area and introduction of an extensive mussel culture. Although eutrophication in the fresh waters started already around 1950, nutrient concentrations in the western Wadden Sea remained fairly constant until about 1970, due to the retention of nutrients in Lake IJssel, the main source. From 1970-1980 concentrations increased strongly, and during the last years the situation has stabilized. Mussel culture was introduced in 1950 and expanded during the next decade to an area of 70 km^2, all situated in the sublittoral area. From 1960 the area of mussel culture remained about constant with fluctuating yields of between 35 and 120

millions of kg fresh weight. Due to a lack of data for the period until 1970 the impact of eutrophication and mussel culture on the ecosystem, cannot be assessed. From 1970 onwards an increased biomass and production of the macrofauna in the intertidal zone has been observed, which is attributed to eutrophication. The hypothesis is postulated that the introduction of mussel culture between 1950 and 1960 has resulted in an increased food competition in the area, leading to a decreased stock of the macrofauna in the intertidal. Eutrophication from about 1970 onwards has improved the food conditions and as a result both in macrofauna in the intertidal and the mussel in the sublittoral area would have increased in biomass, allowing higher maximum yields of the mussel culture. The importance of monitoring programs is stressed to follow these trends in the near future and to check the above hypothesis in areas where it is decided to introduce or intensify mussel culture.

Veer, H. W. v. d., W. v. Raaphorst, and M. J. N. Bergman (1989) **Eutrophication of the Dutch Wadden Sea: External nutrient loadings of the Marsdiep and Vliestroom basin.** *Helgoländer Meeresuntersuchungen* **43**:501-515.
{Dutch Wadden Sea; nutrients; nitrogen; phosphorus}

The increasing P and N content in the two main tidal basins in the western Dutch Wadden Sea, the Marsdiep and the Vliestroom basin, has been reconstructed from the 50s onwards. The area is enriched with nutrients by two sources both originating from the river Rhine, one being the discharge from Lake IJssel and the other the exchange with the coastal zone of the North Sea. Due to a buffering by Lake IJssel for about 15-20 years, the eutrophication of the western Wadden Sea showed a time lag compared with the continuously increasing nutrient concentrations in the river Rhine and the coastal zone of the North Sea. At present, the primary production in part of the area still seems to be nutrient limited in summer, while loadings have already been decreasing in recent years. So far, no severe, negative effects on the ecosystem have been reported. Some remarks are made on the eutrophication in other parts of the Dutch Wadden Sea in relation to the hydrographic characteristics of these areas.

Vidakovi´c, J. (1983) **The influence of raw domestic sewage on density and distribution of meiofauna.** *Marine Pollution Bulletin* **14**:84-88.
{sewage; meiofauna; abundance; density; Adriatic Sea}

The influence of raw domestic sewage on density and distribution of meiofauna in the sea bottom sediments in the Northern Adriatic Sea, in the area of Rovinj (Yugoslavia), was investigated, comparing meiofaunal density at the stations which are under direct influence of sewage and the stations which are far from the source of pollution. It is concluded that raw domestic sewage does not have a negative influence on the density and distribution of meiofauna, but Parker's index of pollution indicates that meiofauna at these stations were under stress.

Vogt, H. and W. Schramm (1991) **Conspicuous decline of *Fucus* in Kiel Bay (Western Baltic): What are the causes?** *Marine Ecology Progress Series* **69**:189-194.
{seaweeds; Baltic; *Fucus*; model; biomass}

In the framework of investigations on possible effects of eutrophication on the macrophytobenthos in Kiel Bay (Western Baltic), a large-scale survey of the distribution and occurrence of the genus *Fucus* was carried out in 1987/88. For large-scale quantitative mapping, underwater television was employed or direct observations from the water surface were made. Species composition and quantitative biomass data were obtained by dredging and SCUBA-diving. Comparison with the results of earlier investigations revealed a drastic decline in *Fucus* biomass from between 40 000 and 45 000 t wet wt down to only 2400 t wet wt in 1987/88, which means a decrease by 94 to 95 %. Whereas *Fucus vesiculosus* as well as *F. serriatus* were still frequent at depths below 2 m down to 13 m in the seventies, during our investigation *Fucus* spp. was not found in water depths greater than 2 m. Possible causes for the observed changes are discussed, and it is concluded that decreased light levels or increased epiphyte growth as a result of eutrophication, and the reduction of substrate for algal growth due to stone fishing and sand deposition, are the main causes for the decline of *Fucus* spp.

Vollenweider, R. A., A. Rinaldi, and G. Montanari (1992) **Eutrophication, structure and dynamics of a marine coastal system: results of ten-year monitoring along the Emilia-Romagna coast (Northwest Adriatic Sea).** In: R. A. Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication.* Elsevier, Amsterdam.
{oxygen, phosphorus, Adriatic Sea}

The process of eutrophication, which has been in progress for some two decades in the coastal area of the Northwest Adriatic Sea, shows mainly cyclic-seasonal features. In winter and spring, large blooms of diatoms usually occur determing the so-called "dirty waters", while in summer blooms of dinoflagellates cause "red tides". Low salinity and high nutrient loads from the River Po and most minor rivers favour the production of these blooms.

Recurrent episodes of anoxia in bottom waters cause fish kills and other nuisances that impair fisheries. Algal blooms over the years, and two episodes of mucilage formation during the summers of 1988 and 1989 have become a serious menace to the regional tourist industry.

Vukadin, H. (1991) **Impacts of nutrient enrichment and their relation to the algal bloom in the Adriatic Sea.** *Marine Pollution Bulletin* **23**:145-148.
{nutrients; algal bloom; sewage; stratification}

Extraordinary manifestations of eutrophication in the Adriatic Sea during the last few years have been due to the combined effects of different physico-chemical and meteorological factors. Permanent inputs of nutrients, particularly in the northern Adriatic via river runoffs and municipal sewage during calm summers, cause marked stratification of the water column and reduction of the horizontal advection. These two effects provide the ideal conditions for single species bloom. An attempt has been made to calculate the nutrient balance which allows a better interpretation of algal blooms in the Adriatic.

Vukadin, I. and V. Hulji´c (1981) **Nutrient salts in the surface microlayer and subsurface layer of Kastela Bay waters.** *Thalassia Jugoslavica* **17**:89093.
{nutrients; nitrogen; phosphorus; microlayer; subsurface; Kastela Bay}

This paper gives values of the inorganic form of the main nutrient salts in the surface and subsurface layers of Kastela Bay waters (the Middle Adriatic). Analyses of all nutrients dissolved show an enrichment in nutrients in the surface layer if compared with the subsurface water. Only silicon in the surface layer showed no significant enhancement with respect to silicon in the subsruface water.

Vuorinen, I. and E. Ranta (1988) **Can signs of eutrophication be found in the mesozooplankton of Seili Archipelago Sea?** *Kieler Meeresforschungen, Sonderheft* **6**:126-140.
{mesozooplankton; Archipelago Sea; hydrography; composition}

In this study, we evaluate whether it is possible to distinguish the effects of eutrophication from other, i.e. hydrographical, factors affecting zooplankton. We illustrate our arguments with examples from an old set of zooplankton data which includes 9-year records of mesozooplankton and hydrography collected from Seili, off the south coast of Finland. The present study shows that hydrographic changes override or mask, at least the time period studied, possible eutrophication effects.

Vuorinene, I. and E. Ranta (1987) **Dynamics of marine meso-zooplankton at Seili, Northern Baltic Sea, in 1967-1975.** *Ophelia* **28**:31-48.
{zooplankton; Baltic; *Kelatella*}

Long-term (1967-1975) dynamics of meso-zooplankton population densities at Seili (Northern Baltic Sea) are described. The data were obtained from quantitative net hauls taken at 10 day internals during the open water season and once a month in winter. Water salinity and temperature were recorded concurrently. Altogether 34 taxa (species, species groups, instars) were frequent enough for time series analysis.

The most abundant rotifers were *Synchaeta* species (*S. baltica* and *S. monopus* for the most part). Among cladocerans *Podon polyphemoides* and *Eubosmia longispina maritima* were numerically dominant, while *Acartia* spp. and *Eurytemora affinis hirundoides* were the most abundant copepods. The nauplii of *Balanus improvisus* were the most frequent and abundant meroplankton.

In winter meso-zooplankton biomass is dominated by copepods (nauplii), in spring rotifers increase, followed by cladocerans and then by copepod copepodids and adults in autumn. From 20 to 100% of the total meso-zooplankton biomass is attributable to copepods. There is considerable year-to-year variation in meso-zooplankton composition. For example, biomass in the summers of 1968 and 1974 was dominated (40-60%) by rotifers, while in 1967, 1970 and 1973 rotifers were less important (10-15%) in the biomass.

The salinity at Seili rose substantially during 1970-1971, followed by another inflow of saline water in 1973. These salt water intrusions kept the salinity at an elevated level to the end of the sampling period. The meso-zooplankton taxa responded to the salinity change: 11 out of 34 taxa increased in numbers (seasonal effect removed), while most (23) of the taxa decreased in numbers. However, in most cases these changes were not distinguishable from random fluctuations. Presently it is difficult to assess the significance of other factors (human-caused eutrophication, or biotic interactions) to the documented abundance changes.

Wærn, M. and S. Pekkari (1973) **Outflow studies. Nutrients and their influence on the algae in the Stockholm Archipelago during 1970. No. 1.** *Oikos Supplymentum* **15**:155-163.
{nutrient; nitrogen; phosphorus; Baltic}

When comparing 1970 with other years in order to study the effects of different treatments of sewage water in the Stockholm Archipelago some strong influences depending upon climatic causes have to be taken into consideration such as,

1) the accumulation of nutrients inherited from the years before,
2) the discharge below the lasting ice cover,
3) the vigorous spring flood, and
4) the extremely small discharge from Lake Mälaren during the summer.
The years 1968-1970 had 3) and 4) in common.

In the Baltic proper an upwelling of phosphate-rich water appeared in 1970. In the Åland Sea the N:P ratio varied between 11:1 and 19:1 when total N and total P are compared. When the mineralized fractions were compared (below the photosynthetic layer) the N:P ratio varied between 2.1:1 and 2.6:1. This is far from an N:P ratio by assimilation of 7:1 (all ratios on a ug basis).

Walker, D. I. and R. F. G. Ormond (1982) **Coral death from sewage and phosphate pollution at Aqaba, Red Sea.** *Marine Pollution Bulletin* **13**:21-25.
{sewage; coral; Red Sea; algal growth; sediment}

Localized pollution of coral reef areas is occurring at Aqaba, Red Sea, as a result of sewage discharge, and as a result of spillage of phosphate dust during loading of phosphate mineral onto ships. The rate of death of colonies of the coral *Stylophora pistillata* was found to be 4-5 times as great in the polluted area as in a control area. Coral damage in the control area is generally caused by grazing or by extreme low tide, but the cause of coral death in the polluted area was not readily apparent. The growth of algae, both on damaged corals , and on glass slides placed out in the reef, was greatly stimulated in the polluted area, but it appeared that such algal growth was not the direct cause of coral death. Corals in the polluted area may be under stress because of reduced light intensity, inhibition of calcification by excess phosphate, and increased sediment load. It was found that in the polluted area there was a greater weight of sediment settling on the glass slides for a given weight of algae. But in addition, since algal growth was faster in the polluted area, the sediment load was increased by the sediment trapping capacity of the enhanced algal growth. Thus, it is suggested that increased algal growth stimulated by increased nutrient concentrations may be important in greatly increasing the sediment load experienced by corals.

Wallström, K. (1988) **The occurrence of *Aphanizomenon flos-aquae* (Cyanpphyceae) in a nutrient gradient in the Baltic.** *Kieler Meeresforschungen, Sonderheft* **6**:210-220.
{blooms; blue-green algae; N/P ratio; nitrogen; phosphorus}

The investigation area, Himmerfjärdan Bay situated at the Swedish coast of the northern Baltic Proper, receives waste water from a sewage treatment plant. Phosphorus is efficiently reduced in the sewage treatment resulting in a high N : P ratio (≈ 65 : 1) in the discharge. In the near future also the nitrogen discharge will be reduced, and it is feared that a lowered N : P ratio in the receiving waters may favour an undesired increase of nitrogen fixing blue-green algae. This study is focused on the development of a common nitrogen fixing species in the area, *Aphanizomenon flos-aquae*, at varied nutrient loadings in 1983-85. The biomass as well as the number of heterocysts was low near the treatment plant and increased with increasing distance from the sewage discharge. The low biomass and number of heterocysts in Himmerfjärdan Bay is interpreted as an effect of competition with other algae and of low level of phosphorus relative to nitrogen, i.e. unfavourable conditions for nitrogen fixation. The abundance of *Aphanizomenon* was highest in 1984 when the phosphorus load was higher than the other years of investigation. As a tentative conclusion it is suggested that nitrogen fixing algae may increase as a result of reduction in the nitrogen discharge to Himmerfjärdan Bay in the future. At the reference station outside the Bay, nutrient conditions favoured nitrogen fixing algae, as interpreted from inorganic N:P ratio less than 10:1 during the summers of the investigation period. Here the variation in biomass between the years was mainly due to the variation in water temperature; *Aphanizomenon* was most abundant during the warm summer of 1984 and less abundant during the cold summer of 1985. A significant correlation was obtained between the heterocyst frequency and concentration of inorganic phosphorus in the trophogenic layer at the reference station.

Walsh, J. J., G. T. Rowe, R. L. Iverson, and C. P. McRoy (1981) **Biological export of shelf carbon is a sink of the global CO_2 cycle.** *Nature* **291**:196-201.
{carbon; cycle; nutrients; shelf; CO_2}

Measurements of carbon metabolism, production and exchange along food webs suggest that large fractions of the organic matter produced on continental shelves must be exported to continental slopes. The annual loss of organic matter from continental shelf ecosystems is far greater than in the open ocean. If part of the loss of nearshore primary production has increased in those coastal zones where anthropogenic inorganic nutrient supplies have been consistently increasing since the industrial revolution, then burial and diagenesis of this material in slope depocentres could represent the 'missing BMTs of the carbon' in global CO_2 budgets.

Wang, Z. (1987) **Evaluation of water quality in the Zhujiang Estuary, China.** In: T. Okaichi, D. M. Anderson and T. Nemoto

(ed.) *Red Tides: Biology, Environmental Sciences, and Toxicology*. Elsevier, New York.
{phytoplankton; abundance; red tide}

This paper presents preliminary results of a monthly comprehensive investigation of eutrophication and red tides in the Zhujiang (Pearl River) estuarine area, beginning in February, 1987. The purpose of this paper is to discuss the trophic level of water quality in the Zhujiang estuary during Spring and Summer. A single parameter as well as a multiparameter Trophic State Index was adopted to assess the trophic status in the estuarine area. Using nutrients (DIN and DIP), COD loading, and changes in phytoplankton (cell counts and chlorophyll a) as the major parameters, a synoptic assessment was made.

Weaver, A. M. (1978) ***Aspects of the effects of particulate matter on the ecology of kelp forest (Macrocystis pyrifera) (L.) C.A. Agardh) near a small domestic sewer outfall.*** Dissertation for Ph.D., Stanford University.
{particulate; sewage; *Ulva* ; sedimentation; kelp}

An investigation of the relation of particulate matter to the ecology of a kelp forest was undertaken near a small sewer outfall located on a flat shale reef in 11 m of water which supported a canopy of the kelp *Macrocystis pyrifera*. The sewage effluent had an unusually high particulate content which varied several fold through time. The area immediately in front of the outfall terminus, as compared to adjacent stations, was conspicuously more turbid, had higher sedimentation and many patches of exposed shale devoid of organisms, including *Macrocystis*.

The purpose of the study was fourfold: 1) to observe how the quality and quantity of particulate matter fluctuated through time and space; 2) to determine some of the major reasons for these fluctuations; 3) to determine the influence of the quantity and quality of particulate matter on the distribution of benthic organisms; and 4) to determine if and how the sewer outfall influenced particulate matter in the study area.

Particulates were trapped over time in plastic tubes mounted vertically on the bottom at stations located within and outside of the sewage field as defined by coliform levels. The contents were subjected to various analyses.

Total sedimentation (grams of particulate matter trapped per unit time per unit area) fluctuated through time in a seasonal cyclic manner, increased in the fall, was at its maximum in the winter and decreased again in the spring. This pattern was observed at 11 different stations separated by a maximum distance of 1400 meters. At any one point in time, however, large differences (up to 20 fold) in sedimentation were observed between individual stations.

Water movement generated by onshore swells appeared to be a major influence on total sedimentation both in time and space. The amount and proximity of bottom sediments also played a major role in determining spatial differences.

Total sedimentation in the area of the outfall was disrupted. Pronounced gradient in total sedimentation were demonstrated both laterally (parallel to shore) and in a seaward direction. However, these differences appeared to derive from the outfall structure and the local topography rather than the direct sedimentation and accumulation of sewage particles.

The lack of organisms at the near sewer station was attributed to (1) the scouring of organisms from the substrate when total sedimentation was at a high level, (2) burial of available substrate during periods of high sediment accumulation.

Like total sedimentation, macrodetritis (fragmented plants and animals) content of the trapped sediments displayed a seasonal behaviour, generally increasing and decreasing with total sedimentation.

The fluctuations in macrodetritis levels appeared to be a major influence upon the levels of organic carbon in the particulates within the study area.

The outfall station had consistently higher macrodetritis levels than adjacent stations and the fall macrodetritis at all station within the sewage filed contained large quantities of detached *Ulva* not found elsewhere.

The occurrence of the *Ulva* bloom (which took place annually for three consecutive years) appeared to be based on: 1) the high water clarity during periods of low sedimentation which allowed sufficient light for *Ulva* growth at 11 m depth; 2) the presence of sewage effluent which is known to stimulate the growth of *Ulva*.

Distinct concentration gradients of copper were often, but not always, demonstrable in the sediments trapped around the outfall. The highest concentrations were at the outfall station.

During the period of high sediment accumulation (summer), the direct sedimentation of copper with particles from the sewage effluent appeared to be responsible for the gradient. However, during the fall, copper accumulating in the detached *Ulva* appeared to be responsible.

The importance of these findings to future environmental surveys and the location of sewer outfalls is discussed. The significance of the *Ulva* phenomena as a potential pathway for toxins to get into the food chain is also considered.

Weigelt, M. and H. Rumohr (1986) **Effects of wide-range oxygen depletion on benthic fauna and demersal fish in Kiel Bay 1981-1983.** *Meeresforschung* 31:124-136.
{abundance; biomass; benthic; macrofauna; oxygen; anoxia; hydrogen sulfide}

In late summer 1981 an extraordinary and wide ranging oxygen depletion killed most of the benthic fauna below the halocline (>20m) in Kiel Bay. This catastrophic period lasted for several weeks, and even areas were affected where such events had never been observed before. Fishermen reported mass catches of moribund polychaetes and migrations of fishes into nearshore waters. Only a few macrofauna species survived (*Arctica, Astarte, Corbula, Halicryptus*).

About 30,000 t of macrofauna died in Kiel Bay, but recolonization in the following months was rapid. Stomach analyses of demersal fish revealed significant changes in food composition of cod and dab.

In late summer of 1983 a similar, but not so severe oxygen depletion caused the total breakdown of the *Syndosmya alba* stocks below the halocline as well as that of other species.

Welsh, B. L. and F. C. Eller (1991) **Mechanisms controlling summertime oxygen depletion in western Long Island Sound.** *Estuaries* **14**:265-278.
{Long Island Sound; oxygen; mechanism; depletion; hypoxia}

Physical profile data (salinity, temperature, oxygen, and downwelling irradiance) and in situ incubation of light and dark bottles were used to characterize vertical structure and elucidate mechanisms controlling summertime hypoxia in western Long Island Sound. The period of oxygen depletion corresponded with the period of thermally-controlled stratification. Bulk density differences between surface and bottom waters were only 1.2 to 2.7 sigma-t units; but they were apparently sufficient to resist destratification by winds and tides. Thus oxygen depletion was a cumulative process through the summer. During the stratification period, net oxygen production (measured using light BOD bottles) was confined to a narrow surface zone of 1.8-4.5 m. Below this zone was an intermediate zone of high net oxygen uptake, beneath which was a subpycnoclinic zone where oxygen uptake was very low. Rates of total oxygen uptake (dark bottles) were greatest in the surface layer and diminished with depth. There was close coupling between physical conditions and metabolic structure. Vertical structure patterns of oxygen production and removal were strongest in calm weather. The location of the intermediate zone corresponded with that of the oxycline. The thickness of the zone and the steepness of the oxycline were determined by the depth and intensity of both physical stratification and biological production and respiration. The biological structure was weakened by physical mixing in the upper water column, and the intermediate zone disappeared with fall destratification. We hypothesize that biological uptake within the water column influence oxygen depletion through two mechanisms. (1) In bottom waters, uptake rates per unit volume are low, but bulk uptake is a significant factor in oxygen depletion because of the large volumn of water involved. (2) The intermediate zone, where respiratory uptake is also significant, is strategically located between the surface zone of oxygen renewal and the bottom zone of depletion, where it constitutes an active filter which reinforces the pycnocline as a barrier to vertical oxygen dispersion. The magnitude of direct oxygen removal in the water column relative to removal by sediment oxygen demand and the potential effects of this biological filtering mechanism are important considerations for understanding eutrophic dynamics and managing Long Island Sound. Dynamic models which (1) underestimate the role of water column uptake and (2) incorporate only the two-zone characteristics of physical stratification will tend to (a) overestimate the contribution of sediments to summertime oxygen deficits and (b) overestimate rates of vertical dispersion and reventilation of bottom waters.

Weston, D. P. (1990) **Quantitative examination of macrobenthic community changes along an organic enrichment gradient.** *Marine Ecology Progress Series* **61**:233-244.
{abundance; biomass; macrobenthos; community; trophic; size; richness; distribution; Puget Sound}

Organic enrichment, both natural and anthropogenic, is one of the most common forms of disturbance in the benthos. The effects of organic enrichment on the benthos in the vicinity of a large mariculture facility were examined as a general model for enrichment, without the confounding effects of toxicants often associated with anthropogenic inputs. Stations nearest the facility were subject to continuous input of fish feed and fecal matter, and gross structural changes in the macrofaunal community (e.g. reduced species richness, dominance of opportunistic species) were similar to those commonly reported for other enriched sites. More complex community and population responses were indicated by changes in body size, vertical distribution of infauna and patterns of trophic dominance. Enriched areas are generally assumed to be characterized by macrofauna with small body sizes, and mean individual size did, in fact, decrease with proximity to the farm. At stations farthest from the farm, however, size distributions were skewed by a few large individuals, indicating that trends in mean individual size are susceptible to the methodological limitations inherent in adqeuately sampling rare individuals. While interspecific measures of animal size decreased with increasing enrichment, intraspecific measures indicated a tendency for larger individuals to occur at the most

enriched sites. Enriched areas may represent increased food resources, and thus increased potential growth and attainment of larger body sizes in those species capable of exploiting such habitats. Organically enriched areas are generally considered to be characterized by infauna living at or near the sediment-water interface. Increasing organic enrichment resulted in the loss of large, deep-dwelling species and dramatically altered the vertical biomass profiles, but, because these individuals were numerically few, had little effect on the vertical abundance profiles. Changes in trophic dominance did occur along the trophic groups and assign species to them. The utility of trophic grouping approaches in identification of enrichment-induced disturbances is thus limited.

Whiteledge, T. E. (1985) **Nationwide Review of Oxygen Depletion and Eutrophication in Estuarine and Coastal Waters.** NOAA, {oxygen; estuary; coastal; nutrients; production; United States; hypoxia; depletion}
No abstract

Widbom, B. and R. Elmgren (1988) **Response of benthic meiofauna to nutrient enrichment of experimental marine ecosystems.** *Marine Ecology Progress Series* **42**:257-268.
{benthic; abundance; composition; meiofauna; nematode; polychaete; harpacticoid; bivalve; ostracod; kinorhynch; MERL}

The long-term (2.4 yr) response of benthic meiofauna to eutrophication of experimental marine ecosystems was studied at the Marine Ecosystems Research Laboratory, Graduate School of Oceanography, University of Rhode Island (USA). Ammonium, phosphate and silicate were added daily in the mesocosms in a logarithmic progression (0X, 1X, 2X, 4X, 8X, 16X, and 32X), with the 1X addition being N = 2.88, P = 0.225, Si = 0.205 mmol m^{-2} d^{-1}. Phytoplankton production and biomass in the tanks increased with increasing nutrient enrichment. The benthic community gave a quantitatively less marked response to the gradient of nutrient input. The meiofauna showed remarkably little response in terms of biomass and abundance, but significant effects were found on major taxa, leading to a changed meiofauna community structure. Nematode and juvenile polychaete abundance increased with increasing nutrient input, especially in early summer, whereas kinorhynchs, ostracods, harpacticoids and juvenile bivalve decreased. The lack of a positive biomass response of the total meiofauna in the enriched tanks suggests that the meifauna was limited not only by the availability ot food, but also by biotic interactions.

Wilcox, W. H. (1979) ***The effect of nitrogen and phosphorus enrichment on salt marsh.*** Dissertation for Ph.D., The University of Tennessee.
{salt marsh; biomass; dominance; periphyton; composition; Florida}

Fertilization of a *Batis maritima* and *Salicornia virginica* dominated salt marsh in Florida, with a combined nitrogen and phosphorus fertilizer applied at four rates (50:8; 100:16; 150:24 and 200:32 kg/ha/yr N:P) produced the following responses: 1) dominance shifted to *Batis*, 2) *Batis* aerial biomass increased from 428 g/m^2 (control) to 1062 g/m^2 (highest rate) while *Salicornia* showed no positive response to fertilization, 3) highest fertilization plots had a 9% higher decomposition rate than control plots (0.00728/day versus 0.00668/day), 4) no luxury consumption of nutrient was measured, 5) *Batis* stem biomass reached an asymptote of 750 g/m^2 (295 g/m^2 control) after 2 years fertilization at 150:24 and 200:32 kg/ha/yr N:P, 6) *Batis* biomass at 328 g/m^2 (133 g/m^2 control) had not reached an asymptote after two years fertilization. Measurement of initial changes in snail numbers and periphyton biomass and species composition, in response to fertilization could not be repeated, probably due to a drying trend in the marsh and a drastic reduction in snail and periphyton numbers.

Wittberg, M. and W. Hunte (1992) **Effects of eutrophication and sedimentation on juvenile corals. I. Abundance, mortality and community structure.** *Marine Biology* **112**:131-138.
{sedimentation; corals; abundance; mortality; community structure; reef; size}

This study investigated effects of eutrophication and sedimentation on juvenile abundance, juvenile mortality and community structure of scleractinian corals on fringing reefs on the west coast of Barbados, West Indies, in 1989. Juvenile abundance was lower on eutrophic/high-sediment reefs than less eutrophic/low-sediment reefs, but juvenile size was larger on the former. The larger size could result from size-selective mortality against smaller juveniles on the eutrophic reefs, or from lower recruitment to the eutrophic reefs, or from faster growth on the eutrophic reefs. Juvenile mortality was higher on the eutrophic reefs than the less eutrophic reefs and may result from increased smothering of corals by eutrophic reefs, probably in response to elevated nutrients and/or because grazers (*Diadema antillarum*; herbivorous fish) were less common on eutrophic reefs. Juvenile community structure on all reefs was dominated by Type 1 corals (high recruitment, high natural mortality), but Type 2 corals (low recruitment, low natural mortality) became more common in adult communities on the less eutrophic reefs. This transition in community structure did not occur on

the eutrophic reefs, adult community structure continuing to be dominated by Type 1 corals. The fact that the pattern of relative abundance of species in the juvenile community is maintained in the adult community on the eutrophic reefs suggests that juvenile mortality rates of different species are similar on eutrophic reefs, and hence that differences in adult community structure between eutrophic and less eutrophic reefs may be largely explained by interspecifics in juvenile mortality becoming smaller on eutrophic reefs.

Wolff, W. J. (1988) **Impact of pollution of the Wadden Sea.** In: W. Salomons, B. L. Bayne, E. K. Duursma and U. Förstner (ed.) *Pollution of the North Sea. An Assessment.* Springer-Verlag, Berlin.
{phytoplankton; production; microphytobenthos; Dutch Wadden Sea; biomass; macrobenthos; review}
No abstract

Wong, P. S. (1987) **The occurrence and distributiuon of red tides in Hong Kong - Applications in red tide management.** In: T. Okaichi, D. M. Anderson and T. Nemoto (ed.) *Red Tides: Biology, Environmental Science, and Toxicology.* Elsevier, New York.
{red tide; bloom}

The occurrence of red tides in Hong Kong is reviewed based on reports received by the Aquaculture and Fisheries Department. Interesting patterns of distribution of some common red tide species in Hong Kong are obtained. Data on seasonal occurrence and distribution of each species, particularly the toxic ones, would enable better planning of preventing measures or management actions in different coastal regions. Knowledge of toxicity of different species would facilitate the initial assessment of risks involved. Further suggest the possibility of development a system for forecasting red tide occurrences.

Wu, R. S. S. (1982) **Periodic defaunation and recovery in a subtropical epibenthic community, in relation to organic pollution.** *Journal of Experimental Marine Biology and Ecology* **64**:253-269.
{benthic; defaunation; Tolo Harbour; Tolo channel; Hong Kong; abundance; biomass; composition; oxygen; recovery; diversity}

A monthly survey was carried out for two years on the epifaunal community in Tolo Harbour and Tolo Channel, Hong Kong, a subtropical embayment subjected to a gradient of organic pollution. The number of animals and species, biomass and species diversity (Shannon's function H' and eveness J), were higher at less polluted stations in the outer Harbour and Channel than at the polluted stations in the inner Harbour. The Channel community was dominated by the crab *Portumus hastatoides* Fabricius and the gastopod *Nassarius crematus* (Hinds). Along an increasing gradient of organic pollution, *Nassarius crematus* was gradually replaced by the crab *Charybdis vadorum* (Alcock), and a community dominated by *Portumus hastatoides* and *Charybdis vadorum* was found in the polluted inner Harbour. The abundance and dominance of predatory gastropods also showed a decrease from the Channel to the inner Harbour, reflecting changes in the trophic structure of the community in relation to pollution. No significant change in the percentage of deposit-feeders was found along the pollution gradient. Summer mortality of benthos appeared to occur regularly in inner Tolo Harbour, and was attributed to summer oxygen depletion resulting from eutrophication. The benthic community was, however, soon restored to its original state by rapid winter recolonization. It is postulated that the cyclic phenomenon of summer mortality followed by winter recovery may be a common characteristic in subtropical benthic communities subjected to a high level of organic pollution.

Wulff, F. and A. Stigebrandt (1989) **A time-dependent budget model for nutrients in the Baltic Sea.** *Global Biogeochemical Cycles* **3**:63-78.
{nitrogen; phosphorus; nutrient; loading; model; budget; Baltic}

Overall budgets for nutrient and humus are described for the Baltic Sea as well as for the subsystems, i.e., the Baltic proper, the Bothnian Bay and the Bothnian Sea. The residence times for total phosphorus, total nitrogen, silicate and humus are 13.3, 5.5, 11.2, and 9.6 years respectively, compared to 21.8 years for a conservative substance (salt). About 90% of the nutrient losses are due to biogeochemical sinks within the Baltic Sea. Thus only about 10% is exported to external areas (the Kattegat/Belt Sea). For humus the corresponding figures are about 75 and 25%, respectively. This means that the Baltic Sea to a large extent can be regarded as a closed system and perturbations in the water exchange with the North Sea should have little effect on the nutrient budgets. This sinks are parameterized by an expression borrowed from limnology where the net nutrient loss is a function of the winter surface concentration. A budget model is run in a prognostic, hindcast mode with the assumed time-dependent phosphorus and nitrogen loading of the Baltic proper. The computed development of the winter surface concentrations of total P and total N for the period 1950-1988 appears quite realistic. The possibility of having variable sinks which are functions of the surface winter concentrations of nitrogen and phosphorus is described using calculations based on data from the different Baltic subareas. Such sinks should

significantly decrease the winter N:P ratio in the surface water when the nutrient loading increases with time. With better description of in particular the pools of nutrients in the sediment, it would be possible to model future changes of nutrient concentrations in the water column in relation to loading.

Wulff, F., A. Stigebrandt, and L. Rahm (1990) **Nutrient dynamics of the Baltic Sea.** *Ambio* **19**:126-133.
{nitrogen; phosphorus; nutrient; Baltic}
A prerequisite for understanding the large-scale eutrophication of the Baltic Sea is an understanding of the factors responsible for regional and long-term variations of nutrients. This article summarizes recent studies on the changes in overall total amounts and the distribution pattern of nutrients. The total amounts of phosphorus and nitrogen have increased over the last few decades. On the other hand, silicate levels have been decreasing, indicating a higher net primary production and sedimentation of diatoms. A series of models has been used to test our present understanding of the critical processes controlling nutrient and oxygen conditions. It is shown that a few morphometric factors are essential, like shallow sill depth at the entrance of estuarine-like sea and shallow mean depth. It is also shown that phosphorus, nitrogen and silicate differ in terms of residence times and the fate of these nutrients take place in the sediments. A model showing the long-term behavior of this system in response to external loading illustrates the importance of these processes.

Wyatt, T. and J. Horwood (1973) **Model which generates red tides.** *Nature* **244**:238-240.
{red tides; model; bloom; dinoflagellates}
No abstract

Yang, D. B. (1987) **Nutrient and chlorophyll a variations during the red tides in Jinhae Bay, Korea.** In: T. Okaichi, D. M. Anderson and T. Nemoto (ed.) *Red Tides: Biology, Environmental Science and Toxicology.* Elsevier, New York.
{red tides; nutrient; abundance; chlorophyll}
Tidal cycle time series distributions of nutrients and chlorophyll a were measured at a fixed station located at mid-channel of Jinhae Bay, Korea. High nitrate concentrations were observed at the time of low tides whereas high phosphate concentrations occurred occasionally at the time of high tides. Anoxic bottom water appeared to be the major source of high phosphate in the outer bay. Chlorophyll a concentrations were positively correlated with nitrate concentrations in April 1981, May 1982 and June 1983. However, chlorophyll a concentrations were also positively correlated with phosphate in June and August, 1981 and September 1982. Despite positive relationships between nutrients and chlorophyll a, phytoplankton growth is not likely to be limited by these nutrients in Jinhae Bay. The role of growth stimulators in initiating the extensive blooms of red tide organisms in suggested.

Yi, S. K., J.-S. Hong, and J. H. Lee (1982) **A study on the subtidal benthic community in Ulsan Bay, Korea.** *Bulletin of the Korea Ocean Research and Development Institute* **4**:17-26.
{benthic; Ulsan Bay; polychaete; abundance; composition}
A quantitative investigation of the soft-bottom macrobenthic community in Ulsan Bay was carried out from June, 1980 to March 1981. Of the 127 species of benthic organisms found, Polychaeta was the most dominant taxonomic group with 67 species which accounted for 88% of the total number of individuals. The number of species and individuals decreased from the inner bay toward the outer bay stations. At station 1, a sharp drop in the number of individuals was noted from June to September, and this drop was mainly due to decrease in three dominant polychaetes, *Cirratulus cirratus*, *Lumbrineris longifolia*, and *Tharyx* sp.
Based on interstational species similarity, the study area can be divided into two zones; Station 1,2,3, and Station 4,5. The first zone was considered to be under an organic enrichment condition. This was supported, to a certain extent, by hydrological conditions and species composition.

Zambianchi, E., C. Calvitti, P. Cedcamore, F.D'Amico, E. Ferulano, and P. Lanciano (1992) **The mucilage phenomenon in the Norther Adriatic Sea, summer 1989: A study carried out with remote sensing techniques.** In: R. A. Vollenweider, R. Marchetti and R. Viviani (ed.) *Marine Coastal Eutrophication.* Elsevier, Amsterdam.
{Adriatic Sea, gels}
Observations are presented of the mucilage phenomenon which affected the Northern Adriatic Sea in the summer of 1989. The observations were made with data acquired by different spatial and temporal resolution satellite and airborne sensors. The results of our study are presented, together with data from other sources, and analyzed in order to contribute to the understanding of the spatial and temporal evolution of the phenomenon.

Zdanowicz, V. S., D. F. Gadbois, and M. W. Newman (1986) **Levels of organic and inorganic contaminants in sediments and fish tissues and prevalences of pathological disorders in winter flounder**

from estuaries of the Northeast United States, 1984. *Oceans '86* 578-585.
{organic; inorganic; contaminants; sewage; pathology; winter flounder; disease}

The Benthic Surveillance Project of NOAA's National Status and Trends Program seeks to determine prevalences of pathological disorders in demersal finfishes and levels of organic and inorganic contaminants in sediments and fish tissues and evaluate possible correlations between biological effects and contamination. More than fifty of the Nation's estuaries and other coastal water bodies are under study. Preliminary findings from the first year of sampling in the Northeast region of the U.S. reveal that sediments from Raritan Bay, Boston Harbor and Salem Harbor contained substantially elevated concentrations of primary sewage related organic and inorganic contaminants. PCB levels in livers of winter flounder exceeded 10 ug/g in specimens from Boston Harbor, but were 3.2 ug/g or less elsewhere. Distributions of certain pathological conditions, such as the presence of gigantic cells in the tubular epithelium of winter flounder kidney, paralleled the distributions of sediment contaminants, whereas distribution of other pathological conditions, such as winter flounder pancreatitis, did not.

Zingone, A., M. Monitresor, and D. Marino (1990) **Summer phytoplankton physiognomy in coastal waters of the Gulf of Naples.** *P.S.Z.N.I: Marine Ecology* 11:157-172.
{phytoplankton; Gulf of Naples; nutrients; abundance; diversity; bloom}

Thirteen sampling cruises were conducted at weekly intervals in the inner part of the Gulf of Naples in the summer of 1983 to investigate the effects of excess nutrient inputs on phytoplankton communities. High surface phytoplankton concentrations (up to 1.15×10^8 cells l^{-1}) were recorded, particularly near Naples harbour and along the eastern coast, two locations that receive most of the area's sewage and industrial discharge. Phytoplankton populations were generally dominated by small species, mainly diatoms, which were associated with small phytoflagellates. Species diversity values were relatively high ($H' \leq 3.62$) in most samples. Throughout the sampling period a high spatial and temporal variability for phytoplankton abundances and species composition was observed.

Appendix: Keyword List

abiotic
abnormal
abnormalities
Abra
abundance
acid
acidity
activity
Adriatic
Adriatic Sea
Aegean Sea
Alexandrium
algae
algal bloom
algal growth
alkaline phosphatase
Ammonia toxicity
ammonia
ammonium
ammonium/nitrate ratio
Ampelisca abdita
amphipod
annelids
anoxic
aquaculture
aquatic vegetation
archipelago
archipelago sea
Arkona
Arkona Sea
Asia
assay
assemblage
assessment
Atlantic menhaden
Atlantic shelf
atmosphere
auhwuchs
Aurococcus
Australia
autoecology
bacteria
bacterioplankton
Baltic
Barbados
beach
benthic
benthic algae
benthic communities
benthic fauna
benthos
Berrow Flat
bioassay
biogeochemical cycling
bioindicator
biomass
bird
bivalve
bivalves
Black Sea
Blanca Bay
bloom
blue-green algae
Bohai Bay
Boston Harbor
Brachionus
brown tide
brown tide bloom
budget
Burgas Bay
Buzzard Bay
Cadiz Bay
California
capacity
Capitella
carbon
^{14}C production
causes
change
Charlotte Harbor
Chesapeake Bay
chironomonids
chl a
chlorophyll
chlorophyll a
Chrysochromulina
ciliates
Cladophora
classification
climate
CO_2
coast
coastal
coccolithophores
colored tides
community
community structure
comparison
concept
contaminants
copepod
copepods
copper
coral
coral reef
corals
Corophium
Crassostrea
criteria
crustacea
culture
cyanobacteria
cycle
cycles
cycling
cyst
decapod
decomposition
decrease
defaunation
demand
demersal
denitrification
density
deoxygenation
depletion
deposit-feeder
depth penetration
desert
development
diatom
diatoms
Dictyocha
diel
dinoflagellate
dinoflagellates
Dinophysis
disappearance
discharge
disease
dissolved oxygen
distribution
diversity
Dogger Bank
DOM
dominance
dredging
Dunaliella
Dutch Wadden Sea
dynamics
dystrophic
ecosystem
ecosystem health
eelgrass
effects
effluent
effluents
egg
egg production
Eh
Elefsis Bay
Ems estuary
energetics
energy flow
enrichment
environment
environmental condition
epifauna
epiphytes
epiphytic
Erie
estuaries
estuarine ponds
estuary
eutrophic
eutrophic marine ecosystems

eutrophicated
eutrophication
evidence
excretion
Exuviaella
Far East
fate
fats
fauna
faunal composition
feeding
filamentous
Finland
fish
fish farming
fish kill
fish yield
fishkill
fjord
flagellates
floating
Florida
flounder
fluorescence
flux
food
food web
Forth estuary
fouling
framework
freshwater
Fucus
Furcellaria
gels
general model
German Bight
gonad index
gonads
Gonyaulax
Gotland Sea
grazing
Greece
green algae
green tide
Greifswald Bay
growth
growth form
growth potential
growth rate
Gulf of Maine
Gulf of Naples
Gulf of Patras
Gymnodinium
H_2S
habitat
harpacticoid
Hawaii
health
Helgoland
herring
heterotrophic uptake
historical
Hong Kong
Hudson River
Hudson River estuary
humic
hydrogen sulfide
hydrogen sulphide
hydrographic
hydrographic dynamics
hydrography
hydromedusae
hypoxia
impacts
increase
index
indicator
Indo-Pacific
infauna
inorganic
inorganic nutrients
interface
intertidal
Irish Sea
iron
Italy
Japan
Kanaohe Bay
Kastela Bay
Kattegat
Kelatella
kelp
Kiel Bay
Kiel Bight
kinorhynch
lagoon
Lake Kinneret
Lake Ontario
lake
lakes
Laminaria
larval development
Lebanon
length
life cycle
life history
light
limitation
loading
lobster
log-normal
Long Island
Long Island Sound
Louisiana
Macoma
macroalgae
macroalgal mats
macrobenthos
macrofauna
macronutrient
macrophytes
macrozoobenthos
Madracis
management
mariculture
marine
Marsdiep
marsh
mats
Matsushima Bay
maturation
mechanism
Mediomastus ambiseta
Mediterranean
meiobenthos
meiofauna
MERL
meroplankton
mesocosm
mesoplankton
mesozooplankton
metabolism
methane
method
methods
Mexico
microalgae
microflora
microheterotrophs
microlayer
micronutrient
micronutrients
microphytobenthos
microplankton
microzooplankton
mining
model
modeling
modelling
mollusc
morphotype
mortality
mucous aggregates
mudflat
mussel
Mytilus
N/P ratio
N_2O production
Nahant Bay
nanoplankton
Narragansett Bay
nematode
Nephrops norvegicus
net ecosystem metabolism
net ecosystem production
Netherlands
New Jersey
New York Bay
New York Bight
nitrate

nitrification
nitrite
nitrogen
Nitzschia seriata
Nodularia
North Sea
Norway
Nucula
Nucula annulata
nuisance
nuisance bloom
nutrient
nutrient addition
nutrient enrichment
nutrient limitation
nutrient ratios
nutrients
oligochaetes
opportunistic
organic
organic carbon
organic enrichment
organic matter
Oslofjord
ostracod
oxygen
oxygen demand
oxygen uptake
oyster
Palmico River estuary
paper
particulate
Parvilucina
pathology
pelagic
pelagic biology
pelagic ecosystem
Peridinium
periphyton
pH
Phaeocystis
Phaeodactylum
Philippines
phosphorus
photosynthesis
photosynthetic rate
Phycodrys
Phyllophora
physical energy
physiology
phytoplankton
phytoplankton abundance
phytoplankton assemblage
phytoplankton bloom
phytoplankton species composition
picoalgae
picoplankton
pigments
Pilayella
plankton
Po River
pollution
polychaete
polychaetes
Polydora ligni
Pomatoschistus
population
Portugal
precipitation
prediction
primary production
primary productivity
processes
production
productivity
protein
Providence River
Puget Sound
pulp
Pyrodinium
ratio
recolonization
recovery
recycling
Red Sea
red tide
red algae
redox potential
reef
regeneration
relationship
remedial action
remineralization
remote sensing
reproduction
research needs
reservior
resource
respiration
review
Rhine
richness
River Elbe
rocky shore
rotifer
runoff
salt marsh
salt pond
San Francisco Bay
sand goby
sandflat
sandy beaches
Saronikos Gulf
Scandinavian
Scottish coast
Scottish water
seagrass
seasonality
seaweeds
secondary
secondary production
sediment
sediment transport
sedimentation
sediments
settlement
sewage
shading
shelf
shellfish
silica
silicate
silicoflagellate
silicon
similarity
size
size structure
Skagerrak
Skeletonema
sludge
smelt
spatial
spawning
species
species abundance
species composition
species richness
SPM
stability
stage
standing crop
standing stock
Strait of Georgia
strategy
stratification
striped bass
submerged
submerged plants
submerged vegetation
subsurface
succession
sulfate reduction
survival
susceptibility
Sweden
temperature
temporal
Thailand
tidal flat
tidal marsh
tide
tissue
Tokyo Bay
tolerance
Tolo channel
toxic
toxic algal exudates
toxicity
transition

transparency
trend
trophic
trophic state index
trophic status
turbidity
Ulsan Bay
ultrastructure
Ulva
United States
upwelling
Uronema
Vancouver Harbor
vascular plants
vegetation
Venice Lagoon
Victoria Harbour
Visakhapatnam Harbour
Vollenweider
Wadden Sea
wastewater
winter flounder
yield
Ythan estuary
Yugoslavia
zonation
zooplankton
zooxanthellae
Zostera

★U.S. GOVERNMENT PRINTING OFFICE: 1995-386-543/25406

OTHER TITLES IN THE DECISION ANALYSIS SERIES

No. 1. Able, Kenneth W. and Susan C. Kaiser. 1994. Synthesis of Summer Flounder Habitat Parameters.

No. 2. Matthews, Geoffrey A. and Thomas J. Minello. 1994. Technology and Success in Restoration, Creation, and Enhancement of *Spartina alterniflora* Marshes in the United States. 2 vols.

No. 3. Collins, Elaine V., Maureen Woods, Isobel C. Sheifer and Janice Beattie. 1994. Bibliography of Synthesis Documents on Selected Coastal Ocean Topics.

NOAA COASTAL SERVICES CENTER LIBRARY
3 6668 00003 4886