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ASSESSMENT OF THE EFFECTS ON PLANKTON

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ABSTRACT

Knowledge of plankton composition can help to precise extension and intensi of alterations produced in a costal system by the addition of wastes, usually coming from an effluent and dispersed in an irregular or patchy environment. To be effective, study of plankton must be associated with the knowledge of other elements of the ecosystem, usually in the frame of an appropriate model. Careful consideration has to be given to the variables selected for study, to the sampling program in relation with spatial organization of the ecosystem, to exchange and to the minimal extension required for an adequate understanding of the phenomena. Probably there is no purpose in preparing long lists of indicator organisms, and many simpler methods may be equally useful as the tedious identifying and counting of organisms. More than direct and simple measurements, a number of ratios, including counts of organisms, and other parameters, may be useful as measures of stress and of pollution. It may be convenient to prepare ratios and models based on the output of automatic sensors, without a strict need to project the model on a model based on the more conventional variables used by biologists.

INTRODUCTION

The assessment of the effects of pollution on plankton may be an interesting scientific question. The reciprocal, to use knowledge of plankton and of changes in the plankton to assess distribution of pollution, is an useful application. Engineers and ecologists have different approachs, but they must work together. Engineers need fixed criteria to organize collection of information and to produce clear cut decisions. Ecologists feel that expediency may be poor from a scientific point of view. In fact, use of diversity, of plant pigments, of coli counts, is often uncritical. Simple recipes are not substitute for substantial knowledge. But perhaps ecologists have resented this too much: Everything is allowed and every short cut can be done; the only condition being that one must know what one is doing. I would advocate a benevolent view on distorted use of some originally scientific approaches; and emphasize the need for a more rigorous approach for any synthesis, for stating relations between different parameters, or for combining data over time and space.

The study of plankton involves a tedious identification and counting of organisms, and produces information that cannot be obtained at a lesser effort. Such information may be relevant in a complex frame of study, but often is not tremendously important in relation with actual practical problems. The essential is to have the problem stated. Contamination can be detected usually by methods more simple than the usual biological. I am not going to advocate to prepare lists of indicator organisms to be used to assess water quality, and probably the days of the "Saprobiensysteme" are gone. Nevertheless, biological analysis has the advantage to provide information on an average of past events, and also on single events of pollution that can go undetected by other ways of monitoring. At least in our rivers, polluters tend to behave erratically and great amounts of pollutants are discharged at irregular moments, perhaps expecting protection from such sort of protean behaviour. It is less so in marine environments, but changing patterns of water movement introduced great complication, and communities of organisms integrate and reflect the sequence and combination of many complex processes. The results of the study of plankton have to be interpreted in the frame of a good knowledge of precedent states and of hydrographical conditions, and we reach again the conclusion that the study of plankton has to be integrated in a larger frame of research or else, it is no pamacea.

The prospective contribution of the plankton ecologist may be more important in another aspect. Pollution (often) and fertilization are changes of the same sign. The development of aquaculture has to be combined somehow with the treatment of pollution. One of the future fields of research is the study on how to blend systems, and make the transfer of matter or energy, between them, the less noxious and the most profitable.

One serious difficulty for any review is that data to comment on are few, and very diverse or incomplete. Some situations in the Atlantic area in the region of New York, in the Baltic, in a few spots in the Mediterranean, and in or close to harbours and bays , have been more or less studied. Also single events of oil pollution have induced special projects of research. But it is difficult to relate changes with what would be the unpolluted situation, and the problems that arise can only be discussed in the most general terms.

POLLUTION

In ecological sense, pollution results from poor or incomplete transport. At the same time pollution act as a brake, because stressed systems work at a higher speed and lower efficiency, and take part of the nutrients out of cycle. In plain language, pollution changes for the worse the properties of the environment and is therefore undesirable, but cannot be identified as an environmental factor. Thus, pollution cannot have a precise scientific meaning, a legal meaning maybe. In coastal water there are discharges of domestic, agricultural and industrial sewage, chemicals, warm water. Pathogenic organisms and radiactivity fall out of the scope of this paper.

The degradable organic matter adds nitrogen, phosphorus, other nutrients and consumes oxygen: the results are usually refered to as eutrophization. Other pollutants (chemical) last longer, accumulate and their impact may be progressive. Chemical pollutants represent the metabolites of human culture and from the point of view of ecology are not substantially different from non biodegradable or poorly degradable materials accumulated through action of organisms, as humic substances are.

Apart from directly fertilizing or toxic effects, pollutants can influence otherwise the function of ecosystems: Precipitation of some elements, or changes of pH, or scavenging substances in various precipitates, effects of solid particles as support or absorbers and, eventually, as precipiters, etc.; also chelators and surfactants may have tremendous importance in the biology of single species and of communities.

Pelagic life is affected as well by the suspended materials that, coming with effluents, are finally incorporated to the sediments. They can liberate nutrients directly, or make sediments more reducing , so that they give off nutrients from their own.

Not only the sediment/water interface is important, but also the interface air/water. Oils and other tensioactive substances influence the exchange of energy and the diffusion of gases across the upper boundary of the sea. Several of the arising conditions are reflected in the composition of neuston.

Thermal pollution contributes to thermic gradients and may slow down vertical transport. It can contribute also to horizontal heterogeneity, by formation of bubbles or lenses of warm, and sometimes diluted, water. Intensified metabolism under an increased temperature means a higher oxygen consumption, and may not be compensated by more food.

All these effects are combined in an environment that changes continuously. The spatial structure defined by the presence of a pollution outlet is usually named a "plume", but its form and structure are highly irregular. Diffusion is more rapid along an horizontal axis than along a vertical one, and still more rapid in horizontal direction at the level of pycnoclines. Lenticular bodies of water depleted in oxygen may be found as remnants of past events. Plankton is patchily distributed and migration of animals, never uniform and presumably deflected by heterogeneous distribution of pollution, changes patchiness of phytoplankton and influences regeneration of nutrients, sedimentation of particulated matter and oxygen consumption. Morphology of the bottom may influence general distributions, also through breaking of internal waves. Around a source of pollution the many influences are distributed in a non coincident way, although, in general some exponentially decreasing function can be accepted. In such complex situation, organisms belonging to many different species act as specialized sensors, and knowledge of their distribution may help to ascertain intensity and extension of disturbing agents.

MODELS

A model is a conceptual frame of reference, and must embody a rather complete idea of the system, although it may be difficult to materialize. The model, to start with, must have the form of a theoretical construct, as large as possible, useful as a memorandum of things that we cannot ignore. A model will spring spontaneously from research, and it is a bad beginning to set as the main purpose of a job, to construct a model.

Sometimes in the process of building a model, a large mass of miscellaneous knowledge, important but difficult to put in quantitatively appropriate terms, is left out, and this is a regrettable loss. Now,models are a sort of a fad. It can be explained also because to build a model may be cheaper than to study nature, and, if not cheaper, is made easier by the usual process of development of most research organizations, under the burocratic pressure.

Most of the proposed models have the same basic form, down to essential details that can be traced back to writers that published several decades ago (Volterra; Riley

Stommel, Bumpus).

A number of variables (density of populations of species or groups of species, concentration of nutrients in water, etc.)are related among them through functions -usually consisting in linear combinations of terms- with appropriate constants describing intesity of interaction. Interaction is also made proportional usually to the product of the densities of the reactants. At their turn, the used constants may depend on temperature, light, time, depth, etc. Some random terms can be added, representing inputs from outside the system, or not determined from inside the model.

Similar sets of equations can be writen for different compartments, into whic the space is divided, and supplementary functions of exchange between neighboring compartments added. With present computer facilities, models with a number of state variables x compartments oven one thousand and more can be handled. Such models are realistic only if, starting with a suitable set of initial conditions, converge into an (usually smaller) set of states, that represent stationary states for the system. It is often assumed that actually observed systems or parts of systems are in stationary state, and working back from this some model can be completed, adjusting the constants to the necessary values. But, in any case, validation of the model lies into its application to an independent set of data, or in successful prediction.

The aim of models is to express in abridged form the mechanisms identified in the system. They may serve to predict the consequences of some external -or random- input not generated by the same model, and that pushes the system out of equilibrium. In such way the presumable results of adding nutrients or toxicants can be modelled: the direct effects on local populations, and further effects as they disperse in decreasing concentrations from compartment to compartment. The kind of changes that follow contribute generally to a recovering of a state more like the initial one. But if the stress is continued, the system is maintained with a persistent difference in relation with its primitive state, and the difference can be considered proportional to the importance of pollution. The difference is reflected in all the state variables, and any of them may give some measure of the pollution, and in this sense composition and properties of plankton may be a measure as any other possible.

A model of a polluted area must be a compartment model, since the heterogene ty is important over large areas, adding to the already high degree of small sca organization of coastal ecosystems. An abridged model can consist in a mapping of the differences between the polluted system, and a primitive system of reference, often an hypothetical one, since information relating to state of an area before the polluting events is usually very scarce. Such an abridged mod recommends a few rules: 1) Choose a small number of highly relevant variables to classify the different samples as points in a multivariate distribution. 2) Express exchange or interaction across asymmetric boundaries in a simplified form. 3) Analyze the degree of allowable horizontal dissection of the s stem in vertical adjacent columns.

1) Variables (densities of species, concentration of elements, etc.) are more or less related. Their relevant associations may be detected through principal component analysis. Some particularly important variables may be, then, selected. Very often it will be found that not simple parameters, but their ratios, are relevant in providing a convenient description. There is a number of variables traditional with ecologists, as numbers of cells, amount of chlorophyll, etc. There are other variables , as they come directly from sensors, or otherwise operationally defined, as fluorescence, counts with a particle counter, etc. Models can be implemented on either set, perhaps forgetting for the moment about the correspondence or projection of one set on the other. I mean that sound and reasonable models can be constructed using not numbers of cells of such and such species, but direct outputs of physical or chemical sensors, or any other system of automatic

recording, as he output of a particle counter. This would lead to accept as respectable, ratios as fluorescence per particle of such size, and would simplify a technological approach to the whole problem.

2) The transport between adjacent compartments may be infered from the differences between them. In a pollution plume, the transport of substances along the plume is proportional to local gradients and to diffusivity. Any arbitrary boundary across the plume is asymmetrical. On one side there may be more nutrients and more phytoplankton; at the other side more zooplankton may be. Also different ratios may change accordingly. A compartment with a ratio primary production/biomass higher than in the neighboring volumes, produces an excess matter that through different mechanisms drifts out. This point of view has been developped to a certaing length considering that plankton has a true organization in space (Margalef, 1967). Patches of plankton with a high ratio primary production/biomass , tend to be rounded inside populations of other properties, and thus honeycomblike structures can be created, with a possible periodic repetition of them.

3) Different variables, and variable ratios in adjacent spots imply some asymmetrical exchange across the boundaries. A considerable body of ecological theory assumes that several variables of the ecosystems tend to become more uniform over the space, or, in our case, over the horizontal extension. A final plausible situation would be to have the water body decomposable in a number of vertical columns or prisms, very alike. If it were so, a model of one meter square section might be representative of the whole. This model could be appropriate for some offshore areas, where horizontal gradients are very small, and exchange across any arbitrary vertical boundary is almost symmetrical. But in a stressed system, an upwelling area, or a polluted area, a column of 1 m^2 section is not representative, adjacent prisms are different, and the model can be closed only -in terms of matter- if the so rce of pollution is also included. In limnology, an oligotrophic lake can be modell

as a lake, an even as a column of 1 m^2 section. The model of an eutrophic lake, of the same degree of completeness, turns out to be impossible if the agricultural land of the basin as well as the towns, source of sewage, are not included. Horizontal size of the model, that is necessary to get a model closed, is a measure of stress. Important sources of pollution create large heterogeneous areas, and exige a survey of a large area. This is another reaso why 1 am advocating that the full utilization of biological analysis cannot be based on a few samples, but needs understanding of phenomena in a scale relatively large. The selection of the parameters to be measured has to be supplemented by a study of spatial structure, and of the minimal extension to be studied to understand the organization of the whole system.

SELECTION OF VARIABLES

Models provide a stimulus for getting much information and to give careful consideration to the sampling program, to increase its effectivity, since time, money and people are always in short supply. The different variables have to be measured synchronically, on the same samples of water.

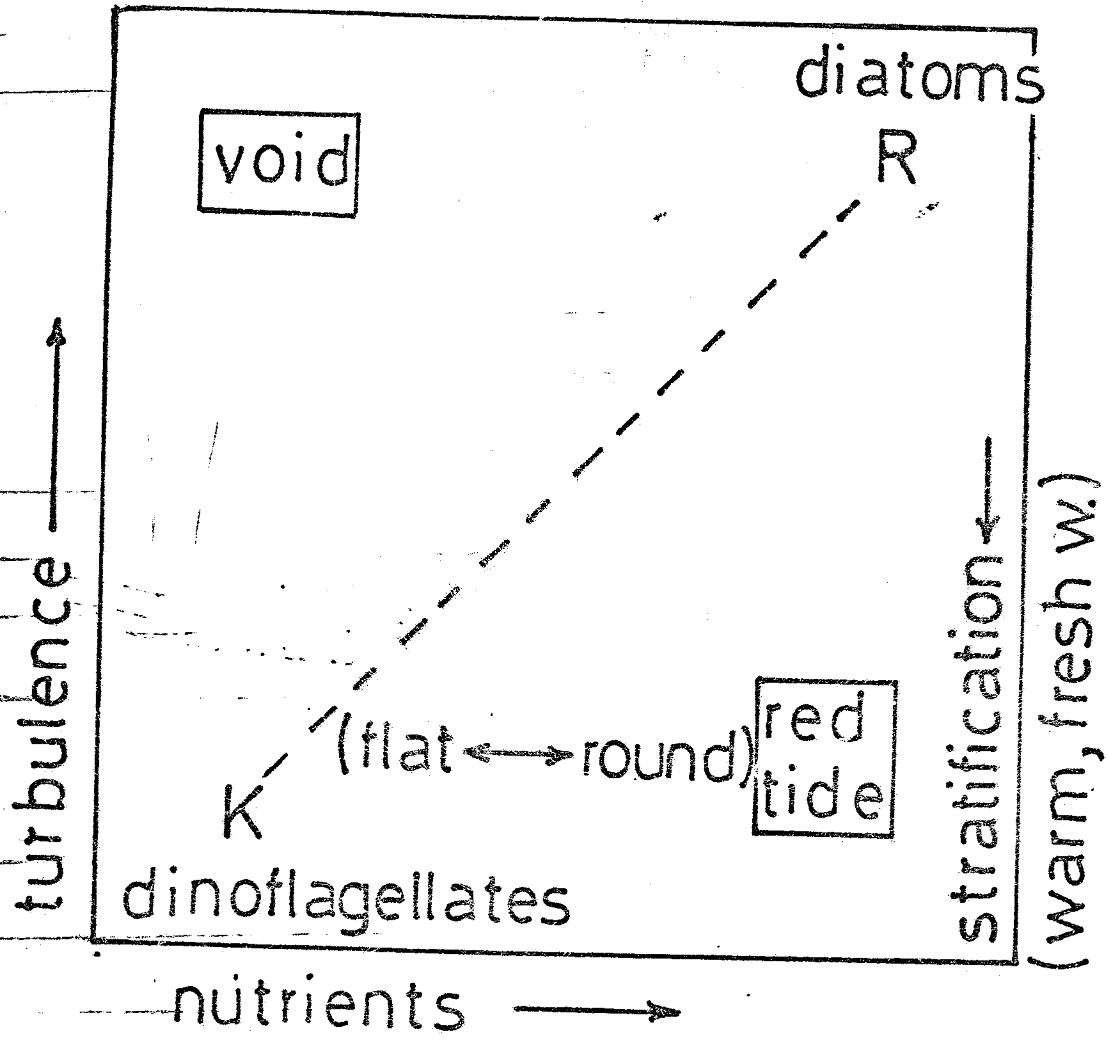
For the study of coastal areas, sampling as usually carried on in large oceanographic expeditions is not suitable, because samples would be too far away in space and time, and coastal processes develop with a high heterogeneity on a small scale, and an orden of dimensions of 100 to 1000 m is relevant. Probably the best solution is to have speedy boats, equipped to pump water continuously from controlled depths, and with sensors to measure in the place many of the desirable parameters. In connection with water samples for biological analysis and zooplankton samples, some criteria have to be adopted to avoid accumulation of samples that never are studied. One of the possible criteria would be to adhere sampling to the rate of change of some selected parameter, that may function as a guide, as temperature. The procedure may be useful in sampling through a pipe which inlet describes a sinusoidal path behind the boat. Every unit step in the change of temperature a sample would be taken. Number of samples would be then larger in the vertical than in the horizontal dimension, and a relatively small number of samples would be collected in laces of uniform water and high turbulence. It would be rewarding get a normal distribution of the properties measured in the samples. Then, distribution of samples would reflect directly the organization of the ecosystem in space. Density of samples could turn to be proportional to the influence of pollutants. Another problem of sampling concerns the track of the ship: a zigzag track may be choosen, but the best control would be to run it twice , in the same or in opposite direction.

To identify and count organisms is hard work, and identifications only to the major groups, or sloppy work, may be a waste of time. There are not such things as indicator organisms, but any practicing planktonologist has many hints to offer. Sometimes they are based on an experience that rarely has been made explicit, for the lack of appropriate information on other variables for reference. Euglenales (Eutreptiella) and green algae (Tetraselmis) develop in surface water rich in nitrogen compounds and with organic matter. Cryptomonads are plentiful in coastal surface water, more or less enriched; but they can be present also in offshore areas. Many species (Prorocentrum, Scrippsiella, Chattonella = Olisthodiscus, etc.) develop blooms in eutrophic harbour water, and their dynamics is much akin to the true red tide species. The series of diatom genera Skeletonema - Thalassiosira Chaetoceros - Rhizosolenia follows a pattern of diminishing nutrient concentration, and may present more or less regular concentric zones outside of the harbours and eutrophication sources. The most important factors in distribution of phytoplankton, besides light, are not temperature and salinity, but nutrient supply and turbulence, and they are usually associated together. In natural environments more turbulent water is usually also more nutrient rich. But in polluted area high nutrient concentration may go on hand with stability. There is a divergent strategy of life in the process of adaptation to the different combinations of the refered factors, embodied mainly in the differences between diatoms and dino- flagellates. In rich and stratified water, rounded and chlorophyll rich dinofla gel- late species may be dominant (fig. 1). The ratio number of diatoms /number of dino flagellates may be, in consequence, significant. Moreover, there is an increasing knowledge of particular nutritional requirements of selected species, and their presences may provide some information about concentrations of vitamins, toxics, etc Specialists on zooplankton could provide also a great number of useful suggestions for interpretation of presence and abundance of different species and of different groups.

Ratios may be more telling that simple counts or estimates of abundance. Following ratios have been chosen in the way that the numerical value usually increases when a system is left close to evolve by itself, and decreases as a consequence of impredictable or random inputs (a stress, as upwelling, or pollution

1) Total biomass /primary production.
2) Total biomass / biomass of bacteria.
3) Zooplankton biomass / phytoplankton biomass.
4) Carnivores biomass /herbivores biomass.
5) Phytoplankton biomass /chlorophyll.
6) Oligotraphent bacteria /bacteria that require high concentration of degradable material.
7) Dinoflagellates /diatoms.
8) Degree of stratification and organization of vertical migration and importance of the transport mediated by migration.
9) Diversity (not always) and steepness of the diversity spectra (= beta diversity, always).
10) Average size of organisms (not always).
11) Reciprocal of the nutrient concentration for maximal speed of assimilation.

The planktonologist is in measure to suggest methods involving easy and some- times automatic procedures, and to correlate the results of the application of suc



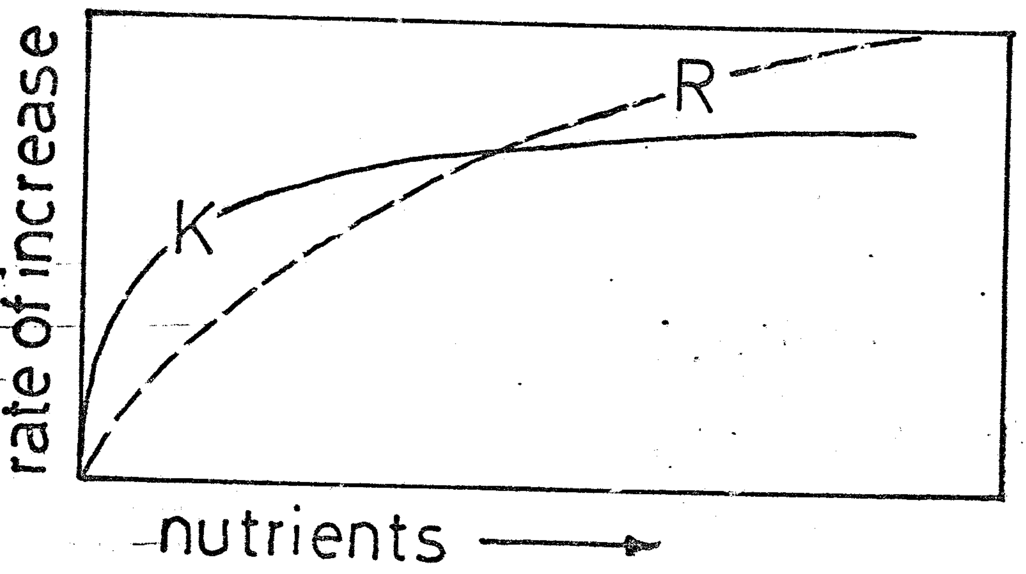


Fig. 1.- Different possibilities of occupation of an ecological space defined by nutrient concentration and turbulence. The usual strategies lie along the line R - K

methods with other properties of actual plankton communities, studied down to identification of organisms in a few selected and well known areas. In doing this, the planktonologist place himself or herself out of job, but, I would say, may be reserved by a better . and most necessary job of integration.

As the number of indirect methods (chemical, optical, acoustic) increase, the basis data for reference (actual counts, analysis of organic carbon in organisms etc.) may be too few. As mentioned before it may be advisable to renounce to traditional ways of expression and construct systems of relations with operationally defined sets of measurements.

In summary, measurements that may be taken into account are:

1) Biomass.- Organisms counted in sedimented samples, or in filters (with the possible use of scanning electron microscope) or collected with nets. Amount of total organic matter, or of selected components, as carbon, nitrogen, phosphorus, chlorophyll, protein.

2) Composition.- Diversity in cells, pigments, fatty acids. Among other results may help to discriminate among different conditions of mixing, with or without toxics, with or without complementarity of nutrients. Inmunological studies.

3) Activity.- Primary production, respiration, electron transport systems, enzyme systems in general, ATP concentration, ratio RNA/DNA.

4) Distribution in space.- Gradients in all variables, exchange, diversity spectra; size, shape and topological distribution of patches; periodici in their distribution. Neuston (collection of different thicknesses of surface film with capillarity collectors of different mesh size).

Some methods are specially appropriate for use in continuous sampling systems:

Pigments.- Extraction of plant pigments and recording the complete spectra of absorption, before and after acidification; analysis of spectra to select ratios (for instance D_{430}/D_{665}) that may be correlated with important properties of the plankton and of the systems. Analysis of fluorescence of water provides an useful shortcut. It would be much better if used together with conventional pigment extraction, since the ratio fluorescence/chlorophyll is higher in the presence of fluorescent pollutants, or of inhibitors of photosynthesis, or of detritic chlorophyll, or at night, and finally, may be related to the dominant algae in the phytoplankton.

Particles.- There are very convenient particle counters. Possibly two machine with different size of hole should be used simultaneously, in order to provide accurate measurements over a wide range of size. Numbers of particles and spectra of its distribution according to size is a good characteristic of water bodies ar may be of much help in describing configurations of effluent plumes.

Diversity indices are of common use in the study of benthos, but must be used critically (Hedgpeth, 1973). Limitations may be more serious in the plankto for following reasons: Diversity spectra, and not just point diversity, are impo tant and much related to turbulence. Difficulty for identification of small components of phytoplankton makes often impossible computation of indices. An index computed on representatives of a single group may be meaningless if such group has a rather narrow ecological range (diatoms, for instance, absent i stratified and nutrient poor water).

FINAL COMMENTS

If the complexity of the basic problem is not lost from view, it is not difficult to single out a number of criteria, some based on the direct examination of plankton, most of them involving comparison of communities with pigments primary production and selected chemical parameters of the environment. Later on, in routine work, the presence and distribution of selected species may be used to recognize intensity and extension of contamination. But probably it is impossible to produce a <u>modus operandi</u> to cover all situations in all seas. In a very large project, the planktonologist cannot neglect to keep an eye and use all the information that is coming. It may be bad to have the whole project cut down at the administrative level in small packaged problems that keep the scientists working happy and forever on small things. If plankton is studied at all, counting of plankton samples develops a tremendous lag. The result is that when decissions are to be made, plankton counts and observations are usually ignored. A realistic approach needs a problem, a motivation, and a selection of methods to be really used in decisions.

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