The Fourth European Conference on Ecological Modelling (ECEM 2004)

Proceedings

Bled, Slovenia, September 27 - October 1

Edited by Sašo Džeroski,
Marko Debeljak, and Bernard Ženko

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Foreword

The Fourth European Conference on Ecological Modelling (ECEM) and the Fourth International Workshop on Environmental Applications of Machine Learning (EAML) were organized jointly in Bled, Slovenia, during the week of September 27 - October 1, 2004. The aim of these events was to bring together researchers from the areas of ecology, ecological modelling and environmental sciences, on one hand, and the areas of data analysis, data mining and machine learning, on the other. In many respects, they were treated as a single event, namely ECEM/EAML 2004.

As environmental concerns grow and information technology develops, more and more data on the different aspects (physical, chemical, biological, ecological) of the environment are gathered. There is an increasing need to analyse the collected environmental data for different purposes, which include the support for environmental management decisions. The International Workshop on Environmental Applications of Machine Learning provided a forum for presenting recent advances in applying machine learning and data mining techniques for the analysis of environmental data.

Ecological modelling is concerned with the development and use of mathematical, computer and simulation models of ecosystems. It is a relatively young scientific discipline, which is rapidly gaining importance, especially because of the use and usefulness of ecological models for the management of natural resources. The European Conference on Ecological Modelling is the premiere European scientific event in the area of ecological modelling and regularly attracts an international audience.

ECEM 2004 covered all topics in the area of ecological modelling. An indicative, but non-exhaustive list of topics is given below:

- Ecological modelling techniques, e.g., artificial intelligence approaches, individual based modelling, machine learning, network analysis, neural networks, qualitative modelling and reasoning, structural dynamic modelling, standard models;
- Modelling for ecosystem management, e.g., wildlife management, ecosystem based management, sustainability, managing renewable natural resources, niche reconstruction;
- Modelling growth and development processes in ecosystems, e.g., modelling biodiversity changes, population dynamics, habitat modelling, ecological energetics;
- Modelling different types of ecosystems, e.g., forest ecosystems (alpine/boreal forests; temperate broadleaved forests; Mediterranean forests), aquatic ecosystems (marine; freshwater - lakes, rivers; lagoons; estuaries), grassland ecosystems, agricultural ecosystems;

- Modelling catastrophic changes in the environment, e.g., modelling the spread of invasive species, ecotoxicology (organism, population, community, ecosystem), outbreaks (pests, wildfires, floods, droughts).

A total of 110 abstracts were submitted and 90 were accepted after a review process. Each submitted abstract was sent to three members of the Program Committee for review. The Program Committee members themselves did the majority of reviews, assisted by a few additional reviewers appointed by the Committee members. Authors of accepted abstracts (for oral or poster presentation) were invited to submit full versions of their papers. These were reviewed separately by the members of the Program Committee and other reviewers for inclusion in a special issue of the journal Ecological Modelling which was to be published after the conference.

The program of ECEM 2004 consisted of three invited talks by Broder Breckling (University of Bremen, Germany), Bai-Lian Li (University of California Riverside, USA), and Jacqueline McGlade (European Environment Agency), as well as oral and poster presentations of accepted contributions.

Many people contributed in various ways to the ECEM 2004 conference. We would especially like to thank:

- The authors of submitted contributions who made the conference possible by presenting their work;
- The three invited speakers: Broder Breckling, Bai-Lian Li, and Jacqueline McGlade;
- The Advisory Committee for their suggestions regarding the Program Committee, invited speakers and encouraging remarks;
- The members of the Program Committee for their efforts in evaluating the submitted abstracts and papers;
- The members of the Organizing Committee;
- The sponsors for their generous support;
- The management and staff of the Albatros Congress Turist Agency, Bled, and the Center for Knowledge Transfer in Information Technologies, Jožef Stefan Institute, Ljubljana for their support;
- The Jožef Stefan Institute for providing the organizational infrastructure.

Sašo Džeroski, Marko Debeljak and Bernard Ženko
ECEM 2004 Program Co-chairs

Contents

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KD–net, The Knowledge Discovery Network
PASCAL – Pattern Analysis, Statistical Modelling and Computational Learning, The network of excellence

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Invited Talks

Individual-based models as tools for ecological theory and application. Understanding the emergence of organisational properties in ecological systems

Broder Breckling (joint work with Ulrike Middelhoff)

University of Bremen, Germany

Individual-based models open a structurally unique (and unifying) approach to ecological applications. Model results also provide an important input to ecological theory. The approach operates on the lowest organisational level considered in ecology. Simulating actions of single organisms allows to study how the properties of higher level ecological entities like swarms, populations and trophic networks emerge. Unlike other approaches working on a higher abstraction level, individual-based models can represent structural-functional relationships in a close qualitative and quantitative relation to the form and content of ecological knowledge. To demonstrate the application range of the approach for the advancement of ecology this presentation takes four steps:

First, a generic model structure for individual-based models operating on the basis of object oriented programming is explained. It allows to capture a large variety of different ecological interactions and thus a coherent representation of ecological knowledge during model development.

In a second step application examples from various fields of ecology will be demonstrated. Plants and animals, active in terrestrial or aquatic environments, exhibit interaction types, which lead to self-organised structural-functional networks resulting from single organismic interactions. Spatial relations, dispersal, bio-energetics, plasticity of growth and form are issues which can be successfully dealt with in individual-based models. The wide range of qualitatively different interactions is responsible for the importance the approach has gained in ecology.

In a third step we show, how the approach is used in a current research project on an advanced, level-integrating study anticipating properties and coexistence implications of genetically modified plants in agriculture. In a holistic approach, an individual-based model is used to simulate dispersal effects of genetically modified organisms (GMO). Oilseed rape (Brassica napus) serves as an example. The model represents cultivation, feral populations, cultivation practice and environmental characteristics. It is run for various environmental conditions to allow an up-scaling from single plots to the landscape level. Physiological data, climate information and remote sensing data were used as model input. The results allow estimations of the presence of transgenic material outside cultivated areas as well as unintended dispersal between cultivated fields.

The fourth and final step discusses epistemological implications of individual-based models. It is concluded, that a successful application of the approach requires detailed biological information about the represented species. This makes a very close involvement of field ecologists essential. On the other side, it also opens a theoretical access how to connect quantitative and qualitative aspects of cause-effect chains in ecology in a conceptual way.

Modelling ecological complexity: Challenges and opportunities

Bai-Lian Li

University of California Riverside, USA

Ecological complexity is an emerging and rapidly growing interdisciplinary field in ecology. It focuses on how and why complex ecological systems emerge from the nonlinear interactions of living entities at all levels and spatiotemporal scales and with all facets of their external environment including the human dimension. The field is based on a complexity theoretical framework for solving real world environmental problems. It has been recognized as the most important and exciting frontier of the 21st century ecology.

Modelling has played the most significant role in studying complex ecological systems and has provided the mathematical tools indispensable for studying their dynamics. In this talk, I will start with a brief overview of current research and paradigm shift in modelling ecological complexity, then outline computational, mathematical and statistical challenges from complex ecology to ecological modelers, along with several examples from our own recent studies (e.g., emergent properties of scaling and power law, spatiotemporal complexity and chaos of ecological pattern formations, ecological phase transitions, assessment of sustainability, etc.). I will also show how we could take those challenges as a great opportunity for seeking a truly quantitative and integrative approach towards a better understanding of the complex, nonlinear interactions (behavioral, biological, chemical, ecological, environmental, physical, social, cultural) that affect, sustain, or are influenced by all living systems, including humans, which may enable us to explain and ultimately predict the outcome of such interactions.

Spatial assessments of Europe's environment

Jacqueline McGlade

European Environment Agency, Denmark

Integrated environmental and ecosystem health assessments rely on combining information from local and global attributes derived from surveys and case studies. In order to properly examine issues such as the impact of climate change, loss of biodiversity, environmental threats to human health or the long-term effects of infrastructure development on Europe's landscapes, the European Environment Agency (EEA) needs to be able to analyse changes across a range of scales and media (water, air, soil etc.). But despite extensive monitoring and research, the current situation in Europe is that we cannot meet the challenge of supporting consistent environmental and sectoral policies at a European, national and regional levels.

The knowledge needed will not be obtained solely through the accumulation of observations on individual systems but, will require such in situ data to be integrated within overall frameworks of models and data analysis to generalise their information content. In relation to the demands of understanding changes in Europe's environments, using spatially distributed data and information on ecosystems and human activities is a key factor, as they:

- can help identify where conflicts in use of the territory take place, and under which type of pressure;
- contribute to the stratification of data and knowledge from existing monitoring networks and research programmes;
- help in designing efficient sampling schemes for new monitoring networks as well as targeting research programmes to priority needs;
- provide important input to modelling, in particular when very heterogeneous information from the bio-physical, social and economic realms need to be integrated and
- can be up- and downscaled to the appropriate levels of decision making of the various public and private bodies.

In this context, land accounts for Europe are being implemented by the EEA. The purpose of land accounts is to observe, qualify and quantify the cover of land resulting from ecosystem and land use. Stocks of land cover are described as well as their change. A first set of land cover accounts is under construction using CORINE land cover data from 1990 and 2000. Within this accounting framework, assessments of ecosystem condition has been produced; for example, in the case of European wetlands, spatial data on the change in extension, fragmentation, connectivity and neighbourhoods can provide insights into the possible destruction and stress. These first variables are being supplemented by data on flora and fauna and by quantitative and qualitative data on water. Other spatial data to be included, are land use in agriculture, urban development and transport infrastructure which will help to identify the sources of stress. These spatial data will be supplemented, at a more aggregated level, with social and economic statistics, from the perspective of the development of land use accounts to show how social and economic activities influence our environment.

The results of land accounts will be fully made available on the EEA website with the aim of facilitating access to these data and approaches to a range of users, including researchers and the wider public.

Contributed Abstracts

A verifiable model for assessing NEP of an even-aged forest

Georgii A. Alexandrov and Yoshiki Yamagata

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Key words: Net Ecosystem Production, verifiability, carbon sink, *Mathematica*

Introduction

Forests play important role in global carbon cycle. They retain large amount of carbon in tree biomass, litter and soil organic matter. The carbon stocks in these pools are either reduced or increased through the changes in land-use and forestry (Alexandrov and Yamagata, 2002), and thus assessing effects of these activities on Net Ecosystem Production (NEP) is essential for National Greenhouse Gas Inventories (Yamagata and Alexandrov, 2001). The models intended for the purpose must provides framework for facilitating exchange of knowledge and building consensus between experts, and hence they should be more *transparent* and more *verifiable* than models intended for academic research.

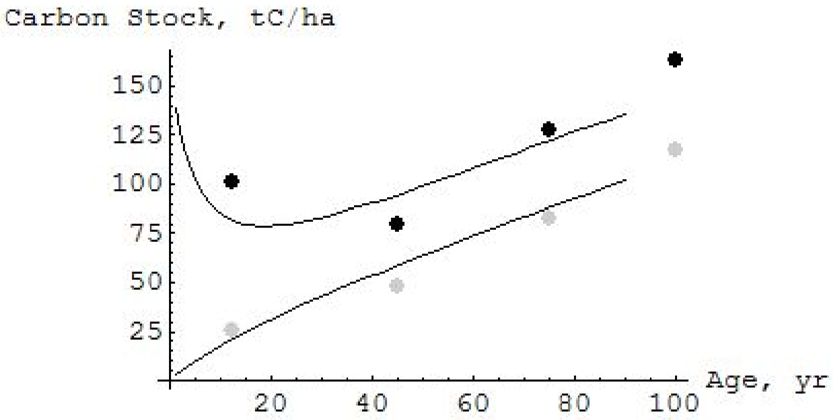

Figure. An example of outside verification that can be done using the digital version of the paper, if it will be run by *Mathematica*. Grey dotes denote carbon stock in the living plant biomass at the stands of a beech forest which are 12, 45, 75 and 100-year old (Kawaguchi and Yoda, 1986), black dotes denotes the total carbon stock of these stands reduced by 100 tC/ha (the amount of carbon which is probably stored in the pool of 'inert soil carbon" which is not changing in course of forest rotation). Lines denote model projections of these carbon stocks.

Results

We improve transparency and verifiability of our model, published earlier in Ecological Modelling (Alexandrov et al., 1999), by presenting its equations in the notation of *Mathematica* (an integrated environment for scientific and technical calculations). The digital version of the paper can be run by *Mathematica* 5.0 under various operating systems (Windows, Mac, Linux, Unix) that facilitate outside verification of both external and internal consistency of the model.

References

Alexandrov, G.A., Yamagata, Y., 2002. Net Biome Production of managed forests in Japan. Science in China, 45 (Supp): 109-115.

Alexandrov, G.A., Yamagata, Y. and Oikawa, T., 1999. Towards a model for projecting Net Ecosystem Production of the world forests. Ecological Modelling, 123: 183-191.

Kawaguchi, H., Yoda, K., Carbon-cycling changes during regeneration of a deciduous broadleaf forest after clear-cutting, 1. Changes in organic matter and carbon storage, Jap. J. Ecology, 1986, 35: 551—563.

Yamagata, Y., Alexandrov, G. A., 2001. Would forestation alleviate the burden of emission reduction? An assessment of the future carbon sink from ARD activities. Climate Policy, 1: 27-40.

Secondary Extinctions in Ecological Networks: Bottlenecks Unveiled

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Key words: secondary extinctions, networks, bottlenecks, error, attack, dominators.

Introduction

Intricate food web makes impacts spreading several links away from the affected taxon, and a single extinction event may precipitate cascades of further extinction. This phenomenon, acknowledged by ecologists with the term "secondary extinction", has important implications for the conservation of biodiversity.

Recently, Albert et al. (2000) introduced the analogous of biological extinctions into computer science and found that the Internet is a system very resistant to random disconnections (error tolerant) but also one in which a coordinate disconnection of a few important nodes (hubs) could isolate entire branches of the net (attack prone).

These features of the Internet network were tested on ecological food webs (Solé and Montoya 2001, Dunne et al. 2002), which resulted to be error resistant and attack prone as well. To test attack sensitivity in these webs the most connected node was removed at first, and other removals followed in decreasing order of node connectivity.

We proposed a new methodology to study the consequences of extinction events in food webs; it makes use of dominator trees, network topological structures that reduce food webs to linear pathways that are essential for energy delivery (Allesina and Bodini, 2004). By using these tools one can identify in advance which nodes are likely to cause the greatest impact on the web if they are removed because any dominator tree highlights interdependence of species for energy intake.

In other words dominator analysis illuminate what are the bottlenecks (overlap of nodes) in the pathways that connect the fundamental source of energy (external source) to any node: Dominator tree analysis has been essentially qualitative, reducing the analytic power of the technique. In this work we present an extension of the methodology that accounts for the different importance of the paths connecting the source of energy to any species by means of a threshold that act as a filter that selects the presence/absence of links.

Results and discussion

The result of a dominator analysis is a dominator tree. In this structure the path going from the source of energy (root R in Figure 1) to any species illuminates the bottlenecks in energy distribution. Removing any node would produce the cascading extinction (disconnection) of the whole branch of the tree that follows that node. In the dominator tree (Fig. 1 right) obtained for a given food web (left) the extinction of certain node A would precipitate in further extinction of all the nodes that are contained in the grey area, some directly, and some mediated (like $A \rightarrow B \rightarrow C$).

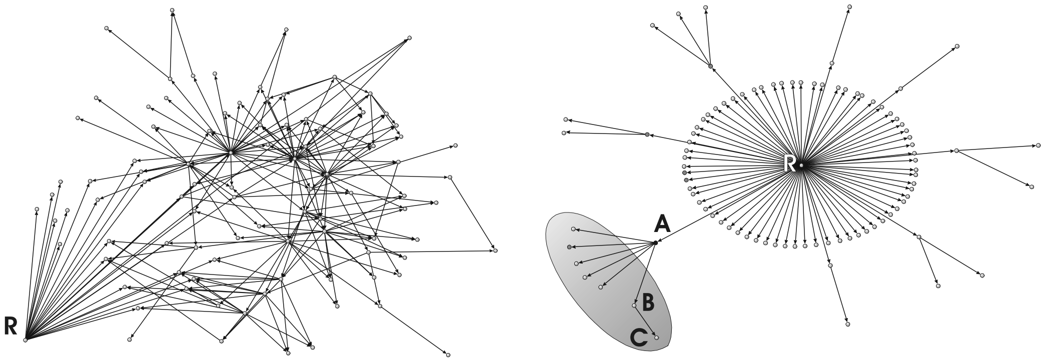

Figure 1 Example of rooted food web (left) and corresponding dominator tree. Node *R* is the source of energy, that in dominator tree becomes the central node.

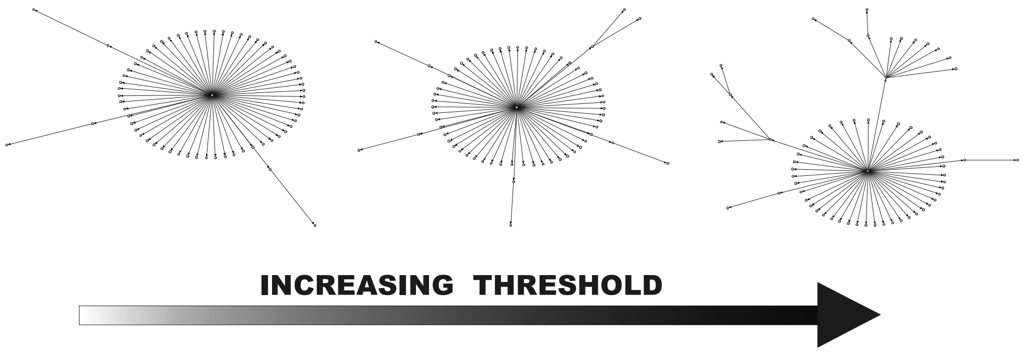

Figure 2 Dominator trees obtained eliminating links that have relative importance lower than a given threshold. Augmenting the threshold the dominator tree becomes more structured, meaning that the food web is less robust with respect to targeted removal.

Indices to account of the error/attack sensitivity are given. Moreover, a threshold for link presence/absence is introduced, enlightening the evolving structure of dominator trees for increasing thresholds. When the weak links are removed, species that seemed to receive energy from a multiplicity of non-overlapping pathways (no bottlenecks, nodes attached to the root in the dominator tree) result to have dominators: this means that the illusion of multiple pathways, due to the use of qualitative data, is challenged by the fact that many of these are constituted by weak links that would not allow the species to survive.

Conclusions

Ecological networks seem to be error resistant but attack prone. The removal of weak links makes the dominator trees more and more structured, underlining the real dominance relationships among species and, consequently, the real degree of tolerance to errors and sensitivity to attacks.

References

Albert, R., Hawoong, J. and Barbási, A.L. Error and attack tolerance of complex networks. *Nature*, 406:378-381, 2000.

Allesina, S. and Bodini, A. Who Dominates Whom in the Ecosystem? Energy Flow Bottlenecks and Cascading Extinctions. *Journal of Theoretical Biology*, In Press.

Dunne, J.A., Williams, R.J. and Martinez, N.D. Network structure and biodiversity loss in food webs: robustness increases with connectance. *Ecology Letters*, 5:558-567, 2002.

Solé, R.V. and Montoya, J.M. Complexity and fragility in ecological networks. *Proceedings of the Royal Society London ser. B*, 268:2039-2045, 2001.

A water quality model as tool for the evaluation of the limiting nutrient

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Key words: water quality model, nutrient limitation, Redfield Ratio, coastal zone

Introduction

In the last forty years, the industrial and agricultural development has unbalanced the natural cycles of nutrient elements as nitrogen and phosphorus, increasing the pressure on the environment. Impacts are very significant especially in coastal zones, being these the ultimate collectors of loads discharged in the environment: intense eutrophication phenomena are commonly observed in the coastal zone affected by a large river discharge, as is the case of Po river in North Adriatic. The identification of the limiting nutrient plays a key role in the study of eutrophication processes: this permits to focus the management efforts on the most sensitive nutrient, to predict the algal group that could easily growth in the ecosystems (allowing thus to predict toxic bloom), to estimate the probability of mucilage formation. Usually in freshwater a P-limitation has been observed, while in marine ecosystems N-limitation is predominant. Coastal zones are typically transitional systems between fresh- and saltwater, where it is not possible to easily choose between a N- or P-limitation.

Usually to identify the limiting nutrient in water body the N:P ratio observed in the water column is compared with N:P stoichiometric ratio in the biomass, called the Redfield Ratio (N:P=16 by molar unit, N:P=7 by weight unit, Redfield 1958).

Results and discussion

This approach is limited because it does not account for the nutrient dynamics (APAT 2002): the availability of the nutrient strongly depends from the cycling time. This limitation is much more evident in transitional systems like Coastal Zone.

Moreover, the Redfield approach is based on the hypothesis that algal growth is proportional to the nutrient concentration in water. In fact, assuming as limiting nutrient indicator the ratio between the nutrient limiting functions f(N) e f(P), if these functions are linear the N:P ratio is equivalent to the functions ratio.

$$f(N) = aN\,,\ f(P) = bP \Rightarrow \frac{f(N)}{f(P)} = \frac{aN}{bP}$$

Clearly the relationship between algal growth and nutrient concentration is not linear but usually a Michaelis-Menten formulation is used to simulate the nutrient limitation on algal growth. With this assumption, the limiting nutrient can be estimated using this equation:

$$f(N) = \frac{N}{K_N + N}\,,\ f(P) = \frac{P}{K_P + P} \Rightarrow \frac{f(N)}{f(P)} = \frac{N}{K_N + N} \cdot \frac{K_P + P}{P}$$

where K_N and K_P are the semi-saturation constant. Their values can be found in the literature or, better, obtained from calibration of a water quality model.

Physiologically, the dependency between growth rate and nutrient concentration in water body is a double-step relationship: a first step where nutrients are uptaken by the phytoplankton, and a second step where the phytoplankton biomass grows depending from the nutrient stored in the cells, i.e. the cell quota (Jorgensen & Bendoricchio, 2000). In this case the nutrient limitation can be expressed with two linear functions of the cell quotas, and the limiting nutrient is estimated with the following equation:

$$f(q_N) = \frac{q_{N,\max} - q_N}{q_{N,\max} - q_{N,\min}},\ f(q_P) = \frac{q_{P,\max} - q_P}{q_{P,\max} - q_{P,\min}} \Rightarrow \frac{f(q_N)}{f(q_P)} = \frac{q_{N,\max} - q_N}{q_{N,\max} - q_{N,\min}} \cdot \frac{q_{P,\max} - q_{P,\min}}{q_{P,\max} - q_P}$$

where q_N and q_P are respectively the cell quota of nitrogen and phopsphorus and the pedix max and min define the maximum and minimum of cell quota.

In this case it is impossible to calculate the indicator without a water quality model, as the nutrient cell quota is not usually measured in the standard monitoring programs.

The different methodologies for the evaluation of limiting nutrients have been applied on the coastal zone affected by the Po river discharge (Italy). For the evaluation of the cell quota a modified version of EPA WASP6 water quality model has been applied on the Northern Adriatic Coastal Zone (Albrigi, 2004).

Conclusions

Nutrient limitation is a key issue in the study of eutrophication problem and in the management of eutrophic systems. In dynamic and potentially eutrophic systems like coastal zones, the standard Redfield approach has limitations that can lead to some misinterpretation of the system behaviour. To better evaluate the limiting nutrient, it is possible to use the results of a water quality model to calculate two alternative limiting nutrient indicators. Moreover the use of a water quality model to evaluate nutrient limitation is useful also to asses the predictive capability of the models.

The methodology for the evaluation of the limiting nutrient presented here, that is based on the limiting functions, could be integrated with the calculation of the indicator proposed by Platt (1977), where the limiting nutrient is defined measuring the increase on the algal growth rate as consequence of an increase of nutrient concentration.

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References

Albrigi, E. *Un modello di qualità delle acque e studio del problema della limitazione da nutriente nella zone costiera del Nord Adriatico influenzata da Po.* Degree thesis (in Italian) 2004

Jorgensen, S.E., Bendoricchio G. *Fundamentals of ecological modelling*. Elsevier, 2001

Platt T., Denman K.L., Jassby A.D. *Modelling the productivity of phytoplankton.* In Goldberg, McCave, O’Brien, Steele *The sea vol.6,* Wiley & sons 1977.

Redfield, A.C. *The biological control of chemical factors in the environment.* Am. Sc. 46: 205-221, 1958

Domain library construction for knowledge-based equation discovery: An application in limnology

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The knowledge-based approach to automated modeling brings together the two basic approaches to modeling dynamic systems: (1) deductive, which is derived from background knowledge (e.g. basic physical, chemical and biological principles) and (2) inductive, which is based on learning models from measured data about the system's behaviour. Recently, Todorovski and Džeroski (1997) and Todorovski (2003) combined these two approaches in LAGRAMGE, a tool for automated modeling based on equation discovery. As input, the tool requires measurements of the variables of the observed system, a library of domain-specific knowledge about the domain of interest, and a specification of the observed system. The provided library knowledge and system specification are first transformed into a grammar that specifies the space of candidate system models. The grammar can then be used by the equation discovery tool to search through the space of candidate models and find the one that fits the given measured data best.

In this paper, we deal with the task of building a library of domain knowledge for modeling lake ecosystems (or more specifically modeling the food chain in a lake) with LAGRAMGE. The models of the food chain take the form of systems of ordinary differential equations. The developed library supports the reconstruction of well-known limnological models, as well as building new ones according to the measured data and the background (expert) knowledge. Basic characteristics of the models that can be built using the library are: (a) 0-dimensional models, (b) multiple box models, i.e., the library supports modelling of lake stratifications and (c) models of fixed internal nutrient levels in primary producers and in animals.

The library is written in the process-based modeling formalism of Todorovski (2003) and is organised as follows. At the top level are mass balances for the state variables (animals, primary producers and inorganic nutrients) in the lake: these are the combining schemes. The mass balances involve a combination of biological processes. Generic processes form the core of the library and include chemical and biological kinetic processes that are influenced by different environmental (external) factors such as temperature, light, available food, etc. Finally, the library also includes several alternatives for the functional forms used to model the processes specified in the core of the library. The following generic processes are defined in the library:

1) Physical processes, such as inflow of nutrients, load of nutrients from land, outflow of a substance with all outflows from the lake, and settling of a substance. Processes that support physical segmentation, i.e., connect different layers in a stratified lake, are (a) the inflow of substances that contribute to the observed state variable as a result of settling from upper or rising from bottom layers and (b) the diffusion of a state variable from one layer to another.

2) Kinetic processes fall in the following three groups:
Primary producer growth
Three formulations of primary producer growth processes, according to the limiting factors combination, are supported in the library. The first formulation is the commonly used expression, i.e., a product of the limiting functions of temperature, light and nutrients. The second one uses the optimal temperature as a time variable and the third formulation couples the effects of light and temperatures into one expression.

Feeding (Feeds_on)
This process represents phytoplankton-zooplankton interactions, which cause a predatory loss (grazing) for phytoplankton and growth for zooplankton. The same process can be used for other types of interactions, such as fish-zooplankton, but not for modeling interactions that involve primary producers and inorganic nutrients, since there is a difference between how phytoplankton and zooplankton feed.

Non-predatory losses
Processes defined in the library enable the construction of simple models, containing a single loss term, as well as more complex models with different kinds of losses, such as losses through respiration, mortality, excretion and sedimentation.

The library was empirically evaluated on artificial and real-world data (measurements for Lake Bled, Slovenia). The real data comprise long-term (1987-present) monthly measurements of physical, chemical and biological parameters. We performed the first experiment on artificial data: from the measurements on nutrients, phytoplankton and zooplankton, we obtained data about detritus and bacteria by simulating a simple hand-made model. Simulated data were given along with the library of domain knowledge to LAGRAMGE to (re)construct a model that is similar to the simple hand-made one used to obtain the data. The model was successfully reconstructed. The second experiment was performed on the real measurement data. A nutrient-phytoplankton-zooplankton model was induced using the knowledge-based approach to automated modelling. The expert knowledge comprised information about nutrient load; light, temperature and nutrients limitation of phytoplankton growth; grazing of daphnia on phytoplankton resulting in daphnia growth and algae predatory loss at the same time; and a simple loss term for all species. Regarding the fairly high complexity of the modeled system, the model with only three differential equations reasonably fit the measurement data. Further work focusses on the induction of a model for a more complex food web, which is at present limited by the computational complexity of the induction of more complex models.

References

Todorovski, L. *Using Domain Knowledge for Automated Modeling of Dynamic Systems with Equation Discovery*. Doctoral dissertation, University of Ljubljana, Slovenia, 2003. Available for download at: `http://www-ai.ijs.si/~ljupco/ed/`

Todorovski, L., Džeroski, S. (1997). Declarative bias in equation discovery. *Proceedings of the Fourteenth International Conference on Machine Learning*, pages 376-384. Morgan Kaufmann, San Mateo, CA, 1997.

Modelling optimization of solar salt production using emergy approach

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Key words: emergy analysis, sustainability, STELLA model, sensitivity analysis, salt production

Introduction

Secovlje saltpans are one of the last examples of formerly extensive and over 700 years lasting traditional salt producing process on the Slovenian coastal area (Žagar, 1991; Kolundrovic and Franic, 1954). The evaporation process itself as well as water decantation is driven by solar radiation, wind energy and potential energy of water as the major totally renewable inflows. Work for salt collecting, transfer, storing and saltpan maintaining etc., is mostly performed by humans and sustainability is therefore dependent upon the percentage of renewable energy driving manpower and some other sinks in the process (Babic, 2004).

Nowadays several different approaches exist for evaluation of sustainability of different systems and processes. The majority of them compare the ratio of invested renewable and nonrenewable energy to the benefit of a process. They result in a list of different inputs and outputs, which are difficult if not impossible to compare. Emergy approach attempts to solve this problem by transforming inputs into a single quality of energy (Odum, 1996). All inputs driving the process are usually transformed into equivalents of solar energy. However, each of these techniques shows to be incomplete, partial, and in the most cases static, which is very inappropriate for environmental analyses. In emergy analysis the analyses performed so far mostly did not succeed to include costs due to environmental loading, the models were static, and they did not include sensitivity analyses. In our work we tested the possibility to surpass those deficiencies with STELLA software package.

STELLA is an object-oriented graphical programming language designed for dynamic systems modelling and process optimization. STELLA is one of the modelling programs, which is most used in business and academia today (Constanza and Voinov, 2001).

Results and discussion

STELLA program enables performance of sensitivity analysis either by varying parameters or by using built-in sensitivity-analysis (Constanza et al., 1998). We identified the highest flows of emergy and tested their effect to sustainability index (SI) during sensitivity analysis. Weather conditions, namely the amount of evaporated water and rain received, caused the highest changes in SI from among environmental flows. Changes in initial conditions and subsequent comparison of changes in graph curves and final emergy indices confirmed that the manual work has the highest impact on the sustainability of the process. At the same time the percentage of nonrenewable energy driving manpower and the total emergy in human work represent the points, where changes should be made in order to improve sustainability.

Other important sinks of nonrenewable emergy were the amount of fuel consumed and the emergy in machinery. Shift from the process using wind-pump to the process using motor-pump caused only slight decrease in sustainability and increase in environmental loading.

Dynamic STELLA model of solar salt production on the Secovlje saltpans enables comparison among several alternatives of the solar salt production process as well as comparison of the process in different climatic conditions. As the major guidelines for the improvement of sustainability and efficiency we could note optimization of the amount of work invested into production process and changes in the process to avoid dilution of highly concentrated brine and consequent loses due to precipitation.

During the process we can observe fluctuations and gradual stabilization of SI during the process. The course of the curves suggests that our observing time was a bit too short, as the values mostly did not succeed to stabilize.

Conclusions

STELLA model of salt production process has been recognized as an applicable modelling tool with many capabilities needed for successful dynamic emergy analysis. Suitable calculations of transformity factors for each individual case could be inserted, which is one of the most challenging steps in emergy analysis nowadays. Moreover it enables simple and evident addition of new factors such as ecological aesthetical and cultural values, environmental loading etc. added to the model. It enables the evidence into the fluctuations of flows and indices, which is important in determining the reliability of results.

As the major deficiency we missed the possibility to run sensitivity analyses on the flows with predetermined, measured and graphically presented courses of flows and the possibility to further process the results of the sensitivity analyses.

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References

Babic J., 2004. Emergy analysis of the salt production process at the Secovlje saltpans, Slovenia. Proceedings of the Third Biennial Emergy Analysis Research Conference, The Center for environmental Policy, Gainesville, FL (In Press).

Constanza R., Duplisea D., Kantsky U., 1998. Ecological Modelling on modelling ecological and economic systems with STELLA. Ecological Modelling, 110: 1-4.

Constanza R., Voinov A., 2001. Modelling ecological and economic systems with STELLA: Part III. Ecological Modelling, 143: 1-7.

Kolundrovic A., Franic M., 1954. Sol i morske solane. Udruženje rudnika i industrie nemetala, Zagreb.

Odum H.T., 1996. Environmental Accounting: Emergy and Environmental Decision Making. John Willey and Sons. New York.

Žagar Z., 1991. The Museum of Salt Making. The Maritime Museum "Sergeja Mašera", Piran.

A system dynamics model for the management of the gooseneck barnacle (*Pollicipes pollicipes*) in the marine reserve of Gaztelugatxe (Northern Spain)

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Key words: system dynamic model; management; marine reserve; gooseneck barnacle; *Pollicipes pollicipes*

Introduction

The gooseneck barnacle (*Pollicipes pollicipes*) is a highly exploited species in Spain and Portugal due to the great commercial demand and the high prices in the market (Barnes, 1996), producing an overexploitation of the stocks (Cunha and Weber, 2001). Due to the inaccessibility of the Gaztelugatxe coastal area, the gooseneck barnacle has maintained one of the greatest populations of the Basque coast in this area (Borja *et al.*, 2000). After the study undertaken by Borja *et al.* (2000), this coastal zone was declared as a marine reserve by means of the 229/1998 (Basque Government) Decree, establishing a two years moratorium in the gooseneck shellfishing. Facing the possibility of the gooseneck barnacle fishery opening in the area of the biotope, it was noticed the need for the development of a management tool, capable to think over the different management decisions: from the complete conservation of the system to the sustainable exploitation of the resource, joining together different social and biological factors, allowing the protection of the firsts (protection of the stock) and the development of the seconds (fishery activity). According to Sterman (1988), the best solution is the development of a system dynamic model applied to the modelization and knowledge of complex systems, in the case of the present contribution, the population structure and dynamics of the gooseneck barnacle and its relation with the surrounding environment and potential human activity.

The model

Based on the population dynamics of the gooseneck barnacle, the developed model is dominated by one positive and three negative loops. The positive loop portrays the reproductive and maturation process, ultimately “producing” more adult gooseneck barnacles. In the absence of any stabilizing, this loop would result in exponential growth of the gooseneck population. As in other populations dynamic models like those described by Borja and Bald (2000), Graves and Stave (2003) and Wakeland *et al.* (2003), the negative loops causes the stabilization as the different stages of the population expire due by natural causes and exploitation of the resource.

Results and discussion

According to the model results, the best management decision is the maintenance of the moratory. One of the aims in the declaration of marine reserves is the preservation of a resource that allows the maintaining of other areas (Borja *et al.*, 2004). Taking into account the dispersion capability of larvae (Grantham *et al.*, 2003), other areas near the reserve, and subjected to commercial exploitation like Ogoño, Izaro and cape Villano, will benefit from Gaztelugatxe production.

In the case of exploitation, the best management decision, which maximizes captures and minimizes the stock looses in a sustainable manner, is an alternate exploitation between

Aketxe and Gaztelugatxe coastal areas of the biotope. This measure coincides with the management recommended by Lauzier (1999a and 1999b), in Canada.

The model makes important assumptions relating to those parameters related with the less studied aspects of the population dynamics of this species, that is, settlement, maturation and natural mortality. All those investigation done in this sense will improve significantly the robustness of the developed tool.

Conclusions

The best management decision for the conservation of the gooseneck barnacle resource in the marine reserve of Gaztelugtxe is the maintenance of the moratory. In the case of exploitation, the best management decision is an alternate exploitation between Aketxe and Gaztelugatxe coastal areas of the marine reserve.

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References

Barnes, M., 1996. Pedunculate cirripedes of the genus *Pollicipes*. *Oceanogr. Mar. Biol. Annu. Rev*, **34**: 303-394.

Borja, A. and J. Bald, 2000. Modelling the Management of Clam (*Ruditapes decussatus*) Exploitation in the Basque Country (N of Spain). *Periodicum Biologorum*, Vol 102, Supplement 1, 395-406 pp. Zagreb.

Borja, A., V. Valencia, R. Castro, J. Franco, J. Bald, A. Uriarte, M. Mendizábal y F. Aguirrezabalaga, 2000. Establecimiento de las bases técnicas de conocimiento del área de San Juan de Gaztelugatxe con vistas a su posible declaración como reserva marina. *Informes Técnicos (Departamento de Agricultura y Pesca, Gobierno Vasco),* 87: 152 p.

Borja, A., J. Bald, I. Muxika and P. Liria, 2004. El recurso marisquero de percebe (*Pollicipes pollicipes*) en el biotopo marino protegido de Gaztelugatxe y en áreas explotadas de Bizkaia, *Informes Técnicos (Departamento de Agricultura y Pesca, Gobierno Vasco),* 101: 112 p.

Cunha, I. y M. Weber, 2001. Actividad reproductora del percebe *Pollicipes pollicipes* en el norte de Portugal. *Libro de resúmenes VII Congreso Nacional de Acuicultura. Ed. Dirección General de Pesca y Alimentación (Gobierno de Cantabria).* 173-175 pp.

Grantham, B.A., G.L. Eckert y A.L. Shanks, 2003. Dispersal potential of marine invertebrates in diverse habitats. *Ecological Applications*, 13(1) Suppl.: S108-S116.

Graves Y.V. y K.A. Stave, 2003. A Model to Understand Population Decline of the Devil´s Hole Pupfish (*Cypronodon diabolis*) and Support Habitat Management Decisions. CD Proceedings of the 21st International Conference on System Dynamics. July 20-24.New York.

Lauzier, R.B., 1999a. *A review of the biology and fisheries of the goose barnacle (Pollicipes polymerus Sowerby, 1833).* Fisheries and Oceans Canada, Canadian Stock Assessment Secretariat, Research Document 99/111: 1-30.

Lauzier, R.B., 1999b. *Framework for goose barnacle (Pollicipes polymerus Sowerby, 1833) fishery in waters off the west coast of Canada*. Fisheries and Oceans Canada, Canadian Stock Assessment Secretariat, Research Document 99/198: 1-24.

Sterman, J.D., 1988. "A Skeptic, s Guide to Computer Models". In: *Foresight and National Decisions: The Horseman and Bureaucrat*. Lindsey Grant Ed., University Press of America.

Wakeland, W., O. Cangur, G. Rueda y A. Scholz, 2003. A System Dynamics Model of the Pacific Coast Rockfish Fishery. CD Proceedings of the 21st International Conference on System Dynamics. July 20-24.New York.

Understanding ecosystem dynamics by using Self Organizing Map

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Key words: Gulf of Trieste; Self Organizing Map, Neural Network; classification

Introduction

Self Organizing Maps (SOM) are competitive learning Neural Network , which can be used for both classification, graphical representation and ordination of large multivariate data set. They are increasingly used in ecological application and environmental science, since – differently from other methodologies- they do not rely on any particular *a priori* assumptions. We applied SOM to a multivariate data set collected in a three years long monitoring program of the coastal area in the Northern part of Adriatic Sea, close to the Gulf of Trieste, which includes measure of physical parameters, such as water temperature and salinity, and water quality parameters, such as concentration of dissolved inorganic and organic forms of nitrogen and phosphorus, dissolved organic carbon, chlorophyll a and pheopigments. The total number of cast is around 18000 data.

Results and discussion

The results of SOM analysis indicated that the data can be projected in around 180 model vectors (best matching units). In agreement with the results of a k-means, these BMUs were then clusterised in 10 groups. Finally, the analysis of the distribution of environmental data within each group returned us a characterization of the water mass for each of the groups.

In this way, each sample was associated to a given water typology, and therefore it was possible to map the time evolution of the multivariate data set into the time evolution of a single, discrete, variable, i.e. the water typology.

This provided also a simple and intuitive representation of how the water mass typology change during the year, which can be followed without delving into the complexity of multidimensional representation.

In this way, correlations among different water typologies and external forcings, and typical succession of water typologies were put in evidence, a fact that in turn suggested possible causal relationship among them, and ultimately gave a possibility to gain a deeper insight into system dynamic.

Acknowledgements

This work was supported by INTERREG EU project.

References

AA.VV., *Interreg II Progetto di monitoraggio dell'Alto Adriatico Relazione conclusiva luglio 1998 - giugno 2001*, Laboratorio di Biologia Marina

Kohonen Teuvo, *Self-Organizing Maps*, Springer-Verlag, Heidelberg, 2001

Uncertainties in regional modelling of climate change impact in future: an example of *Thrips Tabaci* Lindeman in Slovenia

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Key words: climate change, downscaling, uncertainties, *Thrips tabaci* Lindeman

Introduction

Chaotic nature of climate system (Lorenz, 1967) does not enable the predictability of climate years ahead. However, a long-term systematic change in boundary conditions may influence the climate statistics, and the resulting long-term climatic response to such change may still be estimated (Benestad, 2003). The problem of unpredictability remains in the assumptions of possible boundary conditions change (i.e. change in concentrations of greenhouse gasses and aerosols in the future). This is the reason why projections of climate change in the future are usually related to the term scenario and not to the term prediction. And such scenarios are related to a lot of uncertainties that have to be considered during their interpretation.

Insects are the most diverse class of organisms on Earth. As insects have many detrimental effects on humans and natural ecosystems, both directly and indirectly, considerable thought has already been given to the impacts that global environmental change may have on them (Harrington et al., 2001). For quantitative assessment of climate change impact on insects, the regional climate change scenarios are needed. The problem of cumulative uncertainty in regional climate change impact studies is illustrated in this paper on the example of insect pest onion thrips (*Thrips tabaci* Lindeman) in Slovenia, although the general principles may be applied more widely.

Results and discussion

The basic source of uncertainty in climate change studies is the assumption about future socio-economic development and related emission scenarios. Not knowing the exact response of the climate system to the changes of atmospheric composition additionally contributes to the uncertainty of future climate change estimates even on a large-scale. This is illustrated with an example of air temperature (t) change projection across Europe based on climate simulations with four general circulation models (GCM) using SRES A2 and B2 marker emission scenarios (Houghton et al., 2001). The results of simulations were additionally scaled (Mitchell, 2003) to A1T, A1B, A1F, and B1 marker emission scenarios. The expected t increase till the end of 21st century is between 1.5 and 5°C in comparison to the 1990 value.

To bridge the gap between large-scale and local scale, where GCM results are not representative, empirical downscaling was used for the estimation of local near-ground air temperature (*T*) at two locations in Slovenia (Ljubljana and Bilje). As the air temperature will change significantly in the future, its values will exceed the range of values used for empirical model development leading to the problem of extrapolation as an additional source of uncertainty. The estimated change of *T* at locations Ljubljana and Bilje is between 1.5 and 7°C till the end of 21st century in comparison to the 1990 value.

Development of insects is often related to the weather conditions with degree-day (*DD*) models. Different *DD* models for onion thrips in literature indicate that either the pest is capable of local adaptation, or the estimation of *DD* model parameters is not trivial. As at least daily values are needed for a *DD* calculation, the synthetic *T* daily values were generated by a AR(1) model using downscaled monthly values of *T*. Neglecting influences other than temperature (food availability, other abiotic factors, etc.), selection of proper *DD* model, and use of simple *T* generator based on past observations additionally contribute to the uncertainty of final results. However, expected temperature increase will probably lead to more generations of onion thrips per year (*N*), resulting in larger populations of onion thrips that will cause more harm to cultivated plants in case of coincidence of availability of host plants with favourable environmental conditions. The lack of studies about the adaptation capability of onion thrips in changed environmental conditions is another important source of uncertainty in estimation of climate change impact on harmfulness of this pest.

Using Edelson and Magaro (1998) *DD* model, we can see that a similar increase of air temperature expected on the entire area of Slovenia, will have quite a different impact on the change of cumulative *DD* and related *N* due to different present temperature conditions. An example of Ljubljana and Bilje shows that larger increase of *DD* and related *N* is expected for Bilje, with warm sub-Mediterranean climate, than for Ljubljana, with temperate continental climate. More damage will be caused in areas that are already strongly exposed to the problem of onion thrips, but the harmfulness of the pest in the areas, where it is not a serious threat at present, will also increase.

Conclusions

A lot of assumptions have to be made in regional climate change impact studies, and all contribute to the uncertainty in final results. Some of them will probably be reduced in the future by gaining new knowledge, but at least the problem of unpredictable changes of climate boundary conditions will always remain as a source of the uncertainty.

References

Benestad, R. E. 2003. What can present climate models tell us about climate change? *Climatic Change*, 59, 311-331.

Harrington, R., Fleming, R. A., Woiwod, I. P. 2001. Climate change impacts on insect management and conservations in temperate regions: can they be predicted? Agricultural and Forest Entomology, 3, 4, 233-240.

Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., Maskell, K., Johnson, C. A. 2001. Climate change 2001: The scientific basis. Cambridge, Cambridge University Press: 752 pp.

Lorenz, E. 1967. The nature and theory of general circulation of the atmosphere. WMO Publication 218, 59-96.

Mitchell, T. D. 2003. Pattern scaling: An examination of the accuracy of the technique for describing future climates, Climatic Change, 60, 217-242.

Modelling the damage status of silver fir trees (*Abies alba* Mill.) on the basis of stand, geomorphological and climatic factors

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Key words: digital elevation model, fir health status, general linear modelling, macroclimate, raster-GIS

Introduction

The paper investigates the possibility of assessing damage (health status) of silver fir (*Abies alba* Mill.) using multivariate regression models in the function of stand and ecological factors. Research was carried out on limestone-dolomite substrate in the Dinaric part of the silver fir range in the Republic of Croatia. Damage was assessed on 151 plots. A total of 531 trees of silver fir (*Abies alba* Mill.) were sampled. To perform the assessment, tree crowns were compared with the existing photointerpretation key on the damage scale of 5%.

Of stand factors, the following independent variables were used in modelling: 1) breast diameter of a tree as a variable representing competing ability and position of tree in the stand, 2) tree basal area in relation to (divided by) plot basal area, as an indicator of competitive pressure on the sampled tree, and 3) tree age. Other independent variables included: 1) geomorphological (DEM-based) variables (terrain slope, altitude, terrain orientation with regard to the northness and eastness, flow accumulation, sinkhole depth, terrain curvatures, terrain exposure to the horizontal wind flux, latitude and longitude) and 2) climatic variables (monthly mean air temperature, monthly precipitation, monthly mean global solar irradiation on horizontal surface at ground, monthly potential evapotranspiration on horizontal surface).

The basic set of 48 independent macroclimatic estimators (4 variables by 12 months) was reduced to 5 composite estimators (non-linear analogues of principal components) using the five-layered autoassociative NN, which have 48 neurons in the first and last layer (48 basic estimators), 15 neurons in the second and the fourth layer and 5 neurons in the central layer. Logistic function was used as activation function. Using this NN architecture, 99.79% of total macroclimatic variability was explained.

A general linear modelling method was used, where square terms and interaction terms (multiplication products) of original variables were treated as independent linear predictors (Ott, 1993). The 'Backward Stepwise' method was used for model optimisation (selection of a subset of linear predictors entering the final model). A 27 separate models were developed regarding the different subsets of input data (all trees, trees with diameter over as well as bellow 40 cm), different subsets of independent variables (limited number of DEM-based variables, all DEM-based variables, all variables without age, all variables) and different model design (with and without square terms).

Results and discussion

Both particular models developed from separate data sets with regard to diameter of 40 cm (presumed boundary between dominant trees and suppressed or young trees) explained significantly larger part of total variability (in all combinations of other mentioned model characteristics) in relation to the respective models developed for all trees together. Consequently, models developed for all trees were not further examined.

All remaining models were preliminary used for construction of hypothetical spatial distributions of fir damage for entire area of fir in Croatia. Criteria for the final choosing models potentially applicable for spatial prediction of fir damage were: 1) total variability explained by the model and 2) portion of predicted values within the range of input data about fir damage (0-100 %).

Six finally selected models (all of them with reduced set of DEM-based variables and square terms) were tested on the independent data set collected in the frame of International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP; Group of authors, 1989). Significant correlation between model results were yielded only for trees thinner than 40 cm, which can be explained by the impact of forest management which prefer cutting of damaged mature trees.

Conclusions

Yielded results could be preliminary used for spatial predicting and mapping of fir damage in a frame of raster-GIS, for entire area of fir in Croatia. Future research have to be leaded in two major directions: 1) completing of larger field sample aiming at using of more plastic prediction models (e.g. developed by neural networks), 2) integration of spatial forest health prediction models with the spatial models of aeropollutants imissions (Antonić and Legović, 1999).

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References

Antonić, O., Legović, T. Estimating the direction of an unknown air pollution source using a digital elevation model and a sample of deposition. *Ecological Modelling* 124, 85–95, 1999.

Ott, R.L. *An Introduction to Statistical Methods and Data Analysis.* Duxbury Press, Belmont, 1993.

Group of authors. *Manual on methodologies and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forest*, Hamburg/Geneve: Programme coordinating centers, UN/EC 1986 (revised 1989).

INDIRECT EFFECTS AND DISTRIBUTED CONTROL IN ECOSYSTEMS

3. Temporal Variation of Indirect Effects in a Nitrogen Flow Model of the Neuse River Estuary, USA: Time Series Analysis

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Key words: nitrogen cycling; indirect effects; input-output analysis; stability

Introduction

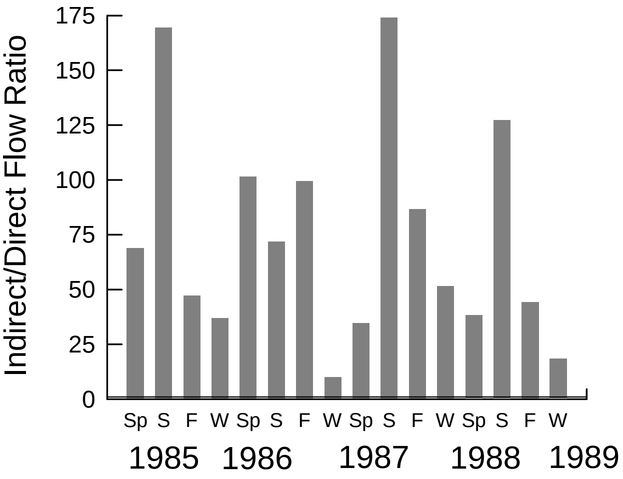
One purpose for developing input–output analysis (IOA) in economics was to trace indirect effects through the network of economic transactions (Leontief 1966). Indirect effects, the ability of one element in a system to impact another without direct interaction, are a critical component of complex adaptive systems (Holland 1995, Capra 1996), including ecological systems (Wootton 1994, Krivtsov 2004). Network Environ Analysis (NEA) is an environmental application and extension of economic IOA. NEA includes analytical methodology to characterize and quantify indirect effects in environmental systems transmitted by a specific element (e.g. energy, carbon, nitrogen, phosphorus, etc.) within a system at steady state. Previous results suggest that indirect effects tend to dominate direct effects in ecosystem environs (Patten 1983, Higashi and Patten 1989). Though at times steady state models are useful, ecologists are typically interested in system dynamics. In this paper, we use NEA to investigate the temporal dynamics of indirect effects in sixteen steady state models of nitrogen cycling in the Neuse River Estuary, USA. These models were originally constructed by Christian and Thomas (2003) as a part of a larger Neuse River Modeling and Monitoring (ModMon) program to study the estuary's response to recently implemented environmental management. Our work had two primary objectives: 1) describe and quantify the temporal dynamics of indirect effects and 2) identify the relative importance of system factors determining the indirect effects.

Results and discussion

Nitrogen flux in the Neuse River estuary was dominated by indirect flows in all sixteen seasons analysed (Figure 1). Based on the output oriented throughflow–specific flow analysis in NEA, the ratio of indirect–to–direct flow ranged from a low of 9.9 in winter 1987 to a maximum of 174 in summer 1987. In all seasons, indirect flow was more than 80% of the total system throughflow. We were surprised by the relatively small amount of temporal variation in indirect effects within the Neuse River Estuary when looking at the ratio of indirect flow to total system throughflow (Indirect/TST). We expected more pronounced seasonal variation, increasing with biological activity in the spring, climaxing in summer and then declining in the winter. This pattern occurs, but differences between seasonal means were very small; all seasonal means were over 90%. Further, there were no statistically significant differences between annual Indirect/TST means.

Our final analysis used a regression model to show that both nitrogen cycling and boundary loading were significant factors in determining the development of indirect effects in these models (Indirect = 226.47 + 1.00*Cycled + 2.14*Boundary, R^2 = 0.9997, $p<0.0001$, C(p)=1.25).

Figure 1: Indirect–to–direct flow ratio for sixteen seasons of nitrogen cycling in the Neuse River Estuary



Conclusions

Indirect effects transmitted by the network of nitrogen transactions dominate direct effects in the Neuse River estuary. Although we must be cautious forecasting from this type of analysis, our results suggest that if the Neuse River estuary maintains its current organization, management efforts to decrease nitrogen loading into the estuary might be important for long-term change, but these efforts will probably not rapidly impact the eutrophic state of the estuary. Dominance of indirect flow due to cycling makes this system state relatively difficult to change by external forcing. In this sense the indirect effects stabilize the system, making it more resistant to external perturbations, though it may be more sensitive to internal alterations.

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References

Capra, F. 1996. The web of life: a new scientific understanding of living systems, 1st Anchor Books edition. Anchor Books, New York.

Christian, R. R., and C. R. Thomas. 2003. Network analysis of nitrogen inputs and cycling in the Neuse River Estuary, North Carolina, USA. Estuaries **26**:815-828.

Higashi, M., and B. C. Patten. 1989. Dominance of indirect causality in ecosystems. American Naturalist **133**:288-302.

Holland, J. H. 1995. Hidden order: how adaptation builds complexity. Perseus Books, Reading, Massachusetts.

Krivtsov, V. 2004. Investigations of indirect relationships in ecology and environmental sciences: a review and the implications for comparative theoretical ecosystem analysis. Ecological Modelling **174**:37-54.

Leontief, W. W. 1966. Input-output economics. Oxford University Press, New York.

Patten, B. C. 1983. On the quantitative dominance of indirect effects in ecosystems. Pages 27-37 *in* W. K. Lauenroth, G. V. Skogerboe, and M. Flug, editors. Analysis of ecological systems: state-of-the-art in ecological modelling. Elsevier, Amsterdam.

Wootton, J. T. 1994. The nature and consequences of indirect effects in ecological communities. Annual Reviews of Ecology and Systematics **25**:443-466.

Applicability of LOICZ derived indexes in complex ecosystem. A multibox analysis for the lagoon of Venice

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Key words: loicz; multibox; Venice; model

Abstract

LOICZ is an IGBP core project established in 1992, whose aim is to develop a predictive understanding of the effects of changes in climate, land use and sea level on the global functioning and sustainability of coastal ecosystems. One of the goals of the project was the compilation of biogeochemical budgets for a number of coastal areas as larger as possible. A biogeochemical modelling procedure was released, which aimed to lay out a robust, widely applicable, uniform methodology, based on minimal data requirements on the use of secondary data. In agreement with it, a water budget was set up first, in order to estimate fluxes at the open boundary, then salt water were taken into consideration, in order to estimate diffusive exchanges. Finally, non-conservative tracers were considered, and budgets on Phosphorus and Nitrogen were computed in order to indirectly derive an index on ecosystem metabolism (Net Ecosystem Metabolism) and estimates on the difference between nitrification and denitrification processes.

Such methodology, however, relies on a few strong assumptions, which not always are verified in practise. The major one is that data give an accurate representation of a system that is homogeneous and in steady state. Multi-box analysis has been proposed as well, in order to overcome the homogeneity constrained, and enable one to apply the procedure also to complex coastal area. In the present work, a coupled water quality transport model is used to produce a synthetic data set which is assumed to represent reality, the output is subsampled by mimicking a monitoring program and LOICZ modelling procedure is applied, both in the traditional and in the multi-box frame.

The resulting Indexes are then compared among themselves, and with the synthetic reality. In this way it is possible to assess reliability of the estimates provided, underline the limits of the procedure and derive a number of suggestion for 'best' application of the LOICZ biogeochemical modelling procedure, and proper interpretation of its results.

Acknowledgements

This work was supported by OGS

References

Gordon, Jr., D. C., P. R. Boudreau, K. H. Mann, J.-E. Ong, W. L. Silvert, S. V. Smith, G. Wattayakorn, F. Wulff and T. Yanagi, 1996. LOICZ Biogeochemical Modelling Guidelines. LOICZ Reports & Studies No 5, 1-96.

Cossarini G., Castellani C., Barbanti A., Bernstein A., Cecconi, G., Collavini, F., Guerzoni S., Montobbio L., Pastres R., Rabitti S., Socal G., Solidoro C., Vazzoler M., Zaggia L., 2002. LOICZ budget analysis: application to the Venice Lagoon. In A Network in support of the IGBP core programme: Land Ocean Interaction in the Coastal Zone (LOICZ) and a contribution to the implementation of the Water Framework Directive with the collaboration of Institute for the Environment and Sustainability. Joint Research Centre, Ispra, Italy

Melaku Canu D., C. Solidoro, and G. Umgiesser, 2004. Modelling the responses of the Lagoon of Venice ecosystem to variations in physical forcings. Ecological Modelling, Vol. 170, pp. 265-289.

On modelling a microcolonial black fungi growth on rock surfaces

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Key words: biofilms; sub-aerial rock; microcolonial fungi; simulation model

Introduction

In ecology, there is no clear concept on the former and present influence of microbial and especially fungal sub-aerial biofilms as a specific type of pioneer ecosystem. Nevertheless, sub-aerial biofilms on solid rocks play a crucial role in energy and matter turnover, and especially in acceleration of rock weathering resulting in soil formation and vegetation colonisation in all natural zones (Staley et al., 1982). The biofilms are a very first stage of any primary succession represented on solid rocks, in many deserts and on monuments, but it is missing practically in all works on ecosystem and vegetation dynamics. Exposed rock surfaces of various origins and under different climatic conditions are colonised predominantly by fungi, but especially inherent for the sub-aerial biofilms is the presence of slow growing yeast-like black fungi often termed as microcolonial fungi (MCF). This living form is developing in the wide group of *Ascomycetes* in the orders of *Dothideales*, *Chaetothyriales* and *Pleosporales* in the harsh conditions of specific ecological niches on rock surfaces (Sterflinger et al., 1999). No models of this wide spread specific type of primary ecosystems have been compiled before.

Results and discussion

The analysis of the existed experimental data on MCF growth allowed for a completion of the following works: (i) a conceptual model of rock dwelling fungal biofilms formed on exposed surfaces of solid rocks; the model illustrates the role of environmental factors and an interaction of MCF with ephemerous algal and bacterial communities; (ii) generalisation of the effect of environmental factors (temperature, water, external input of organic matter) on the development of slow growing black MCF; (iii) the data on MCF growth in culture. This experimental basis allowed for a compilation and analysis of the simulation model of growth for a single fungal microcolony on a solid rock surface. The model exploits the idea of potential growth influenced by the environmental factors and organic nutrition. The effect of the factors is evaluated using the Liebig law of minimum. The model is realised in PowerSim Studio™ software. The structure of the model can be seen on the Figure.

The model sensitivity analysis shows, that a continued lack of organic nutrition is a dominating environmental factor limiting growth of MCF on stone monuments and other exposed rock surfaces in European temperate and Mediterranean climate. The exponential growth of MCF was found at unlimited organic nutrition even with strong reduction of wet growing days with favourable temperature.

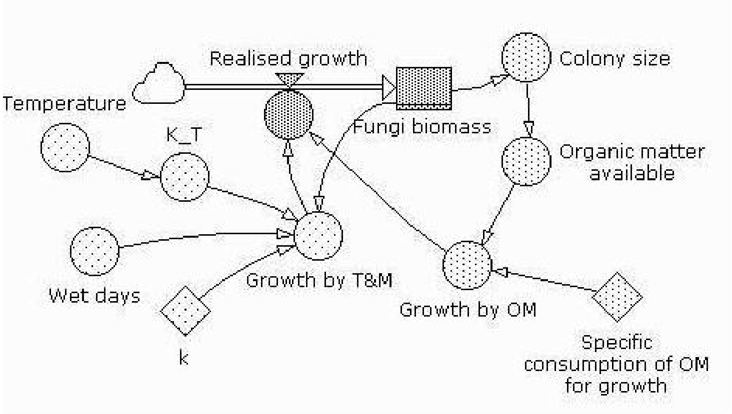

Figure. Flow chart of MCF growth model; ‘k’ means coefficient of potential growth; ‘K_T’ is temperature multiplier

Conclusions

The results of the simulation correspond well to the existing observations of MCF growth in natural conditions (Gorbushina, 1997; Krumbein and Jens, 1981; Staley et al., 1982) mostly at the surface of monuments. The conclusion on the role of a lack of available organic nutrition coincides well with the theory of dust derived growth of chemoorganotroph microorganisms on bare rock surfaces even in remote desert environments referred to by Gorbushina et al. (2001). However, significant gaps exist in our knowledge of the quantitative parameters and the processes of fungal growth and survival under the impact of natural and anthropogenic factors.

Acknowledgements

This work has been supported by DFG Projects Go 897/2-1 and Kr 333/30-1 and by EU Project BIODAM EVK4-CT-2002-00098.

References

Gorbushina, A.A. 1997. Biology of marble injuring micromycetes. PhD Thesis, St. Petersburg State University, St. Petersburg. 148 p.

Gorbushina, A. A., Boettcher, M., Brumsack, H.-J., Krumbein, W.E., Vendrell-Saz, M. 2001. Biogenic Forsterite and Opal as a Product of Biodeterioration and Lichen Stromatolite Formation in Table Mountain Systems (Tepuis) of Venezuela. Geomicrobiology Journal 18: 117-132.

Krumbein, W. E. and Jens, K. 1981. Biogenic rock varnishes of the Negev desert (Israel) and ecophysiological study of iron and manganese transformation by cyanobacteria and fungi. Oecologia 50: 25-38.

Staley, J. T., Palmer, T. E. and Adams, J. B. 1982. Microcolonial fungi. Common inhabitants on desert rocks? Science 215: 1093-1095.

Sterflinger, K., de Hoog, G.S., Haase, G. 1999. Phylogeny and ecology of meristematic Ascomycetes. Stud. Mycol. 43: 5-22.

The use of forest ecosystem model EFIMOD for research and practical implementation at forest stand, local and regional levels

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Key words: spatially explicit simulation model; individual tree growth; tree-soil system; stand, forest unit and regional application

Introduction

Recently, the idea on the necessity to have a cascade of models with a different spatial resolution was dominated in the terrestrial ecosystem modelling (Acevedo et al., 1995). The main argument was to have various specific models for local, landscape and regional levels. However, this idea can be significantly modified now. Here we show the prospects for the implementation of one basic model type to cover different spatial scales in forest ecosystem modelling. To demonstrate multi-scale application of one model type, we used a model EFIMOD (Komarov et al., 2003) for the description of stand growth, soil dynamics and biological cycle of C and N in boreal and temperate forest ecosystems. It is a spatially explicit individual-based stand-level simulator for several boreal and temperate tree species on different forest soils under European climatic conditions. Tree biomass growth is modelled depending on the tree's ecological parameters (silvics), tree's position within the stand and local light and available soil nitrogen. The soil submodel is used to estimate organic matter dynamics and available nitrogen for tree growth.

Results and discussion

The effectiveness of the EFIMOD for theoretical analysis of individual tree growth and ecosystem dynamics at stand level was demonstrated before (Komarov et al., 2003). The recent use of the model at stand level for the quantification of the factors of forest growth increase in Europe allows for a conclusion on the relative contribution of the environmental factors in this process. The simulation shows that high atmospheric nitrogen deposition and growth of temperature in Europe can lead to 5 to 20% increasing of forest growing stock, and 4 to 10% reduction of soil C. The EFIMOD was also used for the study of the effects of two main types of forest thinning: classical one from below (removal of small trees) and from above (removal of large trees). The results demonstrate no ecological difference of these types of thinning but a significant contrast in the size and volume of merchantable wood. The promising results with the EFIMOD were obtained for the evaluation of carbon balance in Canadian boreal forests.

At local level, we have used EFIMOD in a case study in Central Russia. A forest lot in experimental forest “Russky Les” south of Moscow, Russia, has been selected for the case study. The simulated time series shows that strategy of natural development is the best alternative from the ecological point of view. The selective forest scenario is the best corresponding to the concept of sustainable forestry. This case study demonstrates a good applicability of forest stand model for simulation at the local level of forest unit or landscape.

The possibility of the model for the regional level was tested at the evaluation of 50-year regional soil carbon balance in forest ecosystems of Leningrad administrative area, north-western Russia, with total area 3.8 mln ha. The contribution of forests with dominance of different tree species at wide range of soils in carbon sequestration was evaluated. The conclusion is that the forests of the region are sinks of atmospheric carbon. The loss of soil carbon was found in young stands only. The total soil carbon balance reaches a positive value of 8.7 mln ton at the area of the region for 50 years time span.

Conclusions

The examples of the application of stand-level forest ecosystem model for local and regional levels prove the prospects for the use of one basic model type for multi-scale simulation. This approach allows for simulation of the ecosystem dynamics at large scales without loss of information. At the local level, the same method has been used by Chumachenko et al. (2003) for rather big forest territories. At the regional level, the use of one basic model is corresponding to the facilities of Canadian model CBM-CFS2 (Kurz, Apps, 1999) and EFISCEN model (Nabuurs et al., 2003) implemented at national and continental levels. In this relation, we think that the use of the ecosystem model that directly accounts for biomass productivity (NPP) and soil dynamics has a real privilege over the simulators based on standard growth tables.

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The work was supported by the EU Project CT 98-4124, and EU INTAS Projects 01 0633 and 01 0512.

References

Acevedo, M.F., Urban, D.L. and Ablan, M. 1995. Landscape scale forest dynamics: GIS, gap and transition models. In Goodchild, M.F., Stewart, L.T., Parks, B.O., Crane M.P., Johnston C.A., Maidment D.R. and Glendidning S. (eds.). GIS and Environmental Modelling. Progress and Research Issues. GIS World, Fort Collins, Colorado: 181-185.

Chumachenko S. I., Korotkov V. N., Palenova M. M., Politov D.V., 2003. Simulation modelling of long-term stand dynamics at different scenarios of forest management for conifer - broad-leaved forests. Ecological Modelling 170: 345-361.

Komarov, A., Chertov, O., Zudin, S., Nadporozhskaya, M., Mikhailov, A., Bykhovets, S., Zudina, E., Zoubkova. 2003. EFIMOD 2 - - A model of growth and elements cycling in boreal forest ecosystems. Ecological Modelling 170 (2-3): 373-392.

Kurz, WA Apps MJ. 1999. A 70-year retrospective analysis of carbon fluxes in the Canadian forest sector. Ecological Applications 9(2): 526-547.

Nabuurs, G.-J., Päivinen, R., Pussinen, A., Schelhaas, M.-J. 2003. Development of European Forests until 2050. EFI Research Report 15. Brill: Leiden, Boston, Köln. 242 p.

MOOVES : an individual-based model to study the functioning of a tropical ecosystem and its reaction to fishing pressure.

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Key words: individual-based modelling; ecosystem; trophodynamics; fishing impact; Guinea

Introduction

In the context of the Ecosystem Approach to Fisheries (FAO, 2003), we propose to rely on the individual-based modelling (IBM) technique to investigate the functioning of the Guinean marine ecosystem and its reaction to fishing pressure. Our approach aims at representing the complexity of the interactions between species, and between species and their environment. Individual-based models appear to be a relevant approach since the goal of the study is to explore the complex characteristics of the structure and dynamics of an ecosystem (Parrot & Kok, 2000). Many IBM appeared in the fish biology literature during the last fifteen years (DeAngelis & Gross, 1992 ; Grimm, 1999) but few intended to represent an exploited marine fish community and its resources (as did Shin and Cury (2004)).

Results and discussion

MOOVES (Marine Object-Oriented Virtual Ecosystem Simulator) is based on an individual-based model of marine macroorganisms interacting in a simulated environment (heterogeneous ground nature and water masses). The simulator makes the agents move around on a georeferenced grid where abiotic parameters are explicit. The organisms' full life cycle is represented: hatching, foraging, search for suitable environmental conditions, growth, reproduction and death. Agents belong to "bio-functional groups" that comprise species that share habitat, food resources and have similar life-history traits parameters. Diets consist of consumption within source compartments (plankton, detritus, benthos) and/or predation on other individuals, depending only on the predator-prey spatio-temporal co-occurrence and size ratio, whatever the prey taxonomic origin may be. Fishing pressure is formalized as a mortality coefficient.

This approach allows to analyse the consequences, at the ecosystem level, of the functioning hypothesis that are implemented at the level of bio-functional groups. We find out models of life-history processes and individual interactions that are viable to represent a coherent system. By application of this viable set of processes and parameters, we investigate the structuring and controls that occur within and between fish communities. In particular, reaction of the system to fishing pressure is stressed, as this disturbance is high in Guinea

(Domain *et al*., 1999). Various types of scenarios are compared: exploitation of all species, of a few target species, or of fish larger than a given size.

Conclusion

Searching for viable sets of processes provides insight into the origins of the system dynamics. We adopt a pattern-oriented approach (Railback, 2001) to validate the model. From there, we study the impact of fishing and explore various fisheries strategies.

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References

De Angelis, D. L., and Gross, L. J. (Eds.). *Individual-based models and approaches in ecology: populations, communities and ecosystems.* Chapman & Hall, New York, 1992.

Domain, F., Chavance, P., and Diallo, A. *La pêche côtière en Guinée: ressources et exploitation*. IRD / CNSHB , Paris, 1999.

FAO (Food and Agricultural Organization of the United Nations). *Fisheries Management - 2. The Ecosystem Approach to Fisheries.* FAO Technical Guidelines for Responsible Fisheries, Vol. 4, Suppl. 2. Rome, 2003.

Grimm, V. Ten years of individual-based modelling in ecology: what have we learned and what could we learn in the future ? *Ecological Modelling*, 115:129-148, 1999.

Parrott, L., and Kok, R. Incorporating complexity in ecosystem modelling. *Complexity International*, 7: 17pp, 2000.

Railsback, S. F. Getting "results": the pattern-oriented approach to analyzing natural systems with individual-based models. *Natural Resource Modeling*, 14: 465-474, 2001.

Shin, Y. J., and Cury, P. Using an individual-based model of fish assemblages to study the response of size spectra to changes in fishing. *Canadian Journal of Fisheries and Aquatic Sciences*, 61: 414-431, 2004.

Using Data Assimilation for investigating the spatial and temporal variability of the trophic state in the Venice Lagoon

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Key words: trophic state, data assimilation, Venice Lagoon

Abstract

Data Assimilation techniques were applied to an ecosystem model of the Venice lagoon to obtain reliable and coherent estimations of the chlorophyll and nutrient fields, improving the knowledge on spatial and temporal evolution of the trophic state. The model, already released, parameterizes the transport processes in term of pure turbulent diffusion and describes the evolution and interaction of 12 biological compartments. Rivers and urban nutrient loads, energy and matter exchanges at the air-water interface and exchanges with the Adriatic Sea are the input factors which drive the model.

Assimilation procedures utilize monthly observations collected in a monitoring network which covers homogeneously the lagoon during the year 2001. Data were interpolated to the regular grid of the model using an objective analysis technique specifically developed for the lagoon. Such a technique is based on the definition the correlation between points as function of a “characteristic distance”, that accounted for the hydrodynamic condition of the system.

Different estimates of the state of the system provided by different DA techniques were compared to the reference solution, in order to judge the capability of the methods of reproducing reliable seasonal evolution of nutrient and chlorophyll spatial gradients in the lagoon.

In particular, we compared results obtained by simple techniques, such as Direct Insertion and Optimal Interpolation, and more complex, state of art, technique, such as the application of the Error Subspace Statistical Estimation scheme on the Extend Kalman Filter. In the latter case, in addition to the forecast of the state, the methodology enables one to evaluate also the error distribution of the forecast of the model and the assimilated fields in relation to the uncertainty of input factors and model parameters.

Modelling of weather variability effect on fitophenology

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Key words: Plant phenology, Meteorological variables, Statistical models, Slovenia

Introduction

Influence of some meteorological variables on phenological development of different plant species in Slovenia was investigated. The purpose of our work was working out phenological and phenoclimatic multiple regression models for prediction of phenophases appearance considering principle of parsimonious. Phenological and meteorological data for the period 1955-2000 were used in our study, eight locations were selected: Celje, Ilirska Bistrica, Lesce, Ljubljana, Maribor, Murska Sobota, Novo mesto and Rateče, which represented at the same time phenological and meteorological stations. 6 different phenophases (leaf unfolding, beginning of flowering, full flowering, first ripe fruits, maturity, autumnal leaf coloring) and 17 plants respectively were chosen to represent four groups of phenological objects: wild herbaceous plants (ox-eye daisy, snowdrop, dandelion, spring-saffron), forest trees and shrubs (common silver birch, beech, common elder, horse-chestnut, goat willow, hazel, large-leaved lime, black locust, Norway spruce, common lilac), grasses (cock's-foot) and fruit trees (plum tree, apple tree). Environmental Agency of Republic of Slovenia provided phenological and meteorological data.

Results and discussion

Lower threshold temperatures for particular phenophases appearance were determined with the least standard deviation in growing-degree day's method. Thermal time was calculated with rectangular method in three different ways: as growing-degree days above defined lower threshold temperature, growing-degree days above zero, calculated from average daily air temperatures and growing degree days above zero, calculated from minimum daily air temperatures. For the Ljubljana location photothermal time was also calculated. Analysis of variance was performed to test variation in phenological dates between stations and linear trend analysis was used to investigate time series of phenological data. On the base of preliminary correlation analysis multiple linear regression models (stepwise selection) were applied. Models were tested with cross validation method and for the Celje station also on independent data set for year 2000. The temporal variability of phenological data was very high in early spring. The mean linear trends in phenophases appearance were negative, ranged from -1.4 days per decade for leaf unfolding, -2.2 days per decade for late-spring flowering and -3.1 days per decade for early-spring flowering. The correlation analyses were carried out to establish the relationships between phenophases appearance and some meteorological variables. The average defined correlation coefficients between flowering dates and mean monthly air temperatures ranged from –0.7 to –0.8; values for leaf unfolding phases were a little lower. For autumnal phases this correlation was weaker and positive. The correlation between winter North Atlantic Oscillation Index ($NAOI_{win}$) and temperature was highly significant for all stations for the months from December to March, the average correlation coefficient was +0.58. With $NAOI_{win}$ variability we explained the large part of variation in early-flowering phases. Growing degree-days were calculated on the base of statistically determined threshold temperature (GDD_{stat}) and above unified threshold temperature 0ºC (GDD_{uni}). Sums of GDD_{uni} were lower in Rateče, compared to other stations; largest sums were mostly reached in Ilirska Bistrica and Ljubljana, which confirms that the same plant species needs larger amount of heat unit accumulation for its development on warm locations than in colder areas. When we described phenological progress with GDD_{stat} instead with GDD_{uni}, correlation coefficients were higher (from 0.5 to 0.65). We calculated also photothermal time for location Ljubljana; we took into consideration the temperature for the light part of the day only. For all phases correlation coefficients were higher when we used photothermal instead of thermal time.

In detailed analysis of phenophases dependence on meteorological parameters we used multiple linear regression to make phenological and phenoclimatic models. We formed models for 10 different plants respectively for 14 phenophases where forecasting could be useful for particular measures in agrometeorology, medical meteorology, pharmacy or in climate change researches. With single phenological model we have predicted individual phenological phenomenon for particular plant on the base of previous phenological data of the same plant or on the base of previous phenological date of other plants. The most frequently included independent variable in models was common silver birch, the next were dandelion and horse-chestnut. On the base of correlation analysis we included in multiple linear regression analyses as independent variables monthly, two-monthly and three-monthly average air temperatures, monthly amount of precipitations, thermal time, NAOI and photothermal time for the Ljubljana location only. In all phenoclimatic models thermal time respectively photothermal time for Ljubljana was presented as independent variable. In models thermal time was mostly expressed as GDD_{uni} or GDD_{stat} which indicated that both methods are convenient for usage. We could not ascertain general principle that minimum temperatures were more significant for appointed phenophase or plant. Variables of monthly amount of precipitation and NAOI were included in smaller number of models. We validated models with cross validation method. Average correlation coefficient between observed and predicted phenophase data amounted above 0.90 indicating that models represent actual conditions well. Analysis of residuals at cross validation has shown maximal deviations during extremely warm and cold years on all locations. In addition to cross validation method we have tested all models for Celje (this was the only location with data for all treating phenophases) on independent data set for year 2000 where maximal difference between observed and predicted values was 5 days.

Conclusions

Possibilities of predicting phenological phases of plants were studied based on meteorological variables in Slovenia. Predictions of multiple regression models were good with sufficiently long foresight period. Presented equations in this work could be powerfully extended and applied to other places and plant species, provided that a sufficiently long time series of phenological and meteorological parameters of the area involved were available.

Reference:

Črepinšek, Z. Predictions of phenological development of plants based on agrometeorological variables in Slovenia. Doctoral Dissertation. University of Ljubljana, 135 p., 2002.

Modeling ecological absence-presence data along an environmental gradient: threshold levels of the environment

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Key words: binary absence-presence data, environmental gradient, environmental thresholds, Bayesian model selection.

Introduction

Often ecological data are collected as binary absence-presence data, i.e. at a specific site within a region it is recorded whether or not a certain species is present at a particular point in time. Such absence-presence data do not allow a population biological modelling of the intra- and inter-specific dynamics and consequently, the future state of the community may not be predicted. However, if absence-presence data are collected along an environmental gradient, the data may still effectively be used for generating hypotheses on the effects of the environment on community structures. Furthermore, where estimates of the biomass and densities of different species are expected to change within and among years, absence-presence data are less variable in time.

Results and discussion

Generally the modelling of the ecological absence-presence data along one or more environmental gradients have focussed on estimating the right shape of the species response to the environment (e.g. Oksanen and Minchin, 2002). However, for some applied ecological purposes it may be more relevant to focus on specific properties of the species response curve, such as if there are one or more threshold levels of the environment where the probability that a species is present is expected to either increase or decrease significantly. For example, imagine an endangered plant species that is known to be readily outcompeted in a nitrogen-enriched environment; if there is knowledge on a threshold level of nitrogen availability, which has a significant influence on the probability that the species is present, then this information may be used in a conservation management plant. Additionally, it may be important to obtain knowledge on environmental threshold levels in order to test theoretical expectations of the distribution of species along resource gradients (Boyce and McDonald, 1999; Kirkpatrick and Barton, 1997). These models suggest that in a continuous spatial setting the probability of being present might depend on a threshold level of the environment.

Here a methodology for estimating environmental thresholds of binary absence-presence data is presented where the level of the threshold is a parameter. The data is fitted to three complementary different models: an independent null-model, a monotonically increasing or decreasing model, and an optimum model. The range of the three models is strictly between zero and one and the models are therefore well suited for modelling presence probabilities. The results of the three models may be combined by using Bayesian model selection

methodologies. The proposed methodology is exemplified on observed binary absence-presence of *Bauera rubioides* along an elevation gradient.
discussion here.

References

Boyce, M. S., and McDonald, L. L., 1999. Relating populations to habitats using resource selection functions. *Trends in Ecology and Evolution* 14, 268-272.

Kirkpatrick, M., and Barton, N. H., 1997. Evolution of species range. *American Naturalist* 150, 1-23.

Oksanen, J., and Minchin, P. R., 2002. Continuum theory revisited: what shape are species responses along ecological gradients? *Ecological Modelling* 157, 119-129.

Using stage-structured invasion models to assess environmental risks of transgene escape *via* feral oilseed rape

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Key words: population dynamics, seed dispersal, integro-differential model, invasion speed.

Introduction

Within the context of environmental risk assessment, models can provide a convenient tool to check the potential role played by each of the processes involved and to make plans for risk management and monitoring. The introduction of genetically modified (GM) crops is likely to result in transgene escape within the agro-ecosystem. This transgene flow may have an environmental impact *via* different processes, such as the invasiveness of crop species as feral populations outside arable fields. Matrix population models (Caswell, 2001) are particularly useful as they are based on the full life-cycle of the species (structured in developmental stages) and can take into account spatial description and dispersal.

As winter oilseed rape presents feral populations located on field margins, GM risk assessment requires analysing the abilities of GM rape to invade semi-natural habitats. Indeed, if they persist at least one year, feral oilseed rape populations could act as a relay in gene flow (Colbach *et al.*, 2001) and then favour gene escape at the landscape scale. The introduction of an herbicide-tolerance (HT) transgene can increase the fitness of the GM plant in the presence of selective pressure (herbicide application) and then enhance the persistence of feral populations. In parallel with our field survey (France - Pessel *et al.* 2001), we develop a stage-structured invasion model to assess the capacity of feral GM herbicide-tolerant (GMHT) winter oilseed rape to persist and disperse in road verge habitat.

Results and discussion

The invasion model couples a stage-structured model of feral oilseed rape population dynamics (Deville *et al.*, submitted) and stage-dependent dispersal. We take into account both short-distance dispersal (ballistic dispersal *via* pod popping) and long-distance dispersal (*via* vehicle wheels and agricultural engines). This invasion model is based on an integro-differential equation (Neubert & Caswell, 2000) that describes the evolution of plant density $\mathbf{n}(x,t)$ at each spatial location:

$$\mathbf{n}(x,t+1) = \int_{-\infty}^{+\infty} [\mathbf{K}(x-y) \circ \mathbf{A}] \times \mathbf{n}(y,t)dy$$

where **K** is the dispersal kernel matrix and **A** is the matrix of transitions in the life-cycle. This deterministic model allows to compute the growth rate λ and the asymptotic invasion speed c^* of the population and to perform the elasticity analysis of c^* and λ.

Results show that patterns of elasticities are the same for population growth rate λ and invasion speed c^*. Hence the transitions that influence λ most have also a large impact on the value of c^*, as described in Neubert & Caswell (2000). The highest values of elasticities are observed for the transitions producing mature plants and seeds. As dispersal and reproduction are closely linked in the case of oilseed rape, both reproducing and dispersing stages were expected to play a key-role in population growth and spread.

When the proportion of seeds dispersing at long distance switches from zero to extremely small values, simulations show that invasion speed *c** raises largely (from a two-fold to a 28-fold increase). The value of the *c** increase depends on mean dispersal distance. Moreover, when the proportion of seeds dispersing at long distance is less than 10^{-8}, *c** is quite independent of this parameter (fig. 1). For larger values, *c** increases with both mean dispersal distance and proportion of seeds dispersing at long distance (fig. 1). These results point out the main impact of rare events of long-distance dispersal in the invasion process of GMHT feral oilseed rape.

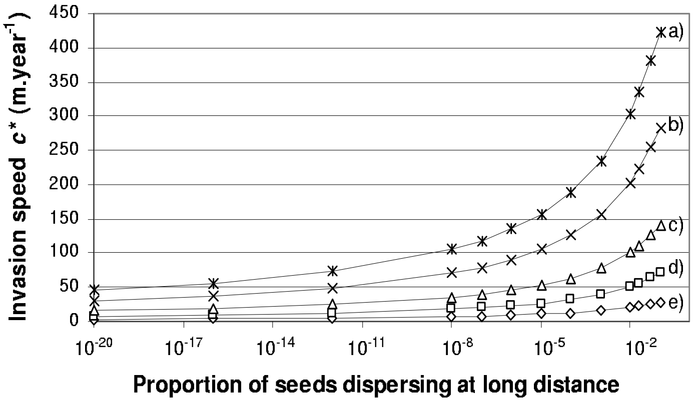

Fig. 1: Effects of the parameters of long-distance dispersal on invasion speed
Values of mean dispersal distance: a) 300 m, b) 200 m, c) 100 m, d) 50 m, e) 20 m.

Conclusions

Stage-structured invasion models provide a convenient framework for GM risk assessment linked to feral populations and makes possible an explicit description of demographic and dispersal processes. Elasticity analysis focuses on the key-impact of rare events of long-distance dispersal on the spread of feral GMHT oilseed rape. More precise information could be obtained about the dependence of invasion speed to dispersal at any distance, using the order statistics of the dispersal distribution (Caswell *et al.*, 2003). Furthermore, the introduction of stochasticity and spatial heterogeneities would make the model more realistic. The results will finally contribute to management measures to limit gene flow in a context of crop coexistence, notably *via* the European project SIGMEA (Sustainable Introduction of GM crops into European Agriculture).

References

Caswell, H. *Matrix Population Models* (Second edition): Sinauer. MA, USA, 2001.

Caswell, H., R. Lensink and G. Neubert. 2003. Demography and dispersal: life table response experiments for invasion speed. Ecology 84: 1968-1978.

Colbach, N., Clermont Dauphin, C., and Meynard, J. M. GENESYS: a model of the influence of cropping system on gene escape from herbicide tolerant rapeseed crops to rape volunteers - II. *Agriculture Ecosystems and Environment*, 83: 255-270, 2001.

Deville, A., A. Garnier & J. Lecomte. (submitted). Modelling the dynamics of feral oilseed rape populations: implications for gene flow management.

Neubert, M.G. & Caswell, H. Demography and dispersal: calculation and sensitivity analysis of invasion speed for structured populations. *Ecology*, 81: 1629-1641, 2000.

Pessel, F., Lecomte, J., Emeriau, V., Krouti, M., Messéan, A., and Gouyon, P.H. Persistence of oilseed rape (*Brassica napus* L.) outside of cultivated fields. *Theoretical and Applied Genetics*, 102: 841-846, 2001.

INDIRECT EFFECTS AND DISTRIBUTED CONTROL IN ECOSYSTEMS

Environ Analysis of a Seven-Compartment Model of Nitrogen Flow in the Neuse River Estuary, USA: The Static Case

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Key words: Network environ analysis Neuse static

Introduction

Network environ analysis (NEA) is a methodology to holistically analyze environmental systems. The core analysis is based on pathways, throughflows and storages oriented to the input and output environs of each system compartment. Four perspectives for analyzing network properties emerge: (1) throughflow-specific oriented to output environs; (2) throughflow-specific oriented to input environs; (2) storage-specific oriented to output environs; and (4) storage-specific oriented to input environs.

In this paper we analyze a seven-compartment static, steady-state model of nitrogen flow in the Neuse River Estuary, North Carolina, USA (Christian and Thomas, 2003). Model data are averages of flows and storages quantified for sixteen quarters (seasons) during the period Spring 1985 - Winter 1989. The compartments are: 1-Phytoplankton (PN-Phtyo), 2-Heterotrophs (PN-Hetero), 3-Detritus (PN-Abiotic), 4-Sediments, 5-Dissolved Organic Nitrogen (DON), 6-Nitrate/Nitrate (NO_x), and 7-Ammonia (NH_4). There are 27 intercompartmental transfers, and all compartments have boundary inputs and outputs. Processes in the model include inorganic N uptake, ammonification, nitrification, N_2 fixation, and denitrification. Trophic transfers include planktonic herbivory and detritivory, and benthic/water column interactions including suspension-feeding and bottom-feeding. Data sources to estimate standing stocks and flows, from most to least reliable, were: (1) direct measurements in the Neuse estuary; (2) interpolations or extrapolations from the Neuse River or related studies; (3) literature values or ecological intuition; and (4) results of mass-balance calculations constrained by established storage for flow values. Units for standing stocks are mmol N m^{-2}, and units for flows are mmol N m^{-2} $season^{-2}$.

Analysis of the model is based on a decomposition of total system throughflow, TST, into total environ throughflows, TET, for each of the seven compartments. Total environ throughflows are further decomposed into compartmental boundary exchanges and intrasystem flows generated by boundary inputs and outputs at individual compartments. The analysis provides a quantitative basis for the development of indirect effects between compartments and the means for analyzing the fate of nitrogen entering the system and the origin of nitrogen leaving the system. The decomposition of TST is also the basis for analyzing the following network properties:

1. Network pathway proliferation: increase of numbers of pathways with path length,
2. Network nonlocality: dominance of indirect (I) over direct effects (D),
3. Network homogenization: tendency to uniformly distribute local causality, and
4. Network amplification: obtaining more than face value from system-level inputs.

The core NEA methodology is described and appropriate interpretations of matrices developed in the analysis presented.

Results and discussion

Total system throughflow based on outputs is 41514 mmol N m^{-2} $season^{-1}$, and based on inputs is 41517 mmol N m^{-2} $season^{-1}$ (Table XXX). The Finn Cycling Index is 0.89 meaning that approximately 89% of total system throughflow is the result of cycling within the network. Throughflow analysis indicates that about 50% of nitrogen entering the system leaves the system through the sediment compartment and only about 2% of all nitrogen entering the sediment compartment is returned to the system as throughflow. Approximately 36% of all nitrogen entering the PN-Hetero compartment is returned to the system as throughflow. In this regard, sediment is dominant in dissipating nitrogen from the system whereas PN-hetero is dominant in retaining nitrogen within the system. Results of system-level indices for the Neuse model from the four perspectives are:

indirect to direct effects ratios ranged 51.6 – 2491,
homogenization ranged 0.912 – 1.88,
amplification ranged 41 - 42.

These indicate great dominance of indirect nitrogen transfers in the system, a significant tendency toward its homogenous distribution among compartments, and large amplification of boundary inputs at the compartments.

Conclusions

Network environ analysis provides a quantitative basis for understanding the role of indirect effects in the network and the contribution of indirect pathways to distribution of local effects along network pathways. Insight gained from the analysis of the Neuse River nitrogen system indicate that large numbers of higher order (indirect) pathways turn over and distribute local nitrogen stocks widely throughout the system.

References

Christian, R.R. and C R. Thomas, 2003. Network analysis of nitrogen inputs and cycling in the Neuse River Estuary, North Carolina, USA. Estuaries, Vol. 26, no. 3, p. 815-828.

A domain-specific language for landscape modelling: The Brittany agricultural mosaic as a case study

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Key words: categorical landscape, modelling plateform, farm practices

Abstract

Recent developments in landscape ecology have emphasised the functional role of heterogeneity of mosaics such as a "patchworks" of agricultural fields. Separately, foresters, agronomists or managers are now deeply involved in the development and implementation of GIS concerning field mosaics, vegetation dynamics, climatic impacts, etc. Spatially explicit models are important tools to study this functional role though, as far as we know, there is no landscape model able to simulate, analyse and represent, simultaneously, any kind of patchy landscape dynamics. We construct a framework for generic landscape modelling (called *L*). This enable us to invest the development of a more integrated tool, based on a parametrisable 2D dynamic model. The objective is to build a perennial, open and dynamic software platform a) to contribute to the design of distinct models and to compare their results; b) to share tools and methods; c) to transfer models to a wide range of potential users; d) and to serve as teaching material. *L* is a portable software, designed around a kernel, which provides an organisational data structure: projects, scenarios and steps. The kernel also proposes generic landscape data descriptions: decisions, processes, actions (geometrical or attributive) and landscape units, to cover the widest range of ecosystems. These descriptions can be extended in modules, one for each model, which implement a proper data structure and a specific evolution function (growth, fragmentation, colonisation…).

The *L* model works at landscape scales and intends to simulate the patch dynamics of fields as well as networks (such as hedgerow ones). Hence, *L* is not a model of dynamics in the sense of forest transition Markovian or Neutral models (With, 1997). The main originality of *L* is not only to simulate dynamics on the basis of landscape processes, but also to authorise attributive as well as geometrical modifications (fields deformations) of the landscape units. These modifications are progressive, can be weighted and combined depending on a chosen priority. *L* uses at least 2 (and possibly many more) scales and works in raster mode (soon in vector mode). An original real landscape or a virtual one is slowly and progressively modified to follow already identified natural (climatic, ecological, topographic…) forces and human (political, sociological, economical…) decisions. Each of them is decomposed in processes, resulting from a set of actions working at different scales and on distinct landscape units (fields, farms, region…). We borrowed the "semantic landscape event" notion to clearly dissociate decisions to the landscape itself and we elaborated a priority queue to organise the processes sequences (Fall, 2001). It permits to integrate possible feedback to fit the decision to the landscape decisions if necessary. Results are detailed landscape evolution scenarios that can be gathered for analysis, depending on the rules chosen. Once a scenario has been

simulated with *L*, a toolbox aiming to analyse environmental indices of the landscape is available. It is based on the landscape ecology concepts to a large extent, but has been improved to compute contagion (connectedness) and heterogeneity (diversity) of the landscape at each place and at each scale of the patchy mosaics. With the principle of a moving window, it is possible to build heterogeneity maps and variograms that analyse patches proportions and arrangements in details. This model acts as a powerful tool able to simulate, represent and analyse a wide range of “discontinuous” scenes, from rural to periurban landscapes.

We present here the first application of the *L* model to an agricultural landscape (called *La*). *La* objectives were to reproduce real (or plausible) Brittany landscape evolutions to test its influences on both insects’ metapopulations and pollutant flows (Burel, 2003). The hedgerow network, following the field’s dynamics, appears to be crucial in terms of constraints for insect movements as well as biogeochemical flows. Data available in Brittany suggest to work with a ~60 km² site over the second part of the XXth century, using a seasonal time step (to integrate cultural successions). *La* also imposes to precisely define decisions, processes, realisation rules, scales and landscape units to be simulated. Guiding decisions of landscape dynamics in our case are purely human and refer to the European Common Agricultural Policies (CAP), to the EU Water directive and to farmer individual land use allocation. There are at least six processes linked to these decisions: increasing farm surface, farm aggregation, field aggregation, land use rotation, hedgerow planting and removal. Each process has set of rules (geometrical, scaling, zoning rules), combined with a probability to occur if these rules are operating. Processes are not simultaneous and need a priority queue to manage their actions. Each process can stand by to test specific hypotheses and influences on the ecological fluxes.

Results are a set of scenarios that reproduces the actual Brittany landscape evolution (1982 – 2001) with different decisions. The parameters describing actual landscape evolution fit quite correctly those of our landscape simulations. These parameters refer to pattern such as land use, differentiation from stream to uphill, frequency of a crop in fields or connections among land uses within farms. Hedgerow densities and landscape connectivity properties concern this application. The simulation model *La* offers landscapes that will later permit to test the effects of land-cover and hedgerow network dynamics of species composition as well as on nutriment fluxes. Our purpose is also to develop a tool to assess the environmental consequences of public policies and technological changes. This model permits to analyse the processes that drive changes in landscape patterns and ecological functioning.

Acknowledgements

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References

Fall, A. & Fall, J. (2001) A domain-specific language for models of landscape dynamics. *Ecological modelling* 141: 1 – 18.

With, K. A., and A. W. King. 1997. The use and misuse of neutral landscape models in ecology. *Oikos* 79:219-229.

Burel, F. and Baudry, J. 2003. Landscape ecology : concepts, methods, and applications. - Science Publishers.

Modelling mixotrophy

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Key words: mixotrophy, plankton bloom, excitable Phytoplankton-Zooplankton system

Introduction

Mixotrophy, defined as the uptake of particulate organic material (= phagotrophy) and photosynthesis by a single individual, is a common phenomenon in aquatic ecosystems, in particular in light or nutrient limited environments. As mixotrophic organisms act both as producers and consumers, they complicate the energy and nutrient flux in the food web and render incomplete the classical model of a marine ecological system. Current theoretical understanding of mixotrophy is insufficient, and it is usually ignored in Nutrient-Phytoplankton-Zooplankton (NPZ)-models. This study seeks to understand how descriptions of different types of mixotrophy should be incorporated into NPZ-models and to explore the consequences for ecological dynamics and carbon flux. Mixotrophy is analysed within a system of coupled nonlinear ordinary differential equations. The method applied is similar, in both concept and implementation, to that used by Pitchford and Brindley (1998) when modelling intratrophic predation (or functional 'cannibalism').

Results and discussion

Consider Type III mixotrophy, involving predominantly heterotrophic photosynthesising 'protozoa' (Stoecker 1998). As a benchmark, we use a non-mixotrophic model for phytoplankton P and zooplankton Z dynamics (Truscott and Brindley 1994):

$$dP/dt = rPA(P) - Zg(P), \qquad (1)$$
$$dZ/dt = \gamma Zg(P) - Z\mu(Z). \qquad (2)$$

Here the function A(*P*) represents competition among algae for light and/or nutrient, g (*P*) is the per capita grazing pressure (a Holling type III grazing function), $\mu(Z)$ models zooplankton mortality, r is the maximum per capita phytoplankton growth rate and γ is a conversion efficiency. Under type III mixotrophy a small fraction ε ($\ll 1$) of the Z also engages in primary production, and therefore competes for light and/or nutrient with the P, while increasing the Z population. This results in a system such as:

$$dP/dt = rPA(P + \varepsilon Z) - Zg(P), \qquad (3)$$
$$dZ/dt = \gamma Zg(P) + \varepsilon ZrA(P + \varepsilon Z) - Z\mu\,. \qquad (4)$$

The nonmixotrophic System (1,2) has one nontrivial equilibrium (Fig. 1). To see the effect of an $O(\varepsilon)$ level of type III mixotrophy on equilibrium structure and stability the null clines and equilibrium value were calculated. As in Fig. 1, the new equilibrium is shifted leftwards and upwards, and is therefore less likely to undergo a Hopf bifurcation from stable to unstable equilibrium. What will be the effect of low-level mixotrophy III in relation to the system's response to parametric forcing? The most obvious change through which one would expect a

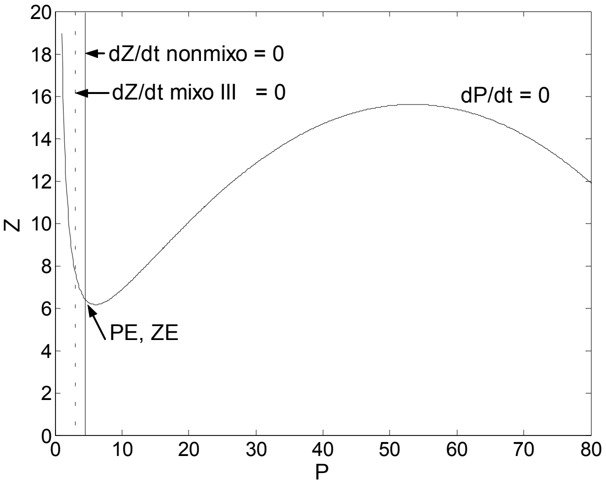

Fig. 1. Null clines for the original excitable P-Z system (1,2) and the mixotrophic III system (3,4). Stable equilibrium at (P_E, Z_E). (dZ/dt) = 0 null cline with introduced mixotrophy III decreased so that Eq. shifts to the left. The new equilibrium is more stable.

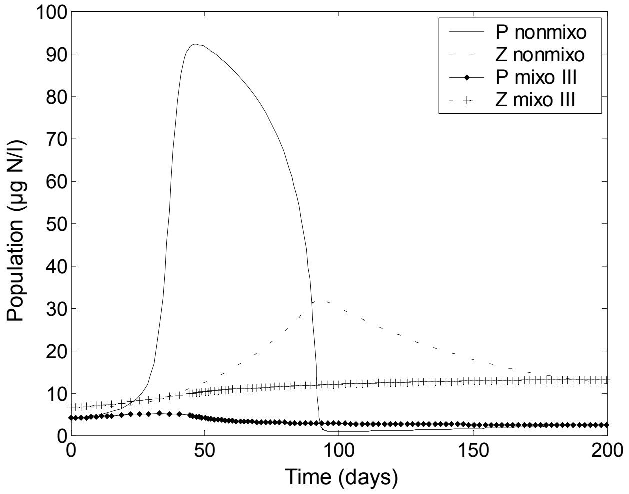

Fig. 2. Evolution of phytoplankton population after perturbation of r (dr/dt = 0.0032), for nonmixotrophic System (Truscott and Brindley 1994) and for mixotrophic type III System.

bloom to be triggered is via an increase in r, the phytoplankton growth. Fig. 2 demonstrates the response of both systems to forcing in r. r is increased from 0.4 to 0.6 at a constant rate over 4 days, with the system starting off at its equilibrium. As dr/dt is increased, the response of the systems undergoes a marked qualitative change, from a slow change of equilibrium position to excitable behaviour. I.e. a rate (*dr/dt* = 0.0031) of forcing is too low to allow P to escape grazing control and no bloom is triggered (not shown). If the increase is slightly faster, (*dr/dt* = 0.0032) a bloom occurs in the non-mixotrophic system. However, this increase is still insufficient for bloom triggering in the mixotrophic system (Fig. 2), for which the onset of the transition occurs over the range of dr/dt from 0.0036 to 0.0037/day^2.

Conclusions

It has been shown, analytically and numerically, that even small levels of type III mixotrophy have significant effects on the system's equilibrium structure and stability. Compared to the nonmixotrophic benchmark, for an outbreak to be triggered in a system with type III mixotrophy a much larger perturbation is necessary for bloom triggering. This has consequences for the modelling of carbon budgets, which remain to be explored. Ongoing work uses similar methods to consider type II mixotrophy, i.e. phagotrophy in 'algae', by allowing a fraction ε of the P population to behave phagotrophically.

Acknowledgements

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References

Pitchford, J.W., Brindley, J. Intratrophic predation in simple predator-prey models. *Bull. Math. Biol.* 60: 937-955, 1998.

Stoecker, D.K. Conceptual models of mixotrophy in planktonic protists and some ecological and evolutionary implications. *Europ. J. Protist.* 34: 281-290, 1998.

Truscott, J.E. Environmental forcing of simple plankton models. *J. Plankton Res.* 17: 2207-2232, 1995.

Truscott, J.E., Brindley, J. Ocean plankton populations as excitable media. *Bull. Math. Biol.* 56: 981-998, 1994.

The Dashboard Analysis of Sustainable Development: Data Problems and Policy Options

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Key words: sustainable development; indicators; index construction; imputation methodology; principle component analysis

Introduction

In the 130 (2000) issue of Ecological Modelling we published the first results of our research on data and index construction for measuring sustainable development (Hardi and DeSouaza-Huletey). In the meantime we have developed a special on-line tool, the Dashboard of Sustainability DB (IISD) which handles aggregation, weighting and data gaps with a software specifically developed for indicator presentation and index construction. In a follow-up paper (Hardi and Robert-Semple) we presented the first results of aggregation methods using the DB. In this paper we present the further results of our research. We use the UN Commission for Sustainable Development core set of sustainable development indicators as the only internationally available set that is endorsed on a consensual basis. The great number of countries in the database (240) and high number of indicators (around 60) makes the smooth functioning of the DB more convincing and the results analytically more relevant. The data used in this analysis were obtained mainly from documents published by the World Bank, UNDP, the World Resources Institute and FAO. For most of the social and economic variables the data was collected from World Bank SIMA while that for the environment was mostly from the World Resources Institute. Other sources were the UN Statistical Division, OECD, International Labour Organization (ILO) and other international agencies.

Results and discussion

The paper is an attempt to provide answers to questions that arise due to the lack of a strong data basis, the lack of sound aggregation methodology, and the lack of objective clustering methods in the application of sustainable development indicators. The main purpose of this paper is twofold:

1. Highlight some of the problems related to data processing and index construction in the light of the DB project and recommend ways in which they can be overcome in order to create robust sets of indicators that can effectively monitor, measure and interpret progress toward SD;
2. Test the robustness of tools such as the DB through comparing the different results arrived at by using different statistical methods that are suitable to address the multidimensional and composite nature of the problem of sustainable development

(SRMI imputation methodology and principal component analysis, as described in the paper).

Section one of the paper gives a concise description of the DB and its functionality. Section two focuses on the data sources and definition of variables used in the analysis. In section three we introduce the imputation methodology to handle the problems of missing data, argue why we adopted the SRMI method, and present the results. Section four discusses the techniques for aggregation and constructing composite indices. In this section, using PCA, we demonstrate how a sustainable development index, together with its components (such as a social health index, an environmental quality index, an economic performance index) can be constructed with appropriate weights and an optimal set of variables that reasonably integrates not only economic but also social, environmental and institutional issues. The final section provides suggested solutions to data problems and recommendations for constructing composite indicators; it will also attempt to answer the question whether the technical differences in constructing composite indicators matter at all.

Conclusions

The overall results indicate that the methodologies applied in the DB are fairly robust to the choice of variables, weights and data sets. Given that the clustering of the indicators was done arbitrarily through expert consensus, this analysis also helps us to see which variables really drive the performance and the positioning of a given country relative to other countries in a given field of inquiry. Our analysis revealed that a number of countries have poor coverage on a number of indicators for sustainable development. We solved the missing data problem through a multiple imputation technique, but this is by no means a substitute for collecting actual data. One way to overcome the cost of data collection might be to reduce the number of variables to a set that best represents SDI and its components. However, data availability and quality of data was in the end the driving force in the composition of the aggregate fields. Thus the choice of an optimal set of indicator in a given field depends very much on the availability and quality of data. Constructing composite indices requires a combination of quantitative and qualitative techniques, but this may prove to be a difficult task since the selection of indicators involves decisions on statistical questions as well as judgments about values.

Acknowledgements

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References

Hardi, P. and DeSouza-Huletey, J. Issues in analyzing data and indicators for sustainable development. *Ecological Modelling* 130:59-65, 2000.

IISD Dashboard of Sustainability, See http://www.iisd.org/cgsdi/intro_dashboard.htm
Hardi, P. and Robert-Semple, P. The DB: From a metaphor to an operational set of indices. Paper presented at the *Fifth International Conference on Social Science Methodology*, Cologne, Germany, October 3-6, 2000.

Asking the monkey about the organ grinder: What monitoring predators reveals about prey availability in a model ecosystem.

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Key words: ecosystem monitoring, krill, harvesting, predator-prey model, life-history characteristics

Introduction

There is a growing realisation that marine fisheries should be managed in a way that accounts for the ecosystem effects of harvesting. Consequently, the Commission for the Conservation of Antarctic Marine Living Resources Ecosystem Monitoring Program (CEMP) aims to monitor the ecosystem effects of harvesting krill by collecting data on the performance of land-based marine predators. An important question is how to use these data to distinguish the effects of harvesting from those of natural variability or long-term environmental change.

The response of a predator population to the availability of a single prey type is likely to be affected by its own life-history characteristics and trophic interactions with other species, such as predation and competition. Here we explore these effects using a model of interacting predator populations. The model was based on a system around South Georgia consisting of mackerel icefish, gentoo penguins, macaroni penguins, and their common prey, krill. Gentoo penguins also feed on mackerel icefish. An initial model was constructed with delay-difference equations in which prey availability controlled the density-dependent growth of the predator populations with a time lag corresponding to the age at first breeding. Gentoo predation on mackerel icefish was a function of the relative abundance of icefish and krill. The abundance of the krill population in each year was independent of either the krill population or the predator populations in previous years.

We investigated the model's output to determine how individual predator populations respond to changes in the underlying availability of krill, and whether monitoring these populations would give a clear indication of the underlying changes.

Results and discussion

The different responses of three predator populations, that were previously at equilibrium, to a temporary reduction in prey availability (caused, for example, by increased harvesting) are shown in figure 1. The timing of the initial response is controlled by the age at first breeding. However, after about two decades, opposite trends are seen in the penguin and mackerel icefish populations. Reduced competition from mackerel icefish allows both penguin populations to recover slightly, but the mackerel icefish population continues to decline. When the initial prey supply is restored, the mackerel icefish population takes longer than the penguin populations to return to its equilibrium level. Simple population models suggest that populations respond to environmental changes at time scales controlled by their growth rates (May et al 1979). In this model, however, the intrinsic growth rate of the mackerel icefish population was higher than those of the two penguin populations, which illustrates that trophic interactions are also important. Monitoring selected populations (the penguins, for example) may not give sufficient information on the overall status of the ecosystem.

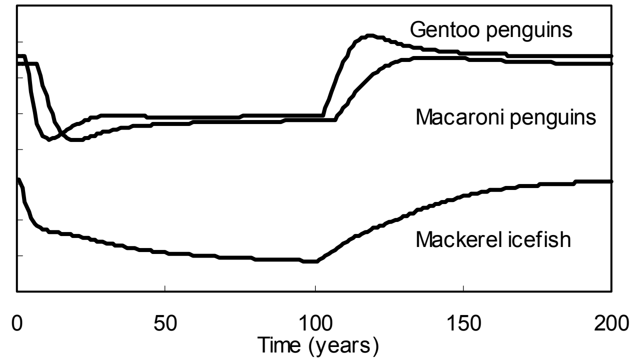

Fig 1: Responses of three predator populations to a reduction in prey availability between years 1 and 100. The populations differed in growth rate and age at first breeding. Mackerel icefish was also an alternative prey species for gentoo penguins.

In further simulations where prey availability oscillated at a range of wavelengths, the oscillations, the predator populations also oscillated, but with phase differences. Even with wavelengths of several decades, the changes in some of the predator populations did not reflect contemporary trends in the abundance of prey, or of other predators. The implications of this are that; (i) combined indices from several predators may mask underlying trends in prey availability, especially when these trends have recently been reversed (for example, as the result of a new harvesting control measure), and (ii) predator populations may reflect the previous, rather than current, status of the prey population.

These preliminary results illustrate the importance of interacting life-history characteristics and trophic relationships in determining the response of predator populations to prey availability. The CEMP monitors performance measures for predators, rather than population size. However, some of these may be affected by life history characteristics that introduce a time lag into the response to prey availability, although others may show a more immediate response.

The next stage is to produce models that more realistically reflect the system under consideration, and the monitored characteristics. These will be used to establish the sensitivity of these characteristics to life-history parameters and the nature of trophic interactions.

Conclusions

Life-history characteristics and trophic interactions control the response of predator populations to prey availability, such that two predator populations can show opposite responses. Monitoring a limited number of populations may therefore give an incomplete picture of the overall status of the ecosystem. Furthermore, combined results from several populations with different response rates may mask these responses. Models that incorporate key life-history characteristics and trophic interactions should therefore be used in conjunction with ecosystem monitoring programs to aid the interpretation of the resulting data.

References

May, R.M., Beddington, J.R., Clark, C.W., Holt, S.J. and Laws, R.M. Management of multispecies fisheries. *Science* 205:267-277, 1979.

Interactions between environmental variability and immigration rate control patterns of species diversity

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Key words: coloured environmental noise, competition, niche, unimodal growth response

Introduction

Theories focussing on local competition processes predict that species diversity is maximised with high-frequency environmental variability or alternatively with intermediate frequencies (Huston 1994). The models coupling regional processes to local explanations of diversity patterns predict that the immigration rate from a regional species pool can strongly increase diversity (Loreau and Mouquet 1999, Mouquet et al. 2002). However, the interaction between local and regional processes in temporally fluctuating environment has received little attention.

Natural populations commonly have unimodal growth responses to environmental variables, such as temperature and salinity, and species differ in the location of optima. Therefore it is plausible that environmental changes can also change competitive ranking of species. We explored in a simulation study how the patterns of species diversity (indicated by Shannon diversity index) are affected by the frequency spectrum of stochastic environmental variations and density independent immigration rate in a competition model. The growth rate of a species had a unimodal response to a continuous environmental variable. The location of optimum and breadth of the growth response in the environmental niche axis is treated as a species-dependent trait.

Results and discussion

Decreasing the frequency of environmental variations produced monotonically decreasing or unimodal “intermediate disturbance type” diversity patterns in the competition model. The level of diversity and type of the pattern was determined by immigration rate, and the number and traits of the species initially placed along the environmental niche axis. Immigration generally increased diversity, but the amount of increase in intermediate immigration rates was strongly modified by the frequency of the environmental variation. Decreasing the frequency of the environmental variation always produced a monotonically decreasing diversity pattern in a two-species system where the growth optima are positioned symmetrically around the mode of the environmental noise. However, increasing the species number and asymmetry of optima makes the diversity pattern sensitive to immigration rate: diversity can be very low and unaffected by the frequency of environmental variation in the absence of immigration, peak in low-frequency environment with small immigration rate (i.e. produce the IDH type pattern), or decrease monotonically with high immigration rate.

Diversity is most sensitive to small changes in the initial species number and position of the species growth optima when environmental fluctuations have high frequency.

Conclusions

That immigration can change the impact of the frequency of the environmental variation on diversity from monotonically decreasing to unimodal (IDH type) pattern emphasizes that the regional process can be important for explanations of the diversity patterns, especially when the immigration rates are uncorrelated to the local conditions. The strong interactions between community properties, immigration rate, and the spectrum of environmental variation suggest that small changes in community properties or in dispersal rates can have a large impact on species diversity.

Acknowledgements

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References

Loreau, M. and Mouquet, N. Immigration and the Maintenance of Local Species Diversity. *Am. Nat.* 154, 429-440. 1999.

Mouquet, N., Moore, J.L. and Loreau, M. Plant species richness and community productivity. why the mechanism that promotes coexistence matters. *Ecol. Lett.* 5, 56-65. 2002.

Huston, M.A. Biological Diversity. The coexistence of species in changing landscapes. Cambridge Univ. Press. Cambridge. 1994.

MODELLING BASIC PHYSICAL PARAMETERS IN ADRIATIC SEA AS THE BASIS FOR MARINE HABITATS MAPPING

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Key words: 3D finite element model, mapping habitats, Adriatic Sea

Introduction:

In the frame of project "Mapping the habitats of the Republic of Croatia" (financed by Ministry of Environmental Protection and Physical Planning of the Republic of Croatia) for the purpose of mapping spatial distribution of marine habitats (see contribution of Bakran-Petricioli et al.), specific oceanographic variables have to be modelled. Those variables were sea bottom temperature, sea bottom salinity and bottom sea current magnitude.

Discussion and conclusions:

To accomplish that aim we used a high resolution 3D finite element diagnostic model based on the three-dimensional shallow water equations (Lynch and Werner, 1987; Lynch et al., 1992). Well known “sigma” coordinate system is used in vertical, with 21 non-uniformly placed nodes whose sinusoidal vertical spacing provides an increased resolution in the surface and bottom layers. This high resolution vertical grid is necessary for adequate simulations of turbulent dissipation and details of the currents, especially along complex Croatian coast. The horizontal finite element grid used in the study consists of 23055 nodes and 37200 elements. The size of triangle areas varies from 0.02 km^2 to 757 km^2, with the length of nodal distances varying from about 500 m in coastal areas up to 44 km in the largest triangle (deep off-shore part of domain). With this mesh we have been able to include in our simulations 77 major islands and recognize realistic topography with lateral geometry capable of representing the key feature of rich Croatian coast (many islands and narrow channels). Model was forced with temperature and salinity fields obtained from available datasets (MEDATLAS database) using optimal analysis. We grouped all data into four seasons (winter = January – March, spring= April – June, summer =

July - September, autumn = October - December) because of low temporal and spatial distribution in order to have seasonal three-dimensional temperature-salinity fields. Those fields in the model generated seasonal current fields used for the worst case scenario of minimum bottom current criteria. We also looked for currents generated with tidal forcing of two main harmonics (M_2 and K_1) at the open boundary, as contribution to previously obtained current fields. Tidal part of study was done previously using the same model and data assimilation technique (Janekovic et al., 2003). Combining those two sets, presuming that tidal dynamics is manly barotropic phenomena not changing through seasons, we computed minimum bottom current magnitude as measure of bottom kinetic energy. Wind-driven circulation was obtained using typical strong wind blowing along basin from south and across basin from north-east direction giving possible high values of current magnitude at bottom used for “the worst case scenario”. Those data as well with temperature and salinity fields were used for criteria in mapping spatial distribution of marine habitats (see contribution of Bakran-Petricioli et al.) as independent variables in neural network training and validation scheme, not described here.

Acknowledgments

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References

Janekovic, I., Bobanovic, J. and Kuzmic, M. The Adriatic Sea M_2 and K_1 tides by 3D model and data assimilation. *Estuarine Coastal and Shelf Science*, 57:873-885, 2003.

Lynch, D.R. and Werner, F.E. Three-dimensional hydrodynamics on finite elements. Part I: Linearized harmonic model. *International Journal in Numerical Methods in Fluids*, 7: 871-909, 1987.

Lynch, D.R., Werner F.E., Greenberg D.A. and Loder J.W. Diagnostic model for baroclinic, wind-driven and tidal circulation in shallow seas. *Continental and Shelf Research*, 12:37-64, 1992.

Carrying capacity for aquaculture in the Velebit Channel (Adriatic Sea)

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Key words: aquaculture, carrying capacity, eutrophication, polycultures

Abstract

A number of criteria are taken into account for estimating suitability for development of aquaculture in the Velebit channel (Adriatic Sea). Among them depth, extreme wave height, extreme wind intensity, intensity of currents, spatial and temporal distribution of temperature as well as characteristics of benthic communities were studied in detail.

The criteria were contrasted and areas not suitable for aquaculture were eliminated. Now the remaining problem to be solved was to determine carrying capacity (GESAMP 1996, MAFW, 2004) of the Velebit channel. It is well known that fish cultures, by releasing organic matter, contribute to eutrophication. Given a level of eutrophication willing to be accepted by a county, and a type of culture, carrying capacity follows.

The next step was to consider variations in the type of aquaculture and see how this changes the carrying capacity. Indeed a large variation in the result is obtained by considering polycultures. Variation in the results of using various combinations of polycultures is discussed and a guidelines for further development are given.

References

GESAMP, The contributions of science to integrated coastal management. *GeSAMP*, 61(1996), 66 pp.

MAFW, *Guidelines for planning integration and monitoring aquacultures*, Ministry of Agriculture Fisheries and Water management, Zagreb, 2004. 50 pp. (in press).

Responses of forest herbs to available understory light measured with hemispherical photographs in silver fir – beech forest in Croatia

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Key words: canopy openness, digital terrain model, LAI, NDVI, phytodiversity

Introduction

Light conditions are very important determinant of forest understory vegetation pattern. To further examine that relation we investigated response of forest herbs to available light conditions in the forest of silver fir (*Abies alba*) and beech (*Fagus sylvatica*) which are most frequent altimontane forest on Croatian karst, using the hemispherical photographs for measuring available light. Our special interest was focused on the possibility of estimation light condition parameters (which are hardly gatherable at field) on the large areas using the remotely sensed data, as potential support to the spatial prediction of phytodiversity and particular plant species occurrences (Jelaska et al. 2003).

All in all 151 circular plots with 25 meters diameter were surveyed, alongside with the ten meters diameter circular plot, positioned inside bigger ones. Data about the floristic assemblage were gathered in four equal sectors of the smaller circle, divided by cardinal points of the compass, and overall for large plots. Hemispherical photographs of forest canopies were taken in the centre of each plot during the 2002 growing season and analysed with Gap Light Analyzer software (Frazer et al., 1999). Using the sky-region grid compound of 36 azimuth and 9 zenith regions taking into account polar projection distortion of the lens two canopy characteristics were calculated for each photograph: Leaf Area Index (LAI) and Canopy Openness. Canopy characteristics were calculated for the whole view of sky, and for portions of the sky that corresponds to the four sectors of the smaller plot. For portion of sampled area satellite Landsat ETM+ image was available which enable comparison of canopy features with Normalized Difference Vegetative Index (NDVI). Relations between mentioned variables (floristic, derived from hemispherical photographs and derived from satellite image) were investigated by univariate correlations, canonical correspondence analyses (CCA; ter Braak and Smilauer, 2002), classification trees (CT) and logistic regression.

Results and discussion

Statistically significant negative correlation was detected between canopy openness and NDVI for best-contrasted photographs, while LAI was positively correlated with NDVI for all analysed photographs. LAI was negatively correlated with number of present plant species for best-contrasted photographs. Using the CCA, herbaceous plant species that are most influenced by the light conditions were detected (Figure 1.). According to CT analysis that included altitude, slope, northness (cosine of aspect) and LAI as predictor variables, LAI was important predictor variable for estimating the number of present plant species, as well as for occurrence of particular plant species. Besides CT, logistic regression models were developed and tested for their accuracy on independent data for selected species as well.

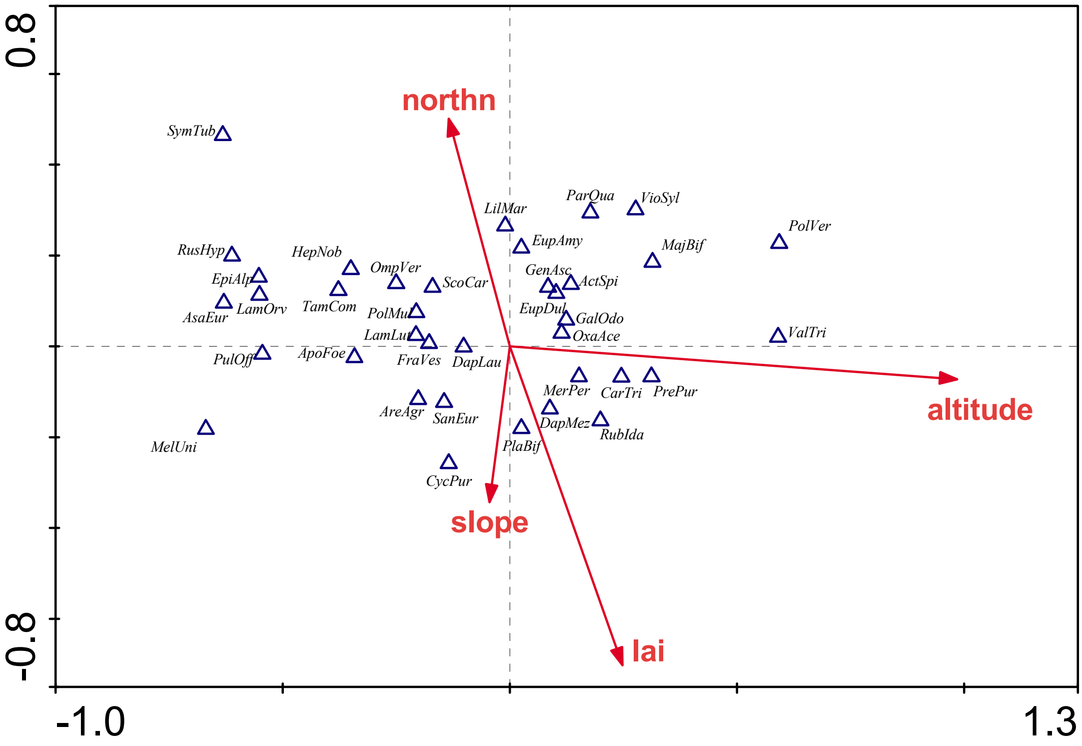

Figure 1. Bi-plot of 38 species and 4 environmental variables after CCA analyses (1st and 2nd ordinal axes).

Conclusions

These results lead to the future modelling of silver fir – beech forest phytodiversity and spatial distribution of particular plant species as a function of environmental estimators (geomorphologic variables based on digital terrain model and light conditions based on remotely sensed NDVI).

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References

Frazer, G.W., Canham, C.D. and Lertzman, K.P., *Gap Light Analyzer (GLA)*, Version 2.0. Simon Fraser University, Burnaby, British Columbia, and the Institute of Ecosystem Studies, Millbrook, New York, 36 pp, 1999.

Jelaska, S.D., Antonić, O., Nikolić, T., Hršak, V., Plazibat, M. and Križan, J., Estimating plant species occurrence in MTB/64 quadrants as a function of DEM-based variables – a case study for Medvednica Nature Park, Croatia. *Ecological Modeling.* 170, 333-343, 2003.

Ter Braak, C.J.F. and Smilauer, P., *CANOCO Reference manual and CanoDraw for Windows* User's guide: Software for Canonical Community Ordination (version 4.5). Microcomputer Power (Ithaca, NY, USA), 500 pp, 2002.

Spatial Forest Plan Development in the Presence of Northern Spotted Owls

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Key words: forest planning, spotted owls, heuristic programming

Introduction

In the Pacific Northwest, forest plans increasingly must address habitat goals that have complex spatial and temporal components to ensure compliance with regulatory restrictions or organizational goals. Landowners who actively manage forests that contain rare species, like the northern spotted owl (*Strix Occidentalis caurina*), need to be able to demonstrate to decision makers how their management strategies affect habitat for these species.

Oregon State University's College of Forestry manages about 1900 hectares on the eastern edge of the Oregon Coast Range. A forest plan constructed in 1993 divided the forest into three zones, and assigned different management approaches to each zone. The theme for one of these zones, the "South Zone" was to actively manage it in a way that achieved the species composition and structural characteristics of a mid to late-seral forest. The predominant silvicultural strategy was single-tree and group selection implemented in a way that promotes the development of large conifers and understory hardwood trees.

One year after this plan went into effect, a pair of northern spotted owls began nesting in this zone of the forest. Spotted owls are listed as a "threatened" species under the U.S. Endangered Species Act, which requires that non-federal landowners avoid harming the species or adversely affecting its habitat. The U.S. Fish and Wildlife Service has issued draft guidelines that call for the retention of 40% of the area within 2.4 kilometers of the owl nest as nesting, roosting, and foraging (NRF) habitat to avoid "take" of the species. This habitat is characterized by older, closed canopy forest with multiple layers, suitable nest trees and adequate flying space beneath the crowns. Although the management theme for this zone (developing mid to late-seral conditions) of the forest seemed consistent with the needs of spotted owls, an analysis of the existing NRF habitat revealed only 39% in the 2.4-kilometer circle and suggested that any type of profitable timber harvest in suitable NRF habitat would render it unsuitable for some time.

Results and discussion

A new planning effort was initiated to develop a process where the amount of NRF habitat for spotted owls could be maintained within the 2.4-kilometer circle, while implementing a replicated experiment that tested four different types of group selection harvest systems across the zone. Three distinct spatial scales were recognized: treatment blocks, patches and parts of patches. Treatment blocks were divided into group selection "patches" that were designed by taking into account the existing road system, the topography, and the potential array of logging corridors. These patches were intersected with the forest inventory stand boundaries that our yields are modeled from to create "parts" of patches.

Timing and treatment of patches had to facilitate an efficient harvesting system and enable assessment of the treatments across a treatment block. A heuristic optimization technique was used to facilitate the development of this spatial forest plan. Three policy objectives were modeled: maintaining a minimum level of 0, 40, and 80% NRF within 2.4 kilometers of a known owl nest site. When NRF habitat levels were constrained to a minimum level of 40%, net present value (NPV) declined by almost 24%, while average NRF value (over a 100-year planning horizon) increased 11%. When NRF levels were constrained to a minimum level of 80%, NPV declined almost 70%, while average NRF increased 29%.

Conclusions

This heuristic spatial forest planning process allows forest managers to examine a number of management options from both economic and ecological perspectives prior to selecting a preferred alternative. It has been used to help the College Forest select patches for harvest which retain the recommended level of NRF habitat around the spotted owl nest.

Acknowledgements

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References

Bettinger, P., D.L. Johnson, and K.N. Johnson. 2003. Spatial forest plan development with ecological and economic goals. Ecological Modelling. 169:215-236.

Simulating the Implications of Alternative Policies for a Large Forested Landscape

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Key words: landscape simulation, biodiversity, forest management, forest policy

Introduction

Biodiversity policies have been recently implemented throughout the world. In the Pacific Northwest, policy makers have developed numerous policies since the early 1990's to deal with contentious biodiversity issues. These policies, which were developed somewhat independently of each other by different federal and state agencies, form a patchwork of different rules and regulations that mirror the underlying diversity of management goals. In the state of Oregon, for example, the Northwest Forest Plan was established to maintain and restore old-growth habitats and salmon habitat on federal lands, while providing limited timber production. The State Forest Practices Act was amended to increase protection for streams on private forest lands, while providing for abundant timber production. New plans for` State forest lands have been adopted that increase harvest rotation lengths, the amount of interior forest habitat and protection for streams. Oregon land use laws, some of the strongest in the USA, have been designed to reduce loss of prime agricultural and forest lands to development.

As experience is gained with biodiversity policies, their shortcomings are becoming more apparent. First, biodiversity may not be very effectively accounted for because policies typically were developed in an uncoordinated manner across multi-ownership landscapes—some components of biodiversity may be under protected while others may be over protected. Second, they are often based on one-size-fits-all approach that ignores environmental variability and diversity of landowner goals. Third, they often take a static view of desired future conditions when disturbances and successional change are inherent to ecosystem productivity and diversity.

In the mid 1990's a group of scientists developed a policy-focused research project titled the "Coastal Landscape Analysis and Modeling Study (CLAMS)." Their goal was to use a systems approach to evaluate the aggregate ecological and socio-economic effects of forest and land use policies in the Oregon Coast Range, one of the most productive mixtures of forests and streams in North America. The scientists were drawn to the 2 million hectare Coast Range Physiographic Province in Oregon because its diversity of ecosystems, the presence of a number of species at risk (northern spotted owl, marbled murrlet, and coho salmon), and the diversity of land owners with very different management goals and policies. Major forest owners are federal (20%), state (15%), industrial (40%), and family forest (25%), with lands of the different owners often intermingled across the landscape.

CLAMS relies heavily on a variety of regional databases and spatially explicit policy simulation models developed during the effort, including the Landscape Policy and Management Simulator (LAMPS), a custom GIS model that can spatially simulate forest structure and compositional change across all ownerships for 100 years at a 0.6 ha resolution. A variety of economic, biodiversity, and disturbance potential models are then used to estimate ecological and economic effects. (More on the project can be found at www.fsl.orst.edu/clams/).

Results and discussion

Our research over the last several years has lead to a number of new insights about current policy and significant technical capability to conduct policy-focused research. Key recent findings include: 1) Trends in old-growth forests and habitat for key species are consistent with recently-enacted policies but 100 years is not long-enough to reach policy goals, 2) New high contrast landscape patterns will emerge as federal lands become dominated by older conifer forest and private industrial lands become dominated by young (<50 years) conifer plantations; 3) Habitat diversity will remain relatively high overall but declines significantly within ownerships as dominant use policies take effect; 4) Land use changes are expected to be relatively small overall but relatively large in forest lands adjacent to valleys and large population centers. In addition, we have already conducted a preliminary cost effectiveness analysis on alternatives to current forest management policies. In this analysis we determined that increased retention of wildlife trees on private forest lands was more efficient at raising a biodiversity index of habitat quality than increasing the rotation age on those forest lands.

Conclusions

Our research also reveals a number of major potential shortcomings of current policies. As an example, federal and state policies addressing freshwater habitat conservation for Pacific salmon target upland streams on forested lands. However, lowland rivers can be disproportionately important for certain salmonid species. Also, small headwater streams do not contribute equally to salmon habitat quality, through debris flow inputs of large wood, but policies do not take advantage of this variation. Also, hardwood and ecologically diverse early successional forest will strongly decline because of a number of factors including current policies that encourage landowners to create conifer plantations or mature and old-growth conifer forests. We are now working to suggest and evaluate policies that might mitigate these problems.

Acknowledgements

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References

Spies, T. A., and Johnson, K. N. 2003. The importance of scale in assessing the compatibility of forest commodities and biodiversity. Pages 211-235 in R. A. Monserud, R. W. Haynes, and A. C. Johnson, editors. Compatible Forest Management. Kluwer Academic Publishers, Dordrecth, The Netherlands.

Spies, T. A., Reeves, G. H., Burnett, K. M., McComb, W. C., Johnson, K.N., Grant, G., Ohmann, J.L., Garman, S.L., and Bettinger, P.S. 2002. Assessing the ecological consequences of forest policies in a multi-ownership province in Oregon. in J. Liu and W. W. Taylor, editors. Integrating Landscape Ecology into Natural Resource Management. Cambridge University Press, Cambridge, United Kingdom.

Modeling two Spruce Bark Beetle Populations (Scolytidae: *Ips typographus, Pityogenes chalcographus*) in Southwestern Slovenia: A Tool in the Management of Economically Important Species

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Key words: bark beetles, population modeling, environmental management, machine learning, regression trees

Introduction

In this paper, we present preliminary results of the analysis of data concerning the density of two populations of bark beetles (Scolytidae: *Ips typographus* and *Pityogenes chalcographus*) in southwestern Slovenia. The research area is on the Karst plateau at an average of 700 m above sea level and measures 618 hectares. This region is a natural transition point from a Mediterranean to an Alpine climate, therefore there are frequent catastrophic weather conditions in this region (windbreaks, snowbreaks and sleetbreaks were recorded for the following years: 1948, 1951, 1952, 1965, 1966, 1967, 1969, 1986, 1987, 1988 ,1992, 1993, 1996, 1997, 1998, according to the Chronicle of the Forestry Unit Planina). More detailed records dealing with this particular region also mention earlier uses of the forest: in 1846 the land was bought by the Windischgraetz family, who used it exclusively for hunting. The region was originally covered with a natural forest community of Dinaric fir and beech forests (*Abieti-Fagetum dinaricum*), which were cut intensively starting in 1895 and then reforested with Norway spruce (*Picea abies* (L.) Karst.) (FMP 1960). Today, this area comprises 1000 ha of 60-90 year old Norway spruce stands in compact complexes. The soil foundation is limestone and dolomite.

Research on the *I. typographus* took place from 1986-2000 and that of *P. chalcographus* from 1993-2000. The population density of the bark beetles was controlled at 5 locations with various exposures (N, NE, NW, S, W, E), using commercial Theyson's traps and pheromones (Pheroprax® and Chalcoprax®). Placing of the pheromones for *I. typographus* was carried out from April 9-26 (of each year); placement of the pheromones in the trap for *P. chalcographus* was carried out from April 16-May 12. The pheromones were changed up to 4 times in one vegetation season and the catch was counted weekly. Quantification was carried out according to Chaloupek et al. (1988), i.e., 38 *I. typographus* or 580 *P. chalcographus* individuals per 1 ml. Quantification of the catch showed that both species have two main generations per year, although *I. typographus* also has two sister generations. The dates of the most distinctive maxima were determined and were compared with the data on the oscillations of populations of *I. typographus* and *P. chalcographus* from other locations in Slovenia. The number of caught individuals shows that there is a relatively large population of bark beetles in the environs of Planina when compared with the available data on bark beetles in Slovenia and neighboring Austria. This is connected to the fact that the Norway spruce found in the research area is alochthonous and thus less resilient and resistant. The second reason for the large numbers is due to the influence of environmental factors. Frequent catastrophic weather events in these Norway spruce stands produce large amount of suitable trophic material for the beetles. In addition, frequent weather-related damage in the region means that there is mechanical destabilization of the Norway spruce' root systems, which are therefore more sensitive to bark beetle attacks.

Experiments

We applied machine learning methods to analyze the gathered data and find dependencies between environmental factors and the abundance of the populations of each species. We used model tree induction, and in particular the M5' system (Wang and Witten, 1997) - a re-implementation of M5 (Quinlan, 1992) within the software package WEKA (Witten and Frank, 1999). The following attributes were used to predict the number of individuals for each of the two species of bark beetle at a given moment in time: position (N, NE, NW, S, W, E), age of pheromones, days since last control, average monthly temperature, monthly rainfall, month, and the number of bark beetles at the previous measurement. Data on the weather conditions, as obtained from the nearest meteorological weather station in Postojna, were also used. Linear equations and model trees were constructed for each species.

In general, two attributes, average monthly temperature and previous number of bark beetles, turn out to be the most important for predicting the present number of bark beetles. The latter increases with each of the two attributes. These are the only attributes appearing in the model tree for *P. chalcographus* and also appear in the linear equations for both species. The number of beetles decreases with the number of the month for both species. The results of the modeling show an important correlation between the abundance of each of the species and the position: N and E positions strongly increase the number of *I. typographus* individuals, while W and N positions increase the number of *P. chalcographus* individuals. This phenomenon can be explained by the adaptation of Norway spruce to extreme conditions at southern exposures. At the N, W and E positions individual trees are more sensitive to drought and mechanical destabilization of the root system (due to catastrophic weather conditions) and are therefore more prone to attack by bark beetles. The models built in our study can be used for the prediction of possible bark beetle attacks and represent a useful tool in the management of forest stands.

References

Chaloupek, W., Pichler, G., Neuhold, M., 1988. Chalcoprax. Neues Pheromon gegen Massenvermehrung von *Pityogenes chalcographus*. Oesterreichische Forstzeitung, 99, 4, p. 62-63.

FMP, 1960. Planina Forest Management Plan, 1955-1960, 1971, 1977, 1993, 2001 (in Slovenian).

Quinlan, J. R., 1992. Learning with continuous classes. In Proceedings of the Australian Joint Conference on Artificial Intelligence, pages 343-348, World Scientific, Singapore.

Wang, Y., Witten, I. H., 1997. Induction of model trees for predicting continuous classes. In Proceedings of the Poster Papers of the European Conference on Machine Learning, Prague. University of Economics, Faculty of Informatics and Statistics.

Witten, I. H., Frank, E., 1999. Data Mining: Practical Machine Learning Tools and Techniques with Java Implementations. Morgan Kaufmann, San Francisco.

The cellular automata model of two-species plant community with spatial interaction between species

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Key words: cellular automata, plant population, spatial interaction, spatial complexity

Introduction

First applications of the cellular automata approach to simulation of plant populations or community dynamics were developed in the 1980th (Edelstein, 1982; Komarov, 1982; Inghe, 1990). A summary of results is given by Ermentrout & Edelstein-Keshet **(**1993). A number of papers were published by J. Silvertown et al. (1994 and references there). A short review with a list of references of cellular automata models in ecology is given by Balzter et al., (1998). The most important peculiarity of our approach is the link between spatially explicit cellular automata and the concept of discrete description of the ontogeny of plants developed in Russian Population Ecology of plants (Rabotnov, 1978; Gatzuk et al., 1980). The continuous process of individual plant development may be subdivided into several stages on the basis of morphological indicators reflecting functional importance of plants at different stages. Number and duration of age stages may vary from species to species, among life-forms within species, and under different environment conditions. The duration of age stages and the probability of transition from one stage to another for an individual plant depend on the plant's neighbourhood pattern, the type of ontogenesis and the site conditions (Komarov et al., 2003). Such data are available from numerous field studies. The cellular automata approach allows for uniting the spatial structure of population and development of individual plants with its different role in the population's life. The age stages of these automata can be changed according to simple rules, which reflect the types of plant ontogenesis, different life spans of age states, and different sizes of plants in the neighbourhood.

Results and discussion

The cellular automata model of two interacting populations of creeping plants is considered. The rules of cellular automata, which reflect the discrete ontogenetic stages of the particular plant species with its specific properties, are defined and the examples of realistic parameters for the model calibration are discussed. Earlier (Komarov et al., 2003) we analyzed short-rhizome plants' population dynamics at random extinction of individuals with different intensities. It was shown that a complete absence of destructive impacts (i.e. under the conditions of "strict preservation") has the same after-effect as a very strong destructive impact due to weak restoration capacity. Some other types of nonlinear population dynamics were analyzed in that paper in terms of cellular automata models. Here we consider a model of populations of two different short-rhizome species of plants. The rule of the interspecies competition is defined as a phytogenic field in Uranov's sense. It implies that the seedlings of two different species can occupy a free site with the probability that depends on the distance to the neighbor plants of the contrary species. We simulated two long rhizome plants populations with different sets of probabilities representing the interspecies interaction. We found that the numbers dynamics of both species is significantly dependent on the presence or absence of the phytogenic field. At the presence of interaction the model community represents a specific spatial pattern which governs the vegetative propagation of ramets and thus influences the plant dynamics. The development of cellular automata models of plant populations and communities was also kept on for analysis of the influence of multiplicity of ontogeny ways (asynchronous change of age states) (Zhukova, Komarov, 1990), interspecies interactions and random external extinctions for the population stability and community structure. Using simulation lattice model the increase of genotypic diversity was found as a sequence of weak external extinctions. The conditions of this effect were revealed and dynamics of genotypes at different levels of random extinction was shown. The rise of stable spatial structures from initial random pattern was found in the model of two-species plant community with spatial interspecies interactions Uranov's phytogenic field type. The stability of the structures versus weak external random extinction was the most remarkable finding.

Conclusions

It was shown that the approach uniting cellular automata modelling and methods of discrete description of the ontogeny of plants can efficiently utilize data of Plant Population Biology, and by this represents a powerful tool for studying different peculiarities of the plant population dynamics.

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References

Balzter, H., Braun, P.W. Kohler, W. Cellular automata models for vegetation dynamics. *Ecological Modelling* 107:113-125, 1998.

Edelstein, L. The propagation of fungal colonies: a model for tissue growth. *Journal of Theoretical Biology,* 98:679-701, 1982.

Ermentrout, G.B. Edelstein-Keshet, L. Cellular automata approaches to biological modelling. *Journal of Theoretical Biology,* 160:97-133, 1993.

Gatzuk, L.E., Smirnova, O.V., Vorontsova, L.I., Zaugol'nova, L.B., Zhukova, L.A. Age state of plants of various growth forms: a review. *Journal of Ecology*, 68:675-696, 1980.

Inghe, O. Genet and ramet survivorship under different mortality regimes - a cellular automata model. *Journal of Theoretical Biology*, 138:257-270, 1989.

Komarov A.S., Palenova M.M., Smirnova O.V. The concept of discrete description of plant ontogenesis and cellular automata models of plant populations. *Ecological Modelling*, 170:427-439, 2003.

Rabotnov, T.A. On coenopopulation of plant reproducing by seeds. *Structure and Functioning of Plant Population, Amsterdam: North-Holland.* p. 1-26, 1978.

Silvertown, J., Lines, C.E.M., Dale, M.P. Spatial competition between grasses - rates of mutual invasion between four species and the interaction with grazing. *Journal of Ecology*, 82:31-38, 1994.

Zhukova, L.A., Komarov, A.S. Ontogenetic multi-ways and plants' population dynamics. *Journal of General Biology (Moscow).* 51:4:450-461, 1990. (In Russian).

Modelling and evaluating climate-change-caused changes of land use in North-West-Germany

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Key words: ecological modelling, agricultural use, conflict handling, prediction of environmental change

Introduction

Especially in an interdisciplinary context, the prediction of land use changes is a typical task for an ecological model. Land use can be a main parameter for geographers, economists and even political scientists, i.e. handling conflicts between various users or concerning questions of risk management. As shown in the joint research project KRIM (Climate Change and Preventive Risk and Coastal Protection Management on the German North Sea Coast), land use can be an parameter to connect data and results from different scientific disciplines for example in a decision support system (Schirmer 2003).

The aim of this work is the presentation of a computer model that evaluates alternation of land use caused by climatic changes (Kraft 2004). The rule-based model BONU calculates the suitability for farming of a given site based on its characteristics, adapted from a general soil map. On a regional level it brings out the distribution of biotopes. A downscaled climate scenario and land use scenarios give the input values. The soil characteristics are taken from a national data base. Based on GIS the model generates maps of the today's and future conditions for land use. Soil moisture, one of the main habitat factors, is deduced from characteristic values like water table, climatic water balance and type of soil. Regarding the degree of utilisation, the potential land use is evaluated. The model also generates maps that mark areas of potential future conflict between farmers and conservationists. Based on the goals for conservational development the potential for conflict between both users is calculated.

Research area is the marsh of the Lower Weser located in the North-West of Germany. Reference here is the year 2050.

Results and discussion

Three different scenarios of land use are compared. Modelling future on-site conditions shows a distinct move towards drier conditions. Especially on the high-located parts, the marsh ameliorates. This leads to a change in intensity of agricultural use, which in turn causes more or less severe conflicts with conservational goals. The computer model shows that even an unchanged land use leads to a more intensive use in areas, which should be developed more extensively, according to conservational goals. On the other hand, the model proves that conservation can succeed in a scenario of extensification. Comparing the results of the single scenarios, hot spots of sensitivity for climatic changes can be detected. Astonishingly the today intensively used parts of the landscape are particularly sensitive; habitats that are used in a traditionally way, are more or less insensitive.

Validation with land use mappings like Corrine land cover show a high self-consistency of the data from BONU. Especially the distribution of biotopes is accurately described.

Although the intensity of conflicts between the users is overstated in some cases, the evaluation marks the tender points. Nevertheless, the possibilities of BONU can be enhanced by taking into account the spatial structure of the landscape like ditches and distance to the next farm. Data that are more detailed would lead to an enhanced accuracy of the computer model. In addition to the conflict evaluation, ecological values could be calculated (Kraft 2002).

Conclusions

BONU proves to be a praxis oriented, ecological model for the modelling of agricultural use and the evaluation of potential conflict. It is able to show the hot-spots of sensitivity for climate change on a level that is relevant for nature conservation. A responsible conservational politic should include a risk assessment and take into account the climate-cased alternations and there consequences.

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References

Kraft, D. Modellierung klimabedingter Nutzungsveränderung, doctoral thesis, in press, 2004.

Kraft, D., Wittig, S. and Schirmer, M. Scientific Risk Construct: Environmental Aspects. *Proc. of the SRA Europe Conf. - 2002 Annual Meeting*, pages 48-49, Berlin, 2002.

Schirmer, M., Schuchardt, B., Hahn, B., Bakkenist, S. and Kraft, D. KRIM: Climate change, risk constructs and coastal defence. *DEKLIM German Climate Research Programme - Status seminar Proceedings*, pages 269-273, 2003.

Achieving Sustainability Of Waste Management In Southampton (UK): A Case Study Within The Framework Of Industrial Ecology

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Key words: energy, roundput, industrial ecosystems, natural ecosystems

Introduction

Roundput is arguably the most important functional principle for industrial and natural ecosystems alike. Basically, it relates to the degree to which energy and matter are recycled and used in cascade type operations (Krohonen, 2001). Here we show using a case study from Southampton (UK) that increasing the efficiency of the waste management programme could be achieved by increasing recycling rates for plastics and other wastes, thus benefiting the overall functioning of the corresponding industrial ecosystem.

Current progress in waste management is hampered by the lack of methods capable of evaluating sustainable practices. The tools used for comparison of alternative scenarios, involving collection, separation, and processing of waste fractions, must have a rigorous conceptual basis, and account not only for economic considerations, site-specific logistics and governmental guidelines, but also for environmental issues. In other words, society needs evaluation tools able to optimise (within given local, regional and global constraints) existing waste management practices by minimising the required energy budget and both present and future environmental impacts.

Results and discussion

The energy and materials flow model for evaluation of alternatives for processing domestic and commercial waste presented here provides a step forward towards ultimate optimisation of industrial ecosystem functioning and achieving sustainability of human development. The model has been designed in Microsoft Excel and Visual Basic, which were chosen due to their user-friendly interface and common availability. In the model calculations, the input data on material flows, waste quantities and mass balances are combined with information on the energy requirements for different types of collection and processing systems for re-use, recovery, recycling and disposal, and on the energy benefits (e.g. related to the production of heat by incineration or gas by anaerobic digestion, pyrolysis, etc.) of these options. The output shows the energy balance of the current practice, and also allows a comparison with a number of alternative scenarios.

The stage of the study reported in this paper addressed only household wastes, and widening the system boundary to include commercial and industrial wastes remains the scope for further research. The results obtained through the interpretative analysis of model simulations clearly suggest that improving the recycling of, in particular, paper and plastic would considerably decrease the energy footprint of these wastes and therefore benefit the overall development of the industrial ecosystem. These results are directly applicable only for the study area. However, following certain modifications the methodology used may be easily applied elsewhere.

Analysis of multicomponent natural ecosystems is greatly aided by application of simulation modelling techniques (Krivtsov *et al.* 2000; Krivtsov 2001). Complex interplay among system components has previously been taken into account in a number of waste management and industrial ecology studies (Abou Najm *et al.* 2002a, b; Adamov *et al.* 1999; Bjorklund *et al.* 1999; Clift 1998; Cosmi *et al.* 2000; Korhonen *et al.* 2001; Krivtsov *et al.* 2004a). The results of the research presented here are, therefore, in good agreement with the previous studies. The patterns observed in industrial ecosystems are in many respects similar to the patterns characteristic of natural ecosystems, and a comprehensive account of this similarity within the overall framework of Industrial Ecology may help to reduce the conflict between the two systems.

References

Abou Najm M., El-Fadel M., Ayoub G., El-Taha M. & Al-Awar F. (2002a) An optimisation model for regional integrated solid waste management I. Model formulation. *Waste Management & Research* 20: 37-45.

Abou Najm M., El-Fadel M., Ayoub G., El-Taha M. & Al-Awar F. (2002b) An optimisation model for regional integrated solid waste management II. Model application and sensitivity analyses. *Waste Management & Research* 20: 46-54.

Adamov E. O., Ganev I. K., Lopatkin A. V., Orlov V. V. & Smirnov V. S. (1999) Self-consistent model of nuclear power development and fuel cycle. *Atomic Energy* 86: 337-344.

Bjorklund A., Dalemo M. & Sonesson U. (1999) Evaluating a municipal waste management plan using ORWARE. *Journal of Cleaner Production* 7: 271-280.

Clift R. (1998) Engineering for the environment: The new model engineer and her role. *Process Safety and Environmental Protection* 76: 151-160.

Cosmi C., Cuomo V., Macchiato M., Mangiamele L., Masi S. & Salvia M. (2000) Waste management modeling by MARKAL model: A case study for Basilicata Region. *Environmental Modeling & Assessment* 5: 19-27.

Korhonen J. (2001) Industrial ecosystems - some conditions for success. *International Journal of Sustainable Development and World Ecology* 8: 29-39.

Korhonen J., Wihersaari M. & Savolainen I. (2001) Industrial ecosystem in the Finnish forest industry: using the material and energy flow model of a forest ecosystem in a forest industry system. *Ecological Economics* 39: 145-161.

Krivtsov V., Corliss J., Bellinger E. & Sigee D. (2000) Indirect regulation rule for consecutive stages of ecological succession. *Ecological Modelling* 133: 73-82.

Krivtsov V. (2001) Study of cause-and-effect relationships in the formation of biocenoses. *Russian Journal of Ecology* 32: 230-234.

Krivtsov V., Banks C. J., Heaven S. & Dacombe P. (2003) Sustainable waste management - the energy question. *Wastes Management, Chartered Institute of Wastes Management* January 2003: 34-35.

Krivtsov V., Wäger P. A., Dacombe P., Gilgen P. W., Heaven S., Hilty L. M. & Banks C. J. (2004a) Analysis Of Energy Footprints Associated With Recycling Of Glass And Plastic - Case Studies For Industrial Ecology. *Ecological Modelling*: in press.

Liao S. H. (2003) Knowledge management technologies and applications - literature review from 1995 to 2002. *Expert Systems with Applications* 25: 155-164.

Lukasheh A. F., Droste R. L. & Warith M. A. (2001) Review of Expert System (ES), Geographic Information System (GIS), Decision Support System (DSS), and their applications in landfill design and management. *Waste Management & Research* 19: 177-185.

Investigating indirect effects in aquatic ecosystems: a case study, and the implications for hindcasting the past, and predicting the future environmental dynamics

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Key words: indirect interactions, simulation modelling, phytoplankton, biogeochemical cycling, ecosystem dynamics

Introduction

Natural ecosystems are complex, and are characterised by a multitude of interconnected relationships between ecosystem components. The understanding of these complex interactions is paramount for sustainable development of Mankind. However, ecological research mainly tends to concentrate on investigations of direct relationships, whilst indirect interactions (and especially the less obvious, e.g. the delayed ones) are often overlooked and/ or understudied. Mathematical techniques (e.g. correlation, multiple regression and factor analysis, simulation modelling, path analysis and methods of network analysis, etc.) may be very helpful in investigations of indirect relationships in ecosystems. Here we refer to some examples of the recent relevant studies in freshwater and marine systems, and, in particular, give a brief account how mathematical techniques have been helpful in investigating indirect effects in a eutrophic lake (see Krivtsov et al., 1998, 1999, 2001, and references therein) where indirect relationships appeared to occur on (and across) various levels of organisation (i.e. on intracellular, population and ecosystem levels).

Results and discussion

Statistical analysis of the datasets obtained within a comprehensive monitoring programme, and sensitivity analysis by a mathematical model 'Rostherne', helped to reveal the previously overlooked relationships between Si and P biogeochemical cycles coupled through the dynamics of primary producers (Krivtsov, 2001; Krivtsov et al., 2000). It was found that spring diatom and summer cyanobacterial blooms where inversely interrelated, which provided the basis for a new method of eutrophication control. Complex interplay between direct and indirect effects in the ecosystem revealed by the dynamic ecosystem modelling included effects related to the influences of temperature, light, inflow/outflow characteristics, and interactions among nutrients, algae, detritus, zooplankton and fish. This work has eventually led to the postulation of the 'Indirect regulation rule for consecutive stages of ecological succession', applicable to wide a range of systems (Krivtsov et al., 2000). Both in freshwater and in marine ecosystems, a numerical simulation of biogeochemical fluxes underpinned by coupling physical forcing functions with definitions simulating biological and chemical processes, offers the potential for quantitative interpretation of sediment proxies in the stratigraphic record. Combination of models and sediment proxies, calibrated by training sets, can provide information on water column structure, surface heating, mixing, and water depth, thus providing a basis for reconstruction of past regimes in lakes and shelf sea. The investigations of indirect effects are especially useful when applied within a recently developed (Krivtsov, 2002) framework for a comparative theoretical ecosystem analysis.

References

Jago, C.F. and S.E. Jones , Observation and modelling of the dynamics of benthic fluff resuspended from a sandy bed in the southern North Sea. *Cont. Shelf Res.* **18** (1998), pp. 1255–1282.

Krivtsov V., Bellinger E., Sigee D. & Corliss J. (1998) Application of SEM XRMA data to lake ecosystem modelling. *Ecological Modelling* 113: 95-123.

Krivtsov V., Bellinger E. G. & Sigee D. C. (1999a) Modelling of elemental associations in Anabaena. *Hydrobiologia* 414: 77-83.

Krivtsov V., Sigee D., Corliss J. & Bellinger E. (1999b) Examination of the phytoplankton of Rostherne Mere using a simulation mathematical model. *Hydrobiologia* 414: 71-76.

Krivtsov V., Tien C., Sigee D. & Bellinger E. (1999c) X-ray microanalytical study of the protozoan Ceratium hirundinella from Rostherne Mere (Cheshire, UK): Dynamics of intracellular elemental concentrations, correlations and implications for overall ecosystem functioning. *Netherlands Journal of Zoology* 49: 263-274.

Krivtsov V., Bellinger E. & Sigee D. (2000a) Incorporation of the intracellular elemental correlation pattern into simulation models of phytoplankton uptake and population dynamics. *Journal of Applied Phycology* 12: 453-459.

Krivtsov V., Bellinger E., Sigee D. & Corliss J. (2000b) Interrelations between Si and P biogeochemical cycles - a new approach to the solution of the eutrophication problem. *Hydrological Processes* 14: 283-295.

Krivtsov V., Corliss J., Bellinger E. & Sigee D. (2000c) Indirect regulation rule for consecutive stages of ecological succession. *Ecological Modelling* 133: 73-82.

Krivtsov V. (2001) Study of cause-and-effect relationships in the formation of biocenoses: Their use for the control of eutrophication. *Russian Journal of Ecology* 32: 230-234.

Krivtsov V., Goldspink C., Sigee D. C. & Bellinger E. G. (2001b) Expansion of the model ' Rostherne' for fish and zooplankton: role of top-down effects in modifying the prevailing pattern of ecosystem functioning. *Ecological Modelling* 138: 153-171.

Krivtsov V., Sigee D. & Bellinger E. (2001c) A one-year study of the Rostherne Mere ecosystem: seasonal dynamics of water chemistry, plankton, internal nutrient release, and implications for long-term trophic status and overall functioning of the lake. *Hydrological Processes* 15: 1489-1506.

Krivtsov V. (2002) Indirect Effects in Ecosystems: a Review of Recent Modelling Studies and a Methodological Framework for Comparative Theoretical Analysis. In: *Integrated Assessment and Decision Support. Proceedings of the first biennial meeting of the International Environmental Modelling and Software Society (also available at http://www.iemss.org/iemss2002/proceedings/pdf/volume%20uno/410_Krivtsov.pdf)* (eds. A. E. Rizzoli & A. J. Jakeman) pp. 233 - 238, Lugano.

Population dynamic consequences of adaptive growth rate in fluctuating environment

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Key words: Environmental noise, genetic diversity, spectrum of population dynamics, unimodal growth response

Introduction

The type of environmental variability, biological properties of populations and their interactions can determine the population response to environmental variation (Roughgarden 1975). Linkage between environmental variability and population renewal processes is commonly assumed invariable in standard population models. There is, however, evidence suggesting that individual responses to the environment may be adaptive, with repercussions on population growth over ecological time scales (Johnson and Agraval 2003). However, the consequences of evolving environmental responses are not well understood under density dependent population growth, especially if population fluctuations are cyclic or chaotic. Moreover, natural environmental fluctuations are predominantly temporally autocorrelated (i.e. ‘coloured’), whereas environment in theoretical studies is commonly assumed to be uncorrelated.

We explored the consequences of introducing adaptive, density-dependent population dynamics in a setting where the population consists of individuals differing in the location of their optimum growth performance curve relative to an environmental variable. Growth performance of the phenotypes is determined by a unimodal function of the environmental variable, which also has a unimodal distribution. Unimodal growth responses are commonly found in natural and laboratory populations, for example in the response to temperature, humidity or salinity (Laakso et al. 2003).

The dynamics of adaptive populations were compared to non-adaptive populations with similar but constant unimodal growth response. We also analysed the dynamics of genetic diversity (indicated by Shannon diversity index) and variance in the performance optima trait. The simulations varied the spectrum of environmental variations, the breadth of growth response of the individuals (assumed constant within a population), and maximum growth rate in the environment producing optimum growth.

Results and discussion

Adaptive dynamics generally causes a significant increase in mean growth performance of the population and decreases its variance when compared to populations with constant growth responses. Population time series also fluctuate more rapidly, indicated by a blue-shifted spectrum. The blue shift occurs over a wide range of population growth rates and frequency spectra of the environmental fluctuations. The blue shift caused by adaptive dynamics is in contrast with views that evolutionary processes cause slow fluctuations in population time series due to slow changes in population properties.

In addition to population dynamics, genetic variance in the performance optima trait and genetic diversity are influenced by the spectrum of environmental variation and the breadth of the growth performance curve. Mean genetic variance in locations of growth optima is maximized with high frequency or uncorrelated environmental variations, and genetic variance is generally largest when the breadth of growth performance curve is small. Small breadth populations also have a distinct minimum variance occurring in slowly fluctuating environments. Genetic variance in the performance optima trait and diversity of genotypes also fluctuate temporally. Temporal variability of genetic variance increases when the environmental fluctuations become slower, and populations with small response breadth have highest variability of genetic variance. Genetic diversity is lowest in environments dominated by very slow or very rapid changes. The maximal diversity is generally achieved in intermediate environments, and the spectrum of environmental fluctuations maximizing diversity depends on the strength of selection for optimum genotype: weak selection requires more slowly fluctuating environment to maximize diversity than strong selection. The temporally variable genetic variance and diversity suggest that models assuming constant amount of genetic variability (equilibrium variance) may not always be successful in predicting the consequences of environmental changes.

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References

Johnson, M.T.J. Agraval A.A. The ecological play of predator-prey dynamics in an evolutionary theatre. *Trends in Ecology and Evolution* 18: 549-551. 2003.

Laakso, J., Löytynoja, K., and Kaitala, V. Environmental noise and population dynamics of the ciliated protozoa Tetrahymena thermophila in aquatic microcosms. *Oikos* 102: 663-671. 2003.

Roughgarden, J. Population dynamics in a stochastic environments: spectral theory for the linearised N-species Lotka-Volterra competition equations. *Theoretical Population Biology* 7:1-12. 1975.

Krk Submarine Outfall: Prediction of Effects on a Marine Ecosystem

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Key words: wastewater, eutrophication model, hypoxia model, outfall length model, Adriatic Sea

Abstract

Krk City (on the Krk Island, Adriatic Sea) is planning to build a submarine outfall which will carry wastewater from the city and surroundings into the bottom of the Middle Gate channel located between Rijeka Bay and the Sea of Kvarnerić. In connection to the project, two problems are being addressed in this paper: a) the length of the outfall, b) the effect on the marine ecosystem, especially eutrophication and possible hypoxia on the bottom.

An initial estimate of the length is based on the well known Brooks approach (Fisher, et al, 1979, Legović, 1997). The second estimate is based on the Plums set of models (Baumgartner *et al.*, 1994). Finally, the third estimate is obtained by running a 3D nonlinear finite element model in time, expanded with reaction module, capable of capturing full 3D advection, diffusion and reaction processes in the sea environment (Janeković *et al.*, 2003; Legović *et al.*, 2003). The three methods are compared and finally the appropriate length is chosen based on the existing water quality criteria.

The effect on eutrophication is computed using a simple mass balance model. The effect on hypoxia on the bottom is estimated using a model that includes deposition, resuspension, bacterial decomposition and measured sea currents.

Based on the results of predicted impact an appropriate monitoring program is proposed. The program is a result of a desire to verify predictions at a minimum cost.

References

Baumgartner D. J., Frick W. E., and Roberts P. J. W. Dilution models for effluent discharges. *Environmental Protection Agency*, EPA/600/R-94/086, Cincinnati, 1994

Fisher H. B., Imberger J., List E. J., Koh R. C. Y., and Brooks N. H. *Mixing in inland and coastal waters.* Academic Press, 1979.

Janeković I., Bobanović J., and Kuzmić M. The Adriatic Sea M2 and K1 tides by 3D model and data assimilation. Estuarine, *Coastal and Shelf Science*, 57 (2003), 873-885.

Legović T., Janeković I., Viličić D., Petricioli D., and Smoljan Z. Effects of Freshwater Release to a Marine Bay. *Journal of Environmental Science and Health*, A38 (2003), 1411-1420.

Legović T., Modelling for seawater quality management. *Journal of Comuting and Information Technology*, 5 (1997), 71-85.

Significance of landscape structure on moose population management

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Key words: *Alces alces*, dispersal, management, hunting, risk analysis

Introduction

The population sizes and harvest rates of Finnish moose (*Alces alces*) have been monitored over three decades, due to its importance as game animal (e.g., Nygren & Pesonen 1993, Luoma et al. 2001). However, there is not much information about moose dispersal or migration, although those factors do effect on the population dynamics and thus the hunting strategies of moose population. Hence one can ask, should there be different hunting strategies in areas with higher or lower dispersal rates? We analyse potential consequences of moose dispersal on population dynamics and annual harvesting in a structured landscape.

We use an individual based, stochastic population renewal model to study the differences of moose populations in areas with different dispersal possibilities. As a landscape we use a lattice of 16 cells, dispersal occurring only inside this area. Thus we have four sub-units in corners (only two edges open for dispersal and thus very limited dispersal possibilities), eight bordering units (three edges open for dispersal) and four central units (all edges open for dispersal). The dispersal is distance dependent and we have several scenarios for different dispersal rates and also cases where only young individuals disperse. Adding harvesting into the model, we can analyse how harvesting rate affects the risk of population size decline, and see if this risk differs in areas with different dispersal patterns. The main aim of this modelling exercise is to gain understanding whether any differences in risk scenarios arise for moose harvesting policy depending to what extent the landscape allows dispersal to take place. If any differences arise, our research will prompt for spatially realistic moose harvesting models in landscapes.

Results and discussion

In the absence of harvesting, population renewal in a spatially structured setting results in local differences in population size. The corner populations (limited dispersal) tend to be the smallest ones, and the central populations the largest ones. Matching harvesting, applied on each population sub-unit, with equal dispersal of all age groups and both sexes, results in higher risk of population size decline in units where dispersal is limited (i.e., border and corner units). When we assume more realistic dispersal for moose, i.e., juvenile-biased redistribution, borders and corners indicate even much higher risks of population decline as compared to the centre units. This means that moose populations living in the areas with limited dispersal possibilities are more vulnerable to overharvesting.

Conclusions

Our results show that dispersal of moose affects local population size. Thus dispersal should be taken account when deciding the annual harvest rates, so that hunting rates should be lower in regions where immigration is limited. A problem arises without knowledge of the dispersal behaviour of moose in Finland. We don't know how much these animals disperse; how long distances or which animals. Also dispersal barriers (in our model the outer limits of the landscape lattice) might in nature appear in different scale, e.g., large lakes, ridges, as well as moose fences near almost all Southern highways in Finland might affect the movements of moose (Seiler et. al. 2003). We emphasise the urgent need for more detailed information about the annual redistribution patterns in moose which could be useful for the management of moose populations and in particular for determining local hunting quotas.

Acknowledgements

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References

Luoma, A., Ranta, E. and Kaitala, V. Moose (Alces alces) hunting in Finland - an ecological risk analysis. *Wildlife Biology,* 7: 181-187. 2001.

Nygrén, T. and Pesonen, M. The moose population (Alces alces l.) and methods of moose management in Finland 1975-89. *Finnish Game Research,* 48:46-53. 1993.

Seiler, A., Cederlund, G., Jernelid, H., Grängstedt, P. and Ringaby, E. Highway E4 and moose in the High Coast Area - Final report. *Proceedings of the IENE conference "Habitat fragmentation due to transport infrastructure",* 2003.

Modelling opportunistic macroalgae productivity and biomass in a shallow eutrophic estuary. The role of macroalgal zoospores.

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Key words: modelling, GIS, spores, macroalgal productivity,

Introduction

A model is developed to describe the productivity and biomass of opportunistic macroalgae (*Enteromorpha* spp.) at the system level (Mondego estuary, Western coast of Portugal) by coupling modelling and GIS tools. The model describes both the adult and the microscopic life stage of macroalgae because experimental evidence suggests that, the onset of algal growth occurs preferentially in places with the presence of suitable substrates for spores attachment and growth (e.g. empty shells) (Lotze et al. 1999, 2000; personal observation). Life stage microscopic processes and parameters included in the model are based on field and lab experiments still ongoing at the Mondego estuary (Martins, unpublished). According to this, sporulation is described by a sinusoidal expression, which peaks every 30 days, corresponding to field measurements where, at least in some months, the highest spore biomass values were measured during full-moon (Martins, unpublished). Spore germination and spore consumption by grazers are also described taking into account experimental data. Adult macroalgal biomass (centigrams wet weight.m^{-2}) depends on germination of spores, net growth, decomposition, grazing and advection. The bathymetry of the estuary is also accounted in the model and, consequently, the light intensity reaching a certain algae will depend on the light extinction coefficient and on the depth of the water column above it, which in turn depends on its position in relation to the sea level and on tidal height. Model results are obtained at a scale of 1 m^2 and simulations run for 365-days with a time step of approximately 1-hour. Subsequently, model results are upscaled to the whole system, using remote sensing and GIS, through bathymetry superimposition on a system map. The model was developed with STELLA® 7.0.3., while GIS analysis were performed with ArcGIS™.

Results and discussion

The model is able to predict the seasonal variation of macroalgal biomass, corresponding to increasing values from winter to spring and summer (Fig. 1). In accordance with observations, the model also simulates that, during winter and autumn, the macroalgae located in the upper part of the intertidal area (2 m) show higher biomass than the macroalgae located below this level. However, in spring and summer, this situation is inverted and the macroalgae located at lower levels (1 m) present the highest biomass. This is in accordance with observations and PFD (photon flux density) variation in the Mondego estuary. In winter, when PFD is low, the macroalgae located at the upper parts are the most productive because they receive more light, however, in spring and summer, due to PFD increases (≥1500 μmol. photons.m^{-2}.s^{-1} Martins et al. 2001), macroalgae located at the upper levels are easily photoinhibited (600 μmol. photons.m^{-2}.s^{-1}, Beer and Shragge 1987), while macroalgae located at lower levels (1 m) are more productive because they stay immersed during longer periods.

According to the model, significant decreases of spore germination cause important reductions of adult macroalgal biomass, which suggests the importance microscopic life stages for the maintenance of the adult standing stock, particularly, during winter and autumn, when the biomass of adults is lower.

At the system level, simulations suggest that whenever low salinity values occur in the system, which is related to the amount of precipitation and river management (see Martins et al. 2001), not only adult growth but also spore germination will be lower. These predictions are in accordance with observations. Previous work has shown that adult macroalgae grow less at lower salinities (Martins et al. 1999) and still ongoing experiments suggest the same relationship between spore growth and salinity.

Conclusions

According to this work, macroalgae dynamics can only be fully understood if, microscopic life stages are also taken into account. The approach used in this work, which coupled modelling with GIS through bathymetry, proved to be an effective tool in understanding macroalgae dynamics at the system level.

Acknowledgements

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References

Beer S., Shragge B. 1987 Photosynthetic carbon metabolism in *Enteromorpha compressa* (Chlorophyta). *Journal of Phicology* 23: 580-584.

Lotze H.K., Schramm W., Schories D., Worm B. (1999). Control of macroalgal blooms at early developmental stages: *Pilayella littoralis* versus *Enteromorpha* spp. *Oecologia* 119: 46-54.

Lotze H.K., Worm B., Sommer U. (2000). Propagule banks, herbivory and nutrient supply control population development and dominance patterns in macroalgal blooms. *Oikos* 89: 46-58.

Martins, I., Oliveira, J. M., Flindt, M. R., Marques, J. C. 1999. The effect of salinity on the growth rate of the macroalgae *Enteromorpha intestinalis* (Chlorophyta) in the Mondego estuary (west Portugal). *Acta Oecologica* 20, 259-265.

Martins, I., Pardal, M. A., Lillebø, A. I., Flindt, M. R. & Marques, J. C. 2001. Hydrodynamics as a major factor controlling the occurrence of green macroalgal blooms in a eutrophic estuary: A case study on the influence of precipitation and river management. *Estuarine Coastal and Shelf Science* 52, 165-177

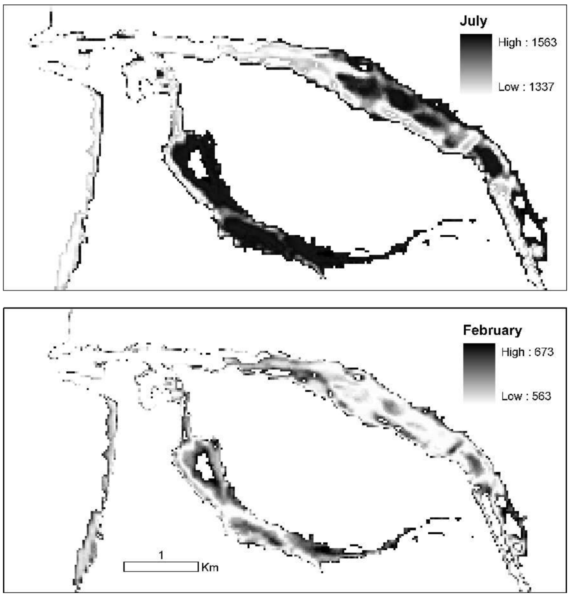

Figure 1- Distribution of adult macroalgae biomass (centigrams of wet weight.m^{-2}) in the Mondego estuary in February and July according to simulations.

Modelling post fire succession in a Mediterranean Forest; implications from a Markovian approach

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Key words: Mediterranean ecosystems, Markov processes

Mediterranean-type ecosystems have the characteristic of regenerating naturally after fire if the rate of disturbances (as additional fire and grazing) doesn't exceed some threshold. So wildfires are considered as an integral part of these type of ecosystems. In an attempt to describe regeneration processes, following fire, in Mediterranean type ecosystems, we try to compare various approaches in order to elaborate the most adequate as for the scale being used. Many researchers used Markov processes (mainly time-homogeneous, first order Markov chains) as models to describe vegetation dynamics, especially primary and secondary succession by considering either an individual by individual replacement or vegetation type's replacement. One of the major drawbacks of the homogeneity assumption is the "stopping time" (as induced by disturbance) of the whole Markovian process.

In that view our main concern is to extend the Markovian approach of a stochastically changing mosaic pattern in order to incorporate ecological pressure, that renders the environmental invariance hypothesis non applicable for long-term prognosis. We develop a methodology that allows us to determine the critical factors in the calculation of the transition probabilities by taking into account the issue of scale of the process, given that some mechanisms can be important only over some time or space scale.

A simulation study for population viability of sea turtles; the role of nest census data for population trends

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Key words: population viability analysis, Caretta-caretta, stochastic model

Introduction

Understanding the factors that are important for the implementation of an accurate trend analysis and those that are needed for a reliable representation of long term collected quantitative information is of great interest to ecologists. In the present study we develop two alterative models for investigating the importance of clutch size at the accuracy of predicting numbers of nesting sea turtles. The first is a stochastic model developed to simulate reproductive performance of the species. The second modelling approach extrapolates a widely used Population Viability Analysis (PVA) approach, adapted to our subject of study. The former approach is based on diffusion approximation that has been widely used for assessing extinction risk of threatened plant and animal populations. We used sea turtle data series comprised of annual nesting number of mature individuals as a representative data series of structure of the populations and investigate the effect of clutch size on future predictions of population dynamics. We investigate quantitatively the importance of the specific parameter and its effect on the accuracy of relative measurements of population trends and viability.

Results and discussion

Under a series of optimistic assumptions, the results of our models illustrate that clutch size has a significant effect on all relative measures of accuracy used. The model results show a profound effect of the variability of clutch size as a stochastic model parameter upon models' prediction accuracy. The number of nests individually laid, did fluctuate as they were subjected to stochastic process such as nesting attempts and maximum number of nests. The results of the stochastic models generate two main findings. First, by comparing the intervals of the predicted size of nesting females as they were produced by the two alternative models, we can clearly see that under the first model which incorporates lower levels of stochasticity, higher variability in the predicted intervals are obtained. On the other hand, the calculated estimates derived from the second model are highly upwardly in comparison to the first model, indicating that exclusion of existing information could lead to upwardly biased estimates.

Conclusions

In this study we tried to investigate the effect of an additional form of variation of sea turtle nesting data upon the accuracy of different measures of population trends and dynamics two simple models were developed. The results of this simulation study indicate that clutch size is a significant factor for the implementation of an accurate trend analysis hence the reliable representation of long-term collected information. Concluding we suggest that it would be most effective to maintain quality monitoring programs and to present collected data, aiming towards better management options and enhancing future research dimensions.

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References

Dennis B., Munholland, P.L. and Scott, J.M.. Estimation of growth and extinction parameters for endangered species. *Ecological Monographs* 61, pp. 115–143 1991

Broderick, A.C., Glen, F., Godley, B.J., and Hays, G.C. 2003. Variation in reproductive output of marine turtles, *Journal of Experimental Marine Biology and Ecology*, 288, 95-109.

Burgman, M., Ferson,,S., and Akçakaya, H.R. *Risk assessment in conservation biology*. Chapman & Hall. New York. 1993

Investigating the effect of temporal variation at reproductive performance of green sea turtles (*Chelonia mydas*) by using an individual based model

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Key words: Individual based model, age of first breeding, re-nesting, sea turtles, temporal variability.

Introduction

Marine turtles show great variability in annual somatic growth increment and reproductive performance. Fluctuating environmental conditions are closely linked with reproduction, while recent empirical information suggests the existence of a possible density-dependent mechanism upon somatic growth. We developed an individual-based model to simulate the effects of a varying environment on population dynamics. The developed model uses as modular objects different units of individual animals, and aggregated groups with specific age and stage structure, and incorporates both environmental and demographic stochasticity. One of the main aims of the study is to investigate population responses, considering a varying age of the first breeding as resulted by fluctuated environmental conditions. Temporal variability of reproductive performance was included in our model, by considering autocorrelated and random sequence of years as an indicator of good and bad environmental conditions. An additional form of variation was included by assuming a density-dependent growth affecting age of first breeding and re-nesting periods. To illustrate whether the density dependence regulator should be applied, a biological reference point was adapted. The probability of population extinction was estimated for all alternative hypotheses developed.

Results and discussion

The analysis indicated that temporal variability, closely linked with food availability could have a significant effect on population persistence. The extinction probability varied according to fluctuated times of maturation age and re-nesting intervals. The density dependent buffer mechanism as an additional form of temporal variability has also resulted in an increased proportion of the simulated populations to get extinct. A sharp population decline occurred during the first simulation years, as a result of the initial population size distributed within age classes. Moreover, an increased egg production in comparison with next year recruitment was also observed thought initial conditions. However, after about one generation time the total population size as well as egg production reduced significantly and fluctuated within a range of values obtained by the simulated population. A biomass index as a metric of individual abundance within size specific distributions followed the same patterns. In an attempt to closely investigate the intrinsic population responses after the transition form the population abundance initialized by the system to the simulated population size, a plot of population fluctuations and the corresponded mean age specific distribution showed that average age of the individuals is reversely correlated with population abundance, indicating that higher population declines are subjected to reductions in the lower age classes.

Conclusions

The present analysis was based on an individual based model, and provides the first insights in an objective that has received a great amount of attention. Thus based on a theoretical manner we suggest that varying remigration internal caused by fluctuated environmental conditional is strongly associated with the viability of sea turtle population. We also conclude that even under absent of important information modular model, such as individual based approaches, could efficiently incorporate, identify and quantify several mechanisms and their relative contribution to population dynamics. It also stresses the need for more comprehensive information on species life history and the interaction with the environment and their implementation in a more realistic simulation model. We therefore suggest that a development of a spatially explicit individual based model, incorporating spatial information on species distribution, forage utilization, migratory routes, episodic effects and various levels of stochasticity would be necessary for a closer representation of the studied system and could provide solutions to fundamental questions.

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References

Heppell, S. S., Crouse, D.T., and Crowder, L.B. A model evaluation of headstarting as a management tool for long-lived turtles. *Ecological Applications* 6, 556-565. 1996.

Limpus, C. J., and Chaloupka, M. Non parametric regression modeling of green sea turtle growth rates (southern Great Barrier Reef). *Marine Ecology Progress Series*, 144, 1-12 1997.

Scheffer, M., Baveco, M.J., DeAngelis, L.D.,Rose, A.K., and van Nees, H.E. Super-individuals; a simple solution for modelling large populations on an individual basis, *Ecological. Modelling*. 80,161-170. 1995.

Shin, Y., and Cary. P. Exploring fish community dynamics through size-dependent trophic interactions using a spatialized individual-based model. *Aquatic Living Resources*. 14, 65-80 2001.

Analysis of the transferability of a simple lake model to lakes of different trophic state

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Key words: water quality modelling, transferability, sensitivity analysis, parameter estimation, generality of models

Introduction

A model that describes the nutrient, oxygen and plankton dynamics in Lake Zürich, Switzerland, was developed by Omlin *et al.* (2001a). The model is one-dimensional, resolving the depth of the lake, and describes the concentrations of algae, zooplankton, ammonia, nitrate, phosphate, oxygen, and degradable and inert dead organic particles in the water column and adjacent sediment layers. The model considers growth, respiration and death of algae and zooplankton, mineralization, nitrification, mixing, sedimentation and phosphate uptake on sinking particles. In this work this model was applied to three lakes of different trophic state: Lake Zürich (mesotrophic), Walensee (oligotrophic) and Greifensee (eutrophic). The transferability of the model was tested and improved by revising the model structure and adapting parameter values. The need for lake-specific calibration was assessed by evaluating a minimum subset of parameters that need to be changed for the different lakes.

Results and discussion

The transferability of the model to similar systems was tested by comparing simulations with data from the three lakes. First simulations were made with the parameter set from Omlin *et al.* (2001a), which was estimated with data from Lake Zürich (mesotrophic). These first simulations also showed good results for Walensee (oligotrophic) but not very good results for Greifensee (eutrophic). Some parameters were changed manually and simulations for all lakes were made with revised parameter sets to improve the model results.

When qualitative agreement of the simulations with the measurements was reached, system analytical techniques (sensitivity analysis, identifiability analysis and parameter estimation) (Brun *et al.* 2001, Omlin *et al.* 2001b) were applied. Based on prior estimates of parameter uncertainty (Omlin *et al.* 2001b) and on linear error propagation of this uncertainty through the model, a sensitivity ranking of the parameters according to their error contribution was made. Identifiability analysis techniques were applied to analyze the approximate linear dependence of the sensitivity functions. Based on the sensitivity ranking and on information on potential identifiability problems, a parameter set was selected and fitted using the data of the years 1988 and 1989.

Parameter estimations were made for all three lakes simultaneously to find a parameter set which leads to good results in all three lakes with a minimum subset of parameters which have different values in the different lakes.

The steps of sensitivity ranking, identifiability analysis and parameter estimation needed to be repeated several times until a satisfying result was achieved. This procedure finally led to a parameter set with a subset of two parameters that have different values for the different lakes. Those parameters only have different values for Greifensee but are the same for Lake Zürich and Walensee.

Simulations with this parameter set show good correspondence with data for all lakes. As compared to the literature, all model parameters are in a reasonable order of magnitude.

For the following reasons two parameters had to be changed in Greifensee to get a good fit:

- In Greifensee a large number of insect larvae (Diptera) which are feeding on zooplankton is usually growing during the first half of the year. This does not occur in the other lakes because they are too deep to allow the larvae to go to the sediment during the day. Because of the large influence of these larvae for Greifensee, an additional death rate of zooplankton needed to be introduced.
- Due to the eutrophic state of Greifensee, the sedimentation rates of organic particles are much higher than in the other lakes. This leads to a higher density of bacteria degrading those particles and to larger gradients of oxygen and nitrate in the sediment surface layers. As bacteria are not explicitly modelled and the sediment is resolved only by two mixed layers, this process had to be accounted for by increasing the mineralization rate in the sediment by decreasing the thickness of the surface sediment layer.

Conclusions

It is well accepted that biogeochemical models of aquatic systems need site-specific calibration (Hammilton and Schladow, 1997). For this reason, it is a remarkable result of this study that good simulations can be achieved for three lakes of different trophic state with a minimum of parameter changes. This demonstrates that the attempt of making models more universal seems to be achievable to some degree even for biogeochemical models. This leads to the hope that it is possible to improve the predictive power and of such models by increasing their calibration base to a larger set of lakes. The reasons for the differences in the two parameters could be identified and conclusions could be drawn regarding which model extensions would be necessary to make the model more universal.

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References

Brun, R., Reichert, P. and Künsch, H.R. (2001), Practical identifiability analysis of large environmental simulation models, *Water Resources Research* 37(4), 1015-1030.

Hamilton, D.P. and Schladow, S.G. (1997), Prediction of water quality in lakes and reservoirs. Part I – Model description, *Ecological Modelling* 96: 91-110.

Omlin, M., Brun, R. and Reichert, P. (2001b), Biogeochemical model of lake Zürich: Sensitivity, identifiability and uncertainty analysis, *Ecological Modelling* 141(1-3), 105-123.

Omlin, M., Reichert, P. and Forster, R. (2001a), Biogeochemical model of Lake Zürich: model equations and results, *Ecological Modelling* 141: 77-103.

Simulation modelling of forest ecosystem development under the different forest management scenarios

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Key words: Simulation modeling, individual-based models, carbon balance, different silvicultural strategies, sustainable forest management, SFM, stand composition, boreal forests, broad-leaved forests

Introduction

The new paradigm of sustainable forest management (SFM) requires effective prediction of tree growth and changes of ecological characteristics of the ecosystem related to biodiversity, ecosystem stability and carbon budget. The system of models, EFIMOD (Komarov et al., 2003) was used for the simulation of ecosystem dynamic under the different forest management scenarios. The system consists of tree sub model, soil sub model (ROMUL) and statistical climate generator (SCLISS). The tree sub model simulates the stand as a population consisting of separate trees. It is a spatial-individual-based model, i.e., the growth of each tree is simulated as a function of the light competition, which depends on the tree's position within the stand, and the amount of nitrogen available for this tree. ROMUL is the model of dynamics of forest soil organic matter (Chertov et al., 2001). It is based on the concept of succession stages of soil organic matter decomposition marked by different groups of soil fauna inherent to forest soils. The model allows to calculate the dynamics of soil organic matter and corresponding dynamics of nitrogen including the evaluation of amount of mineral nitrogen which is available for plants. A soil climate generator SCLISS (Bykhovets and Komarov, 2002) allows for estimation of soil temperature and moisture using measured standard long-term meteorological data. A set of input parameters is mainly based on ordinary and traditional experimental data. Output variables are the inventory stand data (height, diameter, basal area of trees et al.), pools of carbon and nitrogen in the stand and soil, the dynamics of CO2 emission and some other characteristics. Structure of the model system allows for the simulation of different types of cuttings.

Results and discussion

The forest selected for the simulation modeling is situated 100 km South of Moscow (Russia) on Central East European Plain with continental climate of the border between coniferous and broad-leaved forest zones and consists of the part of State Forest Enterprise "Russky Les"(about 300 Ha). The State Forest "Russky Les" occupies left bank of Oka river with sandy and loamy sod-podsolic soils. The territory was intensively exploited in 17th-20th centuries, and secondary forests are now widely spread in the "Russky Les". These 'managed forests' represent mosaics of stands of different age and composition in dependence of previous clear cuttings and type of forest regeneration. Four simulation scenarios were compiled for the analyzing of forest dynamic at different silvicultural regimes: a) natural development; b) Russian legal practice; c) selective cutting system; d) illegal practice. Natural development scenario describes development of unmanaged forests. Scenarios with management differ in the attributes: type of thinning (low thining, high thinning), intensity of thinning, time interval between thinnings, how much of the total product of rotation is removed as thinnings et al. The values of the attributes also depend on the current stand composition. Russian legal practice includes 4 thinnings and final clear cutting, with successful natural regeneration by target species with mixture of deciduous species with removal of cutting residues. Selective cutting system represents managed forest with 2 thinnings and then selective cuttings each 30 years in uneven-aged stands (30% of basal area from above). Illegal practice consists a heavy upper thinning and removing of the best trees, clear cutting without conservation of natural. There is full removal of cutting residues. The EFIMOD runs have been performed for 200-years stand growth and soil changes in every forest compartment for four scenarios of forest management. The analysis of the simulation results shows what scenario is the best from ecological point of view, what scenario leads to maximal wood productivity and ultimately what scenario is described as scenario for sustainable forest management (SFM). The strategy of natural development leads to maximal stock of carbon in the forest and in the soil pools. The Russian legal forest management is the best from economical point of view. Mean total carbon amount in the forest ecosystem is stable. The forests under selective cutting system be characterized high level of productivity and biodiversity. The illegal practice leads to fast decreasing of forest productivity and soil organic matter with dominating of birch forests.

Conclusions

Results demonstrate interesting spatial mosaic of carbon stock and stand structure which is specific for each scenario. Difference between separate stands in natural development scenario arises due to different initial soil conditions and initial stand composition. Cuttings result in a multiplex mosaic structure in the managed forests.

Acknowledgements

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References

Bykhovets, S.S., Komarov, A.S. A simple statistical model of soil climate with a monthly step. *Eurasian Soil Science*, 35: 392-400, 2002.

Chertov, O. G., Komarov, Nadporozhskaya, M. A., Bykhovets, S. S., and Zudin, S. L. ROMUL - a model of forest soil organic matter dynamics as a substantial tool for forest ecosystem modelling. *Ecological Modelling*, 138: 289-308, 2001.

Komarov, A., Chertov, O., Zudin, S., Nadporozhskaya, M., Mikhailov, A., Bykhovets, S., Zudina, E., Zoubkova, E. EFIMOD 2 - A model of growth and elements cycling in boreal forest ecosystems. *Ecological Modelling,* 170 (2-3): 373-392, 2003.

Application of cellular automata modeling for plants invasion model

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Key words: cellular automata, ontogenesis, age stages, plant population, invasion

Introduction

There is an increasing interest in cellular automata models in plant population ecology because they allow for analyzing of spatial structure of plant population and base on simple rules of plant development (Ermentrout, Edelstein-Keshet, 1993; Baltzer et al., 1998). Cellular automata are dynamic models being discrete in time, space and state. Plant population is simulated as a set of cellular automata located on the place and changing their age state accordingly simple rules depending on the state of a plant and its nearest neighbours. The link between cellular automata modeling approach and the concept of discrete description of the ontogenesis of plants is of concern. Importance of the linkage is described in (Komarov, Palenova, 2001; Komarov et al., 2003). Individual plant development may be treated as a number of successive stages on the basis of morphological indicators reflecting functional importance of plants at different stages. Population is described as a set of individuals belonging to certain age stages with their corresponding distribution - age stages spectrum.

Results and discussion

Either whole plant or the certain part of plant could be treated as an element of the model. In our investigation we consider sprout as a modeling element, allowing for vegetative expanding of individual plant and seed dissemination.

The population dynamics is defined by following rules:

- plants are assigned to bounded cells of a two-dimensional integer lattice, with no more then one sprout per cell;
- population consists of plants which originate either from seeds or from vegetative dissemination;
- plants change their age states, in the age of vegetative distribution plants spread its daughter plants on neighbor cells;
- on reaching the generative age state the sprout is in blossom and dies on following years, with corresponding cells vacating;
- seed rain is defined as a probability of random appearance of a seedling plant in an empty cell or in dependence on the distance from blooming plant (some special assumptions about other mechanisms of seeds transportation such as zoochoric transfer can be included into the model rules;
- time step is equal to 1 year.

Ontogenetic development of plants in our model consists of six age states. Seedling is a first year plant with one sprout. Juvenile plant is an older plant with one sprout only. Immature state has five sprouts) and starts vegetative expanding. Next state is virginal (more then five sprouts). Generative age state is reached if plant has one or more blossom sprouts. Senile state is last, when the mortality of sprouts is faster then the appearance of new sprouts for the plant. Plant transition to next age state depends on the presence of nearest neighbour cells unfitting for occupation. Using this approach we developed models describing the dynamics of three plant species (*Aegopodium podagraria* L. *Stellaria holostea* L., *Asarum europaeum* L). that are notable for rate of development and different type of vegetative dissemination. They differ in the geometrical properties of propagation of ramets, rate of expanding and intensity of appearance of ramets along sprouts. The dynamic pattern of sprouts and their relative abilities were simulated in correspondence with experimental data. We investigated various scenarios: 1) the invasion of different species separately on bare soil; 2) the role of shadowing, which changes some species characteristics; 3) the role of plant community at invasion, we define the the role of community as heterogeneity of territory for plants' occupation as presence of busy cells, which prevent sprout propagation. Such experiments are carried out with different probabilities of busy cells with random distribution using Monte-Carlo techniques. In first scenario we found that *Aegopodium podagraria* L. has the most rapid growth of the population number at invasion on bare soil. At shadowing *Stellaria holostea* L. has an advantage over other species at obliteration of bare soil. All species have their specific dynamics at third scenario. If the probability of unfit cells presence is more then some critical probability being specifically for the species from number of all cells, the invasion stops.

Conclusions

In general the models demonstrate that the rate of invasion depends on the sprout life duration and the number of offspring per year. The resulting age state distribution agrees with experimental age spectrum of plants with respective type of vegetative propagation.

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References

Baltzer H., Braun P.W., Kohler W. Cellular automata models for vegetation dynamics. *Ecological Modelling*, 107:113-125, 1998.

Ermentrout, G.B. Edelstein-Keshet, L. Cellular automata approaches to biological modelling. *Journal of Theoretical Biology*, 160:97-133, 1993.

Komarov A.S., Palenova M.M Simulation modeling of interacting populations of two creeping plants. *Bulletin of Moscow Naturalists Society, Biology section.* 106(5):34-41, 2001.

Komarov A.S., Palenova M.M., Smirnova O.V. The concept of discrete description of plant ontogenesis and cellular automata models of plant populations. *Ecological Modelling*, 170:427-439, 2003.

ISOLATED POPULATION DYNAMICS WITH PERIODIC DISTURBANCES

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Key words: population dynamics, periodic disturbances, model

Introduction

During the winter periods for insect populations in boreal forest zone there are no activities of individuals. It means that it is not necessary to construct special equations for the description of process of insect population changing at this period and it is possible to describe it as a "jump down" of model trajectory. The similar situations are typical for populations at harvesting and periodic using of chemical poisons against the pests (but without the after-effects onto population dynamics). At the description of all of these situations we can assume that we have broken trajectories which describe the periodic decreasing of population size at selected time moments. Moreover, it is possible to find in modern literature (Isaev et al., 2001) an opinion that winter conditions play a very important role in the beginning and development of mass propagations of forest insects. For the description of these situations described above it is better to use the ordinary differential equations with impulses (Poulsen, 1979; Aagaard-Hansen, Yeo, 1984; Nedorezov, Nedorezova, 1995).

Model

Let t_k, $k = 0,1,2...$, $t_{k+1} - t_k = h = const > 0$, be time moments of the beginning of winter periods. Population dynamics for every time interval $[t_k, t_{k+1})$ can be described as

$$\frac{dx}{dt} = xR(x),\ R(0) > 0,\ \frac{dR}{dx} < 0,\ R(\infty) = -\infty, \tag{1}$$

where $x(t)$ is the population size at moment t, $R(0)$ is the Malthusian parameter. Let $x(t_k - 0)$ be the population size at the beginning of k-th winter period, and p, $0 \le p \le 1$, be the quota of individuals survived to the beginning of the next vegetation period. Thus at moments t_k we have $x(t_k) = px(t_k - 0)$. Let $x_k = x(t_k)$ and

$$\psi(x) = \int \frac{dx}{xR(x)}.$$

Model (1) can be presented in the form:

$$x_{k+1} = p\psi^{-1}(\psi(x_k) + h). \tag{2}$$

If $p \equiv const$, function in right-hand-side of equation (2) is monotonously increasing function. For all initial values population size in model (2) changes monotonously. In general case the regimes with several non-trivial stationary points can be realized in (2). Let τ, $\tau \le h$, be the time after the "jump down" and, respectively, $t_k + \tau$ are the time moments of population size fixations, $x_k = x(t_k + \tau)$. For $R(x) = \alpha - \beta x$ and $p \equiv const$ model (2) has the form:

$$x_{k+1} = \frac{Ax_k}{1 + Cx_k}, \tag{3}$$

where coefficient C is equal to

$$C = \frac{\beta}{\alpha}\left(e^{\alpha(h-\tau)} - 1 + p(e^{\alpha\tau} - 1)e^{\alpha(h-\tau)}\right).$$

If $R(x) = \alpha - \beta x$ and

$$p = \exp\left(-b\int_{t_k}^{t_{k+1}} x(s)ds\right),\quad p = \left(\frac{\alpha e^{\alpha\tau} - \beta x_k(e^{\alpha\tau} - 1)}{\alpha e^{\alpha\tau} + \beta x_k(e^{\alpha h} - e^{\alpha\tau})}\right)^{\frac{b}{\beta}};$$

this last expression we have to put into model (3) that allows us to obtain one-parametric family (τ is a parameter of this family) of discrete models which are "produced" by the model (1) under the considering assumptions. Note that well-known Hassell model (Hassell, 1978) is element of last family.

Conclusions

Analysis of isolated population dynamics under the periodic impacts which lead to the decrease of population size shows, that at constant value of probability of surviving after the impacts there can only be realized the regimes of monotonous stabilization of population size. It is very important to note that in general case the regimes with several stationary states can be realized within the framework of analyzed model. This result can be considered as additional support for the hypothesis that winter conditions play very important role in the beginning and development of forest insect mass propagations. Analysis of partial cases when the population dynamics describes by the Verhulst model between moments of impacts showed, that there are no trigger regimes in phase space of system if probability of surviving is constant or exponentially decreasing function on average of population size. On the other hand, analysis of these partial cases allowed us to obtain one-parameter sets of discrete models which can be "produced" by unique continuous-discrete model. Moreover, it allowed us to show that type of discrete model of population dynamics can depend on the time moments of population size measurements.

References

Aagaard-Hansen, H., and Yeo, G.F. A stochastic discrete generation birth, continuous death population growth model and its approximate solution. *J. Math. Biol.* 20: 69-90, 1984.

Hassell, M.P. *The Dynamics of Arthropod Predator-Prey Systems.* Princeton, 1978.

Isaev, A.S., Khlebopros, R.G., Nedorezov, L.V., Kondakov, Yu.P., Kiselev, V.V., and Soukhovol'sky, V.G. *Forest Insect Population Dynamics.* Moscow, 2001.

Nedorezov, L.V., and Nedorezova, B.N. Correlation between models of population dynamics in continuous and discrete time. *Ecological Modelling* 82: 93-97, 1995.

Poulsen, E.T. A model for population regulation with density- and frequency - dependent selection. *J. Math. Biol.* 8: 325-348, 1979.

Model Abstraction Techniques: an Overview of Applications in Contaminant Hydrology

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Key words: model complexity, model structure, hydrology, contaminant transport, modeling process, uncertainty

Introduction

An increased level of detail in models of complex systems does not necessarily imply increased accuracy of simulation results, but usually increases computational complexity and/or data collection burden, and may make simulation results more difficult to interpret. Model abstraction is a methodology for reducing the complexity of a simulation model while maintaining the validity of the simulation results with respect to the question that the simulation is being used to address. The objective of this work was to summarize existing model abstraction techniques and provide an example pertinent to the contaminant transport modeling.

Results and discussion

Model abstraction explicitly deals with uncertainties in model structure. Model abstraction techniques and examples of their application in contaminant hydrology include (a) using pre-defined hierarchies of models, (b) simplifying process descriptions based on the specific range of input parameters, i.e. reducing dimensionality, (c) parameter elimination based on simulation results, i.e. sensitivity analysis, (d) combining system states whose distinctions are irrelevant to the simulation output, i.e. combining individual stream tubes in a stochastic transport model, or upscaling based on aggregation, (e) dividing a model into loosely connected components, executing each component separately, and searching for constraints that execution of one component can impose on other components, i.e. running a flow model independently of the transport model, (f) combining states involving similar sequences and distinctions among the individual sequences that are irrelevant to the final outcome, i.e.

abstracting the iterative plume construction to the transport of particle ensembles undergoing non-Brownian motion, (g) replacing continuous variables by class variables, i.e. using regression trees to develop pedotransfer functions used for hydraulic parameters estimations, or genetic algorithms in model calibration, (h) temporal aggregation, i.e. replacing several closely-spaced events with a single event, (i) aggregating entities in a natural hierarchical structures, i.e. replacing a heterogeneous soil profile with an equivalent homogenous profile, (j) function aggregation to provide a coarser list of states or output information from existing entities, i.e. representing the water regime of a soil layer by means of either infiltration or evaporation, while neglecting redistribution, (k) using probabilistic inputs to develop lumped models, i.e. statistical averaging of flow and transport behavior for temporal and spatial upscaling, (l) using look-up tables to simplify the input-output transformation within a model by means of a decrease in computational effort, (m) rule-based solutions of model equations, i.e. using cellular automata in flow and transport problems, (n) meta-modeling with machine-learning methods, i.e. neural network approximations of a range of output scenarios for a particular site, (o) spatial correlation-based meta-modeling, i.e. using spatial correlations in flow and transport data assimilation.

Our case study comprises modeling water transport at an extremely intensively monitored site in Bekkevoort, Belgium. We focused on water fluxes in soil profile and considered model abstraction using simplified process description (dual porosity model → single porous medium → tipping bucket model), simplified domain description (layered soil → single material layer), simplified parameter estimation (inverse problem → laboratory measurements → a family of pedotransfer functions) and simplified modeling based on multiple simulations (neural network modeling → nearest neighbor). We have found that model abstraction may encounter limitations imposed by data, software, and scale. For the case study and seasonal temporal scale, model abstraction was efficient. Effect of scale on model abstraction efficiency presents an interesting avenue to explore.

Conclusions

There exists a potential for developing a comprehensive model abstraction strategy in contaminant hydrology that will enable risk assessments to be run and analyzed with much quicker turnaround, with the potential for allowing further analyses of problem sensitivity and uncertainty. Model abstraction also has the potential to enhance communication as simplifications that result from appropriate model abstractions may make the description of the problem more easily relayed to and understandable by others, including decision-makers and the public. It is often imperative to explicitly acknowledge the abstraction strategy used and its inherent biases, so that the modeling process is transparent and tractable.

INDIRECT EFFECTS AND DISTRIBUTED CONTROL IN ECOSYSTEMS

1. Environs and Network Environ Analysis: Introduction and Overview

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Key words: network environ analysis, input–output analysis, environs, indirect effects, control

Introduction

Environs are mathematical partition elements of the flows and storages in compartmental models representing intercompartmental and boundary transfers of conservative energy or matter in systems. The interconnecting links form a network of conservative transactions and mixed conservative/non-conservative, informational relations. Each component in a system has an environment, within the system and beyond its boundary. The within-system portions are environs, and each component has two of them, one incoming from the system boundary (input environ) and the other outgoing to the boundary (output environ). Steady state input-output methodologies to describe these environs and their properties constitute Network Environ Analysis (NEA). A set of NEA methods forms the base methodology for this series of numbered papers on "indirect effects" and "distributed control" in ecosystems.

Results and discussion

NEA methods are based on tracing conservative substance around interconnecting networks - forward (for output environs) from its time and place of introduction, and backward (for input environs) from its time and place of exit. Loss of substance is the mechanism of 2nd-law thermodynamic dissipation, and also the mechanism behind convergence of mathematical power series to achieve network transitive closure - accounting for all pathways of all kinds and lengths involved in substance transfer during its lifetime in the system. Accordingly, the base NEA methodology is to (1) construct dimensional direct conservative flow matrices F = (f_{ij}), denoting flows from compartments j (columns) to i (rows); (2) non-dimensionalize these to matrix forms to represent different properties of environs; (3) compute and characterize relationships for all orders, m, of the normalized forms by matrix multiplication; and then (4) compute the infinite series as $m \to \infty$, to generate the convergent transitive closure matrix, $(I-W)^{-1}$, I the identity matrix, W the normalized matrix, and $(I-W)^{-1}$ the convergent transitive closure matrix. The present NEA methods form five groups, three foundational (pathway, throughflow, and storage analysis) and two derived (utility and control analysis). The foundational methods are described below; how they elucidate indirect effects is treated in papers #2, #3 and #4 of the series. Of the derived methods, utility will not be discussed and control, much modified and expanded, is the topic of papers #5 and #6.

Pathway analysis: Adjacency matrices $A = (a_{ij})$ are derived from F and their powers A^m computed to enumerate pathways of lengths m leading from each system component j to each other component i. This exercise shows the large numbers of direct ($m = 1$) and indirect ($m > 1$) pathways involved in reaching transitive closure in incoming and outgoing environs. Different forms of A are produced for input and output environs, and for non-storage and storage analyses. Pathways are termed paths in the non-storage case, and walks when storage is involved.

Throughflow analysis: The paths identified in pathway analysis carry boundary flows forward (through output environs) and backward (through input environs) to steady-state throughflows. Throughflow is the sum of inflows or outflows (equal at steady state) at each compartment k. Let $z = (z_k)$, $T = (T_k)$, and $y = (y_k)$ be vectors of boundary inputs, throughflows, and outputs, respectively, to, at, and from each k'th compartment of an n-compartment system ($k = 1, ..., n$). Throughflow analysis derives from F two non-dimensional transitive closure matrices $N = (n_{ij})$ (output–oriented) and $N' = (n_{ij}')$ (input–oriented) which map boundary inputs and outputs into throughflows: $Nz = T$ and $yN' = T^T$ (transpose). The form Nz traces each j'th input z_j forward through the j'th output environ E_j to its appearance as the j'th element T_{kj} of thoroughflow T_k at compartment k. The form yN' traces each i'th output y_i backward through the i'th input environ E_i' to its appearance as the i'th element T_{ik} of thoroughflow T_k at the k'th compartment.

Storage analysis: The walks identified in pathway analysis carry boundary flows forward (through output environs) and backward (through input environs) to steady-state storages (standing stocks). Throughflow is the steady-state sum of inflows or outflows at each compartment k. Let $x = (x_k)$ be the vector of steady-state storage at each k'th compartment. Storage analysis derives from F two nondimensional transitive closure matrices, $S = (s_{ij})$ (for output environs) and $S' = (s_{ij}')$ (input environs), which map boundary inputs and outputs into storages: $Sz = x$ and $yS' = x^T$ (transpose). The form Sz traces each j'th input z_j forward through the j'th output environ E_j to its appearance as the j'th element x_{kj} of storage x_k at compartment k. The form yS' traces each i'th output y_i backward through the i'th input environ E_i' to its appearance as the i'th element x_{ik} of storage T_k at compartment k.

Conclusions

Indirect effects develop in the mappings $Nz = T$, $yN' = T^T$ and $Sz = x$, $yS' = x^T$ from the fact that the transitive closure matrices N, N' and Q, Q' (where $S = Q\Delta t$ and $S' = Q'\Delta t$, Δt a discrete time interval) decompose into power series of non-dimensional flow matrices derived from F, namely G and G' for throughflow, and P and P' for storage:

$$I + W + W^2 + W^3 + ... + W^m + ... = (I - W)^{-1} = \text{convergent transitive closure matrix}$$

where W represents G, G', P, or P', depending upon the analysis. Direct effects are measured in these series by the 1st-order terms: G, G' and P, P' and indirect effects are the summations of the higher-order terms. The latter typically exceed the former, leading to the central NEA dogma that indirect effects are dominant in ecosystems.

INDIRECT EFFECTS AND DISTRIBUTED CONTROL IN ECOSYSTEMS

6. Distributed Control in the Environ Networks of a Seven-Compartment Model of Nitrogen Flow in the Neuse River Estuary, USA: Time Series Analysis

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Key words: Environ, Network, Control

Introduction

The methods of network environ analysis (NEA) require that models be static to be analyzed. Networks of real ecosystems are not static, but dynamic. The mathematics required for true dynamic analysis is daunting, and has never been fully developed. One approach to overcoming this limitation is to analyze a discrete-time series of static models, each a steady-state snapshot for the period it represents. The environs generated for each static network can then be compared to determine how they change over time.

Ecosystems do not contain any obvious sources of control. This property must somehow reside in the complexity of organization, complexity captured in the interactive networks of ecosystem models. We speak of such control as diffuse, decentralized, or remote, for which we adopt the general term *distributed control.* Within the NEA framework this kind of control can be investigated by defining appropriate concepts and measures.

In the abstract for Paper #5 (Schramski et al.) of this series we distinguished three concepts of control. The c*ontrol ratio,* cr_{ij}, and *control difference,* cd_{ij}, expressions denote a pair-wise dominance relationship between two components, i and j, related proximately (directly connected) or distally (indirectly connected) in a network. When one component i in a system transfers a greater fraction of its throughflow of energy or matter to another j than j does to i; i controls j in the dominance sense. Unlike the *control ratio*, derived with uncommon denominators, the *control difference* magnitudes can be compared to each other for relative control strengths between pairs of components. Their magnitudes are relative to the system. As such, the *control difference* magnitudes can also be added to determine a component i's relative combined strength with regard to the system (remaining components combined). The s*ystem level control,* cs_i, vector captures this magnitude whereby a $cs_i > 1$ value denotes a system control of the specific component i. Likewise a $cs_i < 1$ value denotes a specific component's, i, control of the entire system.

Results and discussion

These three forms of distributed control were approached in the framework of NEA throughflow analysis and were explored for the 16 consecutive seasons of the steady state models of nitrogen cycling in the Neuse River Estuary, North Carolina, USA (Christian and Thomas 2003). The seven compartment nitrogen model included: phytoplankton, heterotrophs, sediment, dissolved organic nitrogen, nitrate and nitrites, ammonia, and abiotic detritus. We followed the kind of protocol described for time series environ analysis in the abstract for Paper #4 (Whipple et al.) of this series, employing the methods outlined in that for Paper #5 (Schramski et al.). For each of 16 steady-state nitrogen networks the NEA control metrics were calculated and comparisons made. Temporal comparisons included between years for the same season, between adjacent seasons over the 16-season time series, and between the four-season patterns of each year. Subtle changes in nitrogen control relationships were observed over time, e.g., on average, phytoplankton dominates the system in all four seasons with its least control dominance occurring in the winter. Sediment remained dominated, $cs_i > 1$, by the overall system throughout all years and seasons while nitrates and nitrites, NO_x, dominated the system, $cs_i < 1$, in all years and seasons.

Conclusions

Our results lead to important questions still to be answered: (1) To what extent do nitrogen turnover times within each component affect the perception of environ control as derived from NEA throughflow analysis,? (1) What parts of the Neuse River nitrogen system control seasonal changes at the whole environ level? (2) To what extent are physical or biological events (hurricanes, unusual river discharge, anoxic episodes, or extreme temperature) controlling salinity, nutrient loading, or other physical regimes? (3) What factors are driving control patterns in environ variations? (4) What kinds and degrees of control are needed to remediate the Neuse system? (5) Can NEA-based studies of nitrogen time series establish if the river system has enough control capacity to sustain basic ecosystem health?

References

Christian, R. R. and C. R. Thomas. Network analysis of nitrogen inputs and cycling in the Neuse River Estuary, North Carolina, USA. *Estuaries* 26(3): 815-828, 2003.

Qualitative models about stream ecosystem recovery*: an exploratory study*

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Key words: Qualitative Reasoning, Conceptual Models, Stream Ecosystems, Education.

Introduction

Rivers and other water bodies are complex systems of interest all over the world because, despite their recognised importance for all living systems, they suffer from damage caused by human actions. From the ecological point of view, the worst effect of water pollution by organic matter (OM) is the reduction in dissolved oxygen (DO) concentration. OM influences the concentration of DO due to the increased activity of decomposers. Respiration reduces the amount of available oxygen and eventually affects the whole biological community. The reduction of DO is selective for some fish species and may cause fish mortality to increase. This is a well-known problem, described in textbooks for undergraduate students. However, integrated models covering the wide range of factors that may influence this problem are difficult to build because of partial understanding of the community structure and functioning and because data available is incomplete, uncertain, and often represented in qualitative (linguistic) terms. This paper describes an exploratory study about how to build conceptual models for explaining changes in a river community under the effects of pollution by sewage and the consequences of good and bad management practices, using Qualitative Reasoning (QR) techniques.

The QR modelling approach

QR is an area of Artificial Intelligence that provides means for reasoning with incomplete knowledge about a system. The capacity of representing only the most relevant states of the system (from the qualitative point of view) creates compact descriptions of system behaviour. Explicit representation of objects, relations between objects and quantities, situations, processes, and conditions for things to start and stop, provide a rich vocabulary for describing a system. The possibility of including representations of assumptions in the models provides a better understanding of their limitations and allows users to change them if they want. Previous work on population and community dynamics has shown the potential of QR for addressing ecological problems (Salles & Bredeweg, in press; Salles et al. 2003).

Our models are implemented in the qualitative reasoning engine GARP (Bredeweg, 1992) and are based on a process-oriented ontology (Forbus, 1984). We built a library of model fragments that capture partial knowledge about the system and can be combined to create different models. Different scenarios set initial values for the quantities and conditions for the selection of the model fragments during the simulation. These selected model fragments create representations of qualitative states of the system.

Models and simulations

The model described in this paper includes entities (objects) that represent a segment of ‘river’, viewed as a ‘container’ that contains ‘biological entities’. There is also a (human) ‘manager’, that ‘performs a task’ (human action), namely ‘pollution control’ of the river. Relevant properties of these entities are represented as quantities. For example, the river contains substances represented by the quantities Nutrient, Organic Matter and Oxygen. The amount (mass) of aquatic plants, decomposers and fish are modelled by the quantity Amount_of. Processes change the qualitative values of these quantities. Decomposer growth, Fish growth are the rates that affect respectively the Amount_of decomposers and fish. Amount_of plant is directly influenced by Net_production rate, which is calculated as [Photosynthesis rate – Respiration rate]. Actions of management (controlling pollution) are modelled by means of the quantity Control, representing an aggregated of processes taken in order to control pollution. Control is a direct influence on Organic Matter. If the management practice is good, Organic Matter decreases.

A simulation of good management practice produces 17 states, showing that OM decreases, the mass of plants and DO increases, decomposers decrease and the amount of fish also increase. There is no state in which decomposers become greater than the plants and the fish; also, it does not happen that DO decreases while fish increases. The simulation with bad management produces 69 states, with different combinations of values of the 10 quantities included in the model. As a result, the simulation produces states representing all the possible qualitative situations of the system: (a) both DO and amount of fish have value normal; (b) both DO and amount of fish have value high; (c) DO has value high and amount of fish has value normal; and (d) both DO and amount of fish have value low. Note that the ‘forbidden’ combination (the fish component going to high while DO goes low) is not present in the behaviour graph.

Discussion

Modelling the wide array of physical, chemical and biological aspects of rivers and stream ecosystems puts a number of challenges both for the QR and ecological modellers communities. Some are approached in the exploratory study described here. The explanation why management actions controlling measures influence the OM in the water and how this effect propagate to nutrients, plants, decomposers, DO and fishes is given by the model’s causal structure. Two simulations are presented, showing how good and bad management practices may be used to control fish stocks in the river. However, reasoning about such water systems requires representations of populations and communities, energy flow and nutrient cycling. We argue that a robust qualitative theory of water ecosystems will require at least three ontologies, the number_of ontology already implemented (Salles & Bredeweg, in press) and those we called energy_of and amount_of whose implementation is part of our ongoing work. We believe the use of QR models has the potential to become a major breakthrough in modelling for research, management, training and education in stream ecosystem recovery and other water-related ecological phenomena.

References

Bredeweg, B. (1992) Expertise in Qualitative Prediction of Behaviour. PhD thesis. University of Amsterdam, Amsterdam, The Netherlands.

Forbus, K.D. (1984) Qualitative process theory. *Artificial Intelligence,* 24:85–168.

Salles, P. & Bredeweg, B. Modelling population and community dynamics with Qualitative Reasoning. *Ecological Modelling* (in press).

Salles, P.; Bredeweg, B.; Araújo, S. & Neto, W. (2003) Qualitative models of interactions between two populations. *AI Communications*, 16(4): 291– 308.

The Ants' Garden:
Qualitative models of complex interactions between populations

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Key words: Qualitative Reasoning, Conceptual Models, Interacting Populations, Education.

Introduction

Because few organisms cultivate their own food, fungus-gardening by ants is considered to be a major breakthrough in evolution. It is a symbiosis in which organisms of two different species (ants from the family *Formicidae* and fungi from the family *Lepiotaceae*) benefit each other and create a system that can successfully survive in different environments, being the dominant herbivores in the Neotropics. Recent studies Currie et al. [2,3] show that the *ants' garden* is far more complex than initially understood. A third species, the specialized garden parasite fungi of the genus *Escovopsis* is often involved and may destroy the system, by attacking the cultivated fungi. However, it almost never happens because ants carry on their body colonies of bacteria (genus *Streptomyces*) that produce antibiotics specifically targeted to suppress the growth of *Escovopsis*. Therefore the system consists of four species and of complex balance of interactions in which eventually the ants' garden survives.

Interactions between populations have been a hot topic in ecological theory and practice. Competition, for instance, is still seen as a driving force for shaping biological communities. However, traditional modelling approaches, mostly based in differential and difference equations, are limited in many aspects. Besides the well known difficulties to obtain numerical data of good quality for implementing, calibrating and evaluating the models, it has been shown that even simple mathematical models may produce complex trajectories, with stable points, cycles and chaotic behaviour [6,7]. For example, modelling interactions among populations with ordinary differential equations, Gilpin [5] demonstrated that chaos can be observed when there are at least three populations. Cyclic behaviour has been observed in many populations, but the existence of chaotic behaviour in natural populations is still an open question [8].

Qualitative Reasoning and our Models and Simulations

Qualitative Reasoning (QR) is an area of Artificial Intelligence that may be useful to address complex systems like the ants' garden, including the possibility of developing conceptual models with a rich vocabulary to describe objects, quantities, relations, situations, causal mechanisms of change, conditions for things start and finish. Explicitly represented causality is useful to support explanations about the system's behaviour. Qualitative models can also be used to improve understanding of the structure of the ecological system and allow for valid predictions in situations that mathematical models cannot be used. We use a compositional approach so that a library of *model fragments* facilitates reusing 'simpler' models to *scale up* to complex models. Accordingly, implemented models about single population dynamics, community succession [10], and interactions between two populations

[11] are re-used here to model the ants' garden. Our models are implemented using the qualitative simulator GARP [1] and assume that *processes* are the mechanisms that cause changes in the system [4].

We defined the minimum set of interactions required to model the ants'garden: (a) ants / cultivated fungi = symbiosis (+,+); (b) parasitic fungi / cultivated fungi = parasitism (+,–); (c) ants / bacteria =comensalism (0, +); (d) bacteria / parasitic fungi = amensalism (0,–). We assume that the effect a population can cause on the other one must be represented as a specific quantity (*Effect*). The influences set by the interactions used in the ants'garden model can be summarised as follows: (a) Symbiosis: both Effects are positive, reducing D and increasing B; (b) Parasitism: the effect of the parasite reduces B2 and increases D2, while effect of the host increases B1 and reduces D2; (c) Comensalism: population1 has a positive effect increasing B2 and reducing D2, while population2 does not affect the other one; (d) Amensalism: population1 has a negative effect decreasing B2 and increasing D2, while population2 does not affect the other one. During this modelling effort, we tried a number of alternative combinations of different models of comensalism and amensalism. The models support a rich set of simulations, depending on the initial scenarios of the quantities and what assumptions are to be considered. For example, one of the simulations results in 23 states, showing behaviours such as: coexistence, complete extinction of the garden, ants and cultivated fungi reaching their maximum size and the elimination of the parasitic fungi.

Discussion

Our models of the ants'garden reflect the current understanding of how populations interact. Ongoing work includes implementations of alternative hypotheses to answer some open questions. For example, bacteria / cultivated fungi = (0,+) or (+,+)? ants / bacteria = (0,+) or (+,+)? bacteria / parasitic fungi = (0, –) or (–,–) ? These simulations allow the user to explore a number of possible behaviours. Chaotic behaviour does not appear in coarsegrained models such as those presented here, because quantities do not assume threshold values that would trigger that kind of behaviour. Some features of qualitative models like the explicit representation of causal dependencies and modelling assumptions, and easy to test alternative hypotheses facilitate the refinement of the model. Exercises of these types may help us to better understand the functioning of complex systems like the ants' garden.

References

[1] Bredeweg, B. (1992) *Expertise in Qualitative Prediction of Behaviour*. PhD thesis. University of Amsterdam, Amsterdam, The Netherlands.

[2] Currie, R.C.; Scott, J.A.; Summerbell, R.C. & Malloch, D. (1999a) Fungus-growing ants use antibiotic-producing bacteria to control garden parasites. *Nature*, 398: 701-704.

[3] Currie, R.C.; Mueller, U.G. & Malloch, D. (1999b) The agricultural pathology of ant fungus gardens. *Proc. Natl. Acad. Sci. USA*, 96(14): 7998-8002.

[4] Forbus, K.D. (1984) Qualitative process theory. *Artificial Intelligence*, 24:85–168.

[5] Gilpin, M.E. (1979) Spinal chaos in a predator-prey model. *Am. Nat.* 113: 306-308.

[6] May, R. (1974) Biological populations with non-overlapping generations: stable points, stabel cycles and chaos. *Science* 186: 645-647.

[7] May, R. (1976) Simple mathematical models with very complicated dynamics. *Nature*, 261: 459-467.

[8] May, R. & Oster, G.F. (1976) Bifurcations and dynamic complexity in simple ecological models. *Am.Nat.* 110:573-599.

[10] Salles, P. & Bredeweg, B. Modelling population and community dynamics with Qualitative Reasoning. *Ecological Modelling* (in press).

[11] Salles, P. & Bredeweg, B.; Araújo, S. & Neto, W. (2003) Qualitative models of interactions between two populations. *AI Communications* 16(4): 291–308.

Highlighting model code selection and application process in policy-relevant water quality modelling: Lake Vansjø case story as an example

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Key words: modelling, water management, benchmark criteria

Introduction

There are many good reasons why models are used in providing advice, information and even predictions for the management of our lakes, rivers and other water bodies, that are complex systems and consist of numerous interconnected subsystems. As Dale (2003) phrases it, models help to organise, synthesize, and track information and scientific knowledge and hypothesis in a way that would not be possible otherwise.

This paper describes the modelling "case story" of Lake Vansjø, situated in the southeastern Norway, near Oslo. With "case story" we mean the entire modelling process, starting with the problem definition and model code selection, and ending with the production and discussion of the final model results. With Vansjø as an example, this paper illustrates and discusses some rather simple means to enhance the quality of model-based knowledge input for decision-making. We try to keep our approach pragmatic and avoid getting too much involved in more profound theoretical or philosophical controversies, as discussed in Refsgaard and Henriksen (2004). Our modelling study was carried out as a part of the project *Benchmark Models for the Water Framework Directive*, whose main aim is to develop a set of operational evaluation criteria for (computer) models whose application is intended to support decision-making related to a particular water management issue, e.g. in connection with the implementation of the EU Water Framework Directive.

The Vansjø river basin comprises several small rivers and lakes, and one large lake, Vansjø, with a very irregular shape. Lake Vansjø consists of two major basins, Vanemfjorden and Storefjorden, the latter which is a major drinking water reservoir and the focus of our current study. Despite earlier abatement measures to reduce inputs of nutrients, the lakes and rivers in Vansjø river basin are still eutrophic primarily due to excess loading of phosphorus from municipal sewage, single point sources and agricultural runoff. The phytoplankton is dominated by blue-green algae (cyanobacteria) part of the season, and in 2001-2003 toxin production by blue-green algae was shown.

The main simulated management question was whether the water quality would reach the two preset environmental goals (Lyche Solheim et al., 2001) if phosphorus loading into Vansjø-Storefjorden was reduced by 50%.

Results and discussion

Four different lake model code candidates were originally picked up from an internet-based model code inventory and considered to be used in Vansjø-Storefjorden. These four codes were: DYRESM-CAEDYM, MINLAKE, CE-QUAL-W2, and MyLake. Based partly on the qualitative evaluation of the model code candidates against the benchmark criteria (Saloranta et al. 2003), and partly on our familiarity with the codes, MyLake was finally chosen as the model code to be applied in Vansjø-Storefjorden.

MyLake (Saloranta and Andersen, 2004) is a one-dimensional mechanistic model code for simulating daily 1) vertical distribution of lake water temperature, 2) evolution of seasonal lake ice and snow cover, as well as 3) phytoplankton-phosphorus dynamics. MyLake has a relatively simple and transparent model structure, it is easy to set-up, and is suitable both for making predictions and scenarios, and to be used as an investigative tool. Furthermore, short runtime allows application of comprehensive sensitivity and uncertainty analysis as well as simulation of a large number of lakes or over long periods (decades).

The simulation results from MyLake model indicate that the strictest environmental Goal 2 of total phosphorus < 11 μg l^{-1} will almost be reached in the long-term after a 50% reduction in both particulate (*PP*) and dissolve inorganic phosphorus *(P)* loads. The less strict Goal 1 of total phosphorus < 15 μg l^{-1} could be reached by 50% reduction in *P* load alone, while a 50% reduction in *PP* load has much smaller effect.

Conclusions

On the basis of the experience from our two-fold study, focussing both on the model results themselves as well as on the process of producing them, we believe that by 1) following (and documenting) the step-by-step modelling process outlined in this paper, based on van Waveren et al. (1999), by 2) using available (internet-based) inventories to get an overview of available model codes, and by 3) performing and documenting the model code selection with help of the benchmark criteria approach, at least some of the barriers to model use in environmental management can be removed, and one can easily, with little extra effort, make a modelling study more rigorous, better documented, and more credible and transparent in front of the stakeholders.

Acknowledgements

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References

Dale, V. H. (ed.). *Ecological modeling for resource management*. Springer, New York, 2003.

Lyche Solheim. A., Vagstad, N., Kraft, P., Turtumøygard, S., Skoglund, S., Løvstad, Ø. and Selvik, J.R. *Tiltaksanalyse for Morsa, Vansjø-Hobol-vassdraget: sluttrapport*. NIVA-report 4377, in Norwegian, 2001.

Refsgaard, J. C., and H. J. Henriksen. Modelling guidelines – terminology and guiding principles. *Advances in Water Resources 27:71-82*, 2004.

Saloranta, T. M., and T. Andersen. *MyLake v. 1.1: technical documentation & user's guide*. NIVA-report 4838, 2004.

Saloranta, T. M., J. Kämäri, S. Rekolainen, and O. Malve. Benchmark criteria: A tool for selecting appropriate models in the field of water management. *Environmental Management 32:322-333*, 2003.

van Waveren et al. *Handbook of good modelling practise*. STOWA-report 99/05, 1999. www.info.wau.nl/research%20projects/gmp.htm

INDIRECT EFFECTS AND DISTRIBUTED CONTROL IN ECOSYSTEMS

5. Distributed Control in the Environ Networks of a Seven-Compartment Model of Nitrogen Flow in the Neuse River Estuary, USA: Static Analysis

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Key words: Environ, Network, Control

Introduction

Holistic knowledge of controlling relationships in ecosystems is one of the primary reasons for understanding system structure and function through modeling. With knowledge of proximate (direct), or especially distal (indirect), control points should come an ability to exert control, either close-in or at a network distance — in other words, should give a capability to implement the elusive concept of "ecosystem management."

Notions of "control" in ecology are loose and varied. Control is an umbrella term encompassing a broad set of diverse opposites such as dominating/subordinating, augmenting/limiting, releasing/constraining, liberating/regulating, etc. Categories from formal control theory, like open-loop and closed-loop (negative-feedback) control, are not a part of the ecological lexicon, although concepts like reachability, controllability, and observability are inherent in the extended networks of input and output environs. And, there is a span in ecological usage from more proximate control in classical concepts like limiting factors, limits of tolerance, and limits to growth, to modern concepts like bottom-up vs. top-down control, and systemic or holistic control.

We consider that in ecosystems there are no explicit controllers, like the thermostats and autopilots of man-made systems. Control somehow resides in the complexity of organization — in the interactive networks that join things together, and in the environs into which these networks can be decomposed. Our concept is thus one of diffuse, decentralized, even (at a network distance) remote control; for purposes of the present set of papers we have adopted the term *distributed control.* Within the framework of network environ analysis (NEA) this kind of control can, with definition of appropriate measures derived from the primary environ analyses of pathways, throughlows, and storages, be fruitfully investigated.

NEA assumes each component of a system has an incoming interactive network that brings it energy and matter, and an outgoing network that takes energy and matter away. These are, respectively, input and output environs of that component which partition elements of the entire interior flow–storage network, in two orientations: afferent (input environs) and efferent (output environs). The system of interacting components has an external reference environment with which it, as an open system, exchanges energy, matter, and information.

Starting with "open-loop" control theory parlance, three ecological control terms (*control ratio, control difference, and system control*) may usefully be formulated in the environ framework by considering both pair-wise and system-wide distributed control relationships. We draw on the notations and concepts outlined in the abstract for Paper #1 (Patten et al.):

1. *Pair-wise dominance.* If component i in a system contributes a greater fraction of its throughflow of energy–matter to j than j to i, then i dominates j and to that extent can be said, in an augmentative sense, to "control" it. If i and j are non-adjacent in a network (no direct link between them), then the control is indirect, or distributed. We measure this form of control in throughflow-based NEA by comparing n'_{ji} and n_{ij}, normalized by a respective throughflow T_i, which is subsequently combined into one matrix designated (η_{ij}), where n'_{ji} is the j'th row, i'th column element of N' (throughflow) input environ mapping matrices, and n_{ij} is the i'th row, j'th column element of N output-environ mapping matrices. Two methods are considered: 1) The *control ratio* is a combination difference and ratio formulation of η_{ji} and η_{ij} designated, cr_{ij}. If $0 < cr_{ij} \leq 1$ then j controls (dominates) i; if $-1 \leq cr_{ij} < 0$, then i controls j. On these intervals, control is minimal when $cr_{ij} = 0$, and maximal at the extremes, $cr_{ij} = \pm 1$. 2) The *control difference* is simply the difference of the magnitudes, $|\eta_{ij}| - |\eta_{ji}|$ designated cd_{ij}. If $cd_{ij} > 0$ then j controls i; if $cd_{ij} < 0$ then i controls j.

2. *System level control.* Unlike the *control ratio* comparison derived with uncommon denominators, *control difference* magnitudes can be compared to each other for relative control strengths between components throughout the system. As such, they can also be added. The *system control* vector, designated cs_i, is the sum of the rows of the cd_{ij} matrix. A $cs_i > 1$ value denotes a system control of the specific component i. Likewise a $cs_i < 1$ value denotes a specific component's, i, control of the entire system.

Results and discussion

These control relationships were explored for the average static model of nitrogen flow in the Neuse River Estuary, North Carolina, USA (Christian and Thomas 2003) further described in Paper #2 (Gattie, et al.) of this series. The seven compartment model included: phytoplankton, heterotrophs, sediment, dissolved organic nitrogen, nitrate and nitrites, ammonia, and abiotic detritus. The (cr_{ij}) and (cd_{ij}) matrices yielded similar results. Considering the (cd_{ij}) matrix, the highest magnitude of control exists with component 3, sediment. In fact, not only are there no components to which sediment exerts control but the magnitude of control on sediment represents the seven highest values in the matrix (cd_{31} through $cd_{37} \geq$ remaining cd_{ij} values). To the contrary, nitrates and nitrites, component 5, control each component in the system with relatively high magnitudes. Stated succinctly, sediment is overwhelmingly controlled by the system while NO_x overwhelmingly controls the system. The system control vector cs_i clearly represents these general conclusions.

Conclusions

Sediment and NO_x appear to participate in opposing roles in the seven component model of the Neuse River Estuary. Paper 6 (Patten et al.) of this series explores these control metrics over 16 consecutive seasons. The preceding results are the direct result of a throughflow based analysis; a storage based environ control analysis is now underway to illuminate the contribution of turnover and resident times to these conclusions.

References

Christian, R. R. and C. R. Thomas. Network analysis of nitrogen inputs and cycling in the Neuse River Estuary, North Carolina, USA. *Estuaries* 26(3): 815-828, 2003.

Modeling fish migration path in a river based on its environmental preference

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Key words: fish, environmental preference, migration path evaluation

Introduction

We have proposed a new fish environmental preference model based on laboratory experiments. (Sekine et al. 1997)

$$P^* = \prod_{j=1}^{J} (P_j)^{\frac{W_j}{W_{\max}}}$$

$$W_{\max} = \begin{cases} \max\limits_{j \in V}(W_j) & V \neq \phi \\ \infty & V = \phi \end{cases}$$

$$V = \left\{ j \middle| (\exists i, i') \left(P_{j,i} \neq P_{j,i'} \right) \right\}$$

ϕ represented the null set, $\exists$ was an existential quantifier, and $W_{\max}$ was the maximum weight among the weight sets that have different preference levels in different tanks.

Although we could explain fish distribution in laboratory experiments by using this model, sometimes it failed to explain fish distribution in real rivers. For the next step, we have developed a model which treat fish behavioral mode such as feeding, resting, hiding and spawning. (Sekine et al. 2001)

$$P_i = \sum_m \left\{ Wm \left(\frac{\sum_k M_{i,k} \times Pm_k \times A_k}{\sum_k M_{i,k} \times A_k} \right) \right\}$$

$$M_{i,k} = \max\left(1 - \frac{dist_{i,k}}{Sensible\ Distance},\ 0 \right)$$

$\max(a, b)$ is a function that returns the larger value between a and b, and $dist_{i,k}$ is a distance from the center of the cell i to the center of the cell j. Pm_k is the preference curve for each behavioral modes. P_i, is the total preference for a cell i.

By defining preference parameters for each behavioral mode, we have succeeded to reproduce fish distribution in real rivers by numerical calculation. (Figure 1)

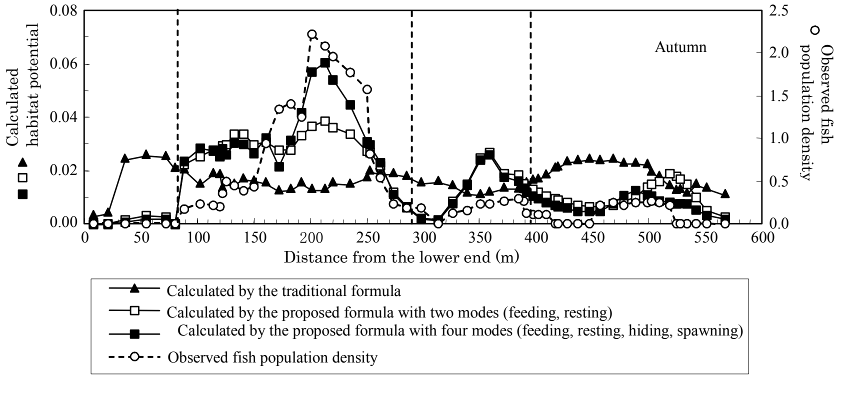


Figure 1. calculated habitat potential and observed fish population density

A new model for evaluating fish migration path

As above mentioned, we have already been able to evaluate fish distribution based on its preference. Now one of our remaining research subjects is to evaluate continuity of rivers for migratory fish. Barrier for migratory fish will be rapid velocity and high gap of water level. These barriers sometimes appear together in shoots and rapids. To pass through rapid velocity, fish need to swim with burst-swimming speed, which last only a few seconds. To pass through high gap of water level, fish need to jump in the air. In the reach where those barriers exist (in this paper we call it a “barrier reach”), there also exist a couple of different phenomenon compared to reaches where fish can swim with sustained swimming speed, such as air bubbles, turbulence and sound pressure. We determine preference curves for these factors based on laboratory experiments. Our new preference model for barrier reach is:

$$P_{\text{barrier reach}} = \left\{ \left(P_{\text{burst swim}}\right)^{\frac{w_{\text{burst swim}}}{w_{\max}}} \left(P_{\text{bubble}}\right)^{\frac{w_{\text{bubble}}}{w_{\max}}} \left(P_{\text{depth}}\right)^{\frac{w_{\text{depth}}}{w_{\max}}} \right\} \times W_{\text{raid velocity}} + P_{\text{gap}} \times W_{\text{gap}}$$

Results and conclusion

Based on the above models, we calculated the preference level for a river reach equipped with two fish ladders, both of them are imitating natural rapid. We also conducted field surveys to count the number of anadromous migration fish which go upstream through these fish ladders (Figure 2 and Figure 3). When preference level for the barrier is low and preference level for the pool is high, few fish go up. When preference level for the barrier is high and preference level for the pool is low, a lot of fish go up. The calculated magnitude of preference for these passes can explain the fish migration number and their path in the reach.

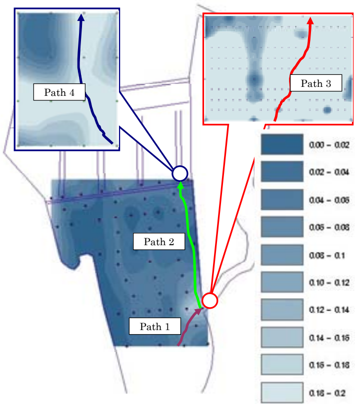
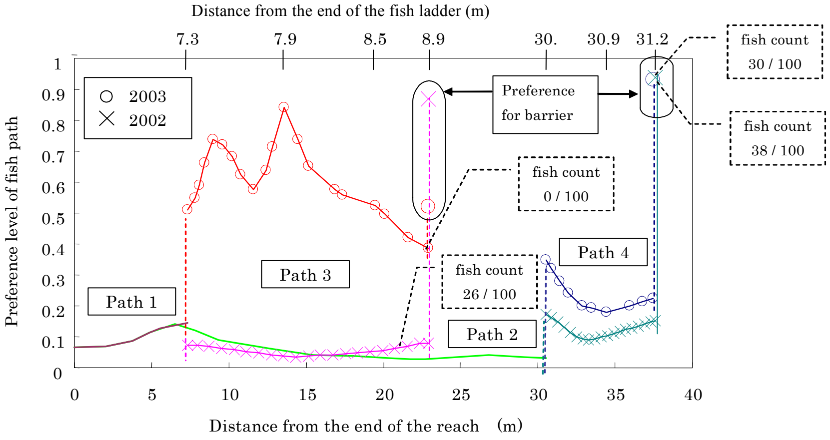


Figure 2. Estimated fish migration paths



“fish count 30 / 100” means 30 fish pass through the fish ladder out of 100 released fish.
2002 and 2003 mean that the calculation of preference and observed fish count are based on the year.

Figure 3. Preference along the fish migration paths

References

Sekine, M. Imai, T., and Ukita, M.. A model of fish distribution in rivers according to their preference for environmental factors. *Ecological Modelling*, 104, 215-230, 1997.

Sekine, M., Yang, J., Ukita, M., and Imai, T. A fish habitat evaluation model based on the behavioral mode. *Proc. MODSIM 2001*, 2, pages 807-812, Australia, 2001.

A Minimal Model for the Precautionary Assessment of Environmental Chemicals with Respect to Global Cold Condensation

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Keywords: cold condensation, global scale model, risk assessment, precautionary principle

Introduction

The cold condensation or global distillation of environmental chemicals in low temperature regions leads to selective accumulation first of all in the polar regions *(1.)* In contrast to isotropic long-range transport, which is based on isotropic spatial range and global lifetimes, cold condensation relates to the longitudinal temperature gradient, being an intrinsically anisotropic characteristic of the earth. For some chemicals such as hexachlorobenzene and the PCBs the cold condensation effect gives an important additional, anisotropic contribution to geographical spreading out. As polar ecosystems are particularly vulnerable the cold condensation phenomenon creates a special environmental threat scenario and corresponding filters should be part of precautionary pre-screening, as lined out in the EC's recently concluded STRATA project PrecauPri *(2)*.

For this purpose a minimal assessment model is presented which combines the essential features of the treatment by Scheringer et al.*(3)* with the advantages of a closed analytical solution. As a result this allows for assessing a chemical's cold condensation potential CCP simply by inserting substance-related constants into a closed formula

$$CCP = \frac{e_{2w}}{e_{1w}} = \frac{k}{\underline{k}(T_2)+k}\frac{\alpha(T_2)}{\alpha(T_1)}$$

$$\alpha(T) = \frac{v_a + v_w + v_s}{v_a K_{aw}(T) + v_w + v_s K_{sw}(T)}$$

where e_{2w}/e_{1w} is the ratio of the exposure in the water compartments of the earth's polar and the non-polar region, v_a, v_w, and v_s are the relative unit world volumes of the troposphere, the upper layer of the oceans and the upper layer of soil, respectively. $T_2 = 273$ K is assumed to be the effective temperature of the polar regions, and $T_1 = 298$ of the non-polar regions. k denotes the transfer coefficient between the polar and the non-polar compartment - as an explicitely calculated function of atmospheric mixing times - whereas K_{aw} and K_{sw} are the chemical's air/water and soil/water partition coefficients. $\underline{k}(T)$ is the effective degradation rate constant, depending on temperature T.

As the present approach is an extremely condensed version of the basic model by Scheringer et al. the risks of an aggregation at this level are discussed in two steps: First one has to consider their basic level IV model. This is done in *(3)*. Second one has to examine the additional simplifications. As for the instant equilibrium approximation this has been extensively done in *(4)*. The remaining points are dealt with by direct comparison of the results with those in *(3)*.

Results and discussion

A first inspection of CCP is performed regarding three reference sets of chemicals: one group commonly assumed to exhibit cold condensation, a second group of unsuspected substances and a third set of chemicals of special interest. Technically, the cold condensation effect is based on the temperature dependence of the Henry's law constant and of the effective degradation rate constant, both entering CCP. The data necessary for a sound calculation of these effects are not always available. First of all this applies to $\underline{k}(T_2)$ which had to be replaced with its better known values at standard temparature T_1.

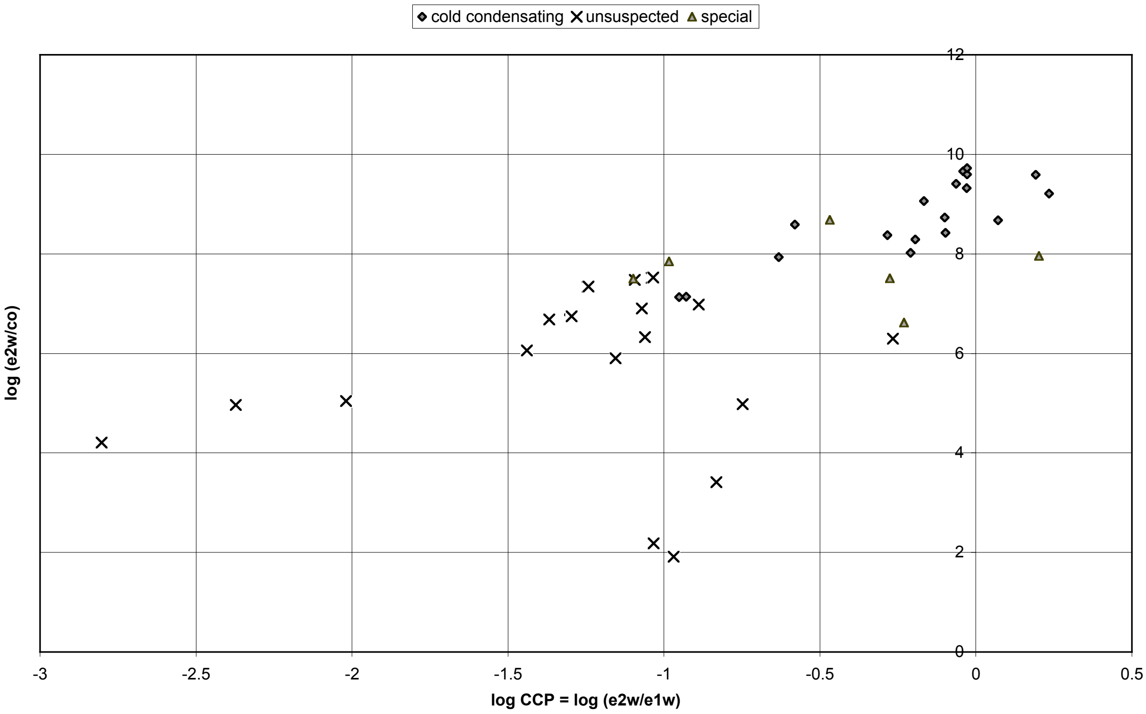

FIGURE 1: Cold condensation potential CCP vs. absolute exposure e_{2w} in the polar compartment (In logarithmic units).

In this approximation already it turns out (i) that CCP separates fairly well between unsuspected chemicals and precarious ones, (ii) reproduces the results of Scheringer et al. for the cold condensation of Mirex, but not of alpha-HCH. (iii) However the result for alpha-HCH is plainly improved if $\underline{k}(T_1)$ is drastically lowered (which mimics its changes with falling T).

Conclusions

Accordingly CCP reproduces essential results of Scheringer et al.'s. much more detailed computer model. The assumption $\underline{k}(T_2) = \underline{k}(T_1)$, however, seems to be an oversimplification. This may impose practical restrictions on a wider use of CCP which, on the other hand, would be a welcome completion in the hazard assessment of new and existing organic chemicals.

References

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1. Wania, F., Mackay, D. *Ambio, 22*, 10–18, 1993..
2. Renn, O. et al Regulatory Strategies and Research Needs to compose and Specify a European Policy on the Application of the Precautionary Principle (PrecauPri), http://www.sussex.ac.uk/spru/environment/precaupripdfs.html
3. Scheringer, M., Wegmann, F., Fenner, K.,and Hungerbühler, K. *Environ. Sci. Technol. 34*, 1842–1850, 2000.
4. Müller-Herold, U. and Nickel, G. *Ecological Modelling, 126*, 191-200, 2000**.**

Chaos in natural and mathematical ecosystems

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Key words: mathematical ecology, non-linear phenomena, chaotic dynamics, structurally unstable models, trophic chains, exergy dynamics

Introduction

The linear world of the mathematical physics of the nineteenth and the early twentieth centuries was harmonious and consistent. Almost the entire evolution of this world proceeded in small neighbourhoods of stable equilibrium where linearisation principle held true. This was a smooth differentiable world, in which there was no room for instabilities, catastrophes, and other inconvenient phenomena. In contrast to many fields of mathematical physics, where linear models have been used very extensively and effectively, mathematical ecology (and mathematical genetics, also) are principally non-linear sciences. The fact is that almost all interactions in ecology, both competitive and trophic, are non-linear.

The problem of choosing an adequate mathematical description in ecology is very acute; physical and chemical ways of descriptions are already exhausted; it is necessary to look for some new non-traditional methods, which can be based on already known mathematical concept and new forms of description and models for ecological realities.

From the mathematical point of view, the first models should be the models of the catastrophe theory. We can hope, that namely the mechanisms with non-linearities of cubic type are responsible for sudden changes of any biological parameter when abiotic parameters are changing continuously, and the task of modeller is to define these critical parameters correctly. Second type of mechanism, which can lead to the formation of discontinuity, is the destruction of some unstable equilibrium under perturbation for the systems possessing a hysteresis effect.

We would like to show that such a non-linear effect as the dynamic chaos exists in the models of mathematical ecology. Nevertheless, the problem how to detect the dynamic chaos in real ecosystems is not yet solved. Of course, we can observe there a similar behaviour, but… the similarity is not a proof. Although from the methodological point of view, this similarity could be interpreted in favour of the application of “chaotic” models as adequate tools to describe some real ecological processes.

In general, the problem to choose an adequate mathematical description is very urgent in ecology. Borrowed from other, more "mathematised" sciences, methods of description have exhausted their potentialities to a considerable extent. It is necessary to look for new unconventional approach that, nevertheless, could rely securely upon the mathematical concepts already known.

Knowledge-based framework for modeling dynamic environmental systems

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Introduction Establishing an acceptable model of an observed system is a challenging task that occupies a major portion of the mathematical modeler's work. It involves observations and measurements of the system behavior under various conditions, selecting a set of system variables that are important for modeling, choosing the modeling formalism, and formulating the model itself. In this paper, we deal with the task of inducing models of dynamic systems based on ordinary differential equations from observed behavior of the selected system variables.

Most of the approaches to modeling are based on one of the following two assumptions — they assume that the structure of the model is provided by a human expert or that the model structure is chosen from some general well-known class of model structures, such as linear equations, polynomials, or neural networks. Modeling based on the first assumption that the structure identification problem is solved by a human expert is known as theoretical or knowledge-driven approach. Following this approach, the expert identifies the processes that govern the behavior of the observed system and based on these writes down a proper structure of the model equations. In contrast to the theoretical approach, the empirical approach adopts a data-driven paradigm, where the expert tries out different model structures in a trial-and-error manner, until an appropriate model structure is found. The second assumption is adopted and a very limited portion (if any) of the domain-specific knowledge is used in the modeling process.

Knowledge-based modeling framework In this paper, we use a modeling framework that integrates the theoretical and empirical approaches to modeling. The framework is based on integration of domain-specific knowledge in the process of inducing models from observational data. The domain-specific knowledge is organized around the central notion of *basic processes* that govern the behavior of the observed system. The basic processes are taxonomically organized in process classes.

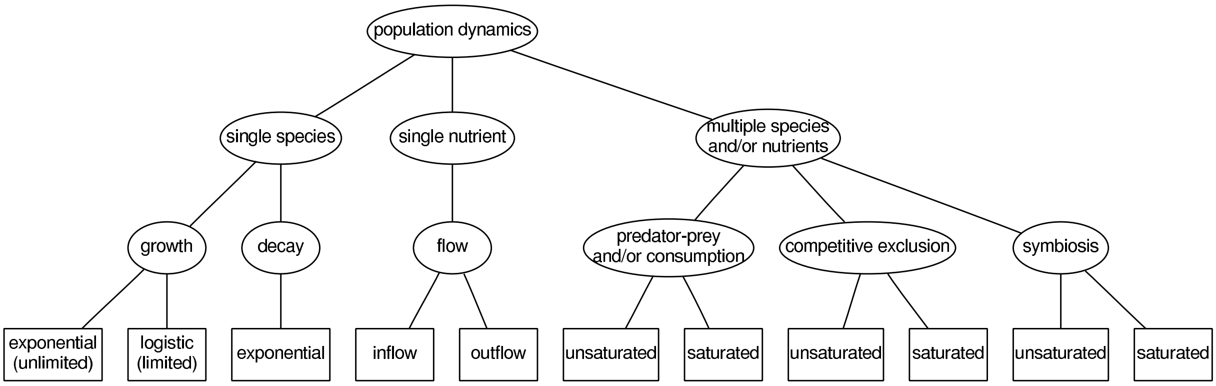

Figure 1: A taxonomy of classes of basic processes in the population dynamics domain.

Figure 1 presents an example taxonomy of basic process classes in the population dynamics domain. On the highest level of the taxonomy, we distinguish between processes that involve single species or inorganic nutrient and processes that represent interactions between two or more species and nutrients. Down the taxonomy tree, the process classes become more specific. For example, there are two kinds of processes that involve a single species: growth of a population or its decay. The leaf nodes in the taxonomy represent particular modeling alternatives typically used by the experts in the domain. For example, the *Exponential_growth* class specifies unlimited exponential growth of the observed population, while the *Logistic_growth* model is more appropriate if the environment has limited carrying capacity for the species. In addition to the taxonomy of basic process classes and models thereof, domain knowledge also contains a combining scheme that specifies how to combine models of individual basic processes into a model of the entire system.

Modeling population dynamics We applied the presented framework for automated modeling to three tasks of modeling environmental dynamic systems from measurement data. The first two tasks are concerned with modeling population dynamics or more specifically algal growth. In both cases, we used the knowledge about basic population dynamics processes presented in Figure 1.

The first task is modeling algal growth in the Lagoon of Venice, which is heavily influenced by anthropogenic inflow of nutrients (nitrogen and phosphorus) that cause excessive growth of algae. The data were sampled weekly for slightly more than one year at four different locations in the Lagoon. The sampled quantities are nitrogen in ammonia, nitrogen in nitrate, phosphorus in orthophosphate, dissolved oxygen, temperature, and algal biomass. The induced model tells us that the limiting factors for the biomass growth are temperature, dissolved oxygen, and nitrogen in ammonia. While the induced model does not fit the measured data perfectly, it correctly predicts most of the peaks and crashes of the biomass concentration.

Second, we address the task of modeling phytoplankton growth in Lake Glumsø (in Denmark), where the inflow of waste water with high concentration of nitrogen and phosphorus caused hypereutrophication. The sampled variables are concentrations of phytoplankton, zooplankton, soluble nitrogen, soluble phosphorus, and water temperature. The induced model identifies phosphorus and water temperature as the main limiting factors for the phytoplankton growth. Furthermore, it provides precise short-term as well as long-term predictions of phytoplankton concentration in the lake. The predictive accuracy of the induced model is better than the accuracy of a black-box linear model.

Population dynamics applications show that our framework is capable of inducing comprehensible dynamic systems' models from real-world measurement data. Our framework performs better than existing modeling approaches on both tasks in terms of performance, flexibility, and comprehensibility of the discovered models.

Modeling hydrodynamics The third task is modeling water level variation in Ringkøbing fjord, a shallow estuary located at the Danish west coast, where it experiences mainly easterly and westerly winds. Wind forcing causes large short term variation of the water level measured at the gate between the estuary and the North Sea. The water level in the fjord responds to the wind forcing, natural and controlled fresh water supply, and the water flow between estuary and open sea that is controlled by opening the gate. The data about the observed variables (wind speed and direction, water levels in the fjord and open sea, and gate opening level) was collected by hourly measurements within the period from 1st of January to 10th of December 1999.

The human experts provided knowledge in terms of partial model structure specification, which include model structure for the processes of natural and controlled fresh water supply as well as the flow of sea water due to the gate opening. The structure of the two remaining parts of the model, sea water flow due to friction and wind forcing, was not specified by human expert. We encoded this kind of knowledge in our framework, by specifying fixed models for the known water inflow and outflow processes and using polynomial models for the processes with unspecified structure.

Given the partial model specification and measured data, we induced a complete model of the water level change in the Ringkøbing fjord. The model can be used to obtain accurate long-term (several months in advance) or short-term (daily or weekly) predictions of the water level. Comparison with the black-box model that does not follow the partial model specification provided by human experts shows that the black-box model overfits the data: while it performs very well on the training data used to induce the model, it fails to provide accurate long-term predictions of the water level in the fjord. Furthermore, the model induced within our framework allows us to compare the influence of different processes on the water level change. The comparison shows that the wind forcing prevails over the gate opening influence most of the time, with an exception that occurs in the period from 80 to 100 days from the beginning of the measurement (the end of March and beginning of April 1999).

In sum, the Ringkøbing fjord experiment shows the capability of our modeling framework to deal with tasks where human experts are able to specify only part of the model structure — they can leave other parts unspecified and use our modeling framework to induce them from measured data.

Large global carbon dioxide model for different landscapes

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Key words: landscape, global CO_2 problem, CO_2 reservoir, carbon flux, greenhouse effect

Introduction

A global carbon dioxide (CO_2) model (Silebi and Schiesser, 1992; Schiesser and Silebi, 1997) is modified to represent different landscapes. The model is a low-order ordinary differential equation (ODE) model for local CO_2 problems (Sellers *et al*., 1997). For each landscape, the Earth's environment is modelled as seven completely mixed reservoirs. Each reservoir is modelled by a single ODE in time that accounts for the fluxes of carbon into and out of the reservoir, and for the accumulation of carbon within the reservoir. Integration of the seven ODEs is performed by a fixed-step, modified Euler integrator. The numerical solution is the carbon concentration in each of the seven reservoirs as a function of time.

Results and discussion

The calculation of the amount of carbon in the seven reservoirs has been carried out from the preindustrial era (1700) to the near future (2005). The variables are carbon in the upper atmosphere (CUA), carbon in the short-lived biota (CSB), carbon in the long-lived biota (CLB), carbon in the lower atmosphere (CLA), carbon in the mixed ocean layer (CML), carbon in the deep sea (CDS) and carbon in the marine biosphere (CMB). The values for carbon in the ocean mixed layer (CML) are superposed to carbon in the upper atmosphere (CUA). Similarly, carbon in the short-lived biota (CSB) and carbon in the deep sea (CDS) appear together.

The most important result in this plot is the exponential rise of the seven carbon reservoirs. Although the exponential trend was not worrying until 1900 as a global problem, the situation has become strongly worsened near year 2000. A particular problem has been the increasing of CO_2 in the lower and upper atmospheres and its expected *greenhouse effect.*

The amount of carbon in the lower atmosphere has been computed for the different landscapes. The order of increasing carbon is forest, rural, coastal, agricultural, standard, terrestrial and urban landscapes. As expected, the rural landscape is intermediate between the forest and agricultural, and the standard landscape is halfway between the rural and urban, and between the coastal and terrestrial landscapes.

The amount of carbon in the upper atmosphere has been calculated for the different landscapes. The order of increasing carbon is the same as for the lower atmosphere.

The relative difference between the urban and forest landscapes has been computed as a function of time for the upper and lower atmospheres. Notice that the values for carbon in the upper atmosphere (CUA) are superposed to carbon in the lower atmosphere (CLA). For both atmospheres, the calculated difference has been 1% *ca.* 1705, 2% *ca.* 1715, 3% *ca.* 1725, 4% *ca.* 1740 and 5% *ca.* 1770.

Conclusions

Provisional conclusions follow.

1. Both advanced development informatic modelling and atmospheric actual measurements exactly agree: in computer modelling, scientifics are allowed to relate the atmosphere to the seas and to other essential elements of the climatic structure of the planet, in order to plan the question of which can be the effects of the CO_2 added. The answers of the computers increasingly corroborate direct observation.
2. During the next decades humankind must face severe restrictions in energy production. Worldly, most part of the energy is produced on the basis of hydrocarbons combustion, and the trend will be to the substitution of the use of fossil fuels with the so-called *renewable energies* (solar, eolic, *etc*.). While other forms of energy production will not be feasible in large scale, man should be accustomed to optimize the existing processes and reduce the use of hydrocarbons.
3. Governments must encourage the public financing of research on technologies of renewable energies that finally will cause the solution that the climatic change obliges.
4. The standard landscape is intermediate between the rural and urban ones and between the terrestrial and coastal ones. On the other hand, the rural landscape is halfway between the forest and agricultural ones.
5. Differences among landscapes appeared in 1700 and have remained almost constant since 1800.

Acknowledgements

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References

Silebi, C. A., and Schiesser, W. E. *Dynamic modeling of transport process systems,* Academic, San Diego, 1992.

Schiesser, W. E., and Silebi, C. A. *Computational transport phenomena*, Cambridge University Press, Cambridge (UK), 1997.

Sellers, P. J., Dickinson, R. E., Randall, D. A., Betts, A. K., Hall, F. G., Berry, J. A., Collatz, G. J., Denning, A. S., Mooney, H. A., Nobre, C. A., Sato, N., Field, C. B., and Henderson-Sellers, A. Modeling the exchanges of energy, water, and carbon between continents and the atmosphere. *Science*, 275:502-509, 1997.

Modelling matter, exergy and emergy flows through ecological and economic systems, within a "zero emission" framework

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Key words: self-organization, emergy, zero emissions

Ecosystems circulate materials, transform energy, support populations, join components in network interactions, organize hierarchies and spatial centers, evolve and replicate information, and maintain structure in pulsing oscillations. The living parts of ecosystems are interconnected, each receiving energy and materials from the other, interacting through feedback mechanisms to self-organize in space, time, and connectivity. Energy drives all these processes and energetic principles explain much of what is observed. As energy flows from driving energy sources to higher and higher order ecosystem components it is transformed from sunlight to plant biomass, to 1st level consumers, to second level and so forth. At each transformation second law losses decrease the available energy but the "quality" of energy remaining is increased. H.T. Odum introduced the concept of emergy in the Eighties, in order to properly account for the quality of matter and energy flows within ecosystems.

Emergy and Transformity

Emergy accounts for the environmental services supporting a process as well as for their convergence through a chain of energy and matter transformations in both space and time (Odum, 1988). By definition, emergy is the amount of available energy (exergy) of one type (usually solar) that is directly or indirectly required to provide a given flow or storage of energy or matter. The units of solar emergy are solar emjoules (abbreviated seJ) to distinguish them from energy joules (abbreviated J). When the emergy required to make something is expressed as a ratio to the available energy of the product, the resulting ratio is called (solar) transformity and is expressed in solar emergy joules per joule of output flow (seJ/J).

The total emergy driving a process becomes a measure of the self-organization activity of the surrounding environment, converging to make that process possible. The transformity which is a ratio of the emergy input to the available energy output is an expression of quality of the output energy; for the higher the transformity, the more emergy used required to make it. For example, the organic matter in forest soil represents the convergence of solar energy, rain, and winds driving the work processes of the forest over many years that has resulted in layer upon layer of detritus that ever so slowly decomposes into a storage of soil organic matter.

Hierarchies and Material cycles

Material cycles in systems of the biosphere are part of the processing of energy transformations. There are cycles of the chemical elements, water, sediments, and waste products of society. Recycle is a part of all systems, from the scale of long term geologic cycles to the scale of ecosystems where nutrients and organic matter are recycled in relatively short term storages of plant and animal tissue. Material recycling is another way that processes are mutually reinforcing. Increasingly materials used by human economic systems are being recycled better as economic systems get better organized. Humans manage material cycles through the environment as part of municipal utilities and industrial ecology. Transformity of a material may be a good indicator of the appropriate part of the hearth hierarchy for its use and recycle. Similarly, hierarchical levels can be indicated by different values of the related transformities. Matching of transformities so that a material can amplify indicates an appropriate zone of the energy hierarchy for interactions. For example, it may be economic for concentrated metals and chemicals to be reused, whereas dilute organic materials and nutrients are appropriately recycled through the environment at concentrations usable by the ecosystems.

Maximum Empower Principle and Zero Emission Patterns

Ecosystems recycle every kind of waste. The by-products and waste material from one component or compartment become a useful resource for another component or compartment. Ecosystems self-organize in order to maximize the total product (e.g., biomass) by optimizing the resource throughput, according to Lotka's Maximum Power Principle (1922), restated by Odum as Maximum Empower Principle (1995). Self-organization for maximum empower ensures that all available resources are utilized to the maximum possible extent and no unused resources are left. Human dominated ecosystem could be reorganized according to the same principle, for zero emissions. The Zero Emission concept "represents a shift from the traditional industrial model in which wastes are considered the norm, to integrated systems in which everything has its use. It advocates an industrial transformation whereby businesses emulate the sustainable cycles found in nature and where society minimizes the load it imposes on the natural resource base and learns to do more with what the earth produces." (ZEF, 1999)

Comparing ecological and economic systems

In this paper, we draw a parallel between ecosystems without humans (100% driven by solar energy) and economic systems (also driven in the past by solar energy, but mostly supported by fossil fuels in the present stage of civilization). Matter and exergy flows in typical ecological and economic systems are quantified and the emergy supporting their growth calculated. Transformities of each hierarchical level and component are also calculated in order to provide a quantitative quality assessment of product and feedback flows. Applying maximum empower constraints to economic systems makes them more similar to ecological systems, within a zero emission framework (increased complexity, maximum emergy throughput, minimization of emissions). Case studies from the food chain in ecosystems, with detritus mineralization and recycle, are evaluated by means of matter, exergy and emergy analyses. Results and characteristics are then compared with those provided by an LCA and emergy evaluation of a combined cycle power plant for electricity and district heating cogeneration, with maximum reuse of co-products (ashes, sulphur) and recycle of reusable machinery and assets.

Pre-requisites for sustainable patterns in economic systems are stressed and suggestions for increased integration of human dominated systems and ecological systems are provided, based on maximum empower constraints and zero emission requirements.

References

Lotka A.J., 1922. Contribution to the energetics of evolution. Natural selection as a Physical Principle. Proceedings of the National Academy of Sciences, U.S., 9: 169-177.

Odum H.T., 1988: Self-Organization, Transformity, and Information. Science 263: 1243-1260.

Odum, H.T., 1995. Self-organization and maximum power. Chapter 28, pp. 311-364 in Maximum Power, Ed. by C.A.S. Hall, University Press of Colorado, Niwot.

ZEF, Zero Emission Forum, United Nations University, 1999. www.unu.edu/zef/

Comparative Environ Analysis of a Seven-Compartment Model of Nitrogen Flow in the Neuse River Estuary: Time Series Analysis

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Key words: **environ analysis, networks, nitrogen, estuary, seasonal comparisons**

Introduction

Network environ analysis is motivated by a desire to investigate ecosystems from a holistic perspective. It provides a quantitative measure of the integral (direct plus indirect) relationship between compartments and their within-system environments. In this analysis, each compartment has an incoming interactive network that brings matter to it from boundary inputs, and an outgoing network that takes matter from it to boundary outputs. These are, respectively, input and output environs (Patten, 1978; Matis & Patten, 1981). One limitation of traditional environ analysis is that networks under analysis must be static. However, ecologists would like to build insight about dynamic ecosystems. The approach used in this presentation is comparison of environ time series. The Neuse River estuary is an ideal subject because a time series of steady state networks has been created. Objectives of the current work are to describe the methodology for comparative environ analysis and present results from analysis of the Neuse River estuary. Two levels of analysis are employed. The first is macro-level analysis of whole environs; total environ throughflow, an index of whole-environ activity, is computed and compared between environs and with total system throughflow. The second is micro-level analysis which involves the individual intercompartmental flow, boundary input, and boundary output elements of the input and output environs for two focal compartments, heterotrophs (x_2-PN/Hetero) and nitrate/nitrite (x_5-NO_x), in the Neuse models. Sixteen seasonal networks of the Neuse River estuary were constructed for the period spring 1985 through winter 1989 by R. R. Christian and colleagues (Christian & Thomas, 2003). Details of the construction of these models and their ecological context are given in the ECEM Bled Conference Paper: Gattie, D.K. et al. 2004. Environ Analysis of a Seven-Compartment Model of Nitrogen Flow in the Neuse River Estuary: The Static Case. Environ theory and computation methods are described in the ECEM Bled Conference Paper: Patten, B.C. et al. 2004. Environs and Network Environ Analysis: Introduction and Overview. For the macro- and micro-analysis levels, three types of temporal comparisons are made: same season between years (e.g. Fall 85 vs. Fall 86) ; between adjacent seasons (e.g. Spring 86 vs. Summer 86); and, four-season patterns between years (e.g. Spring 85 – Winter 85 vs. Spring 86 – Winter 86).

Results and discussion

Of the many possible macro- and micro-scale analyses conducted, one example of the macro scale patterns of the environ time series will be given. The seasonal pattern of total environ throughflow compared to seasonal pattern of total system throughflow for steady state networks is shown in Figure 1; in this figure the values for each environ TET time series or the steady state TST time series are expressed on a percent basis with the largest value for each time series used as the 100% value. This transformation is used to produce a set of distributions that may be compared for differences in central tendency, variance, and shape using the Kolmogorov-Smirnov and Cramer-von Mises two sample tests. The time series distributions of TET for environs 1 (PN-Phyto) and 3 (Sed) are shown to be significantly different from the time series distribution of TST for the steady state networks. The time series distribution of TET for environs 6 (NH_4) and 7 (PN-Abiotic) are shown to be marginally significantly different from the time series distribution of TST for the steady state networks. None of the other environ TET patterns showed significant differences when compared to the TST steady state network pattern.

Time Series of Total Environ Throughflow for Output Environ Analysis of Neuse River Estuary Networks Expressed as a Percent of the Largest Value for each Environ or TST sequence

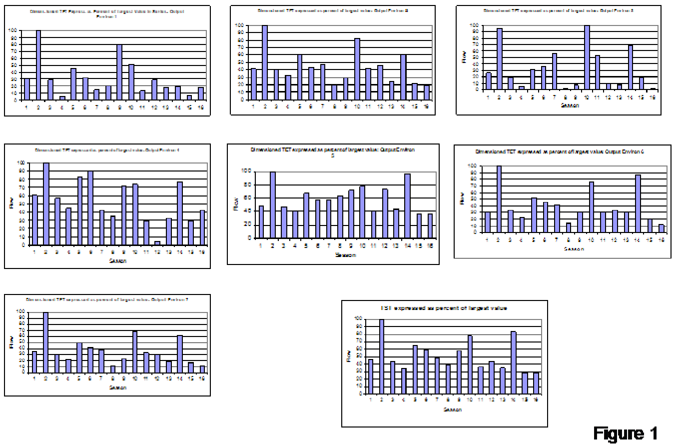

Figure 1

Conclusions

The macro-scale result presented demonstrates that the use of environ analysis as an 'analytical tracer' provides a means to tease out the differences created by parsing the within system environment of each compartment away from the total system and comparing the throughflow patterns generated by such analysis. In this case output environs for compartments PN-Phytoplankton (x_1) and Sediment (x_3) are found to generate TET time series distributions that are significantly different from the TST time series distribution. Since these two compartments are quite different in their model definition, connections within the system, and stock and throughflow characteristics in the steady state networks, there is no a priori means to determine that their environ TET patterns would both be different from the TST steady state pattern. Only environ analysis of the 16 model time series could reveal this.

References

Christian, R. R., and C. R. Thomas. 2003. Network analysis of nitrogen inputs and cycling in the Neuse River estuary, North Carolina, USA. Estuaries **26**:815-826.

Matis, J. H., and B. C. Patten. 1981. Environ analysis of linear compartmental systems: the static, time invariant case. Bulletin of the International Statistical Institute **48**:527-565.

Patten, B. C. 1978. Systems approach to the concept of the environment. Ohio Journal of Science **78**:206-222.

Integrating the fuzzy analytic hierarchy process with dynamic programming approach for determining the optimal forest management decisions

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Key words: forest management, decision support model, dynamic programming, analytic hierarchy process, fuzziness

Introduction

The problem of forest management involves decisions on how to schedule investment, silvicultural and harvesting activities for an existing forestland over a long time horizon, while guaranteeing sustainability, maximizing the expected profit, referring to ecological objectives, and respecting the public's acceptance of decisions. Consequently, the decision-maker in forestry is challenged with a long term, dynamic, ill-defined, multi-objective problem, which has precipitated the development of several decision support models. The presented fuzzy, dynamic and multi-objective model for optimal forest management, is able to determine the sequence of decisions, that jointly maximizes economic, ecological and social objectives subject to prescribed constraints, takes the forest system from its existing state to the goal state, and respects imprecision and public's acceptance.

Results and discussion

In the model, the forest management process is defined in the framework of a discrete deterministic dynamic programming of Bellman's type, i.e., in terms of time periods, states, decisions, and objectives (Zadnik Stirn, 1990). Because the state of the forest is also described with subjective and uncertain variables and value judgments we use for these uncertainties and imprecision fuzzy variables to develop the current and new (transitional and goal) states of a managed forest. How to manage the current state towards the goal state is another problem in which each feasible decision results in a new forest state, determined empirically by a transition function (Zadnik Stirn, 1990), and in a set of possible outcomes, specified by management objectives, which are also not identified with certainty. Thus, the idea of fuzzy analytic hierarchy process (Saaty, 1994) is introduced within a discrete dynamic programming process to evaluate the conflicting objectives. Analytic hierarchy process can accommodate multiple experts, as well as the public, i.e., various representative groups who benefit from the amenity value of the forest. Further, it can incorporate mixed data that may include both qualitative and quantitative judgments, and is capable of analyzing multiple factors, both individually and collectively. The objectives result in a composite utility value of a forest management decision. They are presented in a hierarchical structure and the composite utility value is developed in a two-step process. The hierarchy of objectives is organized around the concepts of objectives and attributes (Schmoldt et al., 2001).

In the first step, analysis is done at the objective level, at which each objective is defined by appropriate attributes, which are modeled as fuzzy variables, to estimate the cumulative impacts of attributes on the forest management decision according to the existing forest state. The cumulative impacts are formulated as a sum over all products of attribute's membership function (Zimmermann, 1987) and its relative importance (weight). The weights are calculated on the pairwise comparisons of the attributes following the analytic hierarchy process. They are normalized and scaled between 0 and 1. The membership function, also with the values between 0 and 1, reflects varying degrees of favourability to the attribute we deal with. At the second level, the cumulative impacts of objectives are measured. The experts and public again provide opinions, through pairwise comparisons, for the elements at this level. The composite utility value is then calculated by combining the values from both levels.

As soon as the composite utility values for each possible state transition under the feasible forest management decisions are defined, the problem is considered as a discrete and dynamic problem, which is presented in a form of a network. Finally, the optimal policy, the one that maximizes the sum of composite utility values over all time periods, is determined using the value-iteration and policy-iteration method for the solution of sequential decision processes of Bellman's type.

Conclusions

To demonstrate this approach, a case study involving a forest located in Panovec, Slovenia (Papež, 2001) was used. The assessments were based on the evaluation of experts, stakeholders and residents (Zadnik Stirn, 2004). This group decision making feature of the model promotes participative and collective involvement of various groups, and enhances the acceptability of any assessment made. Thus, private owners, institutions or enterprises in charge of sustainable forest management under uncertainty, should use the model as a decision support system.

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References

Papež, J. *Panovec*. Občina Nova Gorica in Zavod za gozdove, Območna enota Tolmin, Nova Gorica, 199 pp., 2001.

Saaty, T.L. *Fundamentals of Decision Making and Priority Theory.* RWS Publications, Pittsburgh, 527 pp., 1994.

Schmoldt, D.L., Kangas, J., Mendoza, G.A., and Personen, M. *The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making.* Kluwer, Dordrecht, 305 pp., 2001.

Zadnik Stirn, L. Adaptive Dynamic Model for Optimal Forest Management. *Forest Ecology and Management,* 31:167-188, 1990.

Zadnik Stirn, L. *MEDMONT WP 9.2.* University of Ljubljana, Ljubljana, 217 pp., 2004.

Zimmermann, H.J. *Fuzzy Sets, Decision Making and Expert Systems*. Kluwer, Boston, 335 pp., 1987.

Model of influence of reservoir shape on processes of self-cleaning

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Key words: mathematical model, reservoir water, shallow areas, channel shape, ecological status

Introduction

The self-cleaning of a water reservoir is a combination of biological, chemical and physical processes that restore the initial properties and quality of water. Descriptions of self-cleaning processes of water bodies commonly use mathematical macro-models in which basic system variables are the concentration of dissolved oxygen and the biological consumption of oxygen (Bek, 1981; Streeter et al., 1925). Some studies model biological processes in river and lake ecosystems with a constant level of water, however a reservoir ecosystem represents interactions among live organisms, variable water conditions, and channel properties (Chernyaev, 1999).

Results and discussion

Water volume and channel shape are abiotic components of a reservoir ecosystem, and their changes influence the biotic components of the ecosystem. The change of water level alters the volume of the photosynthetic aeration zone and the area of shallow water where biological activity is highest, thereby influencing the processes of reservoir self-cleaning. The concentration of organic substances, in terms of BOD5, and deficiency of oxygen are influenced by the shape of the reservoir channel and the water level. Four shapes were considered a) channel with steep shores without islands (“box”); b) channel with gently sloping shores without islands (“prism”); c) channel with gently sloping shores and islands (“cone”); and d) channel with wide shallow, submerged terrace (“terrace”).

Conclusions

We show that the equilibrium values of organic substances and dissolved oxygen are primarily defined by shallow places in a reservoir. As changes of water level occur increases and decreases of organic substances and dissolved oxygen depend on channel shape and may be in opposite to each other. For example, in our simulations for a "cone" shaped channel, a reduction of a water level in reservoir of one meter resulted in a 20% increase of organic substance and a 17% decrease of dissolved oxygen.

The results of this model are quite good for a reservoir with good mixing of water. In our opinion when ecological consequences are considered in the design and construction of hydraulic engineering projects on a reservoir, it is important to take into account the influence of channel geomorphology on the processes of reservoir self-clearing as water levels change.

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References

Bek, M. B. Modelling of a content of the dissolved oxygen on a part of the river far from a mouth. *In book: Jams, A. (ed.). Mathematical models of monitoring of water contamination*. (Rus). Moscow: World, 165-200, 1981.

Streeter, H. W., and Phelps, E. B. A study of the pollution and natural purification of the Ohio river. *US Publ. Health Service Bull*., 146:1-75, 1925.

Chernyaev, A. M.(ed.). *Russia: ecosystem's control of water usage.* (Rus). Ekaterinburg: AeroSpace Ecology, 1999.

PA/SA FOR A LILW REPOSITORY IN SLOVENIA - MODELING OF INFLUENCE

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ABSTRACT

Simultaneously with the site selection process the preliminary assessment of the influence of the specific disposal concept on the environment and on the population were developed. The performance assessment team, organized in 1997 by national agency for radwaste management - ARAO, prepared several basic studies in order to clarify the objectives of the performance and safety assessment (PA/SA) procedure: the assessment context, the input parameters for the assessment and the timeframes for the assessment. These studies were followed by research on radionuclide influence on the different materials which compose waste form and migration processes through engineered barriers and geological surroundings, together with their time dependence.

In 1999 the first preliminary performance assessment of two safety cases (surface and underground) for generic site location for a LILW repository was performed. In this approach the recommendations of the International Atomic Energy Agency (IAEA) project entitled Improvement of the Safety Assessment Methodology for Near-surface Disposal Facilities (ISAM) were implemented on the Slovenian safety case. All required data and descriptions of generic location, waste, disposal system and assessment context, were prepared for two disposal concepts/siting options. Calculations, based on the AMBER computer code, were applied at that stage. The results were optimistic and sufficiently accurate for the purpose of this first assessment.

In the year 2000 activities on PA/SA analyses continued. A systematic, generic list of all possible features, events and processes (FEP list) predictable for surface or underground LILW disposal in Slovenia was prepared. Recommended and selected were the most reliable scenarios with conceptual models for LILW disposal in normal and altered evolution conditions. All key elements of the PA/SA model (assessment context, disposal system with radioactive waste identification, scenarios generation, conceptual and mathematical models identification) were defined for surface and underground repositories having in mind the purpose of the assessment which has been limited to the site/disposal concept selection phase, and restrictions resulting from that stage. The characteristics of the individual disposal system were taken from the already prepared basic conceptual designs for both a surface and an underground repository. New verification of the proposed conceptual models started in 2001 with more powerful and accurate models for the surface and underground repository. The location was still unknown, but the assessment was narrowed down to two most probable combinations of geological environment and type of disposal facility: to a surface repository above an aquifer and an underground repository in a plastic rock with low permeability. Increasingly detailed calculations continued throughout 2002 and finished with a thorough deterministic analysis of the whole disposal system by mid 2003.

The consequences of different scenarios were analysed by modelling. This step required the construction of a conceptual and mathematical model for each situation predicted by the scenarios. Detailed simulations of the processes taking place inside particular parts of the repository system were therefore considered. Modelling of the whole disposal system, together with its environment, was divided into three subsystems:

1. near field, or the repository itself with its engineered barriers and its close surroundings, where radioactive isotopes migrate through engineered barriers by advection and diffusion,
2. far field or geosphere, which accounts for the processes taking place from close surroundings of the repository to its juncture with the biosphere; the hydraulic and geochemical conditions of the natural barriers define migration of the radioisotopes, and
3. biosphere - where all different pathways from the groundwater to human population (water pumping, crops irrigation, animal and fish consumption) were taken into consideration.

On the basis of numerical models, developed for the near-field and for the geosphere the calculations of radionuclide transport were performed by means of selected and powerful computer codes. The following computer codes were used:

1. for the near field calculations the PORFLOW [7] and HYDRUS 1D and 2D codes were used, giving the flow paths and the transport time as well as the radionuclide concentrations leaving the near field,
2. for the geosphere calculations, the GMS computer code [8] was applied, first for the hydraulic field calculations and later on for particle tracking and transport calculations for the radionuclides entering the geosphere through the near field;
3. For the biosphere calcualtions, the AMBER code [5] helped us to evaluate the different paths of radionuclides through the biosphere. The starting point for these calculations was the surface water or the ground water (well scenario) radionuclide concentrations, and the ending point was the dose to a member of the critical group.

The performance assessment for the two disposal concepts was prepared on the basis of performed studies for the planned LILW repository, foreign practice and international recommendations. The results of both generic cases for the normal evolution scenarios showed that there is a negligible dose influence on a member of the critical population due to the migration of radionuclides from the planned LILW repository. The evaluation of the non-radiological influence of the repository can be also assessed with this methodology in order to prepare the Environmental Impact Report as part of the EIA process. The methods and approaches used by ARAO and its project team will be presented in the paper.

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