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ECOLOGICAL MODELS AS A NEW POWERFUL TOOL IN ENVIRONMENTAL MANAGEMENT

The research field of ecological modelling has grown rapidly during the last decade, and the international cooperation in the field is accelerating. This paper presents the ecological modelling as a multidisciplinary challange in the application to environmental management. It discusses reductionistic contra holistic approach, as well as the future development of ecological models and their applications.

1. INTRODUCTION

Ecological models give a picture or description of the features that are essential in the context of a given problem. The philosophy behind the use of models can be illustrated by an example. We have, for many years, used physical models of ships to determine the profile that gives the smallest resistance for the ships in water. Such a model is in accordance with the shape and the relative main dimensions of the real ship, but of course does not contain all the details, such as furniture, instruments etc.

Correspondingly, an ecological model will contain the features that are of importance for the management — or scientific problem we want to solve by use of the model.

An ecosystem is of course a more complex system than a ship, which implies that it has been far more complicated to find the main features of importance for a given problem, but by intense research in this new scientific discipline during the last decade, it has been possible for many environmental problems to set up workable models.

The models can be physical, as the ship model, this is called microcosmos, but is most often mathematical — that is, the model consists of a mathematical description of the important parts and processes of the ecosystem.

The scientific models aim toward a realistic description of the ecosystem considered as a unit, in other words, give the properties of the "ecosystem body".

The management models attempt to give a description of the relation between pollution and the harm the pollution involves in an ecosystem. For instance, the relation between

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discharge of organic biodegradable matter and the oxygen conditions in a river, prediction of the growth of phytoplankton in lakes (eutrophication) when the discharge of nutrients is known or the distribution pattern of toxic particulate material emitted to the atmosphere.

The field of ecological modelling has developed rapidly during the last 10 years, essentially due to two factors: 1) the development of computer technology, which has enabled us to handle very complex mathematical systems, 2) general understanding that a complete elimination of pollution is not feasible due to economical reasons — this is often called "zero discharge" — but that a pollution control with the limited economical resources available requires a very prudent environmental policy, which seriously considers the impact of pollution on the ecosystem.

In other words, we can say that the idea behind the use of ecological models for environmental management is to set up emission or imission standards, which are able to preserve the natural conditions in the ecosystems as far as possible with the finances available for pollution control. The major parts of the ecological models developed during the last decade are such environmental management oriented models.

2. A MULTIDISCIPLINARY CHALLENGE

Most management models developed 10-12 years ago were constructed by engineers or mathematicians, who already had worked with hydrological models. Unfortunately, some of these models were not based on sound chemical-biological knowledge of the ecosystems. The "black box" approach, which does not consider the actual processes in the ecosystem, but just relates input and output — for instance discharge to water quality — was often used.

The international biological program started to set up ecological models in the beginning of the last decade. These models, however, often contained too many biological details, which implied that the models had too much uncertainty, because the results of the models accumulated the uncertainty of all the details.

These experiences, however, were not in vain, as they allowed to conclude that the models should contain sound ecological-chemical-biological knowledge of the ecosystem considered and include only the details that were of importance for the problem set up. On the other hand, however, the construction of a good ecological model requires a multidisciplinary team of researchers, covering such disciplines as ecology, biology, chemistry, mathematics, datalogy and hydrology, and meteorology.

It was furthermore acknowledged that general ecological models do not exist. To obtain a useful model it is necessary to take into consideration the properties of the given ecosystem and the specific problem.

The starting point of the modelling exercise is as follows:

Question: Which components and processes are essential for the problem in question in the considered ecosystem? It should be born in mind that the experience obtained from one lake can be used for another lake.

This philosophy is completely in accordance with the holistic ideas behind models, and the practical experience from the use of models in environmental management context confirms the applicability of these principles.

An example shall be used as an illustration. Eutrophication models have been used to relate the discharge of nutrient and the growth of phytoplankton in lakes (fig. 1). The growth rate of phytoplankton as a function of temperature, light and nutrient concentrations is

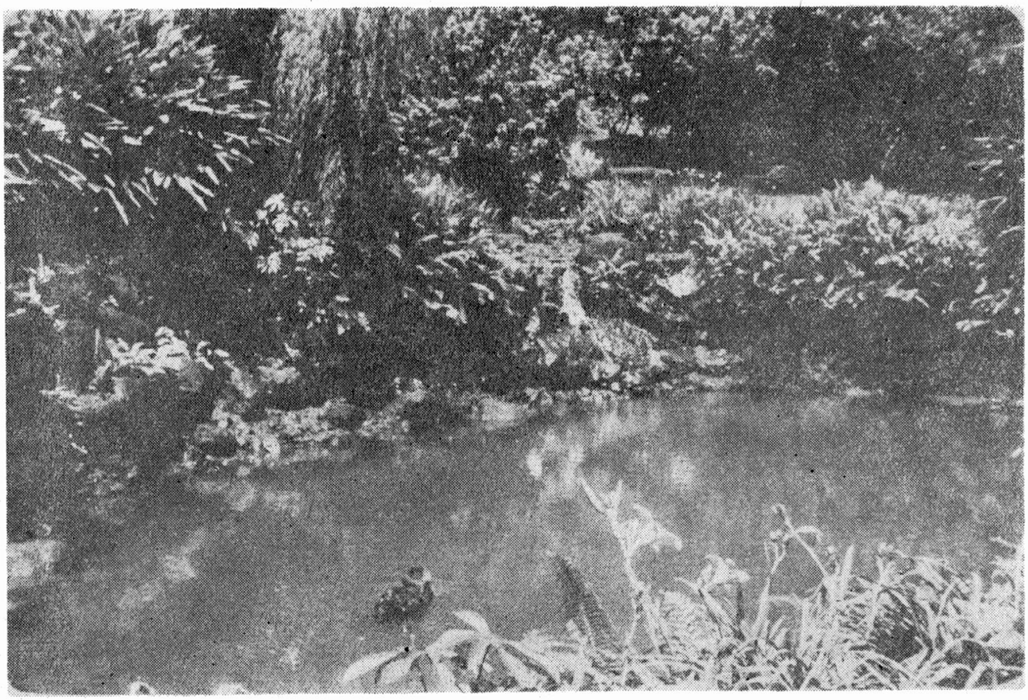

Fig. 1. The photo illustrates hypereutrophic lake in a summer day. The growth of plant is enormous due to a high nutrient concentration in the water, but in the autumn and during the night part of the organic matter made by photosynthesis is decomposed which results in D.O. depletion

Rys. 1. Zdjęcie przedstawia jezioro hypereutroficzne w letni dzień. Wzrost roślinności jest ogromny z powodu dużego stężenia substancji odżywczych w wodzie, lecz jesienią i w nocy część substancji organicznej powstała podczas fotosyntezy ulega rozkładowi, co powoduje wyczerpywanie się rozpuszczonego tlenu

already known from the biological literature. The nutrient concentration is again determined by such processes as input, mineralization of organic material, grazing etc. Our eutrophication model should therefore include the processes that determine the nutrient concentration in the lake water as well as the phytoplankton growth. Fig. 2 gives a flow chart of these processes for nitrogen. We could of course make the flow chart more complex by adding several species of phytoplankton, zooplankton and fish, but experience has shown that in most cases these details are irrelevant for the eutrophication problem, unless of course, we want to know the concentration of certain species of phytoplankton, e.g. blue-green algae. On other hand, a sensitivity analysis will reveal that in most cases the

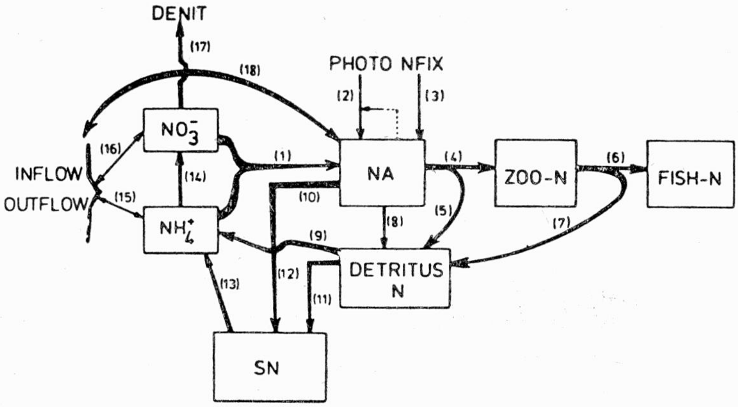

Fig. 2. Nitrogen cycle in the lake

FISH-N — nitrogen in fish, SN — nitrogen in sediment, DENIT — denitrification, NFIX — nitrogen fixation, PHOTO — photosynthesis, NA — nitrogen in phytoplankton, ZOO-N — nitrogen in zooplankton, NH_4^+ — ammonia nitrogen, NO_3^- — nitrate 1 — uptake of ammonium and nitrate by algae, 2 — growth of algae, 3 — nitrogen fixation, 4 — grazing, 5 — loss by grazing, 6 — fish eating zooplankton, 7 — loss by this process, 8 — mortality of algae, 9 — mineralization, 10 — settling of algae, 11 — settling of detritus, 12 — input/ouput of algae, 13 — release of ammonium from sediment, 14 — nitrification, 15-16 — input/output of ammonium and nitrate, 17 — denitrification

Rys. 2. Obieg azotu w jeziorze

FISH-N — azot w rybach, SN — azot w osadzie, DENIT — denitryfikacja, NFIX — wiązanie azotu, PHOTO — fotosynteza, NA — azot w fitoplanktonie, ZOO-N — azot w zooplanktonie, NH_4^+ — azot amonowy, NO_3^- — azotany 1 — pobranie amonu i azotanów przez glony, 2 — wzrost glonów, 3 — wiązanie azotu, 4 — spasanie, 5 — straty spowodowane spasaniem, 6 — ryby jedzące zooplankton, 7 — straty spowodowane tym procesem, 8 — śmiertelność glonów, 9 — mineralizacja, 10 — osadzanie się glonów, 11 — osadzanie się detritusu, 12 — wejście/wyjście glonów, 13 — zwolnienie amonu z osadu, 14 — nitryfikacja, 15-16 — wejście/wyjście amonu i azotanów, 17 — denitryfikacja

details illustrated in the figure for the nitrogen cycle must be included. Obviously, a similar flow chart must be set up for phosphorus and carbon, and where diatom are of importance silica must be also included. The investigations have shown, moreover, that the exchange of nutrient between lake water and sediment must be described in detail, since essential amounts of the total nutrients are accumulated in the sediment, which under certain circumstances can be released.

The process constants — the parameters — in such a model are pretty well known. If the phytoplankton species in the lake are known, then to a certain extent the maximum growth rate of the algae — at least a range for this parameter — is known.

After the model is set up the parameters must be fine-tuned. Although the parameters are approximately known from the literature, their values for the specific ecosystem should be known since they can be influenced by some local factors — at least with the lack of details that we have in our model. For this calibration, as the fine-tuning of parameters is called, the data from the ecosystem examined are required. We simply use the set of parameters which give the best accordance between the model output and the measurements.

The quality of the model depends to high extent on the quality of the underlying data. If the data are uncertain, the model will be coarse and its output considered as a first estimate. This implies that in order to predict the phytoplankton concentration as the function of time and to indicate the data at which the maximum concentration is to be expected, the data should be good, that is, giving information about the day to day variations of the phytoplankton concentration.

The calibration procedure, however, should not be compared with the corresponding procedure for hydrological models; in ecological models, we deal with a narrow range of the parameters before the calibration.

3. REDUCTIONISTIC CONTRA HOLISTIC DESCRIPTION

During the last centuries biology has strictly followed Galilean principle: measure everything which you can measure; but the measurements have no function as such — they should be used to give a total picture of the nature.

In this context the models are a powerful tool, because they give the opportunity to test the importance of the details for the total system. The idea behind models is to express the holistic approach to a description of nature — its scope is to describe the ecosystem as a working unit, not as a collection of details, as the reductionistic approach sugests.

The models cannot contain all details. An ecosystem consists of an immense number of elements, about which we do not have sufficient knowledge. The classical physics presumes that the microscopic properties determine the properties of the total system, but the enormous amount of data which are required to follow this approach makes it impossible to stick to this idea. It is therefore in accordance with modern physics that a complete model does not exist, and that the model can only describe some characteristic features of the system.

Let us again use an illustration and consider a figure representing a house. It does not contain all details, but if it is to give information about the number of floors, windows and main dimensions, it serves its purpose. If we want to learn about the choice of materials or furniture, another figure is needed. We can only include the features of importance for the purpose set up in the model.

The relation between ecological modelling, ecophysics included and other biological disciplines, is to a certain extent the same as that between classical and modern physics.

4. STATE OF THE ART

The research field of ecological modelling has grown rapidly during the last decade. The number of papers published 10 years ago in this field was only about 100 per year, while today more than 1000 papers in ecological modelling are published in one year. The international scientific journal *Ecological Modelling* was started in 1975, with an annual output of 320 pages — today this journal contains 960 pages per year. The international cooperation in this field is distinctly developing. IIASA (International Institute of Applied System Analysis) has enhanced this development. The department of this institute, called REN (Resources and Environment), is very active in development of international cooperation in modelling the application of resources and pollution impact on the ecosystem. ISEM (International Society for Ecological Modelling) was organized in 1978, with ASIT BISWAS as president and the author of this paper as general secretary. The society is very active; it has already published an abstract journal and several books on the subject.

ISEM arranges a conference on ecological modelling every other year. The first took place in Copenhangen in 1978, and the second was in Liege in April this year. The third will take place in Colorado, U.S.A., in May 1982.

5. THE FUTURE

During the last decade more and more environmental problems have been modelled Especially, the models of the distribution and effect of toxic compounds have been developed during recent years. These models though still less certain than, for instance, eutrophication models are nevertheless very useful as an indication that the range or even the magnitude is often very important for toxic substances. The accuracy of these types of models will probably not be improved significantly during the coming decade, but it must be foreseen that a greater experience with such models will be gained during the coming years.

The eutrophication models are today at a workable stage, although long term experience should be gained in the present decade, especially in such cases where the nutrient loading is radically changed and the model has been used to predict the effect.

For the last 5-10 years the models have revealed the lack concerning knowledge of important processes in ecosystem. This knowledge will probably be achieved and the models correspondingly improved.

The development in the computer technology will propably widen the use of ecological modelling and provoke the increased treatment of problems by use of models during the coming years.

Some scientists have started to work with what we would call the next generation of ecological models. That is, models which consider changes occurring in the ecological structure. At present we model the ecosystem in accordance with the observed structure, but we know that under changed conditions the ecosystem will change its structure in order to "meet" the new circumstances. Cybernetics or thermodynamics will probably be included in such models and it must be foreseen that this type of model will prevail in the future.

This type of model will certainly reveal new knowledge about the properties of ecosystems — especially the ability of the ecosystem to resist the impact of pollution, which of course is significant for the use of models for environmental management. It will most probably be a very exciting decade for ecological modelling.

MODELE EKOLOGICZNE JAKO NOWE, SPRAWNE NARZĘDZIA ZARZĄDZANIA ŚRODOWISKIEM

W ostatnim dziesięcioleciu nastąpił szybki rozwój modelowania ekologicznego, jak również współpracy międzynarodowej w tej dziedzinie. Modelowanie ekologiczne zastosowane do zarządzania środowiskiem stanowi dziedzinę wielodyscyplinarną. W pracy przedstawiono możliwości dalszego rozwoju modeli ekologicznych i ich zastosowania.

ÖKOLOGISCHE MODELLE – NEUE, LEISTUNGSFÄHIGE WERKZEUGE ZUR UMWELTKONTROLLE

Im letzten Jahrzehnt erfolgte eine schnelle Entwicklung der ökologischen Modellierung und der Zusammenarbeit auf internationaler Ebene. Die ökologische Modellierung ist interdisziplinär und wird zur Umweltkontrolle angewandt. Im vorliegenden Bericht werden die Möglichkeiten einer Erweiterung dieser Modelle sowie deren Anwendung erörtert.

ЗКОЛОГИЧЕСКИЕ МОДЕЛИ В КАЧЕСТВЕ НОВЫХ ИСПРАВНЫХ СРЕДСТВ ДЛЯ УПРАВЛЕНИЯ ОКРУЖАЮЩЕЙ СРЕДОЙ

В последнее десятилетие наступило стремительное развитие экологического моделирования а также международного сотрудничества в этой области. Экологическое моделирование, применительно к управлению природиой средой, охватывает многие отрасли науки. В работе представлены возможности дальнейшего развития экологических моделей а также их применения.