Testing of indicators for the marine and coastal environment in Europe

Part 3: Present state and development of indicators for eutrophication, hazardous substances, oil and ecological quality

Annexes

European Environment Agency

Contents

Annex 1

Oxygen and chlorophyll-a concentrations as eutrophication indicators — Feasibility study

Summary

Two indicators of eutrophication have been developed and assessed using data from the Danish national monitoring programme. The first indicator describes the frequency of hypoxic conditions, which is defined as oxygen concentrations below 2 ml/l. Hypoxic conditions have severe consequences for the marine ecosystem. The second indicator describes the mean chlorophyll-a concentration in the summer period. High chlorophyll-a concentrations may increase the frequency of hypoxia. Both indicators have been tested and found appropriate as eutrophication indicators. We recommend that the indicators be tested on data from other marine community waters.

1. Introduction

Eutrophication caused by excess load of anthropogenic nitrogen and phosphorus is a major problem in many European coastal areas. Increased nutrient loads on marine community waters have had repercussions on the ecological balance of these systems (Ærtebjerg et al., 2001). The marine ecosystem is composed of a complex mosaic of interacting processes, where changes in the nutrient pressures will inevitably have consequences on the functioning of the ecosystem. Nutrient concentrations are state indicators with the closest link to nutrient pressures. Most marine waters in Europe have experienced increasing nutrient concentrations (Ærtebjerg et al., 2001). This has subsequently led to increased frequency and magnitude of algae blooms and increased risk of oxygen deficiency in bottom waters.

The objective of this study is to evaluate the usefulness of oxygen and chlorophyll-a concentrations as indicators of the state of eutrophication. This feasibility study has been carried out using data from the Danish national monitoring programme only, because the calculations required access to raw data. Aggregated data provided by ICES (Nygaard et al., 2001) could not support the indicator computations for oxygen, and only partially the computations for chlorophyll-a.

2. Oxygen indicator

2.1. Introduction

Enhanced primary production in eutrophic waters increases the sedimentation rate of organic material to the bottom. The subsequent degradation of organic material in the sediments consumes oxygen from the overlaying waters. The oxygen content in bottom waters is determined by two processes:

- the consumption of oxygen due to degradation of organic materials in the bottom water and sediments. The consumption rate depends on the amount and quality of organic material sedimenting to the bottom and on the temperature;
- the supply of oxygen from vertical mixing and horizontal transport processes. The supply rate depends on the hydrographical processes forced by wind, buoyancy and tides.

Oxygen deficiency will occur if the consumption rate exceeds the supply rate for a sufficiently long period of time for the oxygen in the bottom water to be depleted. Oxygen deficiency is only a problem in marine waters with periodic or permanent strong stratification. Marine waters can be classified into three categories.

1. Areas without oxygen deficiency. This is typically well-mixed or weakly stratified waters, where stratification is continuously broken down by tidal mixing, wind mixing, etc. or in stratified waters with a deep bottom layer regularly supplied with oxygen-rich water by horizontal advection.

2. Areas with temporary oxygen deficiency. This is typically waters with strong stratification and low horizontal advection in long periods — in general, most of the summer and autumn period. The oxygen deficiency can be created locally or transported to the area by deeper layer advection processes.

3. Areas with permanent oxygen deficiency. This is typically waters with a permanent strong stratification and low horizontal advection, which applies to many of the deep basins in the Baltic Sea and estuaries with a sill preventing the exchange of bottom water.

## 2.2. Indicator for oxygen deficiency

The yearly minimum oxygen concentration has become a de facto standard for describing the state of oxygen deficiency (Rosenberg, 1990). Further, minimum oxygen concentrations are frequently used in trend analyses based on the assumption of observations with equal distributions. It is recommended not to base an evaluation of oxygen deficiency on minimum concentrations, because the statistical properties of minimum values depend on the number of observations over which the minimum value has been calculated. This is intuitively easy to understand, because the more observations we have from a single year, the lower the expected minimum value will be. Thus, it is unfortunate to use the minimum oxygen concentration for state and trend analyses.

In the international literature, hypoxia is operationally defined as oxygen concentrations below 2 ml/l (Diaz and Rosenberg, 1995). It has been shown that hypoxic conditions can have detrimental effects on the benthic fauna (Diaz and Rosenberg, 1995). A better alternative to the minimum oxygen concentration is to consider the frequency of hypoxia. The frequency of hypoxia is defined as the number of observations within May to November below 2 ml/l divided by the total number of observations. This period could be determined on a regional scale when the period of potential oxygen deficiency has a different extent. The frequency describes the probability of observing hypoxic conditions from May to November. This period has been chosen as the season where hypoxia normally prevails in northern temperate waters.

A statistical method for trend analysis is to consider the number of hypoxic observations each year to be binomial distributed with parameters n and p_i, where n is the total number of observations for year i and p_i is the probability of observing hypoxic conditions in year i. The trend analysis is conducted by testing if p_i is a function of year. This method is known as logistic regression (McCullagh and Nelder, 1989). A virtue of this method is that it weights yearly frequency observations with the number of observations it has been based on. Thus, the frequency of hypoxia determined from a year with many observations of oxygen concentrations has

| Frequency of hypoxia (observations marked by dots compared to the logistic regression line (solid line) with 95 % confidence limits (dashed lines)) | Figure A1.1 |
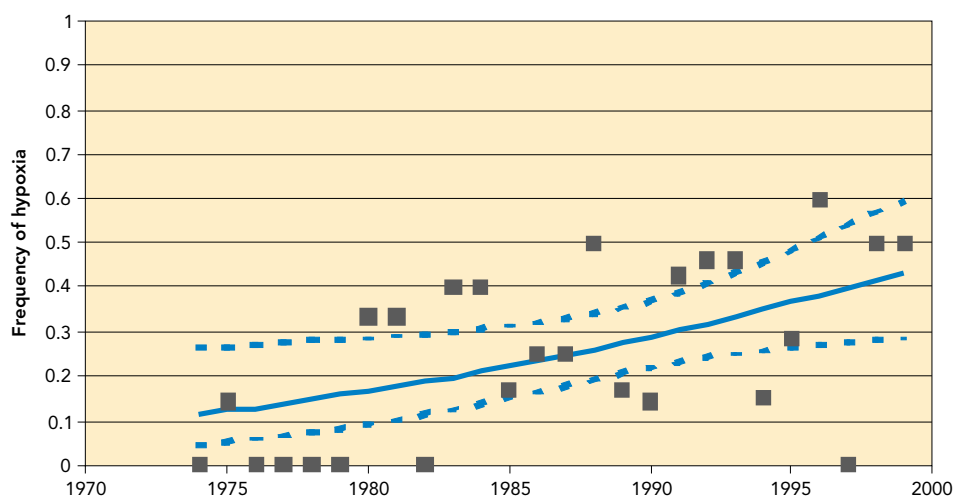
more weight than the frequency of hypoxia determined from a year with few observations of oxygen concentrations.

The use of this indicator will be exemplified with data from a Danish station located in the southern Belt Sea between Germany and Denmark. Figure A1.1 shows the results of the analysis on this single station. The increasing trend in frequency of hypoxia is significant at a 5 % significance level (P = 0.0183). This station was deliberately chosen because it showed an increasing frequency of hypoxia.

2.3. State of oxygen deficiency

Oxygen deficiency is a significant problem in major parts of Danish waters. In the 80s the Kattegat and the Belt Sea were exposed to several events of hypoxic conditions (Andersson and Rydberg, 1988), which subsequently led to political decisions on nutrient reductions. Oxygen deficiency has also been reported in other marine community waters (e.g. Johannessen and Dahl, 1996).

The frequency of hypoxia for the last half of the 1990s (1995 and onwards) and trends of this frequency (no specific period) are shown in Figure A1.2. It is observed that many stations are characterised as stations without oxygen deficiency problems (frequency = 0). This applies especially to all the stations in the North Sea and Skagerrak, where tidal mixing and currents induce a constant

replacement of bottom waters. In Kattegat, the Belt Sea and the Baltic Sea most stations are exposed to hypoxia, and these marine areas must be considered sensitive to oxygen deficiency. Some estuaries (typically estuaries with a sill) are exposed to almost permanent hypoxic conditions. The eastern-most station in the Baltic Sea is located in one of the deep Baltic Sea basins, where almost permanent hypoxia is observed from of depths 60–70 m down to the bottom at 86 m. Almost permanent hypoxic basins are characteristic for the Baltic Sea (Helcom, 1996; Kullenberg, 1981).

The logistic regression analyses show that four out of 153 stations have a significant trend in the frequency of hypoxia (three stations show an increase and one station a decrease). Hence, there is no general trend in the frequency of hypoxia. This is due to two facts.

1. Most time series of oxygen concentration start in the 1970s or 1980s while nutrient loading had already increased significantly in the 1950s and 1960s. We can therefore not evaluate the transition from low pressures to high pressures.

2. Variations in frequency of hypoxia caused by meteorological fluctuations mask variations of lesser amplitude that accrue from changes in anthropogenic loading. Long time series are required to detect changes in the frequency of hypoxia.

| Figure A1.2 | Frequency and trend of hypoxia for stations in the Danish national marine monitoring programme |
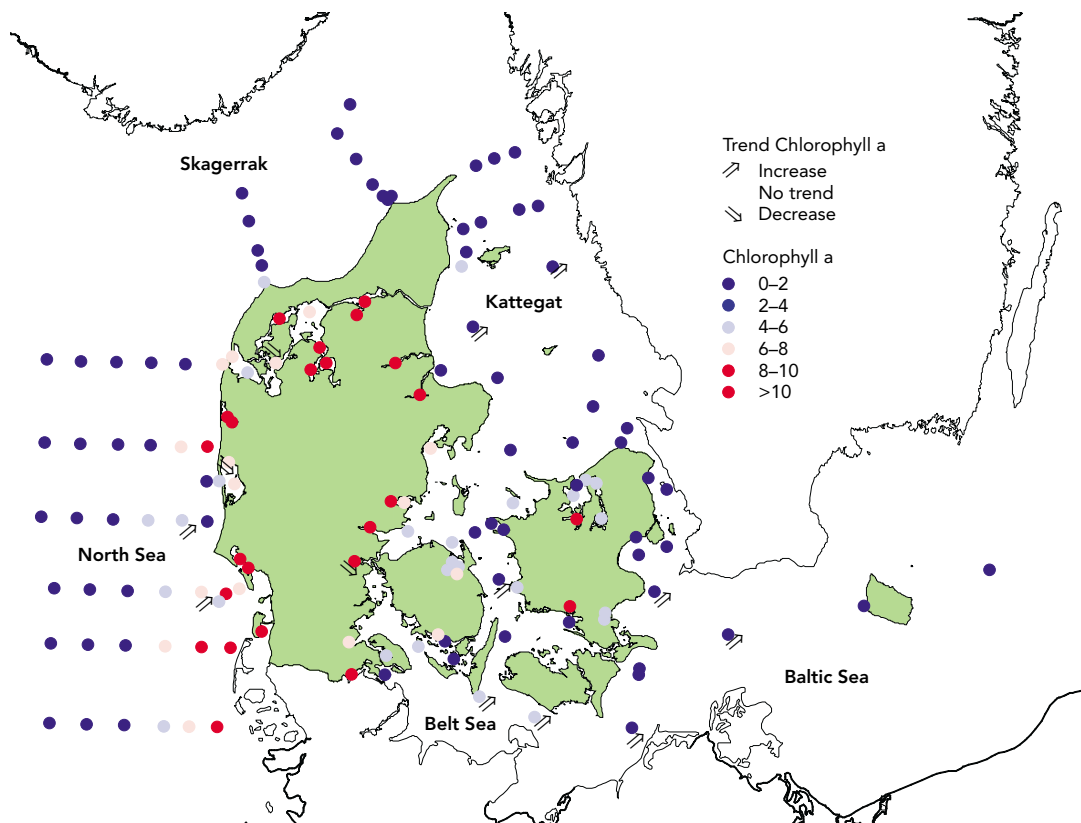
The frequency of hypoxia can be used for classification of marine community waters into areas with and without oxygen deficiency problems. In waters susceptible to oxygen deficiency, the frequency of hypoxia is a good indicator of the state of eutrophication.

3. Chlorophyll-a indicator

3.1. Introduction

Increases in nutrient loading have enhanced primary production in marine community waters (Richardson and Heilmann, 1995); this has the potential to raise the standing stock of phytoplankton organisms. The amount of phytoplankton in the water column is governed by:

• the primary production rate, which depends on the phytoplankton biomass and is limited by the availability of nutrients and light. The phytoplankton community responds quickly to changes in the limiting factors (< 1 day). Primary production consists of new production fuelled by external supply of nutrients from land, atmosphere or deep water mixing, and regenerated primary production fuelled by recycling of nutrients from the loss processes;

• the loss of phytoplankton by pelagic and benthic grazing, sedimentation, decay and advective transport processes. Most of the nutrients in the loss of phytoplankton are recycled and used for regenerated primary production.

The response to enhanced primary production could potentially be an increase in phytoplankton biomass, if grazing on the phytoplankton community is not too high.

Chlorophyll-a is the green plant pigment used for photosynthesis, which is present in all autotrophic phytoplankton organisms. Chlorophyll-a is an adopted measurement technique for monitoring the amount of algae. The content of chlorophyll-a typically accounts for 1/40-60 of the total carbon biomass in the algae, but this ratio varies considerably depending on species composition of the plankton, and on the physiological state of the algae.

Illustration of the seasonal variation in phytoplankton biomass and chlorophyll-a (adopted from Lalli and Parson, 1993)	Figure A1.3
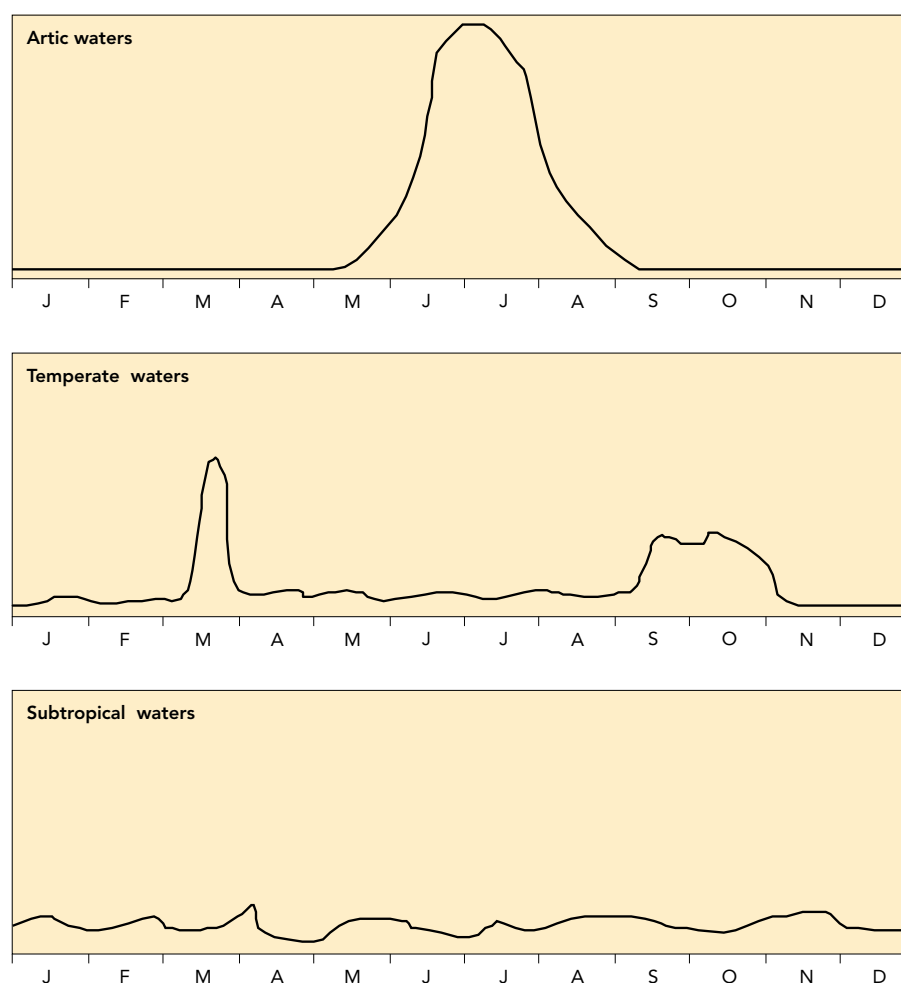
European community waters stretch from Arctic waters in the north over temperate waters to subtropical waters in the Mediterranean Sea and off the Iberian coast. The seasonal variation in phytoplankton biomass depends on the climatic conditions. This is illustrated in Figure A1.3.

Arctic waters have a characteristic unimodal seasonal variation with an intense summer bloom where light conditions are optimal. Temperate waters have a characteristic bimodal seasonal variation with a short intensive spring bloom, a summer period where phytoplankton is mainly controlled by nutrient limitation and grazers, and an autumn bloom where wind mixing events bring nutrients to the surface waters. Subtropical waters have a weak seasonal variation, where phytoplankton biomass does not change much over the year.

3.2. Indicator for chlorophyll-a

In Ærtebjerg et al. (2001) the median summer chlorophyll-a (0–10 m in April to September) was used as an indicator and a weak positive correlation to winter nitrate concentration was found. In temperate waters the period April–September corresponds to the stationary period between the spring and autumn bloom for most years. However, in colder regions of Europe, this period will include a late spring bloom or the unimodal summer bloom characteristic for Arctic waters. As a result, such an indicator may potentially yield higher summer chlorophyll-a values in the oligotrophic waters in the northern-most parts of Europe compared to the eutrophic waters in central Europe.

Another issue is the depth definition used for chlorophyll-a indicators. Hitherto, the chlorophyll-a indicator has been calculated on averaged values from 0 to 10 m. This

depth definition is suitable for the North Sea and the Baltic Sea, but in the Mediterranean Sea the productive photic zone stretches further down in the water column. Thus, the median summer chlorophyll-a (0–10 m) from April to September is an inappropriate indicator of eutrophication when applied to all community marine waters.

Phytoplankton responds quickly to changes in the limiting factors, i.e. nutrients and light. In periods with nutrient limitation and no light limitation the chlorophyll concentration is partly determined by the supply of nutrients; therefore the chlorophyll-a concentration in this period will provide a good indicator for eutrophication.

We propose to use the average chlorophyll-a concentration in the period with nutrient limitation and no light limitation including observations at depths above the pyknocline as a eutrophication indicator. This requires the depth and the time interval to be defined on a regional scale. The depth integration of chlorophyll-a is chosen according to the typical stratification depth of the region, where 0–10 is considered appropriate for the North Sea and Baltic Sea. In the Mediterranean Sea a depth integration of for example 0–50 m may be considered appropriate. The time period from April to September is an appropriate period for the North Sea and southern Baltic Sea, while this period is shorter in the Arctic waters and longer in subtropical waters.

The average chlorophyll-a concentration is used as an indicator instead of the median, because chlorophyll-a concentration in the nutrient limited period often has a skewed distribution. Calculating median values of the chlorophyll-a distribution will neglect the skewness, i.e. high chlorophyll-a concentrations will not affect the median of the distribution. It is, however, important also to include the information in chlorophyll-a measurements of larger magnitude in an eutrophication indicator unless the measurements are faulty. We suggest to apply

Kendall's τ to the chlorophyll-a indicator for trend analysis.

3.3. State of chlorophyll-a

The chlorophyll-a levels in 1999 at stations in the national Danish monitoring programme are shown in Figure A1.4 with arrows indicating if a significant trend was detected using Kendall's t (no specific period specified). It is observed that in the estuaries the nutrient discharges from land give rise to higher chlorophyll-a concentrations. The

coastal stations have lower chlorophyll levels compared to the estuaries, but it is also observed that coastal stations in the North Sea have higher values when approaching the German Bight.
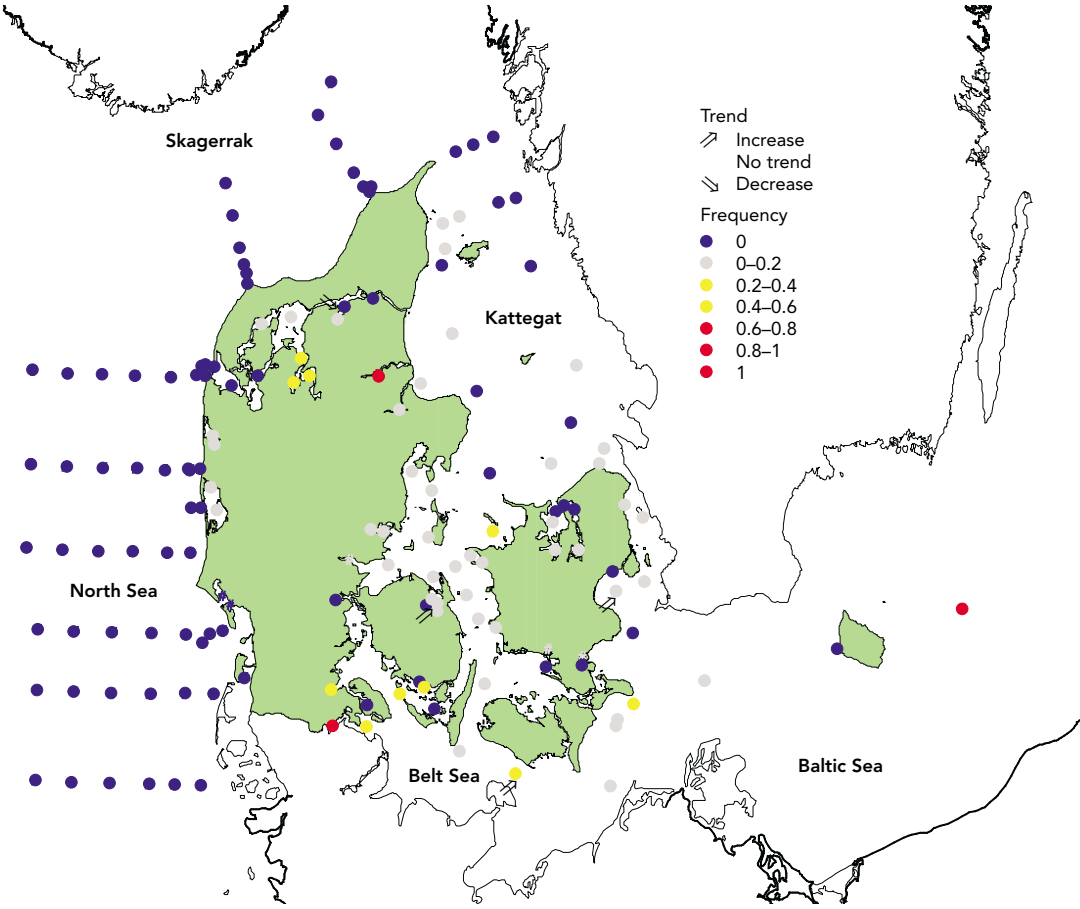
The trend analyses show that 14 out of 141 stations have a significant trend in summer chlorophyll-a concentration (10 stations show an increase and 4 stations show a decrease). Hence, there is no overall trend in the chlorophyll-a concentration, but many stations in the western Baltic Sea and Belt Sea have experienced increasing summer chlorophyll concentrations. Many of these stations have time series going back to the mid-1970s. The time series of summer chlorophyll-a for a single station is shown in Figure A1.5 revealing that most of the change in chlorophyll-a levels occurred from the 1970s to the last half of the 1980s.

Only a few of the monitoring stations in the estuaries have observations of chlorophyll-a from the 1970s, and the large change in nutrient loading occurred in the 1950s and 1960s.

The average chlorophyll-a concentration in periods with nutrient limitation and no light limitation is a good indicator for eutrophication, because the amount of plankton is related to the supply of nutrients during this period. The chlorophyll indicator also shows a consistent pattern with higher concentrations close to sources of land-based nutrient inputs to marine community waters.

| Summer chlorophyll-a concentrations for stations in the Danish national marine monitoring programme (arrows indicate significant trends analysed with Kendall's t) | Figure A1.4 |

Trend
↗ Increase
No trend
↘ Decrease

Frequency
● 0
● 0–0.2
● 0.2–0.4
● 0.4–0.6
● 0.6–0.8
● 0.8–1
● 1

Skagerrak

Kattegat

North Sea

Belt Sea

Baltic Sea

| Summer chlorophyll-a concentrations for Helcom Station BMP K7 in the western Baltic Sea | Figure A1.5 |
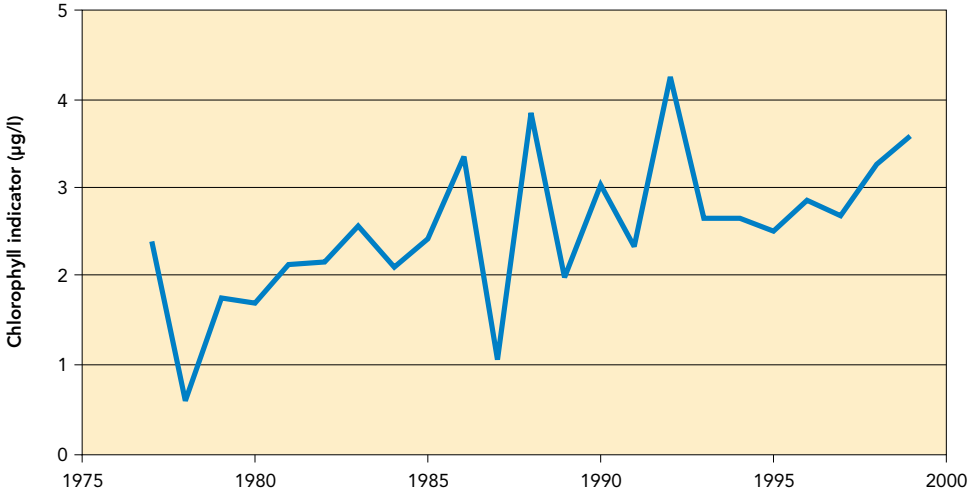
4. Conclusions and recommendations

The minimum oxygen concentration in the summer period has been a widely applied indicator for oxygen deficiency. This indicator is inappropriate, because it depends on the sampling frequency. Thus, an indicator for oxygen deficiency, which is not biased by the sampling frequency, is proposed. This indicator is the frequency of hypoxia, which is the proportion of bottom oxygen concentrations below 2 ml/l. Hypoxic conditions have detrimental effects on the benthic community. The proposed indicator separates marine community waters into three categories: (1) areas without oxygen deficiency problems, (2) areas with temporary oxygen deficiency problems, and (3) areas with permanent oxygen deficiency problems. In areas with temporary oxygen deficiency problems, the frequency of hypoxia provides a good indicator for the state of eutrophication, and trends in the frequency of hypoxia are analysed using a logistic regression.

Chlorophyll-a is a measure of the amount of phytoplankton. In summer periods, where the primary production is limited by nutrients only, the chlorophyll-a concentration is related to the supply of nutrients. We propose an eutrophication indicator calculated as the average chlorophyll-a concentration in a well-defined summer period, when primary production is limited by nutrients only. The chlorophyll-a concentrations are integrated over depths above the pyknocline. Appropriate intervals for the summer period and depth integration are determined according to the local conditions of the different European regions.

The diversity of monitoring data on oxygen and chlorophyll a from different marine waters in Europe should be tested for general applicability as policy relevant indicators within the EEA core set of indicators.

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Annex 2

Soft-bottom benthic indicators

1. Introduction

Soft substrata are the most widespread habitat among seabeds and support high biodiversity and key ecosystem services. The characteristics of benthic macrofauna and the associated sedimentary environment are of key importance to legislative, management and conservation objectives.

Benthic community structure has been said and proved to be a reliable measure of ecosystem 'health'. Thus, monitoring of benthic ecosystems, although it may be time-consuming, has often been applied in environmental impact studies (fisheries, domestic/industrial effluent, dumping of solid waste, etc.).

Historically, knowledge of marine benthic community structure and functioning has relied upon the most widely used benthic parameters, namely:

• number of species (S);
• abundance (N) or population density expressed as number of individuals per m²;
• community diversity using the Shannon-Wiener index (Shannon and Weaver, 1963) or other indices;
• the ecological identity of the dominant species, the so-called 'key species';
• trends in benthic parameters.

A general evolutionary pattern of the macrobenthic biocoenosis of the soft-bottomed substrate under the influence of a perturbation factor (of anthropogenic origin) has been described worldwide, based on the works of Reish, 1959; Peres and Bellan, 1973; Pearson and Rosenberg, 1978; and Salen-Picard, 1983.

The changes that this community undergo under the influence of the disturbance from an initial state of high diversity and richness in species and individuals are as follows.

A. A regression of the species strictly linked to the original conditions of the environment.
B. Certain tolerant species considered as pollution indicators tend to monopolise available space. A limited increase of diversity can be observed in this state. The biocoenosis structure remains recognisable even if degraded (subnormal zone).
C. A destruction of the biocoenosis is recorded; certain species exist and develop, apparently independently of each other. Species diversity decreases and becomes minimal (polluted zone).
D. The macrobenthos disappears (zone of maximal pollution).

These phenomena have been described to apply for the Mediterranean (Marseilles region, specifically the coasts of the Italian peninsula: Trieste, the Bay of Elefsis, the upper part of the Saronikos Gulf, Gulf of Izmir). So a more descriptive zonation pattern has been derived from the above general scheme, applying for the Mediterranean. Three concentric zones or areas can be demonstrated based on faunistic and geochemical data (Bellan, 1985).

• Zone I (zone of maximal pollution). This zone is deprived of all animal macroscopic life and, at times, of the meiobenthos.
• Zone II (polluted zone). The population in this zone is characterised by a very small number of polychaete species. The quantitative evolution of these species can be extremely rapid.
• Zone III (subnormal zone). The subnormal zone is characterised by a notable species enrichment, but also conserves a clear dominance of polychaetes: 70–80 % of the individuals. The species of the preceding zone have practically disappeared. This zone can perhaps be divided into two subzones: an 'internal' subzone corresponding perfectly to the criteria indicated and an 'external' subzone or the 'ecotone zone' intervening before the normal zone where the action of pollution cannot be felt.

Based on real values and/or ranges of values of the above parameters from the Greek seas, they are tested as possible indicators to assess the state of the ecosystem. Finally, using as a

paradigm a well-studied Greek area, a classification system is suggested where benthic 'indicators' alone would be able to 'describe' efficiently the state of the marine ecosystem.

2. Indicators tested and discussion

2.1. Indicator 'Number of species'

The number of species in a benthic assemblage varies greatly with depth. The best-known species number gradient in benthos has been: an increase of species diversity from high to low latitudes in continental shelf regions and in the open sea, a regular change from coast to abyssal plain, and an increase of species from inshore habitats to the open sea. A significant decrease in species number with depth has been observed in Greek waters (see Figure A2.1).

Grassle and Maciolec (1992) argued that coastal diversity is low compared with deep-sea and offshore habitats. In a review work Gray et al. (1997) have shown that species richness per unit area is as high, if not higher, in shallow sedimentary habitats as was reported for the deep-sea data by Grassle and Maciolec. Indeed, one of the central patterns in biodiversity, noted universally, is that the number of species increases with the area sampled. Data from the North Aegean Sea clearly show this increase with increasing sampling effort. A cumulative increase of species number with sampling effort is also exhibited in other areas. Figure A2.2, based on aggregated data collected from nine stations over three years in the Geras Gulf, shows such a trend.

Another factor influencing directly the number of species is the sediment type. Two examples, where different sediment types hold a different species number, are presented in Figure A2.3. The data are from two very well studied areas of the Aegean Sea which, being away from any land-based pollution sources and thus unaffected by anthropogenic activities, serve as reference sites. In the graph, it is clear that species number per sampling unit is not dependent on season. The larger the sampling area, the higher the increase. Thus, from an average of 72.5 species /0.1 m², it increases to 189 species/m² and to 350 species/7 m² in the silty sand site, and from 23 species/0.1 m² to 78.4 species/m², reaching 128 species/7 m² in the silty site respectively.

However, when comparing the species number of a sampling unit with that of the average of either 10 samples (AVG S in figure) or of 70 samples (AVG/0.1m² in the legend of figure), it appears that species number of a given unit (sediment surface area) can be an accurate measure of the state of environment.

Based on data collected over a variety of soft-bottom habitats in Greek waters it appears that number of species, in undisturbed areas (reference sites), ranges between 22 and 165 species per 0.1m², depending on depth and type of substratum.
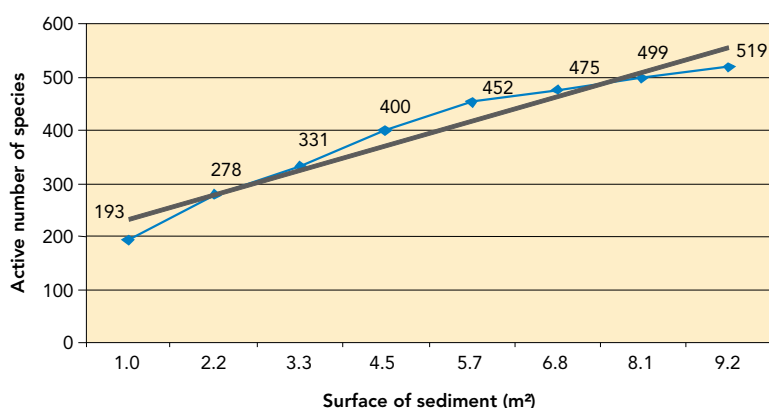
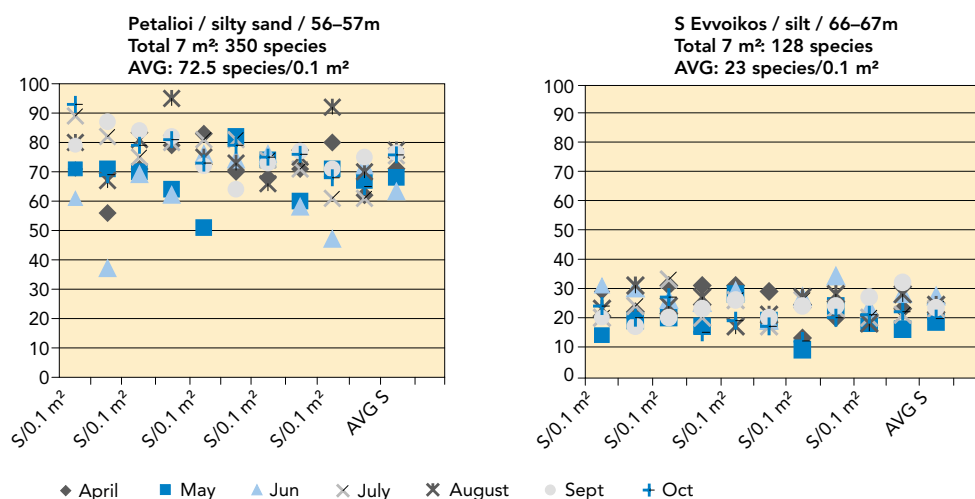| Figure A2.1 | Trend in species number with depth (coloured lines correspond to three different replicates) |

N. Aegean transect
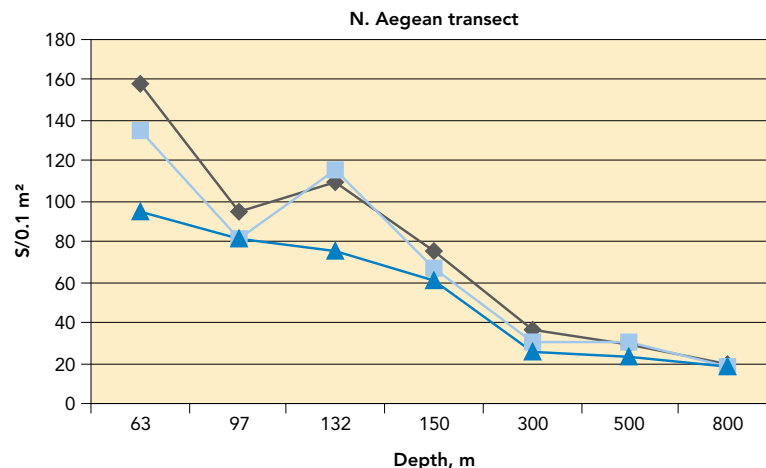
Increase in number of species with sampling effort | Figure A2.2

Variation in species number per sampling unit (0.1 m²) and monthly average (0.1 m²) in different habitats (depth, sediment type) | Figure A2.3

Petalioi / silty sand / 56–57m
Total 7 m²: 350 species
AVG: 72.5 species/0.1 m²

S Evvoikos / silt / 66–67m
Total 7 m²: 128 species
AVG: 23 species/0.1 m²

◆ April   ■ May   ▲ Jun   ✕ July   ✳ August   ● Sept   ✛ Oct

Conclusively, the number of species (S) can be a reliable measure of environmental stress provided that it is used when comparing benthic communities:

a occurring within a well-defined sampling unit (standard 0.1 m²), from samples collected with the same gear (standard grab 0.1m², mesh sieve 0.5 mm),
b at the same depth range and sediment type (ranges to be defined per sea),
c the species identification is being done at the same taxonomic level (four major groups or all groups).

Recommendation: Standard values (range of values) of S for 'normal' communities should be developed for different depths and sediment type to be used as reference values in monitoring studies. These values, however, can be different for different seas and regions. Deviation from such values will then be indicative of the degree of environmental stress.

2.2.   Indicator 'Abundance (N)'

Abundance alone, even if expressed as the same unit, which usually is the number of individuals per m², is not informative enough as a stable indicator for the state of the ecosystem. The reason is that it is too variable to show meaningful changes. A decrease with depth is a recognised trend worldwide. Data from the North Aegean Sea (Figure A2.4) demonstrate this trend. Besides depth and sediment type, abundance also depends on settlement and size of individuals. On the other hand abundance is a parameter independent of sampling effort.

Figure A2.4	Trend in abundance with depth
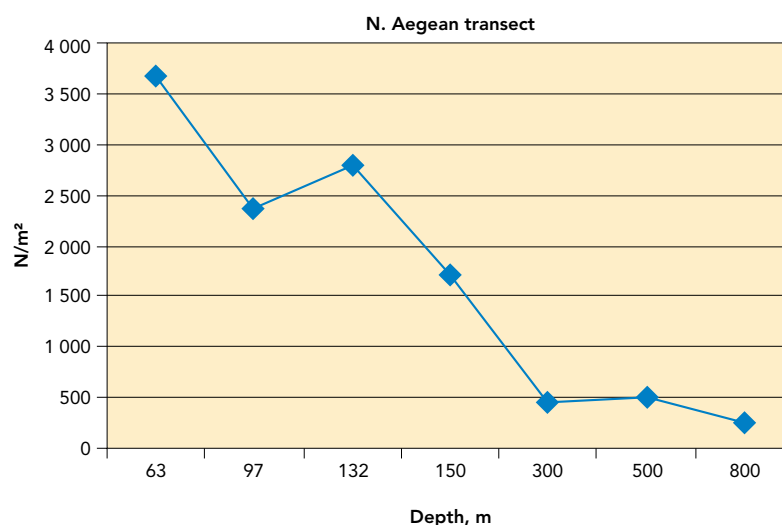
Table A2.1	Key species, indicative of the degree of environmental disturbance

I. Zone of maximal pollution	Azoic
II. Highly polluted zone	Opportunists: *Capitella capitata, Malacoceros fuliginosus Corbula gibba*
III. Moderately polluted zone	Opportunists: *Chaetozone sp, Polydora flava, Schistomeringos rudolphii, Polydora antennata, Cirriformia tentaculata*
IV. Transitional zone	Tolerant species: *Paralacydonia paradoxa, Protodorvillea kefersteini Protodorvillea kefersteini, Lumbrineris latreilli, Nematonereis unicornis, Thyasira flexuosa*
V. Normal zone	Sensitive species e.g. *Syllis sp.*

Abundance values in Greek waters for 'normal' ecosystems can vary from: 217 individuals/m² (average for Kyklades plateau; Zenetos et al., 1997) to 619 individuals/m² (average for Rodos area; Pancucci-Papadopoulou et al., 1999) and 1 439 individuals/m² (average for Sporades marine park; Simboura et al., 1995). In disturbed ecosystems, abundance can reach values as high as 8 695 individuals/m² (Station E7, Ionian Sea; Zenetos et al., 1997) or 4 428 individuals/m² (TP11, Thermaikos Gulf; NCMR technical report). These extremely high values are characteristic of very disturbed ecosystems, from either fisheries activities (the former) or from domestic and industrial pollution (the latter). In both cases, a few opportunistic species dominate at the expense of others.

> Conclusively, the abundance of benthic organisms in a given area is too variable and cannot be used as a reliable measure of environmental stress. On the other hand, trends in abundance of 'key species', if well defined, would be a good indicator.

2.3. Indicator 'Key species'

Based on a synthesis of reviews on the subject and on the data presented here as case studies (Dauvin, 1993; Pearson and Rosenberg, 1978; Bellan, 1985), Table A2.1 shows the zones of pollution with the respective key species.

2.4. Indicator 'Community diversity (H)'

The number of species and their relative abundance can be combined into an index that shows a closer relation to other properties of the community and environment than would number of species alone. The Shannon-Wiener diversity index, developed from the information theory, has been widely used and tested in various environments. Although it reflects changes in the dominance pattern, it has been argued that it is no more sensitive than the total abundance and biomass patterns in detecting the effect of pollution and is more time-consuming. A decreasing trend with depth
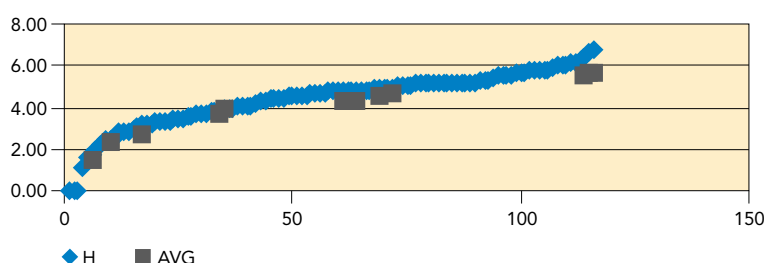
Trend of community diversity with depth	Figure A2.5

N. Aegean transect
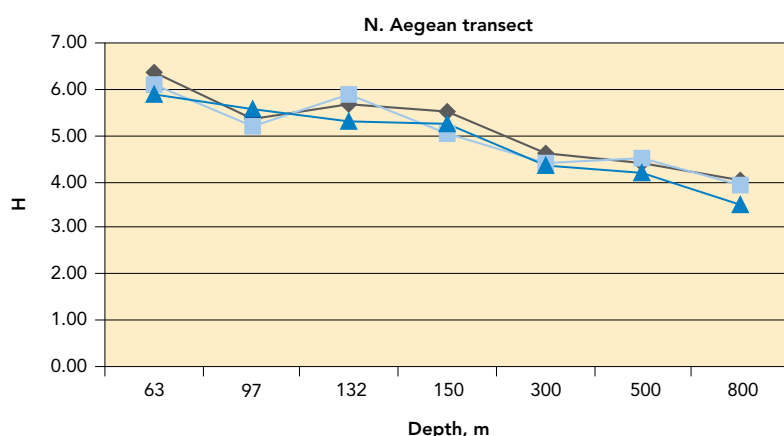
Source: Keycop project, Zenetos et al., 2000.

Distribution of community diversity (H) over 116 Greek sites (AVG: H/0.1 m²)	Figure A2.6

Source: S. Evvoikos, Petalioi Gulfs: TRIBE, 1997; Rodos: Pancucci-Papadopoulou et al., 1999; Sporades: Simboura et al., 1995; Kalamitsi, Ionian Sea: Zenetos et al., 1997.

has been established (Figure A2.5) in Greek seas whereas increasing sampling results in minor changes of the community diversity.

Community diversity in Greek waters has been calculated to range between 1.12 and 6.81, if calculated on pooled data. However, if calculated on a standard sampling unit (0.1m²) the maximal value is 5.76 bits/unit. Figure A2.6 shows the distribution of H in 116 sites all over Greece. Certainly community diversity is lowered by severe pollution stress compared with control areas or years. Values lower than 1.50 bits per unit have been calculated at the badly polluted areas of the Saronikos Gulf (zone I), between 1.5 and 3 for highly polluted areas of Thermaikos and Saronikos (zone II), 3–4 for moderately polluted (zone III) areas, 4–4.6 for transitional zones (zone IV) and over 4.6 for normal zones. The maximum values of H coincide with the pristine areas of Sporades marine park, Kyklades plateau, Rhodes Island, Ionian Sea and Petalioi Gulf Aegean: 6.81 bits per unit.

When evaluating H, one should take into account separately its two components together with the faunistic data, in order to detect extreme abundance of opportunists

indicating disturbance. There are some cases where the diversity is significantly high, even higher than normal, whereas the community is disturbed. The ecotone point is a transitional zone between two successional stages after which the community returns to normal. The community at the ecotone point consists of species from both adjacent environments (enriched and less enriched). After the ecotone point the community often reaches a maximum in the number of species, probably caused by the presence of sensitive species recolonising community and tolerant species, while abundance declines to a steady state level usually found in normal communities. Thus diversity may become higher than that of the normal communities (Pearson and Rosenberg, 1978; Bellan, 1985). An example is the community at Psittalia Station S7 (Saronikos Gulf) where diversity and species number are high

Conclusively, in Greek waters based on the community diversity index alone, five classes of community health can be arbitrarily divided.

Class I: H < 1.5: azoic to very highly polluted
Class II: 1.5 < H < 3: highly polluted
Class III: 3 < H < 4: moderately polluted
Class IV: 4 < H < 4.6: for transitional zones (zone IV)
Class V: H > 4.6: normal

Figure A2.7	Seasonal and inter-annual changes of diversity (H), abundance (N/m²) and species (S) at different locations (S2–S16) in Saronikos Gulf

Source: 1974 data in Zarkanellas and Bogdanos, 1977; 1985 data in Friligos and Zenetos, 1985; Zenetos and Bogdanos, 1987; 1986 data in Zenetos et al., 1990; 1989–90 data in Simboura et al.,1995; 1999 data from ETC/ Water-NCMR.
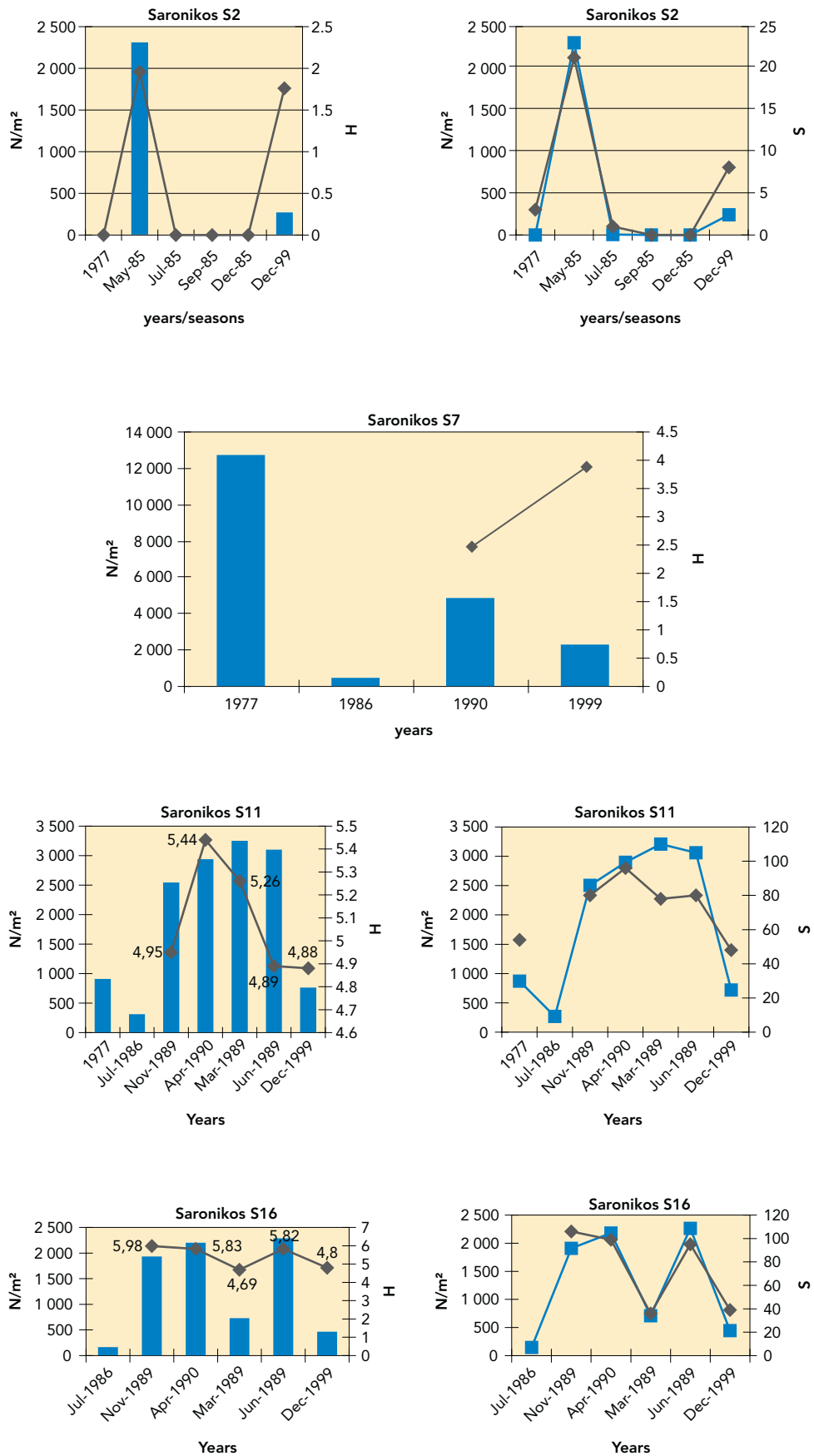
enough to classify the area to transitional zone 4. However the presence of heavy pollution indicators like *Capitella capitata* and *Malacoceros fuliginosus* reaching very high densities classifies the area to zone 2, and probably creates a deterioration of the environment causing a regression in the communities structure.

2.5.   Trends in benthic community parameters

Figure A2.7 gives examples showing seasonal and inter-annual changes of the parameters

discussed above in the Saronikos Gulf. It is clear that Station S2, which became azoic in the 1985 period, has been recolonised as indicated by the 1999 results. A serious improvement is also evident at Station S7, close to the sewage outfall, after the recent establishment of a treatment plan. On the other hand deterioration of the ecosystem is seen at Stations S11 and S16 situated at an increasing distance from the sewage outfall.

3.   Case study: Classification of Saronikos Gulf (Gulf of Athens) based on benthic community data

If one wants to apply the above scheme to a given area, certain modifications must be made.

The benthic communities of the Saronikos Gulf, receiving the domestic and industrial effluent of Athens, have been studied since 1975. Based on data collected between 1974 and 1999, though sparse in time, all of the above zones can be recognised at least over time.

I. Zone of maximal pollution. Stations S1, S2 and S3 have been found azoic during some sampling periods in the past. Station S1 was defaunated during September 1985 sampling, Station S2 during September 1985 and December 1985, and Station S3 of Keratsini Bay was azoic in July and September 1985.

II. Highly polluted zone. Stations S1, S2, S3, S7 of the inner Saronikos Gulf and of Elefsis Bay can be classified in this zone. This classification is based on the combined criteria of the level of the communities' ecological indices and the key species. Specifically these stations are characterised by: very low average diversity $(1.5 < H < 3.89)$ and average evenness $(0.55 < J < 0.86)$ reflecting either very low species richness $(5 \text{ species}/0.1\text{m}^2$, only at Station S2) or very high total densities $(2\ 220 \text{ ind}/\text{m}^2$ at Station S7 and $2\ 070 \text{ ind}/\text{m}^2$ at Station S1) which indicate the presence of few heavy pollution indicators (*Capitella capitata* (S7, S2), *Malacoceros fuliginosus* (S3), *Corbula gibba* (S2)) that reach very high densities.

III. Moderately polluted zone. Stations S8 and S26 can be classified in this zone which is characterised by the following trends: still low diversity but higher than previous zone $(2.66 < H < 4.30)$, higher evenness $(0.72 < J < 0.80)$, higher species number $(13 < S < 41)$, more moderate densities but still high $(600 < N/\text{m}^2 < 1\ 520)$, indicating high densities of few instability indicators like *Chaetozone sp.* $(315 \text{ ind}/\text{m}^2$ in S26 and $215 \text{ ind}/\text{m}^2$ in S8).

IV. Transitional zone (corresponds to subnormal III of Bellan, 1985). The diversity and evenness indices increase more while more sensitive species are encountered. Higher diversity even close to normal but several instability indicators can be significantly abundant (*Paralacydonia paradoxa, Lumbrineris latreilli, Nematonereis unicornis*). Stations S11, S13, S16 of the inner Saronikos can be classified in this zone. Diversity ranges higher than the previous zone $(4.34 < H < 4.64)$, also evenness is fairly high to very high $(0.83 < J < 0.93)$, species richness reaches maximal numbers $S = 49$ in Station S13. Only some fairly high densities $(1\ 385 \text{ ind}/\text{m}^2$ in S13) indicate the high densities of some instability indicators like *Paralacydonia paradoxa* (135ind/m2 in S13) and *Chaetozone sp.* $(190 \text{ ind}/\text{m}^2$ in S13). A subdivision among these three stations can be made assigning Station 13 to the internal subzone of Bellan (1985) and Stations S11 and S16 to the external subzone which is closer to normal. This subdivision is justified mainly by the more moderate presence of instability indicators (abundance lower than $100 \text{ ind}/\text{m}^2$), and the subsequent higher evenness and relative total density compared to S13.

Figure A2.8	Pollution zones in Saronikos Gulf based on benthic community studies

Maximal pollution   Highly polluted   Moderately polluted   Transitional zone
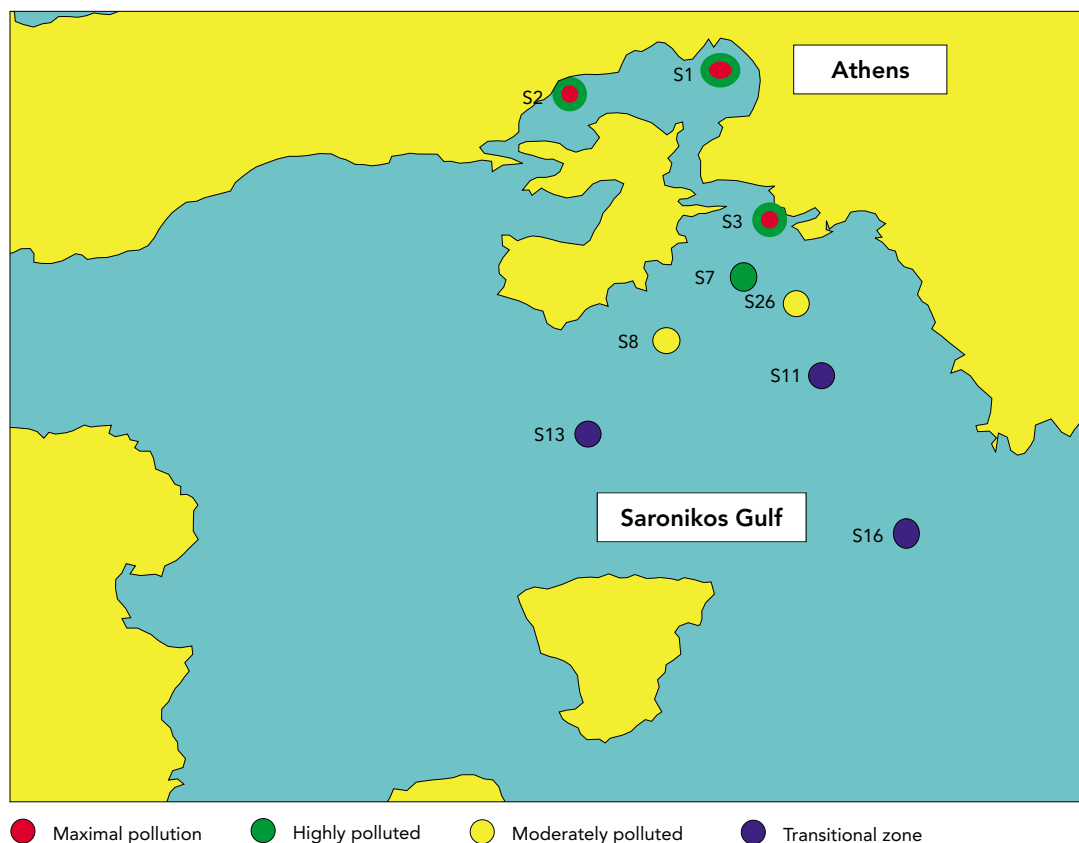
4. Discussion

Table 2 presents some examples of the range of the Shannon diversity index in various regions in disturbed and undisturbed benthic communities in the western Mediterranean and the Atlantic European coasts. It gives the key species and the characterisation of the respective pollution gradients reported from Mediterranean, Atlantic and Pacific areas. Two main conclusions can be derived from this table.

1. The range of the Shannon diversity index should be used as a tool of pollution evaluation, taking into account not only the substrate and depth of the given area but also the regional standards of the case area. For example, the diversity index in undisturbed areas of a mixed sediment infralittoral (22 m) community in the western Mediterranean Ionian Sea reaches the maximum of 4.5 approximately while an analogous community in the eastern Mediterranean

(Petalioi Gulf, Aegean Sea, Greece) reaches the maximum value of 6.11 units (Simboura et al., 1998).

2. The key species characterising a pollution gradient may be different when different geographical areas are examined. It is apparent that the dissimilarity in the key species identity is more pronounced among more distant areas, for example among Mediterranean or European Atlantic and Pacific regions (Los Angeles, San Francisco). It is noteworthy that genetic studies have proved that some apparently cosmopolitan key species such as *Capitella capitata* are rather complexes of sibling species with geographical differentiation.

Conclusively, indicators (diversity index level and key species) can be used as effective tools only when a background data set is available pertaining to the specific ecosystem.

	Examples of the range of the Shannon diversity index in various regions in disturbed and undisturbed benthic communities in the western Mediterranean and the European Atlantic Ocean				Table A2.2

Region	Depth (m)	Substrate	Indicators/abundant species	H	Zone/community
Golden Horn Izmir (Unsal, 1988)	2–40		*Capitella capitata* *Malacoceros fuliginosus* *Polydora ciliata*	0.11 –2.02	Highly polluted (II)
La Coruna (Lopez-Jamar et al., 1995)	16	Mud	*Thyasira flexuosa* *Chaetozone sp.* *Capitella capitata*	1.23 –3.76 2.75 mean	Highly dredged, hypoxic
La Coruna (Lopez-Jamar et al., 1995)	9	Well-orted fine sand	*Paradoneis armata* *Tellina fabula* *Spio decoratus*	2.70 –4.33 3.42 mean	Relatively clean
Ionian Sea (W. Mediterranean) (Alberteli et al., 1995)	30–100 100–200 > 200	Soft bottom	*Amphipods, echinoid* *Loimia meduda,* *Spiochaetopterus costarum* *Sabellides octocirrata,* *Spiochaetopterus costarum*	4.5 3.6 3.2	Undisturbed
Ionian Sea (Apulian coasts, Italy) (Bedulli et al., 1986)	63 18 49 22 22	Mud Mud Muddy sand Sand Muddy sand	*Nephtys hystricis, Sternaspis scutata* *Corbulla gibba, Notomastus aberans, Tellina distorta* *Modiolula phaseolina* *Apseudes latreilli, Amphipoda, Aponuphis bilineata* *Owenia fusiformis, Lumbrineris latreilli, L.gracilis*	3.9 3.8 4.2 4.4 4.5	Unstable, transitional
From Peres and Bellan, 1972					
San Francisco Los Angeles Marseilles Saltkallefjord Finland			*Capitella, Neanthes succinea* *Capitella capitata* *Capitella capitata, Scolelepis fuliginosa* *Capitella capitata, Scolelepis fuliginosa* *Nereis, macoma, Chironomidae*		Marginal or polluted
Los Angeles Marseilles San Francisco Finland			*Cirriformia luxuriosa, Capitella* *Nereis caudata, Cirriformia tentaculata,* *Schistomeringos rudolphii* *Streblospio benedicti* *Tubifex, Mya*	Intermediate zone of pollution	Semi-healthy II
Los Angeles Marseilles San Francisco Finland Saltkallefjord			*Dorvillea articulata, Capitella present* *Tharyx parvus, Cossura candida, Polychaetes* *Polychaetes and molluscs with wide ecological requirements* *Mya arenaria, Macoma incospicua* *Corophium, Mesidothea* *Amphiura filiformis, A. chiajei*		Semi-healthy I 'healthy-enriched' subnormal zone
Saltkallefjord Finland			*Maldane filiformis and Melesina tenuis community* *Harmothoe, Cardium*		Healthy zone, external zone

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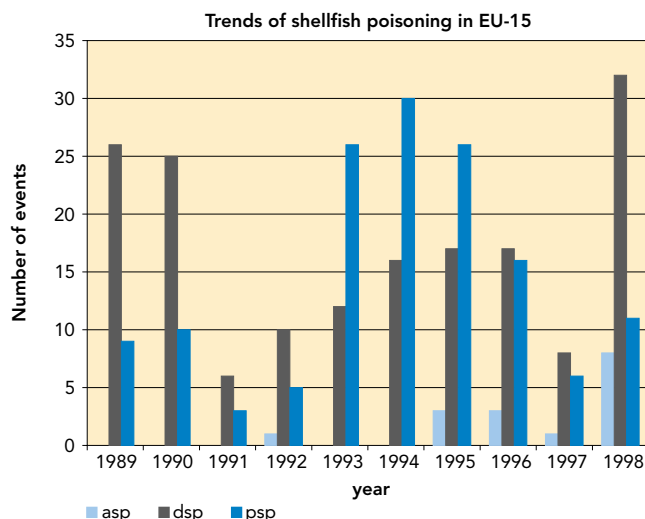
Annex 3

Phytoplankton and phytotoxins indicators
Indicator fact sheet

| Figure A3.1 | Changes in ASP, DSP and PSP in EU-15 from 1989 to 1998 |

Source: ICES-IOC HAEDAT (harmful algae event database).

Trends of shellfish poisoning in EU-15

Note: For trends in shellfish poisoning concentration expressed as a sum of number of events of ASP, DSP or PSP in each country of EU-15, see Table 1.

Indicator	Policy issue	DPSIR	assessment
Phytoplankton and phytotoxins	Do we see the area where policies are useful to protect human health?	State	

Through the numerous phytoplankton species that exist all over the world, several toxic or harmful species have been recorded. Among toxic species, some of them produce toxins directly toxic to marine fauna, and other produce toxins which accumulate in shellfish, fish, etc. They may subsequently be transmitted to humans, and through consumption of contaminated seafood become a serious health threat. Therefore toxins are searched for in shellfish with the aim to protect consumers.

Five human syndromes are presently recognised to be caused by consumption of contaminated seafood:

• amnesic shellfish poisoning (ASP),
• ciguatera fish poisoning (CFP),
• diarrhetic shellfish poisoning (DSP),
• neurotoxic shellfish poisoning (NSP),
• paralytic shellfish poisoning (PSP).

The 15 Member States of the European Union (EU-15) are only concerned with three of them: ASP, DSP and PSP.

> Shellfish poisoning events show fluctuation between years without general trend for EU-15.

Target: to reduce the risk of serious seafood poisoning, intensive monitoring of the species composition of the phytoplankton is required in the harvesting areas in connection with bioassays and/or chemical analyses of the seafood products.

Regulation texts: Council Directive 91/492/EEC of 15 July 1991, modified by Council Directive 97/61/EEC of 20 October 1997, fixes the health conditions for the production and the placing on the market of live bivalve molluscs. The main phytotoxins observed in EU-15 are PSP toxins (maximum level 80µg equivalent STX ([1]) per 100 g of

(1)   STX = Saxitoxin.

Number of events involving ASP, DSP, or PSP toxins in EU-15, by country, 1989–1998																		**Table A3.1**

Source: HAEDAT.

Year	A	B	D	DK	E	EL	F	FIN	I	IRL	L	NL	P	S	UK	EU-15 ASP	EU-15 DSP	EU-15 PSP
1989			0	0	6		17			0		3	9	0	0	0	26	9
1990			1	0	6		14			0		1	10	1	2	0	25	10
1991			0	0	1		5			0		0	0	0	3	0	6	3
1992			0	0	2		9			0		0	0	1	4	1	10	5
1993			0	0	3		8			0		0	24	1	2	0	12	26
1994			1	1	4		2			1		2	29	0	6	0	16	30
1995			0	0	6		2			2		1	33	1	1	3	17	26
1996			0	1	3		0			2		0	21	0	10	3	17	16
1997			2	0	5		2			1		0	1	2	1	1	8	6
1998			1		12		3			2		0	16	1	16	8	32	11

flesh), ASP toxins (maximum level 20µg of domoïc acid per g of flesh), DSP toxins (no positive reaction for biological test). Overviews on events of their presence (irrespective of the level of toxicity) in EU-15 for 1989–98 are included in the ICES countries maps (Maps 1 to 3).

Evaluation: Levels and trends (Figure A3.1) of each shellfish poisoning since 1989 to 1998 for EU-15 show that:

- ASP is episodic with one peak over five events in 1998;
- PSP presents important peaks from 1993 to 1995, over 25 events, then decreases. However the beginning of a new increase appears in 1998;
- DSP was the most regularly observed with a number of events always over five, with three peaks equal or above 25 in 1989, 1990, and 1998.

The results of all toxic events observed are summed up for EU-15 since 1989 in Table A3.1.

To conclude, shellfish poisoning in all countries has increased since 1998, showing the importance of maintaining surveillance measures, especially to protect the consumers of shellfish.

Meta data
Technical information
1. Data sources: ICES-IOC harmful algae event database (HAEDAT).
2. Description of data: ASP, PSP, DSP Original name of the data file (with links): HAEDAT (http://ioc.unesco.org/hab/data33.htm) Original measurement units: occurrences of harmful algae events (HAEs) Original purpose: public health
3. Geographical coverage: ICES area.
4. Temporal coverage: 1989–98.

5. Methodology and frequency of data collection: monitoring of phytoplankton and phytotoxins.
6. Methodology of data manipulation: sum of numbers of event for each year.

Qualitative information
7. Strength and weakness (at data level): available information on individual events varies greatly from event to event or country to country (disclaimer from ICES).
8. Reliability, accuracy, robustness, uncertainty (at data level): to be filled in at assessment.
   Monitoring intensity, number of monitoring stations, number of samplings, stations, etc. also vary greatly and therefore there is not a direct proportionality between recorded events and actual occurrences of, for example, toxicity in a given region. Furthermore, areas with numerous recorded occurrences of HAEs, but with an efficient monitoring and management programme, may present a low risk of intoxications, whereas rare HAEs in other areas may cause severe problems and could present significant health risks. Therefore, these maps should thus be interpreted with caution regarding risk of intoxication by seafood products from the respective areas/regions/countries. IOC and ICES are not liable for any possible misuse of this information.
9. Further work required (for data level and indicator level): decadal data and maps, one year after.
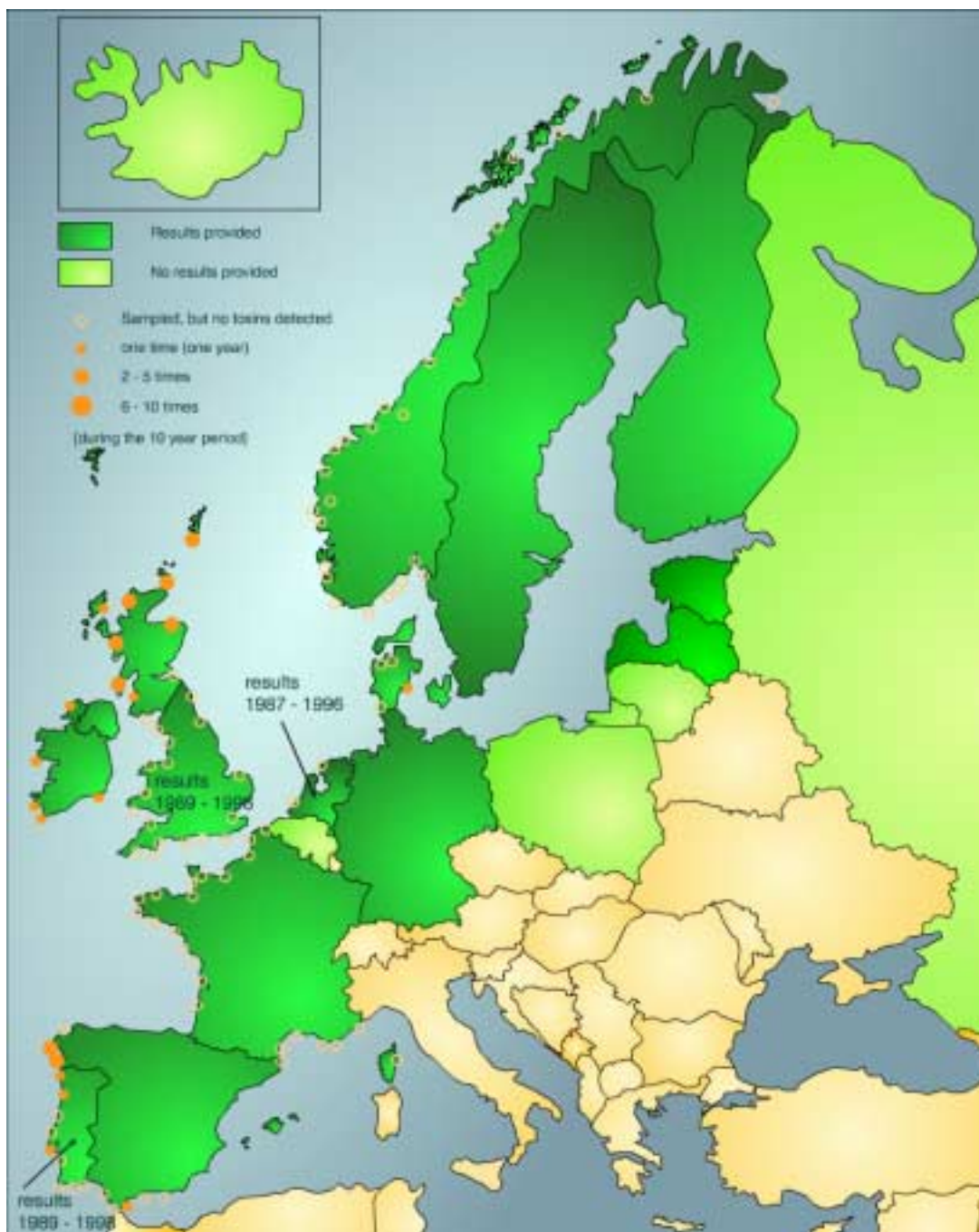
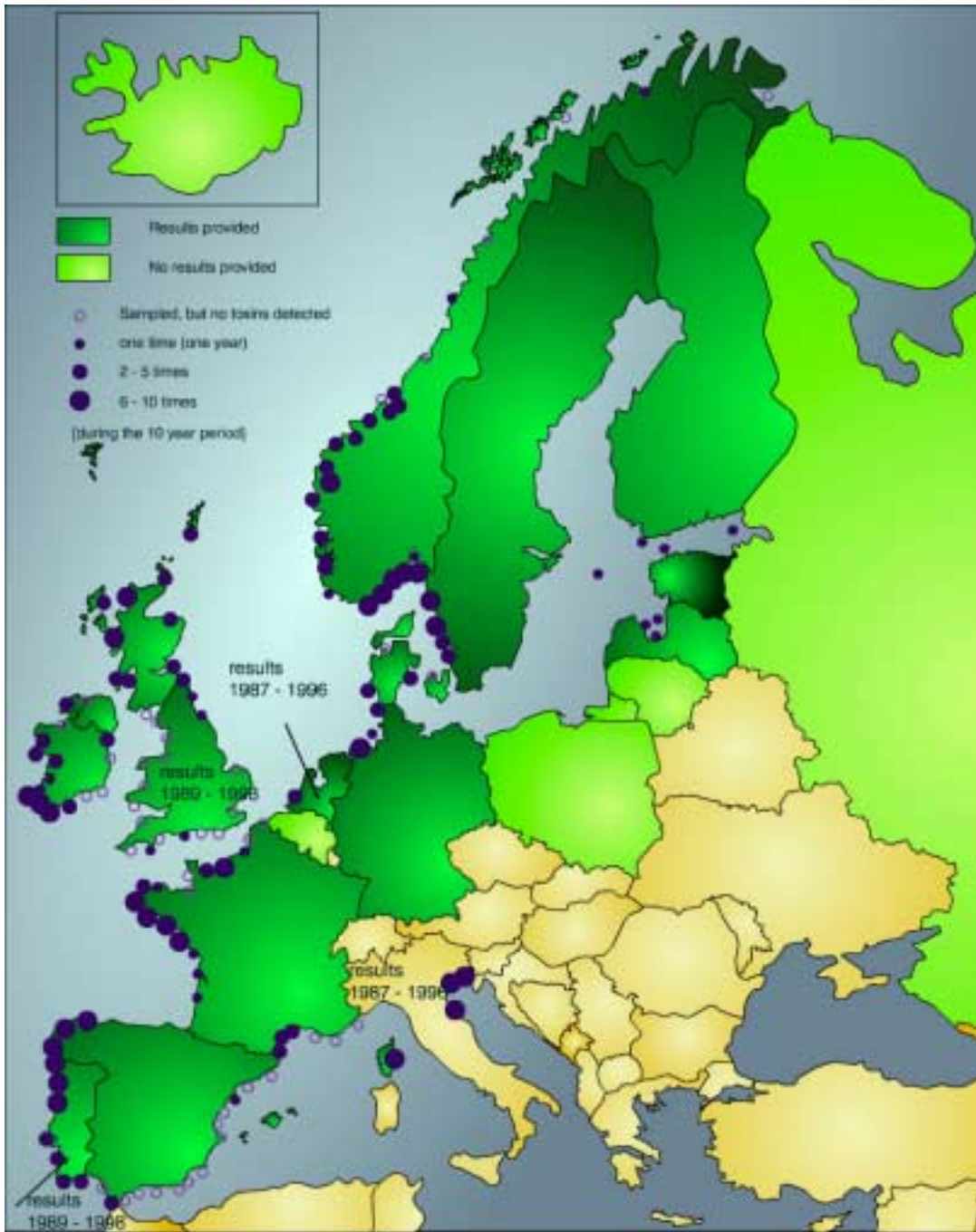**References:** HAEDAT (ICES-IOC harmful algae event database).

Signs used for the assessment:

increase   equal   decrease

| Map 1 | Toxic serial cases for ASP, 1990–99 |

| Map 3 | **Toxic serial cases for PSP, 1990–99** |