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Monitoring eutrophication and pollution in estuarine environments—focusing on the use of benthic communities

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Abstract: In this paper I present a short review on laboratory test methods using mainly macroalgae and the basis for how to monitor phytobenthic communities along salinity gradients. The presentation focuses on problems related to varying salinity combined with pollution outlets.

After briefly describing the rationale for using key species and/or changes in species composition in monitoring programs, I will highlight some of the factors, which can interfere with the reliable use of e.g. macrophytes as monitors of metal pollution. The influence of the physical and chemical properties of the different types of aquatic ecosystems, e.g. lakes, rivers, estuaries, have to be taken into consideration when assessing the impact of toxic agents on living organisms and the function of the ecosystems. Abiotic factors, e.g. salinity, pH in the water and organic content in the sediment may all have an impact on the form in which the compounds are found in the water and thus the bioavailability to the organisms. Most of the pollution hot spots are situated at the coast and the concentration will decrease from the outlet towards the open sea. The pollution gradient interacts with the salinity, and among other things the amount of organic content in the water. This has to be taken into account when measuring the impact on plants and animals along the estuary as well as when the sites for monitoring are selected.

INTRODUCTION

A vast number of chemicals as well as large amounts of nutrients are released into the environment daily and transported via rivers and lakes into the estuarine and marine environment. The need to monitor environmental changes and test for toxic effects is due to the vast number of chemicals as well as large amounts of nutrients that are released daily into the environment. Sooner or later most of these compounds are dissolved in the water and transported into the sea. Today many countries have strategies to document and determine the potential impact of new chemicals and waste water on the marine ecosystem. However, there is a need among environmental authorities to develop more cost-effective and short-term biological test methods and to be able to improve the monitoring programs so that they can be used to detect and predict potential impact on different functions of the ecosystem.

Estuaries are often highly polluted brackish environments with a low number of species. Next to the Black Sea the Baltic is the largest brackish-water area in the world, characterised by a large input of freshwater from precipitation and many large rivers. There is a clear salinity gradient from almost oceanic conditions in the northern Kattegat to almost freshwater conditions in the northern Bothnian Bay. It may be looked upon as a gigantic rivermouth area, an estuary. The Baltic Sea is also an ecologically young sea area with only a limited number of species producing relatively simple foodwebs. Therefore this large, brackish, well studied area may be used to highlight some of the problems met in testing and monitoring environmental pollution effects.

Rocky and softbottom communities have been shown to be sensitive to both local and regional environmental changes, as induced by man. For example changes in macroalgal communities can be due to turbidity, eutrophication and toxic substances or combinations of these factors. The factors may act together, or separately, and are not always possible to distinguish. In order to be able to distinguish changes, observed in receiving areas outside industries from natural changes, it is important to follow reference sites in areas unaffected by local pollution.

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SALINITY STRESS COMBINED WITH POLLUTION EFFECTS ON SPECIES AND COMMUNITIES

The number of species and species composition varies naturally with salinity (Fig. 1A). Estuaries have a low diversity due to the large salinity fluctuations compared to both freshwater, and in particular to the marine environment (Fig. 1A). Most species in the estuarine environment, live under stress, either due to too low or too high salinity depending on their origin from fresh or marine areas. Both in animal and plant species the energy cost to keep a proper salinity may result in smaller size. Since the species are already salinity stressed, any additional stress from pollution will have a large impact on e.g. growth, reproduction and/or survival. Stressed plants may get a reduced growth rate and often show a stunted bushy appearance (1). Similarly, several marine invertebrate species get reduced size (2).

This makes the Baltic Sea and other estuarine environments vulnerable to stress, and if one of the key species, e.g. the bladderwrack *(Fucus vesiculosus)* or the blue mussel (*Mytilus edulis*), disappears due to heavy pollution, no other species can replace it.

Large amounts of nutrients, organic matter and toxic substances are washed out into the coastal zone via rivers (Fig 1B). Due to the nutrient enriched water many estuaries all over the world, are known for being highly productive areas. They are also important areas for a large number of waterfowl and migrating bird species, both for resting and foraging. In this way a toxic substance released into the coastal environment may be taken up by plants and consumed by some fish or waterfowl and thereby transported further up in the food chain.

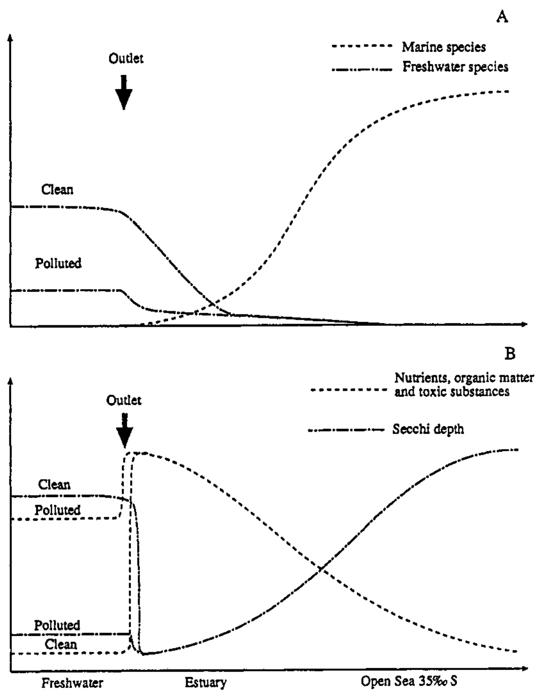

Fig 1. Summarizing environmental changes in a salinity gradient from the river mouth where often the main outlet of pollution occurs, via the estuary to the open sea. The outlet is indicated with an arrow.

A. Changes in secchi depth, nutrients, organic matter and toxic substances.

B. Changes in number of freshwater and marine species along a salinity gradient.

The large nutrient load in many coastal areas have resulted in changes in the macroalgal communities, i.e. the disappearance or decrease of long lived fucoids and kelp species and increasing amounts of opportunistic filamentous algae (3, 4). Today, drifting filamentous algal mats are often readily observed, also by the general public. These algal mats may be a hindrance to fishery and are a nuisance in many areas to recreation activities. Changes favouring the opportunistic macroalgae may also affect other parts of the coastal ecosystem such as the sea grass meadows, and have an impact on the shallow sediment animal communities.

In soft bottom communities the capacity of submerged aquatic plants to take up heavy metals from the water has been shown for many species. As a consequence it has frequently been suggested that chemical analyses of these submerged plants may give valuable information about contamination in the surrounding water (1). Several authors have pointed out the value of macroalgae over rooted plants in that they reflect only the properties of the ambient water rather than a combination of both water and sediments. Contrary, in some areas it might instead be useful to be able to get this integrated value since it represents the amounts of e.g. heavy metals that might be transported further up in the food-chain (5). Because direct chemical analyses of water are already carried out so widely, it may be helpful to summarise the potential advantages of using macroalgae and submerged aquatic plants. Since metal content of the sediment is far higher than that of the water, aquatic plants extending their roots deep down in the polluted sediments will be able to mobilise and circulate metals to a great extent. Also, the transport from roots to shoots in thses plants will have a large impact on the overall turnover of metals in the coastal ecosystem.

The effects of freshwater outflow, reducing the salinity further out in the estuary is most marked after periods of heavy rains. At the same time large amounts of organic matter, nutrients and toxins are also transported to the sea. The large amount of suspended inorganic and organic matter will increase turbidity and primary production by rooted aquatic plants and bentic macroalgae may be drastically reduced. Many plants are however able to survive at low light levels for extended periods. Contrary, reducing the nutrient load, e.g. by treating the sewage water, may improve the light conditions and enable establishment of macophytes on sediment bottoms. They in turn will be able to take up heavy metals deposited deep down in the sediment (6 and ref. cited therein).

At low water levels, caused by tidal changes, the pollution from a sewage outlet in the river mouth is not diluted. Thus, since low water appear twice a day at low tide, the benthic communities will be exposed to two peeks of more toxic water per day. This is also a common period for many intertidal seaweeds to reproduce (7, 8). The gametes of seaweeds, fish roe and young stages in the life cycles are further known to be the most sensitive to stress both from natural factors e.g. salinity and from toxic substances. Therefore the combination of low salinity and high contamination coinciding with the reproductive period of many species, e.g. *Fucus vesiculosus* , will have a very large impact on the survival of the species. Monitoring programs need to address these types of combined effects.

In coastal areas with brackish water where a salinity gradient is present, the speciation of Cd and other heavy metals will change in the water towards Cd complexes in salt water that are less available to plants and macroalgae compared to Cd in freshwater.

Salinity controls flocculation and sedimentation mechanisms in estuarine environments changing the availability of metals. The total concentration of dissolved heavy metals in fresh water is generally much higher than in sea water (Fig. 2A),(9, 10). In the Tiber estuary, (11) showed that with increasing salinity from 15 to 25 â the proportion of particulate Cd decreased and the proportion of dissolved Cd, probably due to chloride complexation, increased. The uptake and toxicity of e.g. Cd in invertebrates from low saline waters will thus exceed those from high saline environments (Fig. 2). Similarly the uptake of Zn and Mn increases with decreasing salinity in the brown alga *Fucus vesiculosus* (12). The effects on metal toxcicity by a number of environmental factors is summarized in Fig. 3.

COMPARISON BETWEEN FIELD MEASUREMENTS AND LABORATORY TESTS

It is at present difficult to design laboratory media where the level of metal bringing about a particular toxic response is the same as that found in the field. Resistance is often, but not always, found to be higher in the laboratory. This presumably reflects in large part the extent to which features of environmental chemistry other than the heavy metal under test closely resemble those in the natural environment. There are difficulties in simulating natural conditions by using standard test media, especially where the field populations come from sites with very low levels of phosphate.

Another problem which is in urgent need of study is the genetic stability of widely used strains of species. The fact that this has not been looked at critically, may prove to be harmless as far as studies on eutrophication are concerned, but there might be too much genetic differences within species with respect

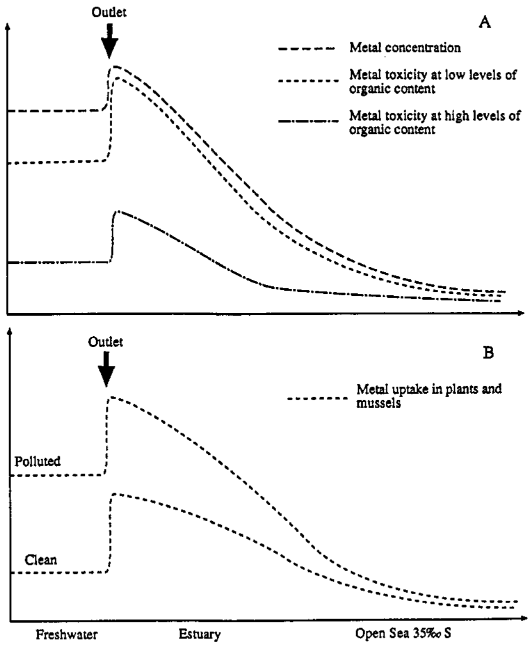

Fig 2. General pattern of environmental changes in a salinity gradient from the river mouth where the main outlet of heavy metal pollution occurs, via the estuary to the open sea. The outlet is indicated with an arrow.
A. Changes in metal concentration and toxicity at low and high levels of organic content in the water.
B. Metal uptake in plants and mussels along a salinity gradient.

to metal tolerance for the problem to be ignored if the species should be of more common use in test methods of heavy metal contamination.

It is very important to measure the response to toxic substances during the reproduction since this is the most sensitive stage in the life cycle of a species. When macroalgae are to be used routinely, both filamentous fast-growing annual species and perennial macroalgae should preferably be included in the sampling programme to provide several suitable species at most times of the year. Contrary, if the information is to be of more than local interest, it is essential that more effort is put into the development of standard methods for sampling, harvesting, washing and digestion.

If species that are used in toxicity tests have been grown under laboratory conditions for many years, they may not be as sensitive as before. The other difficulty in assaying the tolerance of field populations in the laboratory is the possibility of adaptation taking place during the period of assay.

Experiments on tolerant strains provide a further use besides their ability to assay the present toxicity of a metal at a site. Therefore, the influence of environmental factors needs to be quantified on tolerant rather than sensitive strains, if the long-term effects of future polluting effluents are to be predicted accurately.

Instead of trying to simulate natural conditions in the laboratory by using large containers, natural sea water and a suitable temperature and light regime, it may be preffered to carry out the assays at the actual field site or in mesocosms.

The importance of using local species in toxicity tests and in following changes in nutrient load needs to be stressed. Of all the life stages of *Fucus* studied, spermatozoa and newly-fertilised eggs are the most sensitive to toxic substances. Overall, it seems that area increase of *Ulva* discs and several methods involving stages in the life-history of fucoid algae are the most useful test methods for toxicological studies available so far together with the presented method for *Ceramium* using cystocarp production (13). Percentage fertilisation and/or germination, the motility of spermatozoa and the growth rate of newly-fertilised eggs all have potential as short-term toxicity tests.

MONITORING ENVIRONMENTAL CHANGES

In an open estuarine ecosystem the destruction and pollution will go on much longer before the size of the disturbance is noted. On the other hand the recovery may go faster than in e.g. the enclosed bays or the Baltic Sea, with a long retention time. Therefore, monitoring programmes need to be specifically designed to cover the main subsystems of the coast in a way so that it is possible to detect changes within the benthic macroalgal communities. To do this it is essential to use quantitative sampling at fixed sites and to compare this to direct observations of divers, who may overemphasise the importance of eye catching species, e.g. large conspicuous brown algae.

In monitoring programmes macrophytes are frequently used as standard test organisms and as biomagnifiers and bioindicators for toxic substances (14), e.g. *Fucus vesiculosus* as tracer of radioactive components (15) or for testing toxic substances (16). Probably because they are so widespread, fucoids and the green algae *Cladophora* and *Enteromorpha* have been assessed more than any other alga (except perhaps *Chlorella* in the laboratory) for their ability to accumulate metals as well as use as indicators of eutrophication. Since the submerged macrophytes and macroalgae are stationary organisms, a measured effect on these plants living in the recipient increases the ecological relevance of the test result. Further, measurements on an essential factor like the reproductive part in the life cycle of an important key species increases the ecological relevance of the test and monitoring program respectively.

The following sources of variation when using algae for the purpose of monitoring have to be taken into consideration, i.e. the concentration of some metals increases with age and the uptake and release of metals may be markedly slower during winter than during summer at least in temperate regions. To study temporal variations or assessing regional differences samples should be collected at the same time of the year to avoid seasonal differences.

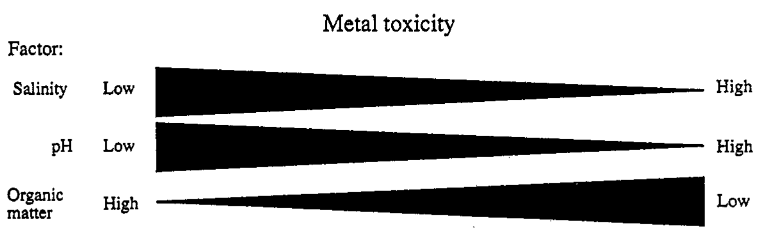

Fig 3. A generalized graph of the effect of salinity, pH and organic matter on metal toxicity. The width of the bar indicates the level of metal toxicity.

Short and long-term changes are easily overlooked. Seasons with extreme weather or spills of toxic materials may modify shore communities for many years and one short term investigation may often give wrong information. Even though long-term surveillance has its own disadvantages, several yearís monitoring is to be preferred. To create the opportunity to separate man-made effects from natural conditions, it is necessary for the distinction to monitor a wide region.

To summarise, much effort has to be put on selecting relevant and cost-effective methods to be able to evaluate and monitor environmental changes in the dynamic coastal estuarine environments. Especially consideration should be taken to the interaction between salinity changes and how this may interact with the toxicity of a specific toxin and the biota.

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