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RESEARCH PROGRAMMES FOR INVESTIGATIONS OF THE BALTIC AS A NATURAL RESOURCE WITH SPECIAL REFERENCE TO POLLUTION PROBLEMS

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PREFACE

This Report constitutes one part of the work carried out by the ICES/SCOR Working Group on the Study of Pollution of the Baltic in response to its terms of reference. It has been drawn up by a sub-group with Professor B Bolin as Coordinator, with the intention of obtaining a document which can serve as a guideline for future scientific studies of the Baltic in relation to pollution problems. The aim has been to give the general background for the conditions in the Baltic, to define and formulate research problems related to the pollution situation, and to identify the most urgently needed studies. These all have the character of process studies to be carried out over a relatively short period of time in which international cooperation is crucial in order to obtain a wide coverage of the different branches of marine science. It is suggested that a series of complementary studies are carried out during a limited period, the International Baltic Pollution Study. The aim is to obtain knowledge of processes in the Baltic, so that a better understanding of man's influence on the conditions can be achieved, a scientifically based monitoring programme can be recommended and predictive models can be formulated and possibly verified.

This Report gives a dynamic formulation of research needs which include the efforts of physical, chemical and biological oceanography as well as fisheries research. The long-term survey programmes and the various national efforts going on in the coastal zones have not been discussed. Clearly they constitute necessary parts of a complete programme.

The ICES/SCOR Working Group is very grateful to Professor B Bolin and his collaborators for the very great effort they have made in working out these proposals. They were endorsed by the ICES/SCOR Working Group in May 1973 and accepted by ICES in October 1973 and SCOR in January 1974 as guidelines for scientific studies in the Baltic, and both organisations agreed that they should be published.

In addition to the programmes outlined here, the ICES/SCOR Working Group is concerned with a study of the input of pollutants to the Baltic from various sources and with a base-line study of the level of toxic substances in some marine organisms from the area. The results of these studies will be published in due course, probably also in the ICES Cooperative Research Reports series.

Copenhagen, in May 1974

G Kullenberg

Chairman

ICES/SCOR Working Group on the Study of Pollution of the Baltic and its Effects on Living Resources

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INTRODUCTION

The increasing pollution of the Baltic in recent years calls for coordinated action by the surrounding nations. It is important that such action be based on the most up-to-date knowledge of its present state and its likely future changes. Since our knowledge is incomplete, a major research effort is required to obtain a more adequate basis for such action. In the light of these circumstances and the desirability of cooperation between the scientists in all countries concerned and in other parts of the world with knowledge and experience of similar problems, the International Council for the Exploration of the Sea (ICES) and the Scientific Committee on Oceanic Research (SCOR) at a joint meeting in Helsinki in the fall of 1971 established a Working Group to deal with this problem.

The Working Group later formed a small ad hoc group which consisted of I Hela (Helsinki, Chairman), A Aitsam (Tallinn), B Bolin (Stockholm), H-G Brosin (Warnemünde), S H Fonselius (Gothenburg), G Hempel (Kiel) and B-O Jansson (Stockholm) and which was given the task of preparing a draft programme. This programme served as the basis for the discussions by the Working Group at its meeting in Kiel, 28 and 29 June 1973. The present publication is a further revision on the basis of the extensive discussions at Kiel, and should represent the views of a good number of scientists actively engaged in research on various aspects of the physics, chemistry, biology and geology of this sea. It might represent an important contribution to the formulation of a joint action programme for the further study and protection of the Baltic, which the countries concerned might be able to agree on. It is tentatively being proposed that the year of 1975 would be "The International Year of Baltic Pollution Research" *) and represent an essential expansion of the cooperative research activities.

It should be emphasized that the Report exclusively deals with problems of the Baltic as a whole, the solution of which requires international collaboration. There are obviously many problems of a local nature which also deserve attention and research resources. A proper balance between the efforts devoted to these two problem areas is important and requires careful study at the national level. In many cases, however, the local problems cannot be understood without a clear view of the behaviour of the Baltic as a whole.

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*) At its meeting in May 1974, the ICES/SCOR Working Group recognised that one year would not be sufficient for the planned tasks, and also that action on some tasks would have to precede others. It was therefore decided to amend the designation to read: " The International Baltic Pollution Study", which designation is used throughout this publication.

THE BALTIC

1. THE DEFINITION OF THE ENVIRONMENTAL PROBLEM

1.1 Characteristics of the Baltic

The Baltic is the largest brackish water area in the world. It is of immense importance to the populations of the seven countries that border it and the signs of increasing pollution with unforeseeable consequences for the future justify a major effort to study its basic physical, chemical and biological characteristics in an attempt to understand how it behaves as a whole. It should be recalled, however, that even during the relatively short time period that has elapsed since the last glaciation, about 10 000 years ago, several quite different regimes have prevailed in the Baltic basin. Therefore very different ecological systems also have existed: The Baltic Ice Lake, The Yoldia Sea, The Ancylus Lake, The Littorina Sea, which finally changed into the Baltic as we know it today. The natural long-term changes of the salinity of the Baltic Sea brought about by climatic conditions are also today characteristic. It is therefore of basic importance to understand how the natural changes of this water body have occurred, and what caused them in order to be able to tell to what extent the changes that have been observed over the last 100 years are natural or have been caused by man's activity.

The following external conditions are of importance for the determination of the characteristic features of the Baltic:

- it is a relatively shallow sea
- the entrances are narrow
- the sill depth of the entrances are quite shallow
- the Baltic proper and the Gulf of Finland may be considered as one sea basin, whereas the Bothnian Sea and the Bothnian Bay are hydrographically separate basins
- the Baltic is situated in the zone of relatively strong westerly winds and characterized by a positive water balance, i.e. the precipitation and run-off from adjacent land areas exceed evaporation
- the river discharge to the Baltic is characterized by acid waters, rich in humus.

Since the Bothnian Sea and the Bothnian Bay are hydrographically separate and essentially of Swedish-Finnish concern, we shall in the following discussion restrict ourselves mainly to the Baltic proper and the Gulf of Finland.

Due to the external conditions briefly summarised above the Baltic has the following oceanographic characteristics:

- the salinity varies between 2‰ and 18‰ (the basic regimes of the Baltic are oligohaline and mesohaline);
- it consists basically of two layers of water separated by a layer of rather rapid change of salinity (the halocline) and therefore of density; the upper layer is homogeneous in winter, but is in summer divided into two layers of different temperatures separated by a transition zone (the summer thermocline); the lower layer, particularly its deepest parts, may consist of more than one layer, each one of them characterized by different salinity and density, age and oxygen content (see Figure 1, p.4);
- occasionally the oxygen content of the deepest water is reduced to zero and hydrogen sulfide appears; above the halocline the water on the average slowly moves towards the Belts and the Sound of Øresund, while the water movements below the halocline have a pulsatory character, which on the average shows a counter-clockwise motion around Gothland and into the Gulf of Finland;
- the great vertical stability of the halocline very markedly prevents vertical exchange;
- the average surface current through the Danish waters is outbound, while the average current close to the bottom is inbound; in reality longer periods of outgoing water flow, swiftest at the surface and along the right hand coast lines, are occasionally interrupted by periods of ingoing flow, which in contrast is swiftest close to the bottom;
- tidal motions are small and the mixing processes in the Baltic are therefore essentially induced meteorologically;
- because of the low salinity much of the northern parts and the coastal areas are covered with sea ice each winter, which reduces the intensity of mixing and exchange processes;
- the character of the biota of the Baltic is chiefly determined by the relatively low salinity of the water, by the relatively low temperature in winter and by the low oxygen content or oxygen deficit in its deeper parts;
- the primary productivity (of plankton) is comparatively low, presumably because of the limited amounts of some basic nutrients and because of the shortness of the production season, in particular in the northern parts;
- the fish production is comparatively high and consists mainly of a few species which are intensively exploited by man.

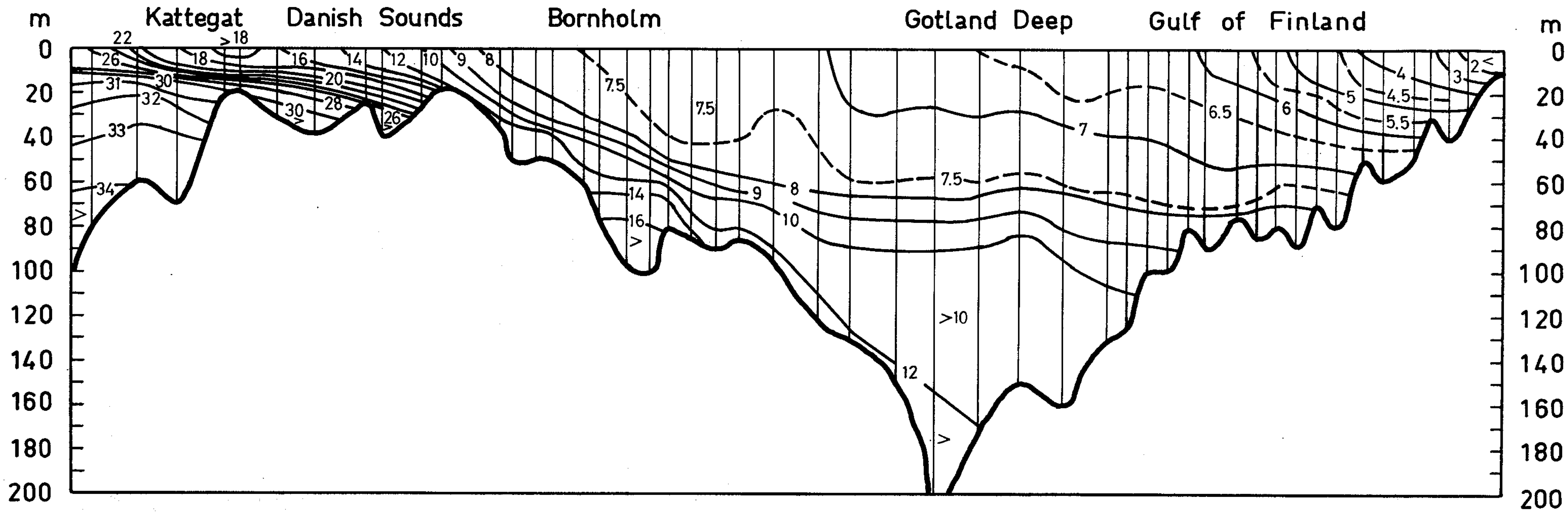

Figure 1. Salinity distribution (‰) from the Kattegat to the Gulf of Finland.

1.2 The Baltic as a Resource and as a Recipient of Sewage

Until quite recently everyone was entitled to use the seas, including the Baltic, freely for his own purposes, i.e. for navigation, fishing, waste disposal and lately, and increasingly so, for other purposes such as aquaculture, mining, water supply and for various types of recreation. These users cannot any longer act independently of each other. In particular the following significant uses of the Baltic are closely interrelated:

- the utilization of the renewable biological resources, essentially fishing;
- sewage disposal, both domestic and industrial, including cooling water from nuclear power plants;
- recreation.

One might well expect that other uses of the Baltic might soon become significant, plans are being developed for using parts of the Baltic as a fresh water reservoir.

It is clear that the Baltic will always to some extent be used as a recipient for sewage, but it is equally clear that such use, if excessive, is bound to affect in a negative way any other use and in particular its use for fishing and recreation. Although the three above-mentioned uses are mainly confined to the coastal zone the relationship between them are closer than one might expect.

Because of the rapidly increasing fishing and the natural limitations of the productivity of the Baltic as a whole, we are quickly approaching a situation of overfishing. It is therefore urgent to regulate the exploitation of the living marine resource of the Baltic and to base such regulations on scientific determination of the relevant limits.

It seems equally important to monitor marine pollution and to take measures to prevent any excessive or harmful pollution.* For practical purposes the pollutants may be grouped as follows:

- <u>Pollutants discharged directly into the sea or via rivers:</u>
-- organic and toxic metallic substances, other substances alien to the marine environment and bacteria and viruses (locally);
-- substances like phosphates that cause eutrophication;

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*) With pollution we understand:

"The introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water, and reduction of amenities".

- Pollution from ships:
  -- oil spills and oil disasters;
  -- dumping and discharge of harmful matter;
  -- wastes from normal ship operations;

- Airborne marine pollution:
  -- long-distance pollution (of international character);
  -- local pollution (of national character);

- Waste heat from condenser waters;
- Discharge of matter caused by water regulations;
- Pollution arising from the bottom during sand, gravel and oil prospecting.

There are good reasons to believe that of these, the following are considerably more significant than the others:

- toxic substances that appear in the food chain
- eutrophicating substances
- oil spills.

We shall return in Section 3 to a more specific discussion of our present knowledge of these matters and a definition of the specific research objectives that appear of prime importance in the light of the increasing use of the Baltic as a natural resource to man and its simultaneous use as a recipient of waste products from human activity.

1.3 How to Approach the Problem?

When trying to assess the present situation and the likely future development of the Baltic it quickly becomes evident that our understanding of the Baltic as an ecosystem is still quite limited, in spite of the research carried out so far. We are in fact not able to answer even rather simple and fundamental questions. Considerably more work is required, particularly concerted actions and cooperation between various branches of science and between nations. Much effort is needed before we can say that we reasonably well understand a complicated ecosystem such as the Baltic. The basic purpose of the present Report is to outline a research programme that will lead to a better understanding of the Baltic as a whole.

It is important, however, that preventive action is not delayed, simply because our knowledge is still incomplete. It is clear that man already today contributes to the material turn-over in the Baltic to an extent that is approaching the natural turn-over (Fonselius,1972). We also know that the exchange processes and the circulation of the Baltic are comparatively slow with a characteristic tine-scale of about twenty years or more, and that it therefore takes decades to restore the undisturbed condition, should a serious man-made deterioration occur. Against the background of such simple facts it is obvious that <u>some preventive measures will have to be taken before anything like final results from research are available.</u>

For the reasons given above it is important to summarize and to systematize our present knowledge concerning the Baltic as well as possible even with all the obvious gaps present. Such a synthesis may serve as a temporary basis for an action programme. At the same time it will be possible to show in which fields increased knowledge is particularly urgent. It will thus result in a plan for further research including a programme for immediate action, which can serve as a basis for deciding on priorities. A study of the kind that is envisaged here must include both an attempt to understand how man influences the Baltic and also the way in which man is dependent upon this big water reservoir. To do so we need a much fuller knowledge of:

a. physical (including optical) oceanography, particularly an understanding of transport and exchange processes;

b. chemical oceanography, particularly the distribution, transfer and eventual accumulation of nutrients and toxic substances and other substances alien to the marine environment as well as processes that are important for their distribution;

c. marine biology, particularly the interplay between abiotic and biotic environmental factors and the interplay between animal and plant life;

d. marine geology, particularly soil erosion, beach processes, sedimentation, exchange processes at the sediment-water interface.

In addition the economic and legal aspects of multiple use must be much better understood.

It is clear that work in each one of these fields cannot proceed far without good knowledge about the development in the others. This evidently is the reason for the necessity of coordinating the research efforts concerning the Baltic. It should be emphasized that theoretical studies and further analysis and interpretation of existing data are of central importance for such a research programme, not the least for the development of an optimum strategy for the increased observational efforts.

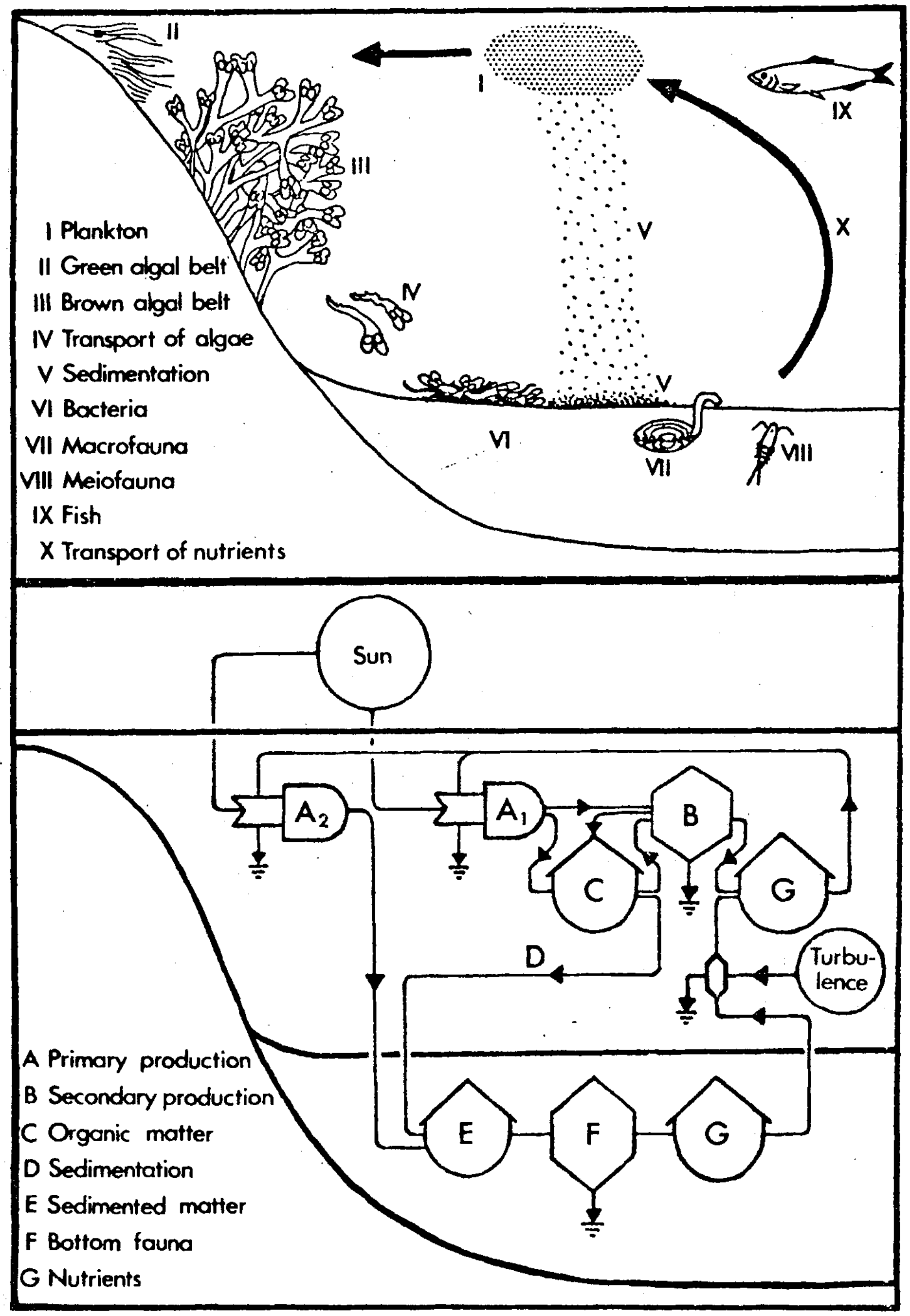
The purpose of this Report is to outline briefly the behaviour of the Baltic as an ecosystem (Chapter 2) to define the more specific research objectives in view of man's interference (Chapter 3) and to propose the required approaches, both individual and concerted, needed both immediately and long-term (Chapter 4).

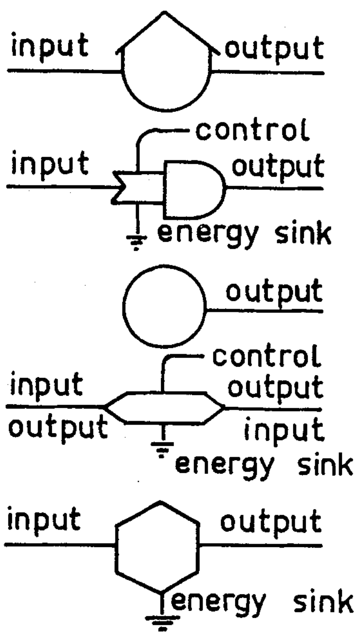
2. UNDERSTANDING THE BALTIC ECOSYSTEM

2.1 Principal Problems

The interplay between physical, chemical, biological and geological processes in the Baltic is complex. A research programme to explore the behaviour of this ecosystem must be built on some kind of modelling hypothesis to permit an integration of the research efforts in the various fields into a unified picture of the system as a whole. The energy circuit approach as developed by Odum and co-workers (see e.g. B-O Jansson,1972) represents one useful approach, and what we today know about the behaviour of the Baltic as an ecosystem has been largely obtained through simple modelling of this kind. Considerable advances have been made in structuring the problem and identifying the crucial links in the system. Particularly important are the attempts to assess the relative importance of the various processes.

The major energy cycle in the Baltic is shown schematically in Figure 2, p.9. The upper figure shows a simplified naturalistic picture of the system and the lower one is the same system expressed in Odum's energy language. A more elaborate model of this type, but still basically treating the Baltic as a two-layer system (surface waters and deep waters), has been extensively used for simulation experiments in a computer by the Askö-group (e.g. Sjöberg *et al.*, 1973). Both the annual biological cycle and possible long-term changes have been simulated and these experiments have provided insight into the dependence of such changes on both external parameters such as intensity of mixing, supply of saline water from the Kattegat and the associated exchange of phosphorus, and on internal processes, such as rate of organic production, rate of sedimentation, rate of biological decay. The model developed so far essentially provides a macroscopic view of processes in the pelagic and algal belts, the hard bottoms and soft bottoms, and reduces drastically the number of steps in the food chain. Each such sub-system in reality has its own complicated pattern of forcing functions, storages and flows and requires more detailed sub-models for proper description.





Passive storage. Energy must be supplied to accomplish transfer in or out of the storage.

Work gate. A process which is controlled by some feature of the system such as photosynthesis being controlled by supply of nutrients.

Energy source such as the sun, weather etc.

Two-way forced diffussion module.

Self-maintained consumer population.

Figure 2. Flow of energy and matter within a coastal area. Above: a naturalistic picture. Below: the same system expressed in H.T. Odum's energy language.

Although interesting results have been obtained with ecological models of this type, they are still inadequate in important respects. The mathematical formulations of how different parts in the ecosystem are interconnected are largely empirical and the simplifications introduced sometimes questionable. Nevertheless it is important to try to further improve them because we need them to be able to carry out integrations over time periods of years, decades and centuries to understand the long-term behaviour for which the short-term variations only play a role statistically. In the future, however, much more systematic use must be made of detailed hydrodynamical models to determine in which way we are going to improve on present ecological models. It is hardly possible to observe a system as the Baltic in such detail and over such long periods of time that the statistical formulations which we require can be determined exclusively on an empirical basis. The detailed hydro-dynamical models properly verified by observations over limited time periods may be used to establish more rigorously the mathematical-statistical formulation of the processes which we need to describe in the ecological models. The direct application of numerical three-dimensional models of the Baltic will for example certainly shed light on the short-term behaviour of this water body in response to variations in meteorological conditions, which is one of the processes that need to be described statistically in a proper way. We face here a basic difficulty and need to understand how to approach this problem, to be able to answer basic questions of the kind: What are the <u>causes</u> of the changes of deep water temperature and the salinity distribution that have occurred during the last century? What determines the characteristic time scale for changes in the Baltic? What is the probable uppermost level to which the halocline and thus anaerobic conditions might spread under different hydrographic conditions?

The aim of any model is to describe and understand the total system quantitatively. No such model, however, can be accepted before its behaviour has been tested adequately against the real behaviour of the Baltic with regard to <u>both</u> the detailed physical, chemical and biological processes incorporated into the model, <u>and</u> the overall behaviour of the model. Such verifications and further developments of models proposed represent a long-term effort. The overall material budget represents one important set of data that is needed in this context. Such data are obviously also needed as a basis for more immediate actions that may prove necessary while awaiting a more complete understanding of the system as a whole.

From what has been said above we conclude that:

1) basic hydrodynamical studies of the mechanisms for exchange and transfer of matter in the Baltic are of prime importance to permit ultimately a physically more correct treatment of such processes in the eco-system models than has been the case so far;

2) more detailed studies are needed of the various biological processes in order to permit a more accurate incorporation of these into any overall model;

3) theoretical and experimental studies must be pursued in parallel.

2.2 Currents and Water Exchange in the Baltic

2.2.1 Basic concepts

The Baltic is one of the largest basins of brackish water in the world. The interplay between a river run-off of about 500 km^3/year and the incursion of saline ocean water from the North Sea creates a salinity distribution which varies from a few parts per mille in the innermost parts of the Bothnian Bay to about 20‰ in the vicinity of the Danish Sounds.

The water exchange processes within the Baltic are such that a marked stratification is established. The characteristic salinity of the deep waters of the Baltic proper is between 11 and 13‰ while that of the surface waters is 7 to 8‰. This distribution is of fundamental importance to the biological processes.

Hydrographic measurements have been made since the end of the last century, and Fonselius (1969) has shown that the salinity of the deep waters has generally increased during the last eighty years, even though the trend since the very marked salt water inflow in 1952 has been the opposite (Matthäus, 1972). A slight increase of the salinity of the surface waters seems also to have occurred. Thus the vertical stratification across the halocline has become more pronounced and the vertical exchange processes may have been influenced thereby (cf. Voipio and Mälkki, 1972). If this is so the changes of the distribution of compounds such as oxygen and phosphorus observed during this century may have been partly caused by a natural process. It is obviously important to establish to what extent this is so or to what extent man is responsible.

The maintenance of saline water in the Baltic is roughly described by Knudsen's formula which, however, merely expresses continuity of water and salt and does not contain any element that relates the stratification to those processes of exchange that determine it. A more fundamental approach must be followed to be able to establish for example in which way bottom topography, sill depth, meteorological conditions etc. determine the depth of the halocline.

Recent theoretical work by Walin(1972,a) has shown that the vertical mixing in a stratified fluid is particularly effective along the lateral boundaries, i.e. where the halocline and the thermocline hit the bottom. It is of basic importance to learn more about these processes and how they determine the retention time of river water and North Sea water as well as their influence on the spreading of sewage etc.

Research in the field of physical oceanography should particularly be aimed at improving our knowledge with regard to the following processes:

2.2.2 The exchange and mixing of water masses between the North Sea and the Baltic and their dependence on meteorological conditions

It is important to obtain:

a) integrated current measurements;

b) statistics on the salinity and temperature, as well as the content of various chemical compounds such as phosphorus, nitrogen and their chemical constituents;

c) covariance between current velocity, temperature and salinity to provide the correlation function and thus information on how the exchange through the Sounds depends on the characteristics of the variability in time.

The transport processes in the Danish Sounds are complicated and their details are not of primary importance. Observations in the Sounds should therefore be combined with regular measurements in cross sections in Kattegat and well into the Baltic as for example between the Bornholm Island and the Swedish coast (through which passage the exchange essentially takes place) where conditions may be less complex. Pilot studies and models are required to establish the optimum way of determining statistically the water exchange between the North Sea and the Baltic.

2.2.3 Exchange with deeper layers in coastal areas

Theoretical studies (Walin, 1972,a) as well as field observations (Walin, 1972,b) in the Baltic suggest that coastal upwelling and the mixing processes extending some tens of kilometers out towards the open sea initiated thereby are important. There are probably important geographical differences dependent on the orientation of the coast to predominant winds and on the existence or not of an archipelago. This calls for intense efforts in selected areas for limited time periods rather than routine monitoring in a sparse network of stations all over the Baltic.

2.2.4 Mixing in the coastal zone and the exchange with the open sea

Most pollution is brought into the sea at the coast. Studies in recent years provide some information on the mixing and dilution in the immediate vicinity of a point of emission. The more far reaching consequences of such emissions (e.g. beyond national borders) have not yet been much studied, nor do we understand well the exchange mechanisms between the coastal zone and the open sea. The coastal currents possibly caused by the variable meteorological conditions may be of importance for this transfer. This is the case in the Great Lakes (cf. Csanady,1972a and 1972, b), but corresponding studies for the Baltic have not been made.

2.2.5 The mechanisms for horizontal transfer in the open sea

These are presumably due to other dynamic features of the system than those operating in coastal regions. The use of ordinary current meters (in tripartite stations) should be supplemented by the use of drifting buoys, which average the water motions over long periods.

2.2.6 Mechanisms for vertical exchange between the upper and lower layers of the Baltic outside the coastal zone

The magnitude of the vertical exchange in the open sea is still largely unknown and we do not therefore know its importance for the overall nutrient balance between the upper and lower layers. Attention is drawn to the possible role of breaking internal waves of which examples have been observed northeast of Gothland (Hollan,1969).

2.2.7 Water motions below the halocline

Measurements during recent years (Fonselius, 1969) have given us an approximate idea of the way the saline North Sea water penetrates into the deep basins of the Baltic proper in a counter clock-wise direction, but quantitative information of the rates and degree of mixing is lacking.

2.3 The Chemistry of the Baltic and its Nutrient Budgets

2.3.1 Basic concepts

A thorough knowledge of the distribution of a number of basic chemical elements and compounds in the Baltic waters is essential for three major reasons:

a) from a knowledge of relevant chemical reactions or lack of reaction in the case of "conservative" substances the water circulation and transfer processes in the sea may be inferred;

b) several of these elements and compounds serve as nutrients for the biota;

c) pollution of the Baltic must be analysed in the light of knowledge of the natural distributions of relevant elements or compounds.

Matter (and thus nutrients) is brought into the Baltic in different ways:

1) with inflowing Kattegat water through the Belts;

2) with river waters bringing minerals released from the soils, organic matter produced on land and industrial and urban wastes into the Baltic;

3) some waste is also released directly into the sea and dumped from ships;

4) as atmospheric fall-out by dust deposition and in the form of suspended and dissolved substances in precipitation. Gaseous exchange with the atmosphere may also take place;

5) by dissolution of matter from the sediments.

A complex system of chemical reactions constantly transforms the compounds in the water. Those that serve as nutrients to microorganisms (plankton) enter the biological cycles which end when they are again set free through bacterial decay or oxidation. The turn-over time or circulation time for different nutrients in these cycles may vary considerably.

The chemical elements and compounds contained in the water finally disappear by outflow through the Danish Sounds and by sedimentation to the bottom.

2.3.2 The phosphorus and nitrogen budgets

Carbon dioxide is always present in adequate amounts in sea water to permit photosynthesis. The two basic groups of nutrients that may be limiting factors for primary production are compounds of phosphorus and nitrogen. Other chemicals may also be important. Both the phosphorus and nitrogen content of the water approach zero concentration during periods of high production. Although usually phosphorus has been assumed to be the prime factor in limiting plankton growth this is by no means established as being always the case. Considerably more attention should be paid to the role of nitrogen and its chemical constituents. Further insight into this problem may be obtained by chemical analysis of plankton. Normally the ratio of nitrogen to phosphorus in the water and expressed in atoms is 16:1. Measurements of the composition of dissolved organic matter and particulate matter in the Baltic yield values between 20:1 and 10:1 (Voipio, 1973, and Gieskes and Grasshoff, 1969). On the other hand the ratio of nitrate-nitrogen to phosphate-phosphorus in the Baltic is about 4:1. It has often been suggested that nitrate and phosphate should be the main nitrogen and phosphorus sources for the primary production. Some species of phytoplankton even prefer amonium-nitrogen and the question of the role of urea is quite open. It is then surprising that the content of inorganic nitrogen and phosphorus decreases simultaneously to zero during periods of high productivity. Clearly this fundamental question needs urgent attention to permit the formulation of adequate ecological models. In this context increased accuracy of the analysis of nitrate-nitrogen content of sea water is very much needed.

Several attempts have been made to establish the nitrogen and phosphorus budgets for the Baltic. This is difficult. Although measurements of the phosphorus content of the main rivers are available, regular monitoring is often not carried out. It is, however, possible to establish rough annual mean values for phosphate and thus also estimate the total river transport. A careful and very useful study of this kind was carried out by an ICES Working Group under the chairmanship of Dybern (1971). Total sums are obtained by applying such figures to other rivers after correction for population and industrial production. Naturally such estimates are quite rough. In addition we do not know how much of this phosphorus actually reaches the open sea. According to Bushinski (1964) most of the river phosphorus is precipitated or removed from the water phase through biological filtering in the estuary area. Efforts to explore relevant processes are highly desirable.

Crude estimates of the river transport of total phosphorus to the Baltic vary from 10 000 tons per year (Voipio, 1969) to 14 000 tons per year (Fonselius, 1972) to 32 000 tons per year (Sen Gupta, 1973). Part of this may well be retained in the Bothnian Sea. The contribution through precipitation is probably not more than 3 000 tons per year; no quantitative estimates of the transfer to and/or from the bottom sediments are available. As shown by Fonselius (1969) this exchange may be appreciable. Since only occasional measurements from the Danish Sounds are available we do not even know the direction of the flow between the Baltic and the Kattegat.

Some attempts have been made to deduce the fluxes of nitrogen (Sen Gupta, 1973), but the results are even more uncertain. We need much more information on nitrate, nitrite and ammonia; furthermore the exchange of nitrogen with the atmosphere, as well as the uptake by blue-green algae is not well known. Much more information is also needed regarding the denitrification processes causing the break-down of nitrogen compounds into free nitrogen.

2.3.3 Metals and organic compounds

Some analyses of metals in Baltic waters have been made (e.g. total iron) but hardly anything is known about the budgets.

Our knowledge of the content of organic matter is somewhat better and even a rough picture of the budget is available (Fonselius, 1972). It is interesting to note that the concentration of organic carbon in the Baltic (5 mgC/l)is considerably higher than in ocean water (1-2 mg C/l). Most of this organic matter is produced in the Baltic itself, but large amounts are also released to the Baltic as humus and humic oxidation products, as well as in the form of waste. During the decay processes the "yellow substance" or "Gelbstoff" is formed. A proper understanding of its overall budget is therefore important for understanding the organic carbon budget.

Finally toxic organic substances (DDT, PCBs, etc.) have been found in the Baltic, primarily in higher steps in the food chain. Since analysis difficulties so far have largely prevented measurements of the concentrations in sea water and plankton and since very meagre information is available on the atmospheric transports our knowledge about their circulation and budgets is poor.

2.4 Biological Processes

2.4.1 General

In most models developed so far biological processes such as primary production, feeding mechanisms, nutrient recycling and fish migration have been included. They are qualitatively so well known that they need not be discussed here (cf. Jansson, 1972). Quantitative information, relevant to the Baltic system as a whole is, however, generally lacking although some estimates have recently been published (Ackefors, 1973).

When attempting to consider the ecological effects of pollution we lack information concerning sublethal effects on the animals as for example destruction of sensors, that may markedly influence their behaviour and thus have an impact ecologically.

Studies of the decomposition of organic material is finally a field that has been nearly totally neglected in spite of its central importance. This calls for an explanation.

2.4.2 Decomposition of organic material

The bacterial processes in the Baltic are very poorly known. Except for the investigations of Seppänen and Voipio (1971), Hallberg *et al.* (1973) and Schippel *et al.* (1973) very little work has been done in this field. The organic material, arising from the primary and secondary production and rivers, sinks through the water column undergoing decomposition by bacteria, most of which are facultative anaerobes. During decomposition various nutrients leak out, nitrogen probably being first, and carbon also successively decreases through CO_2-production in the respiratory process. The sinking time is therefore important and the deacceleration of the sinking material by layers of greater density gradient, e.g. in the halocline, may mean an accumulation of nutrients. Our present knowledge is, however, very meagre and further insight into this chain of processes is urgently needed.

In the sediments below the halocline, the deposited organic material is used as fuel for a rich flora of bacteria, forming "chemical food chains". In the presence of oxygen the aerobes will bring about almost total decomposition, which increases the oxygen consumption. When oxygen is still present the soluble phosphate is bound in the sediment to metal-complexes of iron (Fe^{+++}) and calcium (Ca^{++}). When all oxygen is consumed, anaerobic bacteria take over the further breakdown of organic matter. Sulphur bacteria reduce sulphate producing hydrogen sulphide; phosphate is released from the sediment, increasing the pool of soluble phosphate in the water (Fonselius, 1969). It is therefore of great interest to know the net production of the aerobic and anerobic bacteria, to know the rate of uptake of various sediments, the uptake and release of phosphorus from and to sediments and the rate of hydrogen sulphide production. These tasks require a great effort by experienced microbiologists. Owing to inadequate knowledge these processes have not been included in present ecological models (see below).

2.5 An Integrated Model of the Baltic Ecosystem

2.5.1 General extensions of existing models

A simple model of the Baltic ecosystem was briefly discussed in the introductory section of this chapter. It should be clear from the more detailed considerations of the different physical, chemical and biological processes given in Sections 2.2 - 2.4 that such a simple model is inadequate for drawing firm conclusions. Particularly the boundary regions, i.e. the coastal zones and the bottoms as well as the region of exchange with the North Sea need to be described much more accurately in order to be certain that the contributions from processes in these areas to the total budgets are satisfactorily incorporated. A prime task must therefore be to develop sub-models for the different kinds of shores that are found in the Baltic, verify them by intensive studies in selected representative areas and incorporate them in an overall model. Similarly a much more penetrating analysis of the processes in the Danish Sounds (as well as in the shallow seas outside and inside the narrow straights, i.e. the Kattegat and the area of Bornholm) is needed.

As the next stage we need to develop a model that interconnects these processes. Using the energy circuit language we arrive tentatively at a picture symbolically described in Figure 3 (p.19). In the centre of the Figure the processes in the Baltic proper above and below the halocline are described in a manner quite similar to that given earlier. The North Sea as a source and/or sink both for the waters above and below the halocline is determined by processes (work-gates), essentially meteorologically controlled, shown on the left in the Figure. To the right, one of the coastal regions has been described in a very simplified manner having in mind that a number of such sub-models might be incorporated to describe properly the variable character of the Baltic shores. Some further details of these will be given below.

The reservoirs in the model described in Figure 3 are assumed to be homogeneous bodies of water; in fact they are not. This spatial inhomogeneity represents a fundamental difficulty when trying to develop ecological models further (cp. Section 2.1). In the same way rapid variations in time in comparison with the characteristic time steps used in the integration of the ecological models are ignored and the justifications for doing so are not always convincing. Efforts in two directions seem particularly urgent to eliminate such inadequacies:

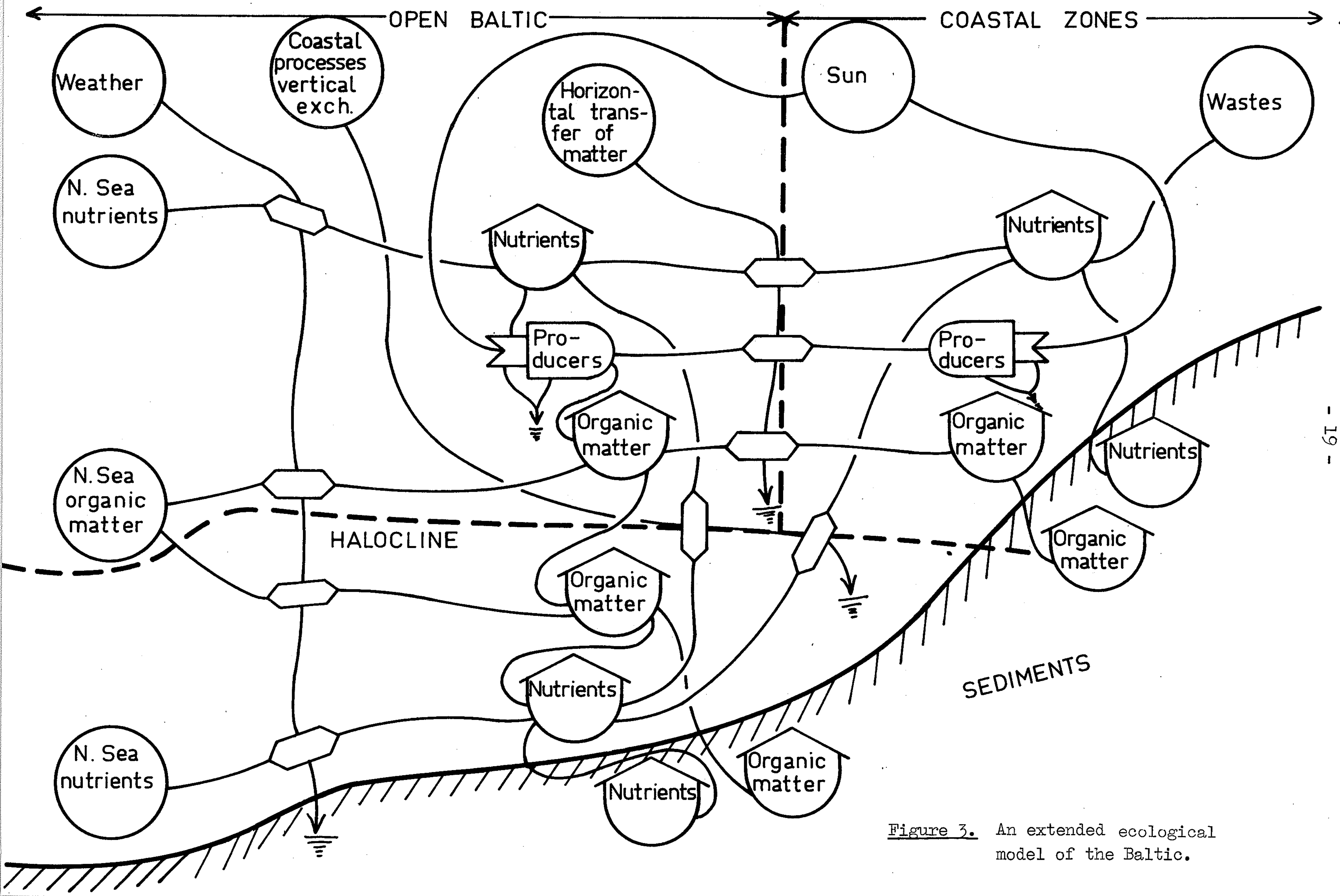


Figure 3. An extended ecological model of the Baltic.

1) An effort should be made to monitor the biological parameters at selected points to establish the variability in space (patchiness) and time. If it is found that considerable variations occur it will be necessary to account for this in the modelling. It may, for example, significantly affect the manner in which the exchange between the coastal areas and the open sea is to be described.

2) Variables describing the biological processes should be introduced into the hydrodynamical models to study in which way the transfer of matter is accomplished. Since this kind of exchange largely determines the characteristic rates with which the system as a whole responds to external influences it obviously becomes of prime importance to explore further the manner in which such exchanges take place.

2.5.2 Coastal processes

The coastal areas are particularly important in the ecological models both because most essential processes occur there and need to be dealt with accurately, and also because we are often concerned with those parts of the system when exploiting the resources of the Baltic. Since the variability in space and time is particularly large near the shores, these parts of the total system need careful study.

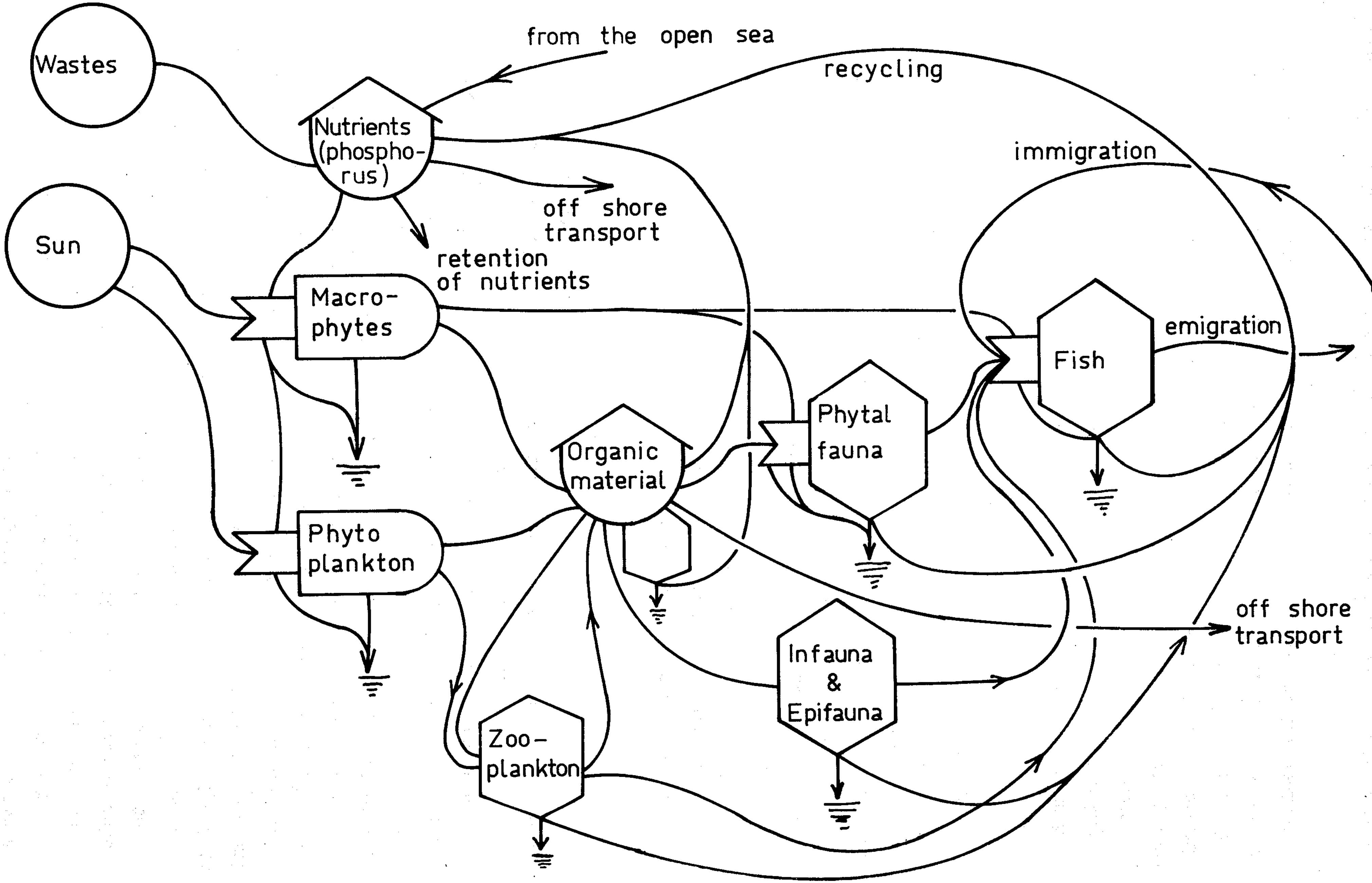
The total model in Figure 3 shows the connection between the coastal zones and the open sea in a very simplified way. The state variables have been restricted to those directly incorporated in the primary production - sedimentation cycle as our information here is far less than our knowledge of oxygen fluctuations or distribution of bottom organisms, for example. The immediate aim is to force the collection of these data as soon as possible, so that more complete models can be constructed and tested.

The modelling of the coastal system of course depends on local conditions. Whereas rocky shores dominate in the north, interspersed with extensive areas of *Phragmites* and other plants of shallow mud bottoms, the southern shores of the Baltic are mainly sandy. The role of the coastal systems in the entire Baltic ecosystem is partly as a feeding and nursery ground for fish, which, like herring and cod move between the offshore areas and the coast, acting as living fluxes of energy and matter. The coastal areas also constitute more or less effective filters for the nutrients in the waste flows from land. They retain the nutrients flowing through the skerries, the estuaries and the "Haffes" by creation of biological matter. Some of the nutrients are also precipitated and so only a proportion of the original amounts reaches the offshore areas. The decomposition processes, working on the dead biological material, especially during the winter season, may release the bound nutrients, thus exposing them to further transport.

Below three different types of shores are described in some more detail: the rocky coast (often including archipelagos); the shallow mud bottoms (with Phragmites, Potamogeton, etc.) and the sandy shores (with very little vegetation). The descriptions are very much simplified for two main reasons. Firstly, neither time nor money will be available to make detailed studies of the coastal systems. Secondly, it is important to get information on the main fluxes in the system as soon as possible to get a reasonably reliable, but simple, basis for the development of models for the coastal zones, both ecological models in the traditional sense and hydrodynamical models with biological parameters included. Examples of more detailed models of coastal systems are given by Jansson (1972). In the models presented below only the most important features are incorporated and compartmentalized. Oxygen e.g. is regarded as a non-limiting factor and therefore omitted. It should be emphasized that even though the following descriptions are given in terms of the Odum's energy-circuit language the processes described could equally well be included in a hydrodynamical model using an appropriate number of chemical and biological parameters in addition to those physical parameters that appear in the basic equations of motion.

Rocky shores

The rocky shores (Figure 4, p.22) are dominated by the macrophytes consisting of sessile green, brown and red algae, forming parallel and stratified bands along the shorelines. Some of these are annual (e.g. Cladophora), others perennial (e.g. Fucus) with a great difference in turn-over times. They also often have epiphytes, which are incorporated in the total biomass. The plants take up nutrients effectively from the water during the photosynthetic process. The annual plants together with torn off or spontaneously fragmented parts of the perennials represent a flow of solid organic matter (detritus), which is deposited on the bottom. During subsequent decomposition it might be transported off shore by bottom currents. This is symbolized in Figure 4 by the arrow from the organic storage, which therefore constitutes one connection to the open Baltic. The phytoplankton along the rocky shores certainly have a much smaller biomass than the macrophytes, but, owing to the much faster turnover time, the net production may attain fairly high values. The dead plankton is more easily broken down than most organic matter. Both phytoplankton and microphytes secrete considerable amounts of dissolved organic matter, which is included in the storage symbol for organic material. The decomposition of the particulate matter, which in coastal areas certainly goes on faster than in the offshore areas, is the result of the desinte-



<u>Figure 4.</u> Rocky shores and shallow soft bottoms.

gration by macrofauna, microfauna and finally by bacteria. These processes are not represented in the model except as a feed-back of nutrients from the organic storage and an outflow from the nutrient storage, symbolizing both the precipitation of discharged nutrients and the uptake of nutrients (especially phosphorus) by the sediments during aerobic conditions. The hexagon representing the bacteria (decomposers) is attached to the storage module for the organic matter because of the difficulty of separating these two variable.

The smaller animals found in the algal belts use the plants mainly as shelter, living on organic material. The pathway from "macrophytes" to "phytal fauna" therefore does not represent any flow of energy but symbolizes the algae as substrate and shelter by a work-gate: the more algae, the more animals. The bottoms off the rocky shores contain areas of soft sediments harbouring animals such as worms, crustaceans and molluscs. They are labelled as infauna in the model. The bare rocky bottoms usually harbour large numbers of blue mussels, included as "epifauna" in the infauna module. The free waters of the coastal zone also maintain large populations of zooplankton, feeding both on phytoplankton and organic material. Both the phytal fauna, the epi- and infauna and the zooplankton constitute food for many fishes, lumped together into one module. This is connected to the offshore areas through the flows of "immigration" and "emigration", which also stress the importance of the archipelago as nursery grounds. The metabolic processes of the various organisms create waste products some of which are incorporated in the nutrient pool as recycling loops. The other connections with the offshore areas represented in the model are the inflow of nutrients from the open Baltic and the outflow of water with the remaining amounts of nutrients.

Shallow soft bottoms

The shallow soft bottoms show in their greatly simplified form considerable similarities with the rocky shore model and can therefore be represented by the same diagram (Figure 4). There are, however, considerable differences in turn-over rates and flows. Soft bottoms favour the higher plants especially <u>Phragmites.</u> This coarse "mechanical filter" catches floating debris which further increases the amount of organic matter. These waters are often rich in nutrients which also favours the phytoplankton; the shallow waters are readily warmed up during spring and constitute a feeding area for many organisms, especially fish which migrate here to spawn. The young feed partly on the rich sediment and its infauna and partly on the rich fauna associated with the macrophytes, e.g. insect larvae, crustaceans and molluscs. The pathway between organic matter and macrophytes symbolizes the amount of substrate available for macrophytic growth. Both the phytal fauna and the fish are positively stimulated by increasing areas of macrophytes (increasing availability of substrate and shelter). By comparing the flow of nutrients from land with the outflow to the open Baltic, a rough idea of the ability of this sub-system to serve as a nutrient trap is obtained.

Sandy shores

The sandy shores (Figure 5, p. 25) have little vegetation, owing to the unstable bottom. In more sheltered places underwater "meadows" of Zostera may attain local significance but generally the sessile diatoms are the most important producers. The phytoplankton and zooplankton are of great importance in this system. The infauna consists mainly of worms and molluscs, which constitute food for flatfish and cod, for example. The shallow sandy areas are also important as nursery grounds. This subsystem has probably the least nutrient-retaining capacity of all the three coastal models.

2.6 Concluding Remarks

Research along the lines outlined above should further advance the description of the Baltic as a complex ecosystem and should yield more specific and firm answers to a series of basic scientific questions. A better understanding of the reasons for the long-term variations is particularly important. For this purpose long-time series of those parameters that describe such changes should be obtained. Investigations of undisturbed sediment cores are very useful in this context. Also a careful study of the history of fishery in the Baltic and its possible dependence on changes in climatic and hydrographic conditions may be of interest. The changing input of toxic substances, e.g. mercury, can be studied using museum collections of fish and sedentary sea birds and comparison with recent samples.

It will be clear from the discussion in the next chapter that the further development of models of the Baltic will permit more definite answers to the basic research objectives that will be formulated in the next chapter. We shall therefore adopt the presentation in previous sections as the basis for a discussion of specific research tasks to be carried out jointly by the Baltic countries.

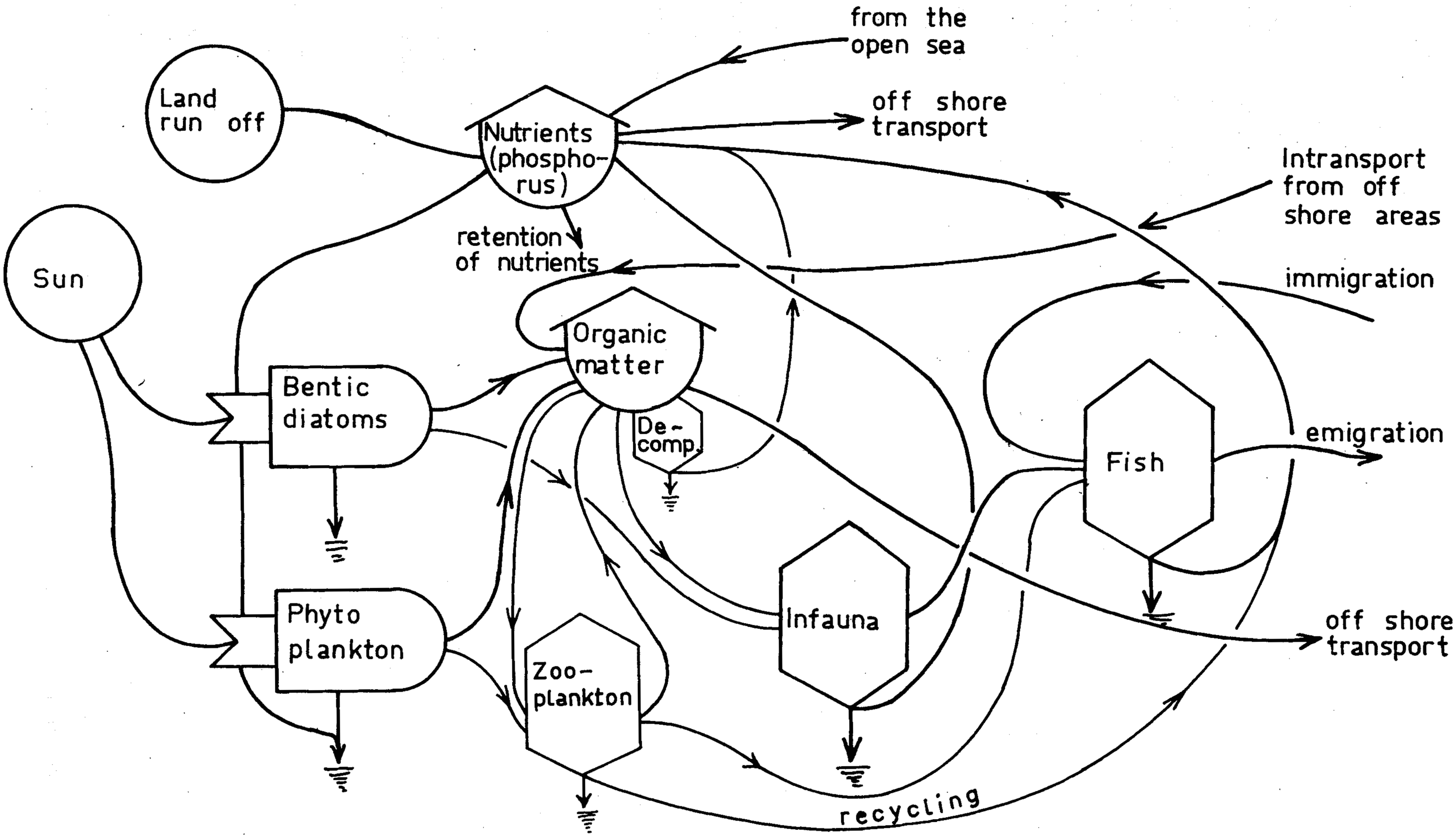


Figure 5. Sandy shores.

3. MAN'S INTERACTION WITH THE BALTIC ECOSYSTEM; DEFINITION OF RESEARCH AIMS

Man's effects on the Baltic have increased with increasing population and industrialization of the bordering countries. The present effect of the exploitation of the Baltic as a natural resource is still rather limited. The primary question besides possible overfishing is related to the increasing flow of organic matter and plant nutrients to the Baltic. Locally and for limited periods of time this may cause excessive eutrophication, but its overall influence is not yet well understood. There is a possibility, however, that the frequent appearance of hydrogensulfide in deep layers during the last decade has been caused by the increasing flow of pollutants to the Baltic. Other pollutants (primarily DDT and PCB) have been found in high concentration in certain species in the southern parts of the Baltic, but an impact of these substances on the ecosystem as a whole has not yet been demonstrated. The transfer and accumulation of those substances in the Baltic ecosystem is causing considerable concern, however.

3.1 The Baltic as a Resource

The Baltic is rich in resources for the human economy, including its function as one of the most heavily frequented waterways of the world - both for cargo and for passenger traffic - and for its amenity value for many millions of people living along its shores or visiting it for recreation.

The Baltic represents an important fishery resource. Furthermore its mineral resources are being exploited - at present mainly gravel, in the future possibly oil and gas. The water itself is being used for cooling purposes and may in the future possibly be made into a freshwater reservoir. Man's use of these resources implies their alteration and therefore an impact on the entire ecosystem. Exploitation of gravel destroys bottom communities and may cause increased turbidity of the water. Both effects are very local, however. The same is true for the use of sea water for cooling purposes. Even a considerable increase in the number of power plants and their output of heated effluents will probably not have far reaching ecological effects. The most serious changes would occur if ever plans materialize to transfer the Baltic, or a large part of it, into a large freshwater reservoir by locking the entrances.

Fishing mainly affects the final links in the food chain and the influence in general is limited to the favouring of competitive species which are not, or little, exploited. Bottom trawling destroys part of the bottom fauna. The major effect of the fishery is on the resource itself. The increase in fishing yields, shown in Figure 6 (p.28), is mainly due to an increase in the fishing effort but also partly due to higher recruitment and/or growth rate in certain species (e.g. cod). A discussion of possible overfishing is not the purpose of the present Report but it should be noted that ICES at its Special Meeting on Cod and Herring in the Baltic, held in Helsinki, September 1971, expressed concern about the rapid increase in exploitation and stressed the need for an international convention in order to ensure optimum use of the resource. The Baltic, as a more or less closed system where fish is the most important living resource for man, offers itself to scientifically controlled international fisheries management.

An understanding of the Baltic ecosystem is, however, necessary to be able to judge what other competitive uses of the Baltic might mean for the fish stock. It should also be stressed that all efforts put into the fishery and its optimum management will be jeopardized by the accumulation of toxic substances in fish. Again we need to improve our understanding of the pathways of toxic substances through the food chain, and reduce or ban the release of toxic substances into the Baltic, whenever it is clear that damage is being caused (see below). Research programmes must be designed to provide the necessary knowledge.

3.2 Excessive Eutrophication

The nutrients are the key factors determining the amount of primary production whenever light conditions are sufficient. Therefore an additional input of a particular nutrient that is a limiting factor in this sense will increase the overall productivity of the area up to a level, at which some other parameter limits a further increase. A supply beyond that level will lead to an accumulation of the given nutrient which later, at times or places of shortage, may be again brought into the production cycle. A recent increase in primary production as suggested by Fonselius (1972) and others could result in an increased production of zooplankton and fish and cause higher yields for Baltic fisheries. The series of data on primary and secondary production in the Baltic are far too scanty to permit the attribution of such trends and their causal relationships to man-made input of nutrient-rich organic matter.

While positive effects of eutrophication on the exploitable productivity of the Baltic are easy to envisage, direct negative effects are less likely. There is, however, the possibility that increased input of organic matter

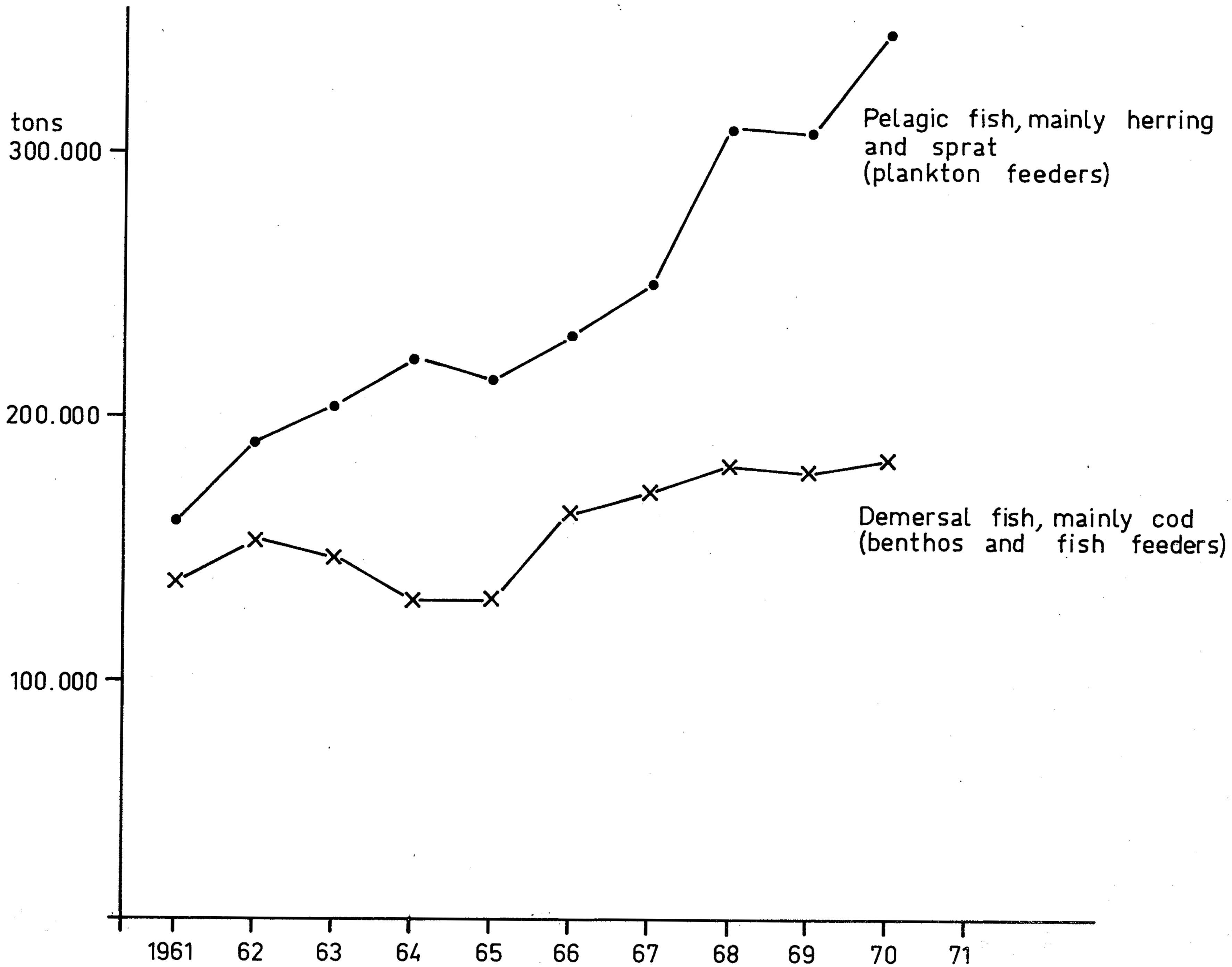


Figure 6. Annual catch in the Baltic (excl. Gulf of Bothnia and Finland) according to Ackefors (1972).

is the cause of the present high production of large medusae (jelly-fish) which cause certain trouble to fisheries and even to tourists. The only serious problem related to eutrophication of the Baltic by natural and man-made processes is that arising from insufficient renewal of the deep water of the Baltic which cannot therefore satisfy the oxygen demand of biological and chemical processes related to the decomposition of organic matter. In certain areas the organic production and/or the inflow of organic matter - both dissolved and particulate - are so high compared with the oxygen supply that anoxic conditions occur at the sea bed and in the lower part of the deep layer. It should, however, be recalled that anoxic conditions have prevailed in deeper parts of the Baltic long before man significantly contributed to the supply of nutrients by sewage disposal. This is for example shown by analysis of bottom samples (cf. Hallberg, 1972).

The extent of the oxygen-free zones in the Baltic cannot be taken as a direct measure of sedimentation of organic matter. The main oxygen source of the layers below the halocline is the Kattegat water entering the Baltic at irregular intervals. We have only very rough estimates of the oxygen budget of these layers (Fonselius, 1972). Fonselius has estimated the amount of organic carbon brought into and produced in the Baltic per year. Applying Redfield's (Richards, 1965) relation between oxygen utilization and carbon oxidation, Fonselius concludes that 10% of the amount of carbon annually added to the Baltic is sufficient to utilize all the oxygen below the halocline. We do, however, not know if the amount of organic carbon in the Baltic has increased during the present century, but there are indications that it has. The oxygen budget of the deep water seems to be the key factor in estimating detrimental effects of the eutrophication of the Baltic. To understand the oxygen budget proper estimates of the transport through the Danish Sounds and of the exchange processes through the halocline and between the coastal waters and the open Baltic are needed. Measurements of sedimentation rate and oxygen demand of organic matter at the bottom are also important.

3.3 Toxic Substances in the Food Chain

During the past few years a considerable amount of work has been reported on the occurrence of toxic substances in organisms in the Baltic. Major efforts have been devoted to the tracing of halogenated hydrocarbons, particularly DDT and PCB and mercury in Baltic fish, birds and seals (see e.g. Johnels et al., 1967; Westöö, 1967; Jensen et al., 1972,a and 1972,b). On the other hand sampling of lower organisms has been more limited. In this case there are, also, considerable difficulties in chemical analysis. Recently, however, the accumulation of chlorinated hydrocarbons in plankton and other invertebrates has been studied in coastal areas of the Baltic (Jensen et al.1972,b; Olsson et al., 1972).

Analysis of sea water has been more or less neglected. There are several reasons for this. Organisms have been used mainly because of their ability to integrate variations in the occurrence of the substances caused by streams, winds, density of the biomass, seasonal changes etc. Almost all of the DDT and PCB are dissolved in organic matter, which in turn is dissolved or suspended in the water. Migration of plankton from one water volume to another will thus concentrate and transport these compounds.

It is well known that nutrients are primarily emitted in coastal waters. This is true also for other compounds released with waste waters such as chlorinated hydrocarbons and heavy metals. However, some of the compounds are also brought to the Baltic as air-borne fall-out. Studies on a few species in littoral and pelagic food webs have indicated stronger accumulation in pelagic food webs compared with littoral. (Olsson et al., 1972). This agrees with more extensive investigations on fish (Jensen et al.,1972a). Further such studies should be made in the open Baltic and its pelagic food web. The great importance of the coastal zones both for the Baltic ecosystem (areas of high floristic and faunistic diversity and of high primary production) and for human activities justify that in national programmes emphasis is given to the study of toxic pollution in the coastal areas. Standardization of methods in field collection procedure as well as in chemical analyses is needed for comparability of results. Special research efforts are also required with regard to the storage, accumulation, metabolism, and later release of pollutants in some well defined and important food webs.

Little is known about the transfer of toxic pollutants from the coastal zones into the open Baltic. This transfer must occur partly by passive transport of organic matter, dead or living, partly by transport of dissolved pollutants and partly by migratory species which accumulate those substances. These transfer processes, together with the atmospheric transport and the inflow from the North Sea, determine the input to the open Baltic. Here the fate of most of the toxic substances is unknown and needs intensive investigation in order to predict future accumulation. The immediate effects of toxic substances on marine ecosystems have until now been restricted to relatively few cases of drastic pollution mainly effecting final consumers such as predatory vertebrates. Sublethal effects in the Baltic area such as eggshell thinning due to DDT-substances have been demonstrated on predatory birds (Andersson et al., 1972). Reproduction decline in salmon from the Baltic environment due to PCB has been reported. However, disturbances on the ecosystems in general are far more difficult to demonstrate.

It should be pointed out that in the Baltic environment organisms live near the limits of their tolerance because of low temperatures over the major part of the year, low salinity and, often in many areas, low oxygen tension. Additional stress by toxic substances therefore might have more detrimental long-term effects than under more favourable conditions.

The long residence time of the water masses in the Baltic and the slow degradation of toxic substances at low temperatures may cause high accumulation.

Extensive forestry and agricultural operations use large amounts of pesticides, a considerable part of which drains into the Baltic. Furthermore, the industries around the Baltic coast drain wastes containing heavy metals and chlorinated hydrocarbons (PCB) and the intense traffic of boats contaminate the water with PCB (Jensen et al., 1972,b). The return of toxic substances to man through fish has created much more attention than man's poisoning effect on the ecosystem but more systematic sampling of food fish and of key elements of the food chain is required before the significance of this development is well understood. It is recommended that a list of species which should be monitored to safeguard man and his interests be established. In order to understand the main storages as well as the pathways of toxic substances through the food chain specialized projects of sampling and analysis of selected key organisms, sediments and seawater are needed. For sediments and seawater much research must be done to define sample objects and methods. For the analytical work calibrating studies must be carried out. Special efforts must be made to separate different metabolic products in order to understand the mechanism of degradation in complete natural systems. Physiological studies on the retention time of well defined toxic substances in different organisms under various environmental conditions are recommended. These must be complemented by field studies of well defined food webs to establish the accumulation degradation and transport in the natural environment.

3.4 Oil Spills and Dumped Solid Wastes

3.4.1 Oil pollution

To quote from the final Report of the Seminar on Methods of Detection, Measurement and Monitoring of Pollutants in the Marine Environment (FAO, 1970): "Oil Pollution ("Oil Pollution" here refers to the forms of pollution that are brought about by heavy crude oil and its various fractions) is the almost inevitable consequence of the dependence of a growing population on an increasing oil-based technology. The widespread production and transportation of oil and its use as fuel, lubricant and chemical raw production leads to losses which are wide, but not evenly spread". Further reference is made to an article by Hela (1972).

The varying harmful effects of incidents of oil pollution are not yet properly understood. One may state, however, that different oils and oil products vary in their toxicity and in the mode by which they interfere with marine life processes. Generally, low-boiling-point fractions are more severely toxic on a short-time scale than the high-boiling-point fractions. Monitoring of oil should aim not only at the detection of spills but also ascertaining long-term changes in marine systems and in the degree of pollution of the seas. The main dangers and/or harmful effects of petroleum (crude oil) and its distillates are: fouling of beaches and shores, toxicity affecting fish and its marketability. In reality, the general public is more aware of some oil catastrophes than of any other kind of marine pollution but at least in the Baltic and at the present time oil pollution is certainly less significant than some other forms of marine pollution.

It is most encouraging that through the efforts of the International Maritime Consultative Organisation and through the active, constructive cooperation between all countries bordering the Baltic Sea, this sea is better protected from dangers of oil pollution than many other seas. Nevertheless, because of the huge, ever increasing amount of oil transport, the dangers of oil pollution must be realistically assessed, and feasible measures must be taken to reduce their possible effects.

3.4.2 Dumped solid wastes

Dumped solid wastes, like floating or sinking containers mainly affect fishing operations; they are also often obnoxious. There is little need for basic research concerning such pollution, except on questions of its transport by bottom currents and disappearance by silting, but preventive measures may well be needed.

3.5 Research Objectives

It is clear from the discussions in this and the previous chapter that the main objectives for research regarding the Baltic should be to answer the following questions:

1. In which way is the characteristic time-scale of changes in the structure of the Baltic (temperature, salinity, stratification) dependent on the climate, the interplay between run-off from rivers, water exchange with the North Sea and the internal mixing processes within the Baltic?

2. What are the decisive mechanisms that determine the budget of oxygen, nutrients and organic matter in the deep waters below the halocline, particularly the vertical exchange, and what are the corresponding steady states towards which the Baltic would change as a result of the adoption of different policies for its use as a recipient for man-made waste products?

3. What are the mechanisms for exchange between inshore and offshore waters and what is their significance to the release of waste in coastal waters?

4. What are the ecological pathways of toxic substances?

5. What is the significance of changes of the chemical regime of the Baltic - in respect of the degree of eutrophication and the occurrence of toxic substances - for the use of the Baltic as a natural basin of food production for human consumption?

6. What predictive models of the Baltic can be developed for management authorities and what degree of confidence can be placed on the predictions?

The six basic questions formulated above are adopted as the major research objectives for an "International Baltic Pollution Study" (IBPS).

4. PLAN FOR ACTION

4.1 General

Considerable efforts are today devoted to research in the Baltic by the different states bordering it. A major part of this effort is devoted to long-term monitoring activity to establish as well as possible the structure of the Baltic system and explore possible secular changes. These activities are the foundation of our present knowledge.

Although it is obviously necessary to continue this effort, special research projects must be developed to provide a better understanding of the most important processes (physical, chemical and biological) that determine the state of the Baltic and which will be affected by man's activity. We shall outline below a number of such projects that are judged to be of prime importance in the present context. It is proposed that such a programme be planned and initiated jointly by the Baltic states. It may well be necessary to extend these studies over more than one year and this will become clear during the detailed planning phase (see below).

It may be possible to divert some of the facilities now being used for the regular observations of the Baltic into such special efforts, but the ongoing monitoring certainly cannot be abandoned during a more extended period. Additional resources must be made available for expanding the research activities in the way proposed.

The emphasis in the present plan is on research directed at the Baltic system as a whole, but it is also clear that some local problems need to be well understood while keeping the overall objective in mind. There are considerable activities going on in the different countries which have been initiated to resolve important local problems, but which are of less relevance to the Baltic problems as dealt with here. Since international cooperation is usually not required for their solution, they will not be dealt with here unless they also have a bearing on the overall problem. It is, however, obviously important to maintain close contacts between researchers in the Baltic countries to exchange information on progress also in these fields of research. On the other hand it might prove necessary to reconsider priorities with regard to some of those activities. It should be born in mind that many of the national inshore and offshore stations have been regularly monitored for many years. The long-term series of data that are being obtained are indispensable for evaluations of possible man-made effects. The continuation of most of these observations (hydrographical; biological, including fishery statistics) is a necessity. The coordination of such activities between the countries concerned will be dealt with here only to the extent it has bearing on the specific research projects that are proposed. It should particularly be recalled that as part of the International Hydrological Decade activity a joint programme for the determination of the water and material balance of the Baltic has been developed. This task of course will require several years of observations, but its further conduct is obviously very essential for an understanding of the behaviour of the Baltic. The project should therefore receive continuous support.

4.2 Selected International Research Projects of High Priority

The Working Group considers that the following seven research tasks should be given high priority.

Task 1: Exchange of Water and Dissolved Materials with the North Sea

This task is aimed at:

a) an understanding of the mechanism that determine the water transfer to and from the Baltic as a function of temperature and salinity and meteorological conditions.

b) the determination of the flux of phosphorus, nitrogen compounds, total organic matter and possibly other constituents to and from the North Sea.

Regular cross sections in the Danish Sounds should be monitored during the whole year (probably several years), with measurements of at least:

a) current velocity and direction

b) temperature

c) salinity

d) total phosphorus

e) nitrogen compounds ($N-NH_3$; $N-NO_2$; $N-NO_3$; urea)

f) total organic matter.

Since it certainly will be difficult from interpretation of measurements in the Danish Sounds themselves to determine the characteristics of water masses that finally enter the deeper layers of the Baltic, it is important to establish the features of the flow at a cross section in Kattegat and also well into the Baltic, e.g. in the Bornholm area. It is proposed that several alert periods of 4-6 weeks are chosen in the spring and in the fall, but it is not necessary that these periods coincide with those chosen for some of the following tasks. It may well be necessary to maintain regular observations for longer periods. Pilot studies before 1975 should help in the final design of the observational effort.

Task 2: Open Sea Experiment

This task is aimed at:

a) an understanding of the mechanism of the vertical transport of momentum and matter in the open sea, especially in the vicinity of and through the halocline.

b) the determination of the possible interaction between the upper and lower layers of the Baltic through breaking internal waves, shear flow and other mechanisms.

c) investigation of water and matter transport in the lower layers.

Three stations (Gotland Basin, northeast from Gotland, Bornholm Basin) should be operated. The operating period of stations and their location might be the same as for the open sea multidisciplinary continuous stations (Task 5; see below) except for the station northeast from Gotland.

Measurements:

a) time series of vertical distribution of temperature and salinity with especially accurate measurements in the region of the thermo- and the halocline

b) continuous measurements of the vertical distribution of the velocity including its vertical component

c) velocity time series in the lower layers

d) vertical transport of materials, measured simultaneously with current velocity using recording probes

e) studies of the dispersion of dye.

Task 3: The Baltic Circulation Experiment

This task is aimed at:

a) an understanding of the general circulation of water and materials in the Baltic

b) the determination of parameters to be used in more advanced dynamic circulation models.

3a: An exploratory numerical circulation model

It is important to develop a reasonably detailed numerical model to determine the optimum deployment of efforts and instruments in Task 3b (below) and other tasks. A three-layer, wind-driven model is probably required.

3b: An observational effort

The task requires measurement of salinity, temperature and if possible current velocities and e.g. silicate or phosphorus at 50-100 stations during a short period (up to a week). The measurements at each station should be carried out at all standard depths. As said above it is important that numerical experiments preceed the design of such an observational effort. The experiment can be carried out if research vessels of all countries bordering the Baltic take part in it.

Task 4: The Coastal Waters Dynamics Experiment

To be able to describe more accurately the exchange between the coastal waters and the open sea and the associated biological processes e.g. primary production, in the lateral boundary layers as roughly modelled in Figures 3 to 5, 4-6 week experiments should be conducted in:

a) a rocky shore area, e.g. Swedish or Finnish coast

b) a sandy shore area, somewhere at the southern Baltic coast, e.g. Polish coast.

Sections perpendicular to the coast should be regularly investigated from the shore to the point beyond that at which the halocline intersects the bottom. To be able to distinguish between transfer processes along the coast and perpendicular to the coast two parallel cross sections at a distance of 20 to 40 km apart are required, probably forming the lateral boundary terminations of any transect planned under Task 2. The possible effect of river out-flow in the region under study need to be considered.

If difficulties arise in maintaining such a programme with full regularity, priority should be given to periods immediately before, during and after spells with moderate to strong winds. The following parameters need to be measured.

1. Current velocities at several depths and with sufficient spatial density to permit the determination of coastal currents.

2. Temperature, salinity, oxygen, phosphorus and nitrogen compounds at the same stations as chosen for current measurements.

3. Phytoplankton - primary productivity.

4. Suspended and dissolved organic material and, if possible, the settling rates.

5. Drifting organic matter on the bottom and, if possible, changes in its distribution during the period of investigation.

Task 5: Open Sea, Multidisciplinary, Continuous Stations (cp. also Task 2).

This task is aimed at improving our understanding of some of the processes that are important in the biological-chemical cycles and thus for a judgment of the possible eutrophication of the open Baltic.

Three stations (Bornholm Basin, Gotland Basin, south of the Åland Isles) should be operating in April, August and possibly November for at least 10-14 days each by interdisciplinary groups. The study of each station should include:

a) Repeated measurements of primary production.

b) Sampling and analysis of seston for phytoplankton content, particle size distribution, C:N:P analyses of seston at different depths.

c) Oxygen consumption of the sea bed. (Measurements on "undisturbed" cores or in situ equipment parallel with the sampling of seston).

d) Sedimentation rates, and C:N:P analyses of sediments.

e) Nutrient concentrations in different layers of water with particular attention to concentrations between the summer thermocline and the permanent halocline and near the bottom, as well as at the sediment surface.

f) Dissolved organic matter (as with nutrients).

g) Microbial activities through the water column and at the sea floor.

h) Vertical distribution of temperature, salinity and possibly currents during the observation periods.

i) Development of methods to determine the vertical transport of dissolved matter (nutrients, organic matter, pollutants, gases) through the halocline.

The study requires, for each station and period, the allocation of a rather large research vessel (or two somewhat smaller vessels). Although the various investigations at each station should be done simultaneously, it is not necessary to work all three stations at exactly the same time.

Task 6: Year-Round Biological Observations (and Experiments) Designed to Optimize Monitoring of Future Changes

Biological monitoring of the productivity of the Baltic will require a network of stations. In preparation of the network a number of year-round stations have to be established at which biomass and wherever possible productivity should be estimated at the different trophic levels. The project of a network requires reliable and fully comparable measurements and therefore considerable methodological standardisation during the preparatory phase. In planning the station system and the details of the measurements for each of the stations extensive use should be made of existing national monitoring activities connecting them to a significant, international system of year-round observations covering the various parts of the Baltic.

The following kinds of measurements and assessments are necessary:

a) primary production of phytoplankton, and benthic macro- and microphytes

b) abundance of zooplankton, particularly herbivores, and of benthos

c) abundance of fish (both non-commercial and commercially important species).

Hydrographical observations are expected to be made during all work at sea and to be coordinated with other hydrographical work.

By frequent repetition of biological sampling attempts should be made to estimate secondary and tertiary production. These estimates cannot be based solely on biomass measurements. Data on reproduction capacity, growth and mortality rates of key elements of the food webs will be required. Use should be made of existing long-term series in fish stock analysis and of catch statistics.

At certain stations investigations on selected food webs and communities will form an important part of this task.

Task 7: Determination of Toxic Substances

The aim of this task is to determine the ecological pathways of toxic substances in the Baltic.

Samples should be collected of some well-defined elements in the food web at outshore and inshore localities in the following areas:

West Bornholm
East Bornholm
Lübeck Bay
Gulf of Gdańsk
Southern Gotland
Archipelago of Trosa
Gulf of Finland
Northern part of the archipelago of Åland
Kvarken.

Two samples of each species from each locality shall be homogenized and analysed and samples will be collected 6 times a year. At each station samples of water and sediments should be analysed for toxic substances whenever it seems feasible with the present sensitivity of methods. The fat and water content should be determined in each sample so that the levels can be given on fresh, wet and fat weight basis. The substances should be measured in a standardised manner:

mercury	PVC etc.
lead	HCB
copper	PCBs
cadmium	pesticides
zinc	
arsenic	

The following elements of the food web need to be analysed:

Pelagic food chain

Surface water:	Phytoplankton Zooplankton Detritus Jelly fish (*Aurelia aurita*)
Bottom water:	Zooplankton Detritus
Fish:	Herring (*Clupea harengus*) and/or sprat (*Sprattus sprattus*)
Birds:	(if available) Razorbill (*Alca torda*)

Demersal food chain

Rocky shore:	Detritus *Fucus* *Cladophora* *Idothea baltica* *Gammarus oceanicus* *Mytilus edulis* Three-spined stickleback (*Gasterosteus aculeatus*) Pike (*Esox lucius*)
Deep bottoms:	Sediment (surface) *Harmothoë* *Mesidothea entomon* *Macoma baltica* Fourhorn sculpin (*Cottus quadricornis*) Flounder (*Platichthys flesus*) Cod (*Gadus morhua*)
Birds:	(if available) Goosander (*Mergus merganser*) Eider duck (*Somateria mollissima*)

4.3 Planning and Implementation

The proposed research programme has five phases.

1. Definition phase. The scientific and practical objectives will be defined and agreed upon. This phase must basically be accomplished by the scientists, but of course with a clear awareness of questions that confront society today in the environmental field. The programme must

be neither a purely academic one nor a shortsighted one aimed only at solving problems of immediate concern. The present draft programme is a first step towards accomplishing this task but this phase will not have been completed until a more thorough discussion among Baltic scientists has taken place. Even though it is important to make reasonably firm decisions on the overall programme objectives, some room should be left for later modifications as knowledge increases during the planning and preparatory phases 2 and 3 (see below). It is hoped that preliminary decisions by responsible authorities to take part in a joint programme for this study of the Baltic Sea will be taken before the end of 1973 or early 1974.

2. Planning phase. During this phase quite detailed and specific plans for the programme are drawn up, agreed upon and authorised by participating Governments. Some such planning work has been started by the Action Planning Group that has been created by the ICES/SCOR Working Group on the Study of the Pollution of the Baltic. It is, however, obvious that a detailed plan cannot be finalized until it is reasonably clear what resources can be made available. When an agreement is reached regarding Phase 1 some indications should also be given on the degree of participation by respective countries. On the basis of such information this phase should be concluded during the first part of 1974 and a firm agreement reached in the latter part of 1974.

3. Preparation phase. Preparatory work in many fields will be required for the successful conduct of the experiments. Some work can start immediately and relevant proposals are given in Section 4.4. Further activities will have to be initiated as the planning phase (2) gets under way.

4. Implementation phase. The implementation of the programme will have to follow a rather rigid schedule (as agreed upon under 2 above). Basically the observational effort will consist of two parts:

   a) Intensified monitoring of selected parameters throughout the study period.

   b) Special observing efforts during "alert" periods of 4-6 weeks. Three such periods are proposed for April, August and November.

5. Evaluation and analysis phase. This phase will start during the implementation phase and one may foresee some meetings during the study period for checks and evaluation to permit an optimum conduct of the

programme during the remainder of the period. The evaluation and analysis of the results will continue for several years, and it should be realised now that the financial resources for this phase are not one order of magnitude less than those for the implementation phase, which regrettably is so often assumed.

4.4 Preparatory Work

The launching of intensive activity in the study of the Baltic in the proposed study requires considerable preparations. Individual research groups will be able to formulate specific research tasks on the basis of the proposals made above. The following projects seem particularly important:

1. Analysis of the data obtained from the Baltic Year 1970.
2. Analysis of available current measurements in coastal areas and/or possibly the launching of a pilot study with a few cross sections to determine an optimum strategy for the conduct of Task 2.
3. Development of exploratory circulation models.
4. Further development and standardisation of analytical methods for pollutants (see the Report of the first meeting of the Working Group).
5. Base-line study of pollutants in commercially important fish and mussels.
6. Methods for measuring the O_2-consumption at the sea bed, even in greater depth, by taking "undisturbed" core samples with the near-bottom water.
7. Investigation of the relative importance of different substances as limiting factors for primary production of phytoplankton, diatoms and macrophytes (bio-assay studies).
8. Estimation of primary production per m^2 in the algal belts and on diatom flats.
9. The inflow of nutrients, organic matter and toxic substances from the land has to be monitored as a prerequisite for many budget estimates. This is the case in spite of the fact that the Baltic has not reached a steady state in which the changes in the Baltic are direct reactions to those inflows. The development of a monitoring system encompassing all larger rivers is an important administrative task in preparation for scientific research of Baltic pollution as well as for any further pollution management.
10. Tank experiments with selected organisms to determine rates and routes of uptake of principal toxic substances and to determine the relative importance of concentration in the sea water and time of exposure.

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The following reference list is in no way a complete reflexion of ongoing research in the Baltic countries, but merely lists the papers to which direct reference is made. The reader is referred to Dybern (1971) to obtain a more representative impression of present research activities and extensive references are also given in many of the other papers listed below.

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