MODELLING THE INFLUENCE OF THERMAL EFFLUENTS ON ECOSYSTEM BEHAVIOUR

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ABSTRACT

An important step in managing thermal effluents is calculation of biological/chemical consequences by means of mathematical models. Different types of models can be used. Primary production models based on mass balances for phytoplankton and nutrients can be used for calculating temperature effects on biomasses and rates of biological/chemical processes. Calculation examples are shown.

Calculations of consequences of entrainment are carried out by means of a combined 2-dimensional transport-dispersion and zooplankton growth-model. The results are presented as iso-biomasses of zooplankton.

INTRODUCTION

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It is difficult to evaluate the total effect of these changes in rates, because the increased temperature will increase as well the primary production process rates as the decomposition process rates. The evaluations are furthermore complicated by the fact that zooplankton entrainment will affect biomasses of both phytoplankton and zooplankton.

Because of these complex interrelations between discharge of thermal effluents, entrainment, and hydraulic conditions in the discharge area quantitative evaluations of consequences by means of mathematical models can be necessary. In this paper two types of models are described:

a one-dimensional primary production model and a two-dimensional zooplankton-entrainment model. The models have been used for planning the location of a nuclear power plant at Gyllingnæs, Denmark, see Fig. 1.

PRIMARY PRODUCTION MODEL

The model used for the Gyllingnæs planning is based on the works by Chen [1] and Di Toro [2]. Models of this type are mainly used for calculating effects of discharges of nutrients to receiving waters. As temperature is an important forcing function in these models, calculations of consequences of thermal effluents can also be carried out, Dahl-Madsen and Møller [3]. A first step in the model-building process is an analysis of the system in view.

Systems Analysis, Hydraulics.

The simplified hydraulic description used for calculating biological/chemical effects is shown in Fig. 1.

The box division and the numeric values in the boxmodel are based on calculations with a two-dimensional hydrodynamic and transport-dispersion model. See Rodenhuis [4].

The transport-dispersion rates are calculated by means of a one-dimensional hydraulic 5-boxmodel. The numeric values used in the boxmodel are shown in TABLE 1.

A complete vertical mixing is assumed in each box. A periodical occurrence of haloclines affects the area by adding nutrients from the nutrient-rich lower water layer. This stochastic phenomena is not taken into account in the model. The accuracy of the modelcalculations is for this reason limited.

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"detritus" in water and sediment
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sedimentation of phytoplankton and "detritus"
mineralization of "detritus"

A detailed mathematical formulation of the process rates is given in a Water Quality Institute Report [5]. The mathematical formulation of the phytoplankton growth differs from most eutrophication models by relating the growth to intracellular concentrations of nitrogen and phosphorus, see Nyholm [6].

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The influence of temperature on the biological/chemical process rates is given by the relation shown in Fig 2.

This simple exponential relationship would be insufficient if the phytoplankton and zooplankton were divided into species or groups of species. A more complex temperature dependency with minima, optima and maxima temperatures for each species group would be necessary as discussed by Scavia [7]. However, when all species are lumped into one group and calculations are confined to total system behaviour between $0^{\circ}C$ and $25^{\circ}C$, a simple relationship is found to give reasonable results. It is naturally not possible by this model to calculate the effect of temperature increase on species succession.

The interrelations of statevariables and processes are shown in Fig. 3. A mass balance for each statevariable and each box produce a set of differential equations which are solved numerically.

Solution and Calibration

In the mathematical equations are used a number of parametervalues. The values are obtained through:

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In TABLE 2 are shown values of some important parameters.

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The calculations can not reproduce the low phytoplankton concentrations in June/July and the high phytoplankton concentrations in August/November. Furthermore the low concentrations of zooplankton in late summer are not reproduced. A number of modelweaknesses can possibly explain these discrepancies.

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In Fig. 5 . are shown comparisons between measured and calculated values of accumulated process rates. Reasonable agreements are obtained except for the rate of sedimentation of "detritus". This rate is measured by use of sediment traps, and the measurement accuracy is rather low because of resuspension phenomena.

A more intensive calibration could eventually produce better agreements between measured and calculated values. However, especially the very simplified one-dimensional hydraulic and topographic description limits the obtainable accuracy. The calibration is for this reason not continued.

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The discharge of thermal effluents in the area will produce en excess temperature as shown in TABLE 1 of approximately 2.7°C in box 1. Furthermore the entrainment is assumed to kill all herbivorous zooplankton and 50% of the carnivorous zooplankton, which pass the cooling water system. Each of these impacts will in itself produce a significant change in variations and levels of statevariables and processes. The combined effect of both impacts are shown in Fig. 6. which compares the standard situation (without effluent) with the situation in box 1, 2 and 3.

It can be seen from the calculated changes in Fig. 6. that generally the changes in biomass and concentrations are small compared to the changes in rates, i.e. turnover rates of the system are considerably increased. The phytoplankton production is increased approximately 30%. A part of this increase is passed through zooplankton as the grazing rate is increased approximately 50%. The biomass of herbivorous zooplankton is lower than in the standard situation contrary to the expected decrease because of the entrainment losses. However, the increase in zooplankton biomass can be explained partly by the higher phytoplankton production partly by the decreased predation on the zooplankton.

Furthermore the rates of sedimentation of phytoplankton and "detritus", and the rates of mineralization are increased. The balance between the rates is changed to produce a considerably lower concentration of organic matter in the sediment (75% lower).

ZOOPLANKTON ENTRAINMENT

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where:
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This equation is solved for each point of the network.

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It is assumed that the zooplankton biomass is reduced 100% by passing the cooling water system. The basis for the transport-dispersion is tidal exchange with an amplitude of .17m. The biomass distribution is stationary after approximately 50 tidal cycles.

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DISCUSSION

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The one-dimensional model is relatively realistic biological/chemically but very simplified hydraulically. The two-dimensional model gives a relatively realistic transport-dispersion pattern, but the growth equation is very simplified. A more realistic total model of the area could logically be obtained by combining the complex primary production model with the two-dimensional transport-dispersion model. A development of this kind would, however, produce formidable numerical computertechnical problems because of the high number of resulting differential equations. Future modelling work will for this sea area be allocated to the attack of these problems. Furthermore developments to increase the realism of the primary production model will be tried.

REFERENCES

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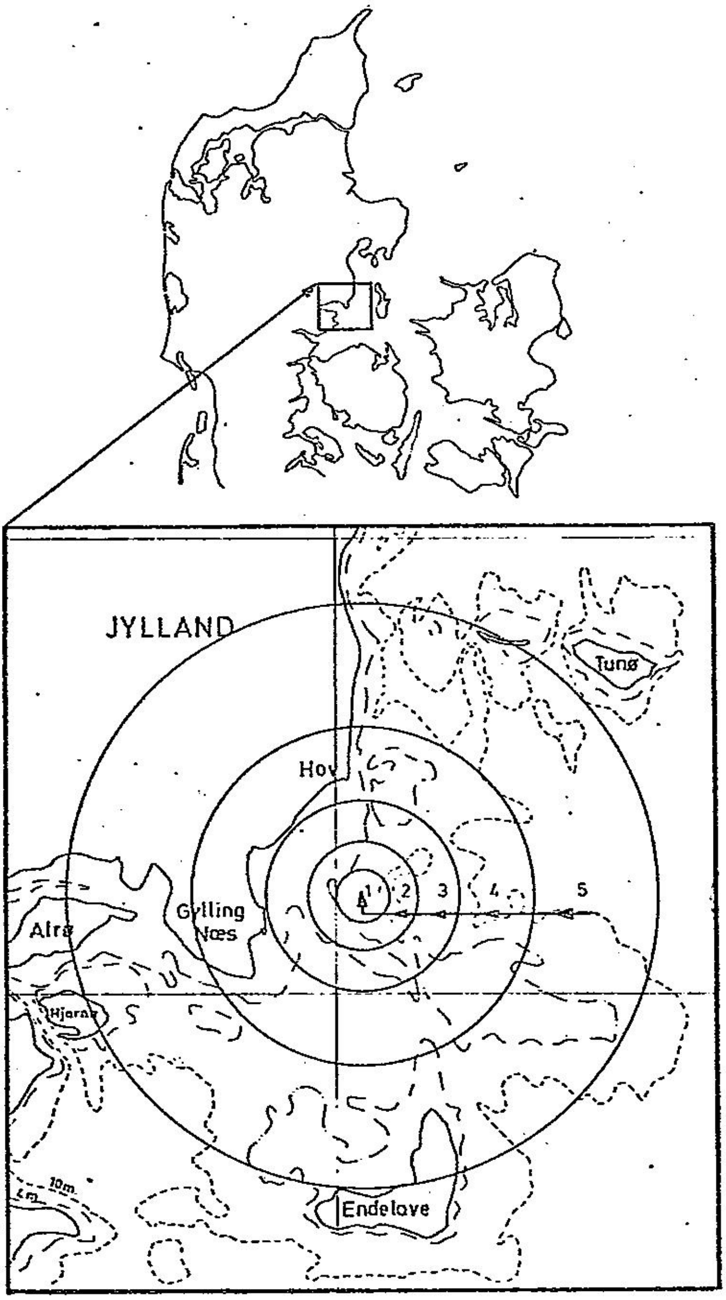

Fig. 1   Survey area and box division for the hydraulic boxmodel.

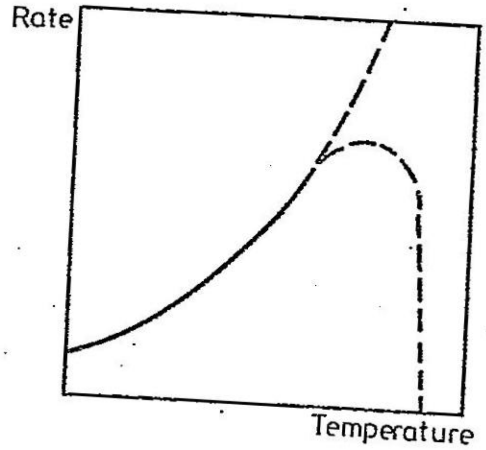

Fig. 2 Influence of temperature on the biological/ chemical process rates.

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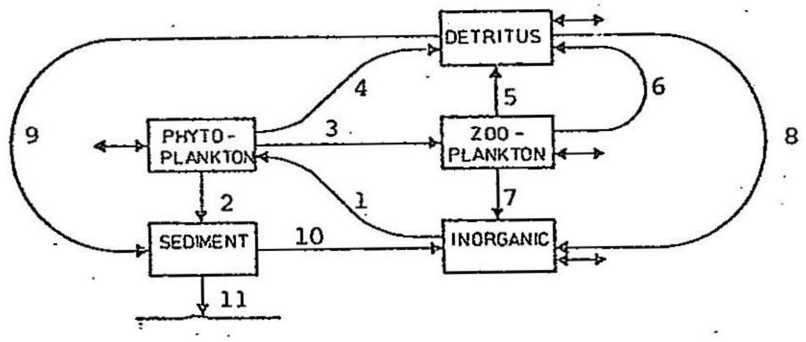
PROCESSES and STATE VARIABLES



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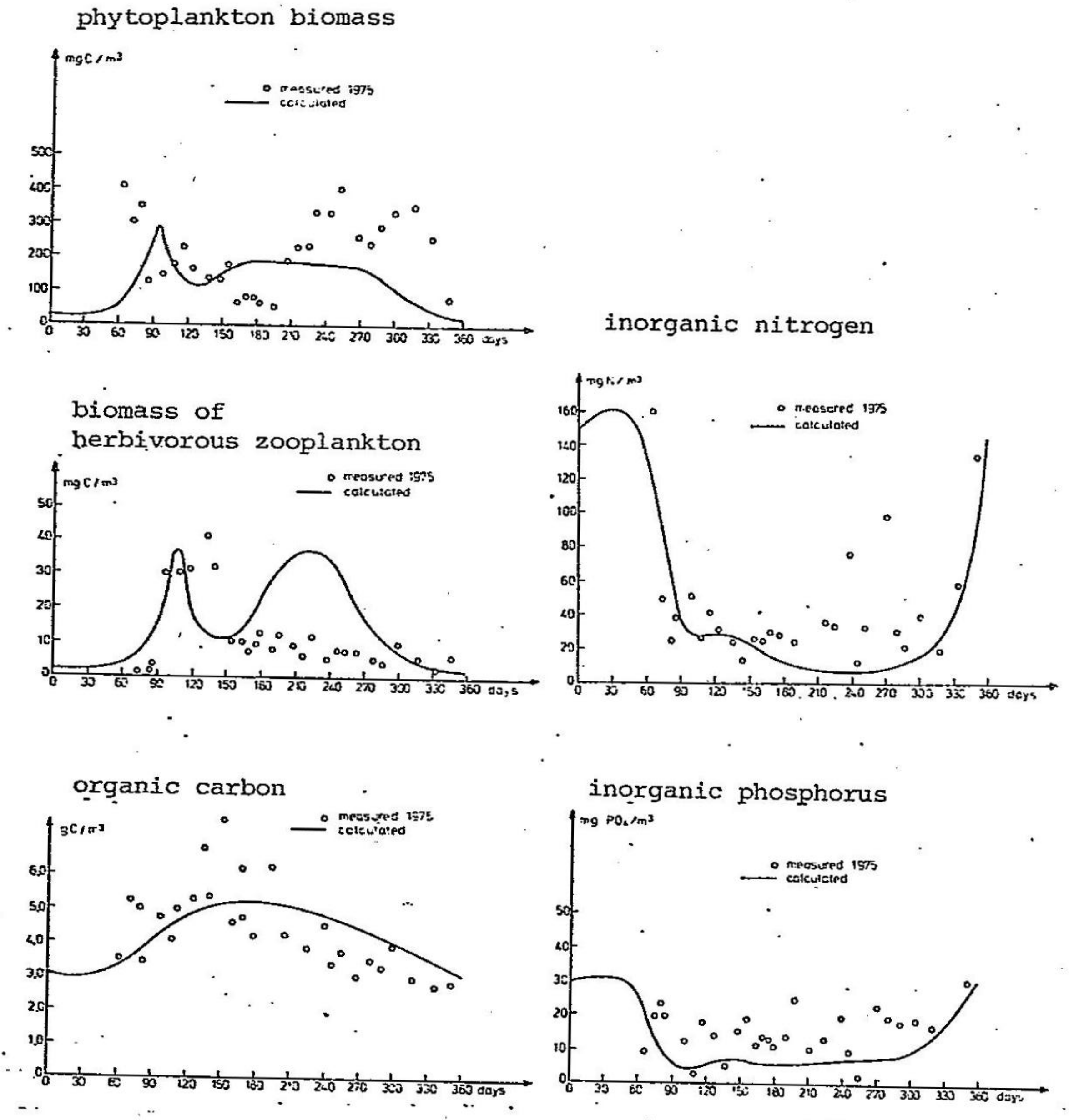
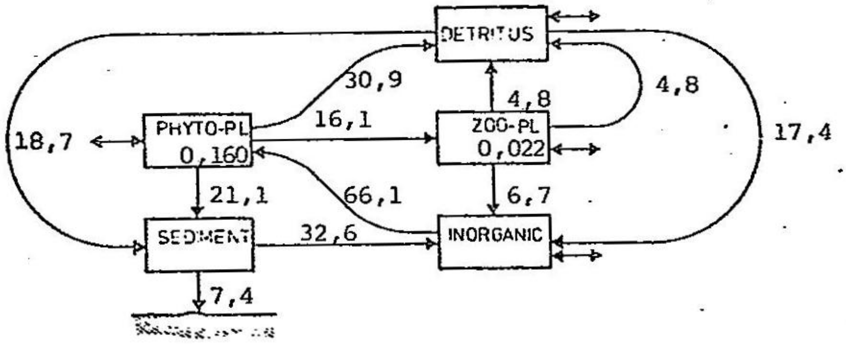


Fig. 4 Comparison between calculated and measured values of yearly variations of state variables.

CALCULATED VALUES



MEASURED VALUES 1975

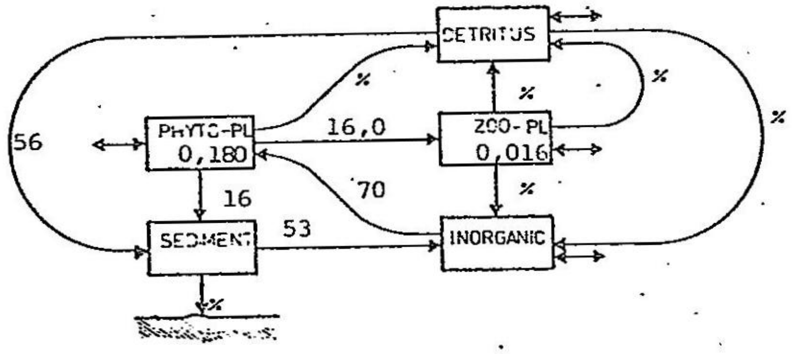


Fig. 5 Comparison between calculated and measured values of accumulated process rates.
The process rates are in gC/m^2/year.
The calculations are averaged for the period March-October.

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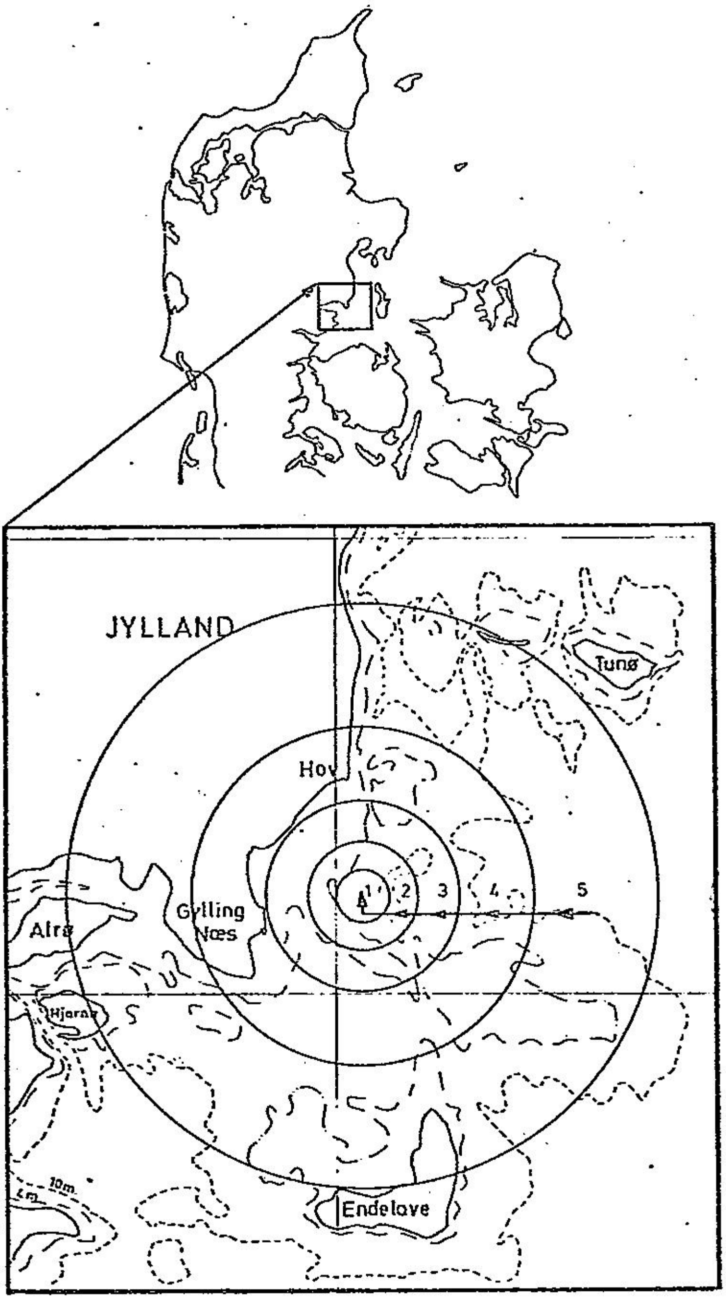
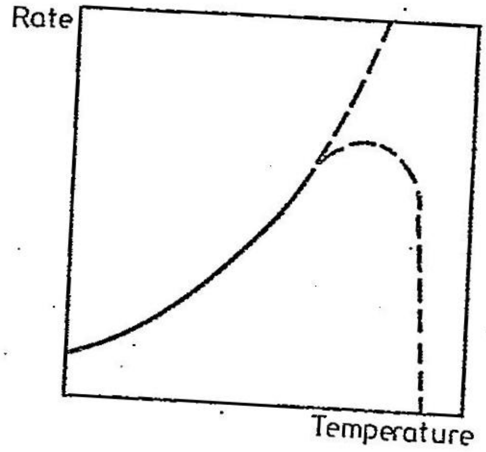


Fig. 1 Survey area and box division for the hydraulic boxmodel.



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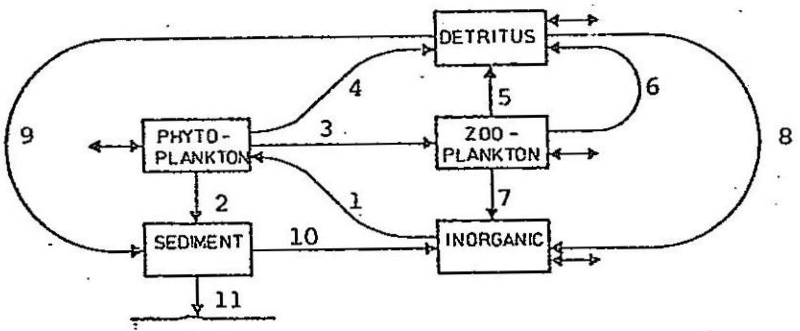
PROCESSES and STATE VARIABLES



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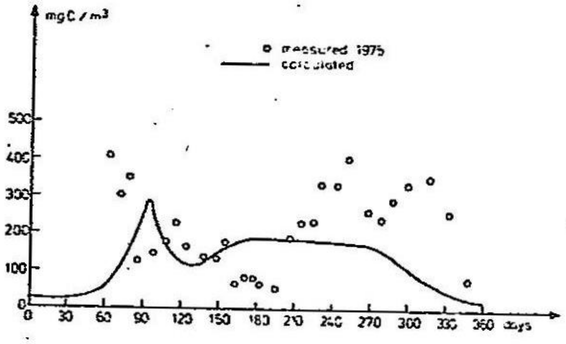
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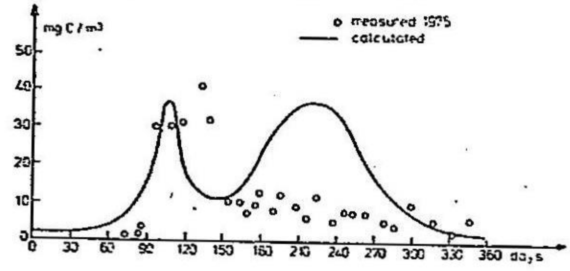
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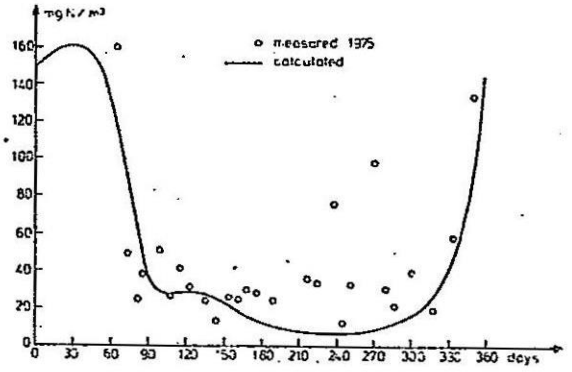
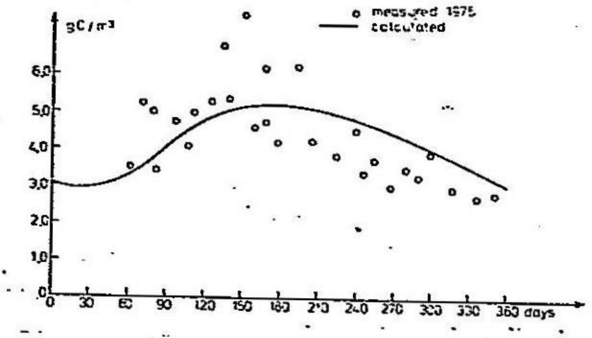

inorganic nitrogen


organic carbon

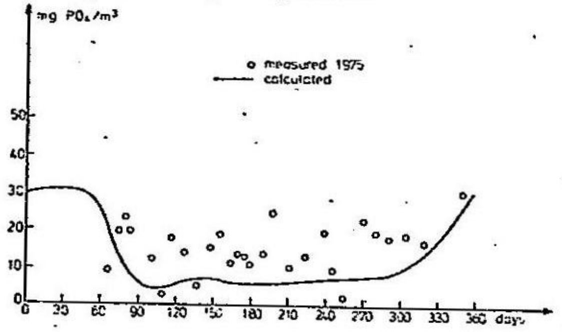
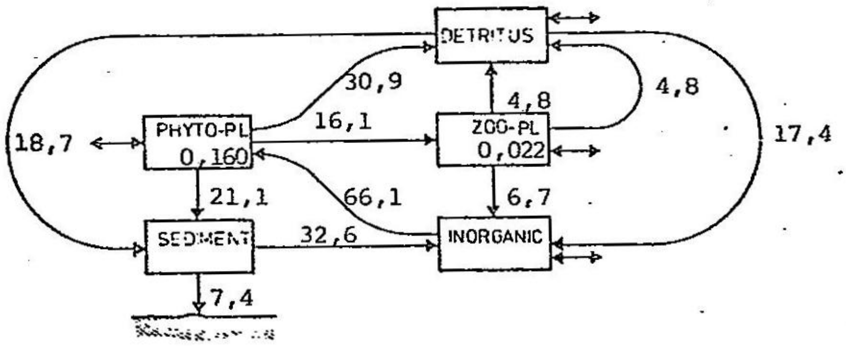

inorganic phosphorus

Fig. 4 Comparison between calculated and measured values of yearly variations of state variables.

CALCULATED VALUES



MEASURED VALUES 1975

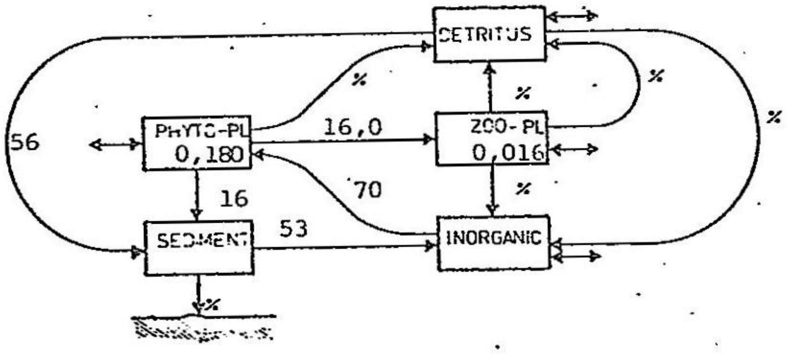


Fig. 5 Comparison between calculated and measured values of accumulated process rates. The process rates are in gC/m^2/year. The calculations are averaged for the period March-October.

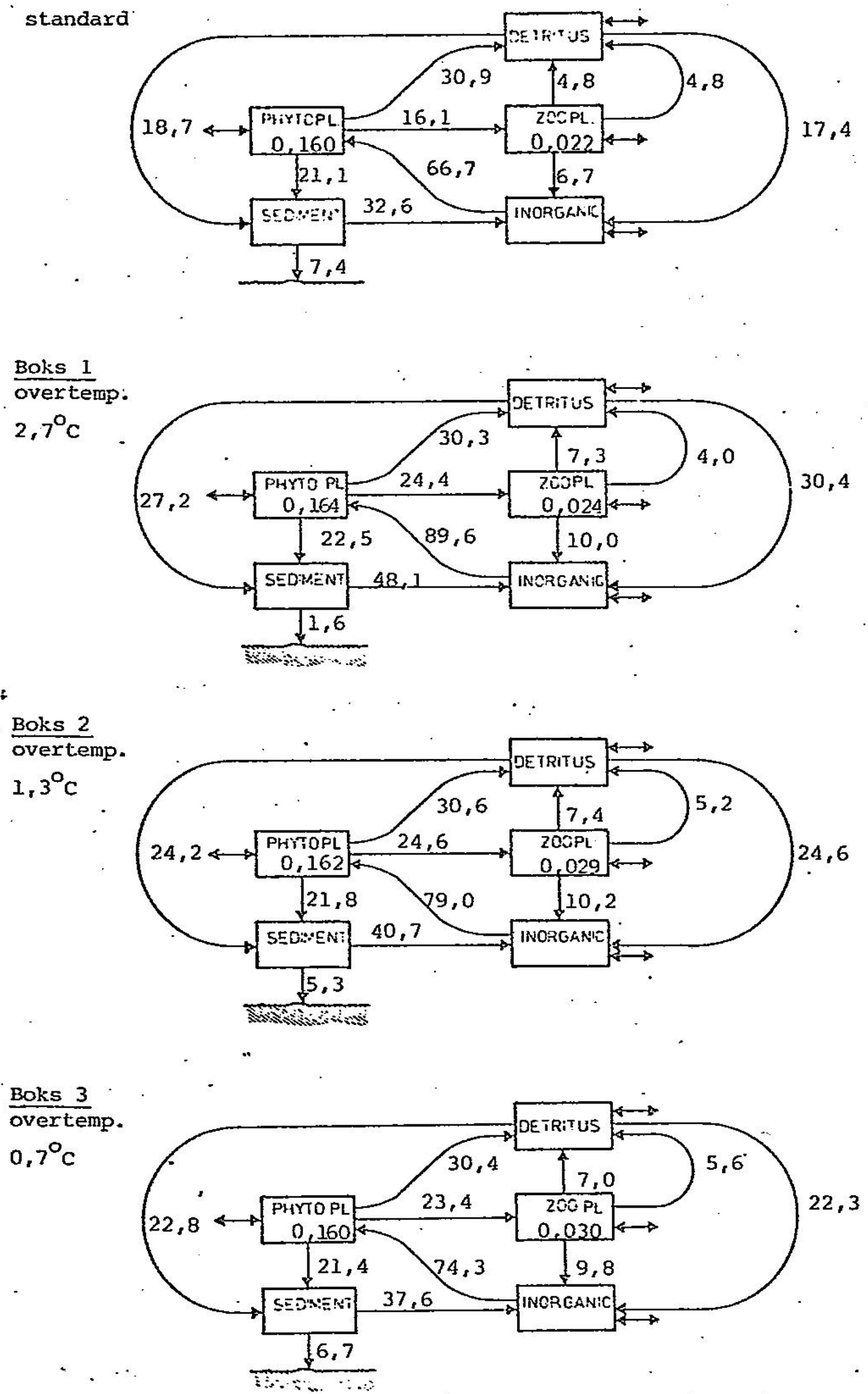


Fig. 6 Calculated changes in process rates caused by increases in temperature.

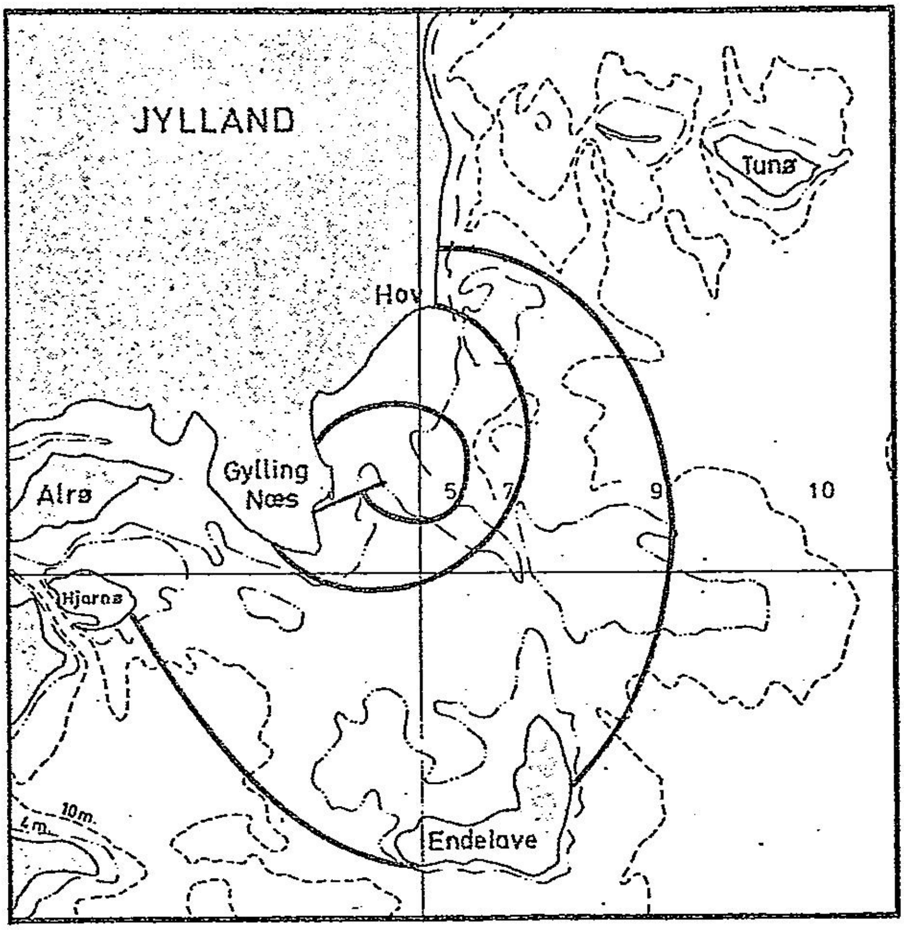


Fig. 7 Relative zooplankton distribution for a zero growth rate.

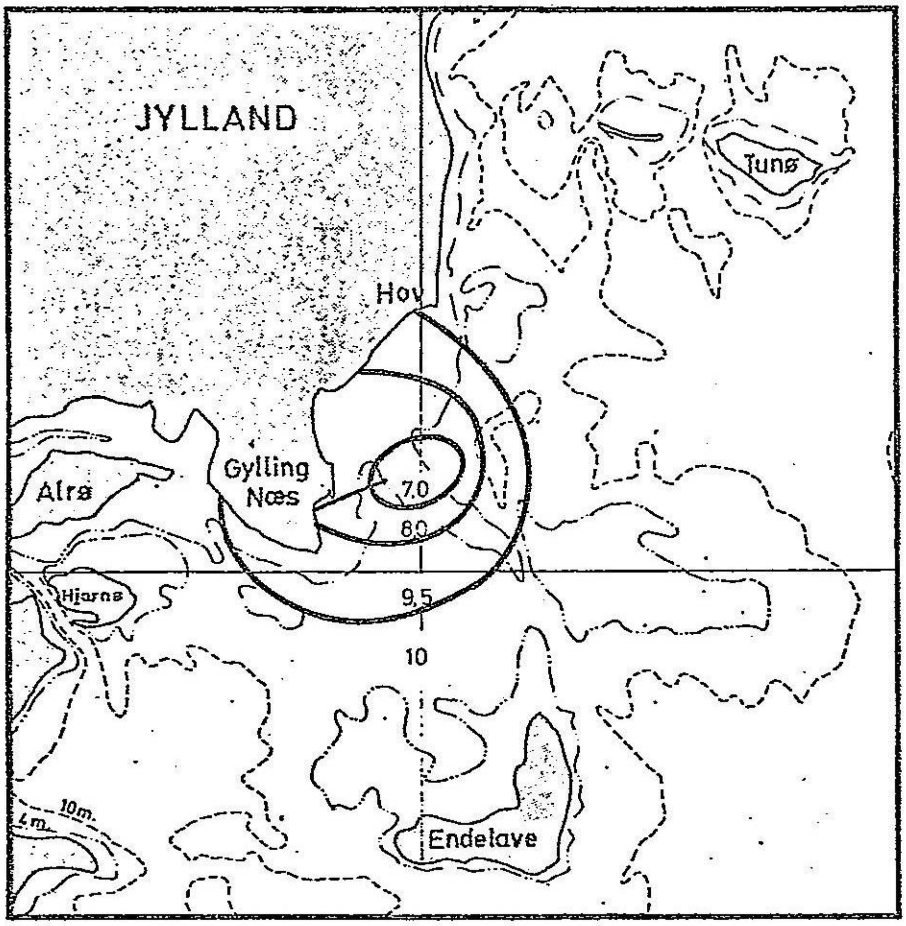


Fig. 8 Relative zooplanktondistribution for a growth rate of 0.1 day^{-1}.