Workshop materials 8 – 10 of August 2017

Modeling regime shifts in ecosystems

TerMARisk

Multidisciplinary approach to anticipate critical regime shifts in ecosystems - deriving management guidance for terrestrial and marine systems at risk

V.V. DOKUCHAEV SOIL SCIENCE INSTITUTE

MODELING REGIME SHIFTS IN ECOSYSTEMS

International workshop of TerMARisk project held on 8-10 of August 2017, Moscow

Workshop materials of the Project «A multidisciplinary approach to anticipate critical regime shifts in ecosystems — deriving management guidance for terrestrial and marine systems at risk (TerMARisk)» funded by NordForsk for Nordic-Russian collaboration activities between the Interdisciplinary Laboratory for Mathematical Modeling of Soil Systems (V. V. Dokuchaev Soil Science Institute) and the Center for Ecological and Evolutionary Synthesis (University of Oslo). Recent advances in ecosystem modeling are discussed on the basis of the Project's modeling systems: Atlantic cod population (marine system) and soil (terrestrial system), with emphasis on spatial-temporal patterns in biological activity and anticipation of its critical regime shifts. The goal is to derive methods for estimating the risk of a preceding shift and according (optimal) management strategies.

TerMARisk

Multidisciplinary approach to anticipate critical regime shifts in ecosystems - deriving management guidance for terrestrial and marine systems at risk

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University of Oslo

Annotation
To predict critical (bifunctional) regime shifts in ecosystems functioning, a mathematical model containing driving mechanisms and feedbacks, capable of reproducing nonlinear behavior of a system with external forcing (climatic and anthropogenic) is needed. For analysis of a complex system an integral characteristic that describes system as a whole is needed, being modeled in feedbacks with physical-chemical environmental conditions. Whereas, in case of intensive anthropogenic pressure or hazards, effects of which are not formalized, the dynamic model requires input of the forced parameters from monitoring data.

While statistical early warning signals on time-series derived from historic observations or experimental data are limited in their applicability and work only in hindsight, analyses of modeled time-series at a wide spectrum of external forcing scenarios may allow the development of an early warning system for anticipating critical regime shifts and adjusting accordingly management.

Аннотация
Для раннего обнаружения критических (бифуркационных) изменений в режиме функционирования экосистем с целью их учета или предотвращения последствий, необходима математическая модель учитывающая ведущие механизмы и обратные связи, способная воспроизводить нелинейное поведение системы при изменении внешних факторов среды (климатических или антропогенных). При исследовании сложных систем важно найти такой интегральный биологический показатель, который отражал бы состояние всей системы целиком, моделируемый в обратной связи с физико-химическими условиями среды. При этом, в случае интенсивной антропогенной нагрузки или катастроф для динамической модели необходимы входные мониторинговые данные изменяемых показателей.

В то время как статистические сигналы раннего обнаружения, разработанные на экспериментальных данных, имеют ограничения и работают только в историческом диапазоне, анализ временных серий получаемых из динамических моделей при большом разнообразии внешних сценариев может позволить разработать систему раннего обнаружения признаков критических изменений в экосистемах и выработки рекомендаций для планирования хозяйственной деятельности.

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About TerMARisk (proposal)

Key goals: Develop novel tools that inform management to anticipate ecosystem collapse, strengthen Nordic-Russian partnership of educational and research institutes started with GreenMAR project (Green growth based on Marine Resources), foster multidisciplinary science, career-building of early- and mid-career female scientists.

Key participants: The interdisciplinary Nordic research team of GreenMAR (Nordic participant), Interdisciplinary Laboratory for Mathematical Modeling of Soil Systems at Dokuchaev Soil Science Institute (ILMMSS, Russian participant I), Computational Mathematics and Cybernetics faculty at Lomonosov Moscow State University (MSU CMC, Russian participant II)

Main content of cooperation

Anthropogenic stress has increased the global risk of abrupt ecological regime shifts. Anticipating ecosystem collapse to ensure long-term sustainable natural resource use and ecosystem's functionality is one of today's major challenges. The goal is to jointly develop a novel approach for anticipating critical shifts of ecosystems and guidance for management. We complement GreenMAR's fruitful partnership with its Russian collaborator, the Computational Mathematics and Cybernetics faculty (CMC) at Lomonosov Moscow State University (MSU), by involving researchers from the Interdisciplinary Laboratory for Mathematical Modeling of Soil Systems (ILMMSS) at Dokuchaev Soil Science Institute and young academics at MSU. We propose to build a network of young (mostly female) researchers working on the interface of biology, economics, mathematics and physics. We aim at a long-lasting Nordic-Russian partnership and contribution to GreenMAR's goal of establishing a new generation of multidisciplinary skilled scientists by proposing:

- Joint cross-disciplinary research resulting in at least three collaborative scientific publications
- Researcher workshop to interact with top-level scientists in the field
- A series of lectures taught for students and young scientists at MSU
- Researcher mobility to ensure true collaboration between different disciplines and cultures

Importance of the cooperation

Growing harvesting pressure together with imminent climatic changes has increased the risk of abrupt regime shifts in ecosystems with important ecological and economic consequences[1]. Anticipating collapse to ensure long-term sustainable natural resource use is a major challenge for science and society, but its success is mainly limited to modeling studies and theoretical concepts[2]. It is needed to develop the necessary decision support tools that help identifying threats and risk of regime shifts in advance and allow for appropriate action before a critical regime shift occurs. This proposal unites ecological, economic, mathematical and physical expertise for a novel, multidisciplinary approach of regime shift anticipation. The proposed methodology will allow identification of key drivers of ecosystem changes, which guides the development of models and direct efforts of data monitoring programs. Ultimately, this project delivers insights that help identifying tipping points and provide the needed knowledge towards ecosystem based management. By linking ecosystem state analysis with control theory, we can evaluate and propose different management strategies dependent on the ecosystem's state and potential future scenarios such as climatic changes. We take fisheries management in the Arctic region as a study system which is a region of

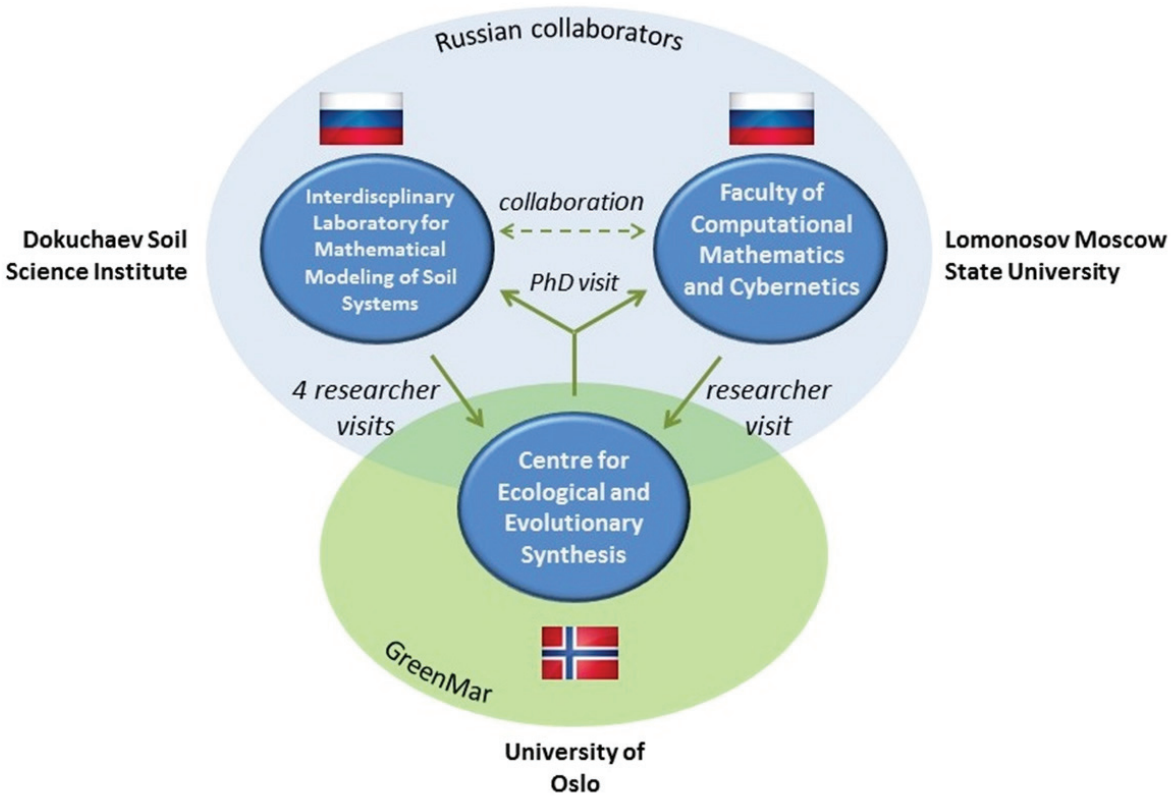
[1] *Richter, A., Dakos, V. «Profit fluctuations signal eroding resilience of natural resources», Ecological Economics, Volume 117 (2015): 12–21*

[2] *Scheffer, M., Carpenter S. et. al. «Catastrophic shifts in ecosystems», Nature, Volume 413 (2011): 591–596*

interest both for Nordic countries and Russia. The Arctic region is especially vulnerable to critical regime shifts, both in marine and terrestrial systems (permafrost soils). Besides addressing a scientific research gap, this proposal establishes long-lasting international cooperation between Russian and Nordic researchers. All key researchers are early and mid-career females, which is remarkable given the field of study. This proposal therefore fosters interdisciplinary research and promotion of female research activities. To achieve our ambitious goals, we put a strong focus on researcher mobility and networking to facilitate collaboration between scientists of different disciplines, professional level and working environment.

Participating institutes

The interdisciplinary Nordic research team of GreenMAR consists of mainly the Centre for Ecological and Evolutionary Synthesis, the Interdisciplinary Laboratory for Mathematical Modeling of Soil Systems and the Faculty of Computational Mathematics and Cybernetics at Moscow State University.



The Centre for Ecological and Evolutionary Synthesis (CEES) at University of Oslo

The CEES was established as a Norwegian Centre of Excellence (CoE) in 2007. It is based at the Department of Biosciences, University of Oslo, and is chaired by Professor Nils Chr. Stenseth. The CoE funding from the Research Council of Norway constitutes approximately 1/10 of the total budget. CEES combines a broad spectrum of disciplines from population biology, statistical and mathematical modelling to genomics. CEES fosters the concept of ecology as a driving force of evolution via selective processes, with a corresponding influence of evolutionary changes on ecology. CEES consists of over 160 members (including Core staff, Postdocs and researchers, PhDs, research assistants, technical and administrative staff, and Master's students) and represents over

30 nationalities. Prof. Nils Christian Stenseth, Dr. Andries Peter Richter, Dr. Anne Maria Eikeset and Anna-Marie Winter are the researchers involved at CEES in TerMARisk.

Interdisciplinary Laboratory for Mathematical Modeling of Soil Systems at V. V. Dokuchaev Soil Science Institute

The Dokuchaev Soil Science Institute is leader in Russian soil science and employer of highly skilled mathematical modelers. ILMMSS is a newly established in 2016 multidisciplinary research group of theoretical physicists, mathematicians and biologists. Principle mission of the laboratory is to develop mathematical modeling of soils as complex systems, and also algorithms for collecting and handling monitoring data of soil properties. . Studied are optimal agrophysical regimes, capable of maximal increase in soil fertility without danger of degradation. Various soil regimes numerical simulations basing on regulation of microprocess dynamics are carried out. Dr. Nadezda Vasilyeva, head of ILMMSS, Dr. Artem Vladimirov, senior researcher and Maria Zaitseva, junior researcher at ILMMSS are the main researchers involved in TerMARisk.

Faculty of Computational Mathematics and Cybernetics at MSU

GreenMAR has a highly successful educational collaboration with the Faculty of Computational Mathematics and Cybernetics (CMC) which led to the successful organization of The Moscow Summer Academy (MSA) on Economic Growth and Governance of Natural Resources in 2015. The initiative of TerMaRisk is a direct result of scientific interactions between GreenMAR and Russian scientists taking place during MSA. CMC is a leading Russian educational center with strong expertise in various fields of applied mathematics. The collaboration addresses particularly the department of Optimal Control (OC). Working on the intersection of ecosystem analysis and control theory and organizing a lecture series for young students at MSU, Dr. Luidmila Artemyeva and Dr. Elena Rovenskaya are the involved key researcher of CMC.

Mathematical modeling framework for developing early-warning system of critical regime shifts in terrestrial and marine ecosystems (TerMARisk)

Changes in marine and terrestrial ecosystems in productivity, behavioural and life-history traits, stock levels, environment fertility factors, turnover rates and food web structure may result from either natural evolution directed by global climate change, or as a result of anthropogenic pressure (harvesting, changing physical and chemical properties of the environment/habitat). These changes may lead to a regime shift undergoing abruptly from one stable state to another through unstable states and thus are impossible to predict with regressions or linear dynamical models obtained from harvesting and monitoring data. Prediction, prevention or accounting for consequences of such regime shifts on population size, productivity, harvest or carbon dioxide fluxes, despite vast studies in the past remains actual problem. Considering possibilities of obtaining continuous monitoring data with modern instruments it can be taken up to a new level of solution using multiscale mathematical modeling of nonlinear systems, bifurcation analysis, dynamic scaling and other approaches[3][4]. It is well known that in nonlinear systems prediction depends on correct capturing of the driving processes and feedbacks that result in complex dynamics unpredictable by statistical

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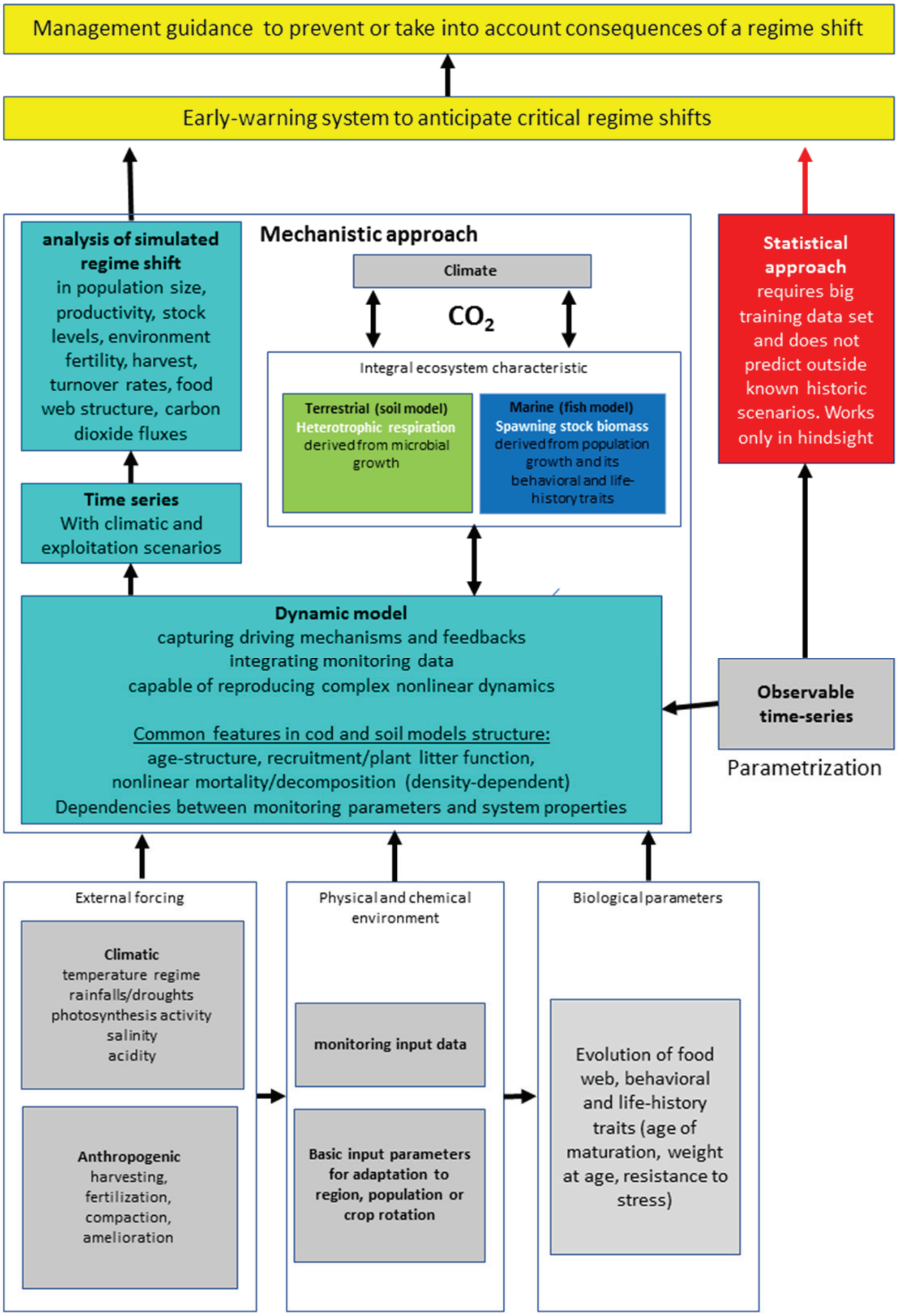
[3] *A. M. Tarquis, J. L. M. P. de Lima, W. F. Krajewski, Q. Cheng, and H. Gaonac'h. Nonlin. Processes Geophys., 18, 899–902, https://doi.org/10.5194/npg-18-899-2011, 2011*

[4] *BL Li. Why is the holistic approach becoming so important in landscape ecology? Landscape and Urban Planning 50 (1), 27–41, 2000.*

methods that require big learning data sets and still are capable to perform correctly only in the region of parameters that are covered in the training dataset (usually for ecosystems data are available for a very limited combinations of factors). Therefore, modeling macroscopic integral ecosystem characteristics for the purpose of anticipating ecosystem regime shifts requires understanding and modeling underlying processes at microscale. Studying complex systems implies finding of such an integral characteristic that would reflect the system state as a whole and would be sensitive to critical changes in all of its most important components. We consider in this context marine and terrestrial ecosystems interacting through the atmospheric carbon dioxide balance that is in both in feedback with climatic factors altering acidity of water, temperature and photosynthetic activity, productivity, turnover rates, environmental properties. As example of terrestrial ecosystem we use a soil model and as an example of a marine ecosystem — a model of North Sea Atlantic cod. The models are developed in parallel, effectively and beneficially exchanging modelling approaches and help developing early warning system to anticipate general ecosystems signals of regime shifts.


Management guidance to prevent or take into account consequences of a regime shift
Early-warning system to anticipate critical regime shifts
analysis of simulated regime shift in population size, productivity, stock levels, environment fertility, harvest, turnover rates, food web structure, carbon dioxide fluxes
Mechanistic approach
Climate
CO2
Integral ecosystem characteristic
Terrestrial (soil model) Heterotrophic respiration derived from microbial growth
Marine (fish model) Spawning stock biomass derived from population growth and its behavioral and life-history traits
Statistical approach requires big training data set and does not predict outside known historic scenarios. Works only in hindsight
Time series With climatic and exploitation scenarios
Dynamic model capturing driving mechanisms and feedbacks integrating monitoring data capable of reproducing complex nonlinear dynamics
Common features in cod and soil models structure: age-structure, recruitment/plant litter function, nonlinear mortality/decomposition (density-dependent) Dependencies between monitoring parameters and system properties
Observable time-series
Parametrization
External forcing
Climatic temperature regime rainfalls/droughts photosynthesis activity salinity acidity
Anthropogenic harvesting, fertilization, compaction, amelioration
Physical and chemical environment
monitoring input data
Basic input parameters for adaptation to region, population or crop rotation
Biological parameters
Evolution of food web, behavioral and life-history traits (age of maturation, weight at age, resistance to stress)

Terrestrial part: Soil

Soil heterotrophic respiration, i.e. carbon dioxide flux evolving as a result of respiration process/organic matter decomposition/transformation by microorganisms can be taken as an integral characteristic of soil state and its functioning. Activity and composition of soil microbial community is related to substrates chemical structure, its physical state (dispersiveness, strength of adsorption onto mineral particles, occlusion/physical inaccessibility for microbes) and physical and chemical properties of soil environment (bulk density, soil pore space configuration, pore-size distribution of water and gases, soil water potential/availability, cation exchange capacity, presence of nutrient elements in dissolved forms, acidity, redox potential, intensity of root exudates inflow). Attempts appear to scale up from modeling microscopic processes that take place on soil phase boundaries and are related to biological respiration activity and organic matter transformations to obtaining global dependencies for carbon dioxide fluxes with climatic scenarios[5].

In agricultural ecosystems state and direction of soil processes depend not only on climate change, but even more on anthropogenic pressure for soil fertility (influencing productivity). Then physical and chemical characteristics are not naturally interdependent with microbial growth but change faster than in natural environment due to human manipulations (tillage and multiple wheel pressure, irrigation, fertilization and chemical amelioration). In this case microbial community is not anymore driving soil processes but rather adapting to rapidly changing conditions and in the best case counteracts — recovering conditions to optimal for vegetation. And in this case the dynamics of soil physical-chemical properties may serve an indicator for rates and directions of ongoing processes that change fertility factors under a certain used farming system. For example, organic matter decomposition changes sorption properties of organo-mineral soil particles surface that sets buffering capacity for nutrient elements and its release rates, catalytic activity of enzymes and ecological barrier potential to toxicants. Modeling the dynamics of surface properties of soil particles, sorption isotherm, hydrophysical properties, may allow us understand the direction of organic matter transformation processes (approaching critical point of degradation start or its recovery), direction of changes in water-holding capacity, water-permeability and water-stability of soil aggregate structure that provide optimal bulk density and air-porosity for roots development. These are soil fertility factors and its dynamics is very informative. Modeling soil respiration dynamics that in turn, as a system-connecting process, dependents on above-listed, allows to simulate time-series of soil respiration with various weather, climate and anthropogenic scenarios needed for the development of early warning signals to anticipate ecosystem regime shifts. Time-series validation for the model is supposed to be carried out using stationary field set for continuous monitoring of soil respiration and its isotopic gas composition.

General modeling framework

The methodology of early regime shifts detection in soil functioning contains a complex process-based mathematical model which gives long-term dynamics of soil characteristics at different time scales (from days to hundred years). The model is based on a previously developed soil

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5 *Evans S.E, Dieckmann U., Franklin O. and Kaiser C. Synergistic effects of diffusion and microbial physiology reproduce the Birch effect in a micro-scale model // Soil Biology and Biochemistry 2016. V.93, pp.28–37*

aggregate model[6] being further developed by dividing processes of profile transport (that gives redistribution of physical-chemical environmental properties) and organic matter transformations as a result of microbial growth. Microbial activity changes composition of soil granulo-densimetric fractions that define local air- and moisture-conductivity of soil (via bulk density, porosity, water-permeability and diffusion coefficients), providing self-consistency of the soil model through multiple feedbacks. The model relates following:

a) process of microbial growth and organic matter transformations in granulo-densimetric fractions;

b) process of plant growth and nutrients consumption, root exudation;

c) dependencies (express-methods) for local soil properties with simply measurable monitoring data:

physical (general hydrophysical constants (pF-curve) and rheological limits, bulk density profile, specific surface area, types of porosity, air-permeability, aggregate and micro-aggregate compositions, aggregate water-stability); chemical (cation exchange capacity, humification degree, hydrophobicity of organic matter, contents of bulk selected nutrients and of its mobile forms); biological (some characteristics of biological activity, such as ammonification activity, multisubstrate consumption evenness and etc.);

- in case of natural soil these properties evolve with a) and b);

- in case of agricultural use these properties are renewed each time by calculating from monitoring data;

d) process of transport, providing spatial redistribution of physical and chemical environmental factors (oxygen, water and nutrients contents, temperature, soil mass);

Model input:

1) Monitoring data: weather (rainfall, photosynthetic active radiation, winter snowiness); morphological (growth phase dates, vegetation condition); physical (profiles of temperature, moisture, electrical conductivity, hardness/resistance to penetration, air-permeability), elevation maps, growth phase maps, green biomass index (NDWI) maps, snow cover distribution maps

2) Basic parameters for model adaptation to soil type, region of application: general climatic, agrophysical (pF-curve, sorption isotherm, structural water-stability, granulo-densimetric composition); chemical (agrochemical survey data, range of measurements for contents of basic nutrient elements and its mobile forms, fractions element composition, control organic matter composition);

Model output

<u>Prediction of soil properties dynamics:</u>

— Comparison of current values with optimal range, correction of optimal ranges, revealing properties strongly deviating from optimal

— Long-term prediction of soil properties, turnover rates of soil components, rates of its transfer between different soil fractions

— Properties regulation techniques: crop rotations, optimization of fertilizer treatment

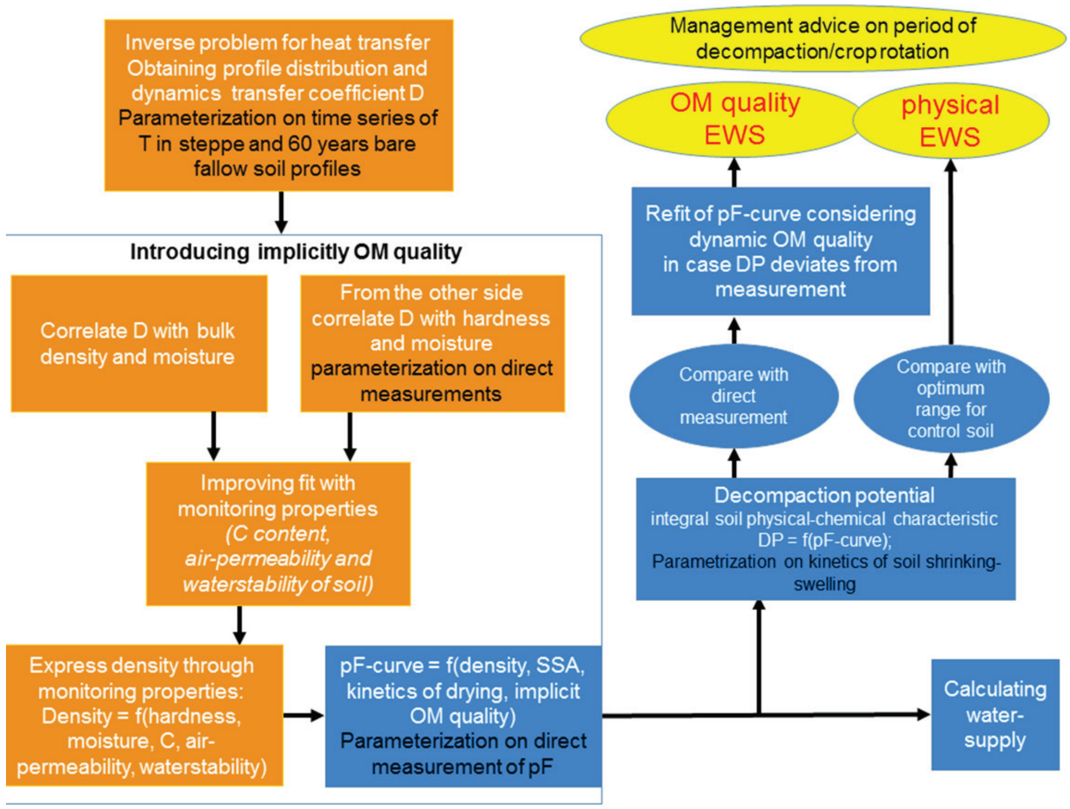
<u>Prediction of ecosystem productivity:</u>

- seasonal and long-term productivity

[6] *Vasilyeva N. A., Ingtem J. G. and Silaev, D. A. Nonlinear Dynamical Model of Microorganism Growth in Soil // Computational Mathematics and Modeling. Springer Verlag, 2016. V. 27 № 2. P. 172–180*

- estimation of yield loss risks in a current season

Early warning of regime shift in a long-term ecosystem functioning



Research plan for EWS derivation from soil modeling physical properties

Marine part: Atlantic cod

For marine fish, spawning stock biomass (SSB) is one main integral characteristic of population condition. SSB depends on the fish abundance, its age distribution, weight, sex, maturity and fecundity at each age. In theory, biomass can reach carrying capacity, where population growth rate becomes zero, at some point below carrying capacity, growth rate is maximum. The corresponding yield is the maximum sustainable yield (MSY) which is an important reference point in fisheries management. In equilibrium and when environmental conditions and carrying capacity are stable, fishing at MSY harvests only surplus individuals thus maintaining a sustainable population size.

An Allee effect or depensation, describes the positive relation between individual growth rate and population size at small population size. Therefore, in contrast to the common, compensatory population growth situation (highest individual growth rate at small population size), strong fishing and reduction of the population size can push its biomass below the critical threshold below which yield and growth rate collapses to zero regardless of the fishing activity. As a consequence recovery and rebuilding of the population will be hampered. In order to prevent such an extirpation, it is therefore required to find the lowest viable biomass level, which still allows positive population growth.

Direct monitoring of abundance, age structure and life history traits of marine fish is a challenging task and cover in practice only small parts of the population. To assess population status (e.g. by size of SSB), different age-structured models were developed, which mainly utilize catch data supplemented by survey data. In such models, number of variables and parameters in general exceed the available data and additional assumptions are required, where reference points (e.g. MSY) are long-term points, based on the population in equilibrium at stable conditions. This kind of models suit well for stock assessment at current situation, but cannot be used for (long-term) predictions outside the historic range of parameters since the relation within the population and its interaction with the environment is not mechanistically grasped in the stock assessment model.

General modeling framework

For the development of the methodology of early regime shifts detection it is necessary to have a mechanistic mathematical model, which accounts for changes in spawning, mortality and growth. Monitoring data is only needed for parametrization. Such a model allows simulation of long time series of different population parameters (e.g. SSB, birth/death ratio, etc.) as function of fishing strategy and environmental factors and can therefore be applied to scenarios outside the historic observed ranges.

Two non-linearities which could potentially lead to a regime shift or collapse, are implemented in the model: inhibition of individual growth rate at small population size, an Allee effect (e.g. by reduced reproduction) and increasing mortality at high population density (competition for limited resources). The model links together different parameters of the population:

1) Number of fish of all ages in each year — main variables, describing internal state of the model.

2) Maturity ogive probability: known for each year of observation period, for prediction — average values are used.

3) Natural mortality is known in observation period, for prediction — function of total biomass is used, taking into account competition for limited resources.

4) Average individual weight, for each year and age: known in observation period, for prediction — it is generated by random walk process, parametrized on historical data.

5) SSB — calculated in the model, compared with historical data for model parametrization.

6) Recruitment function (amount of spawns, survived until 1-year age as function of SSB) is chosen with biological mechanisms taken into account, parametrized by comparison of historical SSB with simulation results. Proposed predator-pit recruitment function in comparison with those described earlier in the literature gives better fit of observed data and has two steady states with high and low population size. We assume, that biological features of different fish populations are described by general structure of the model, while difference in environmental factors can be tuned using parameters of recruitment function.

7) Fishing mortality, for each age and year — known for historical period and for prediction is defined by fishing strategy.

Input model parameters:

1)Information about environmental factors (ocean temperature, salinity, acidity), abundance of phyto- and zooplankton, weather and climate data) and fishing strategy and reference points

2)Input parameters for adaptation of the model to another population or fish species: Information about catch at age for observed historical period, fish life history traits data, obtained from surveys or modeling, trophic chain data, recruitment function.

Output data of the model

Population dynamics prediction:

— Comparison of current population state with reference points, estimation of critical population decline risk with given fishing strategy, minimal allowed population size.

— Long-term prediction of population dynamics, recovery time after collapse.

— Fish population control: harvesting quotas for considered species as well as other species linked with it by food chain

Prediction of ecosystem productivity:

— Short and long-term prediction of productivity, maximum sustainable yield.

Early detection of changes in long-term ecosystem regime.

Early Warning Signals research framework:

Aiming to:

1. predict collapse itself.
2. find the (biomass) threshold at which a collapse can still be avoided (e.g. by changing fisheries management plan from MSY to a more precautionary approach).
3. find the real dynamic values of reference points (thresholds) in contrast to the long-term intrinsic (static) reference points that are based on the assessment model growth rate in equilibrium at constant conditions.
4. Analyze how predictability of collapse (EWS) and finding of real reference points dependent on the fishing strategy (masking signals).

Part I. Obtaining different types of collapses, categorize them and extract corresponding strategies, finding common descriptive features for the obtained categories of strategies

a) complex random-walk algorithm that generated all possible scenarios of fishing strategies composed of fishing plans

b) algorithm for cutting time-series into regions of collapse, recovery and stable states to categorize the collapse

c) obtain generalized EWS by:

i) analyzing time-series and corresponding strategies that have led to No Collapse, Collapse with Recovery or Collapse without Recovery

ii) revealing general common features in time-series of different collapse categories and corresponding strategies

iii) comparing for different stock-recruitment functions (with different Allee-effect)

v) comparing for different Allee coefficients in proposed predator-pit function (imitating different stock of cod)

Part II. Detecting strategy parameters thresholds

a) Obtain collapse frequency as functions of strategy parameters and its threshold

b) Analyze time-series without collapses (above threshold) for EWS. Estimate threshold detectability by EWS without knowing it or having only uncertain estimation from a model dependent on distance from threshold that reflects fishing pressure.

c) Analyze properties of collapses-series and corresponding strategies-series (collapse frequency, distribution by categories, recovery time etc.) approaching threshold.

d) Compare results for different RS-functions and proposed predator-pit function with changing Allee coefficients.

Assumption: EWS works when the model correctly captures general biological mechanisms, although some coefficients are of different order or some terms are not accounted for, if they do not influence common features of SSB dynamics used in EWS.

Part III. Deriving management guidance

We propose to choose safe and economically (highest yield) optimal fishing strategy parameters using obtained collapse risk and its detectability dependencies on the current population state, to construct fishing plans.

Considering that the model captures general mechanisms (age-structure, recruitment function and density-dependence) it can be applied to different cod stocks.

Концепция математического моделирования для системы раннего обнаружения признаков критических изменений в режиме функционирования наземных и морских экосистем (TerMARisk)

В морских и наземных экосистемах могут происходить изменения в продуктивности, признаках биологического цикла, уровнях запаса и величинах факторов плодородия среды, скоростей круговоротов или структуре трофической цепи, как естественные в результате эволюции, зависящей от глобального изменения климата, так и в результате антропогенного воздействия (уровень эксплуатации — сбор урожая/вылов рыбы, изменение физических и химических свойств среды обитания). Эти изменения могут приводить к смене режима функционирования/переходу из одного устойчивого состояния в другое через неустойчивые состояния, которые происходят достаточно резко, и поэтому их невозможно предсказать регрессионными зависмостями, полученными по мониторинговым данным, урожайности/улову, или линейными динамическими моделями. Прогноз, предотвращение или учет последствий таких изменений в биомассе популяции, урожайности, потоке углекислого газа, не смотря на обширные исследования в прошлом, остается актуальной задачей. В свете возможности получения непрерывных мониторинговых данных современными приборами эта задача может быть выведена на новый уровень решения при помощи многомасштабного математического моделирования динамики нелинейных систем, бифуркационного анализа системы, динамического скейлинга и других подходов[7,8]. Как известно для нелинейных систем возможность прогноза зависит от того учтены ли главные процессы и взаимосвязи, обуславливающие сложную и непредсказуемую чисто статистическими подходами динамику, которые требуют большой обучающей выборки и работают только в диапазоне встречавшихся в этой выборке условий (для экосистем, как правило, доступны данные при очень ограниченной комбинации факторов). Поэтому моделирование динамики макроскопических интегральных показателей экосистемы с целью обнаружения смены режимов требует понимания и моделирования причинных процессов на микроуровне. При исследовании сложных систем важно найти такой интегральный показатель, который отражал бы состояние всей системы целиком и был бы чувствителен к критическим изменениям во всех ее важнейших частях. Мы рассматриваем в этом контексте одновременно морские и наземные экосистемы, взаимодействующие между собой через баланс углекислого газа в атмосфере, находясь в обратной связи с климатическими факторами, изменяя кислотность воды, температуру и скорость фотосинтеза, продуктивность среды, скорость круговорота веществ, условия среды. В качестве примера наземной экосистемы мы рассматриваем модель почвы, а в качестве примера морской экосистемы — модель популяции Атлантической трески в Северном море. Обе модели разрабатываются параллельно, эффективно взаимствуются подходы и помогают разработке системы раннего обнаружения общих признаков смены режимов в экосистемах.

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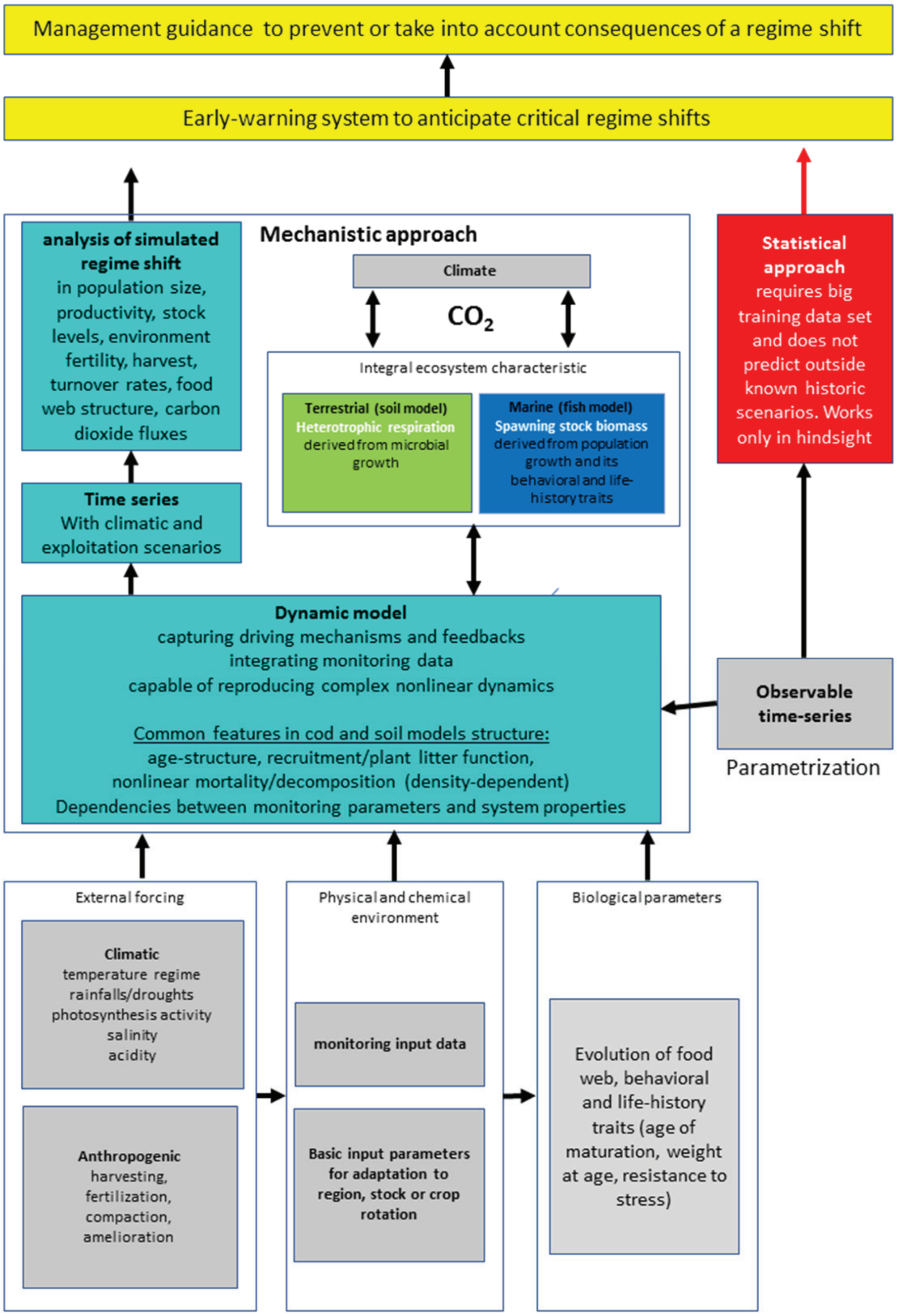
7 *A. M. Tarquis, J. L. M. P. de Lima, W. F. Krajewski, Q. Cheng, and H. Gaonac'h Nonlin. Processes Geophys., 18, 899–902, https://doi.org/10.5194/npg-18-899-2011, 2011*

8 *BL Li. Why is the holistic approach becoming so important in landscape ecology? Landscape and Urban Planning 50 (1), 27–41, 2000.*



Management guidance to prevent or take into account consequences of a regime shift
Early-warning system to anticipate critical regime shifts
analysis of simulated regime shift
in population size, productivity, stock levels, environment fertility, harvest, turnover rates, food web structure, carbon dioxide fluxes
Mechanistic approach
Climate
CO_2
Integral ecosystem characteristic
Terrestrial (soil model)
Heterotrophic respiration
derived from microbial growth
Marine (fish model)
Spawning stock biomass
derived from population growth and its behavioral and life-history traits
Statistical approach
requires big training data set and does not predict outside known historic scenarios. Works only in hindsight
Time series
With climatic and exploitation scenarios
Dynamic model
capturing driving mechanisms and feedbacks
integrating monitoring data
capable of reproducing complex nonlinear dynamics
Common features in cod and soil models structure:
age-structure, recruitment/plant litter function,
nonlinear mortality/decomposition (density-dependent)
Dependencies between monitoring parameters and system properties
Observable time-series
Parametrization
External forcing
Climatic
temperature regime
rainfalls/droughts
photosynthesis activity
salinity
acidity
Anthropogenic
harvesting,
fertilization,
compaction,
amelioration
Physical and chemical environment
monitoring input data
Basic input parameters for adaptation to region, stock or crop rotation
Biological parameters
Evolution of food web, behavioral and life-history traits (age of maturation, weight at age, resistance to stress)

Наземная часть: Почва

Для почвенной экосистемы гетеротрофное дыхание, т.е. поток углекислого газа, образующийся в результате процесса дыхания микроорганизмов/разложения/трансформации микроорганизмами органического вещества в почве, может быть принят за интегральный показатель ее состояния и функционирования. Активность и состав почвенного микробоценоза взаимосвязана с химическим строением субстратов, их физическим состоянием (дисперсность, сила адсорбции на минеральных частицах, окклюдирование/физическая недоступность) и физическими и химическими условиями почвенной среды (плотность, размер и конфигурация порового пространства, распределения воды и воздуха в порах, потенциал/доступность почвенной влаги, емкость катионного обмена ППК, наличие питательных элементов в растворимых формах, кислотность, окислительно-восстановительный потенциал, интенсивности притока эксудатов корней растений). Попытки перехода от моделирования микроскопических процессов, протекающих на границах раздела фаз в почве в связи с биологической активностью дыхания почвы и трансформацией органического вещества, к получению глобальных зависимостей для потоков углекислого газа при изменении климатических сценариев начинают появляться[9].

В сельскохозяйственных экосистемах состояние и направленность процессов зависит не только от климата, но и даже в большей степени, от антропогенной нагрузки на плодородие почвы (меняющей продукционный процесс). При этом физические и химические показатели не являются естественным взаимообусловленным с микробоценозом развитием, они изменяются быстрее, чем в естественной среде за счет манипулирования ими человеком (рыхление и давление от многочисленных проходов техники, орошение, внесение химических удобрений и мелиорантов). В этом случае микробоценоз уже не является двигателем процессов, а скорее приспосабливается к быстроменяющимся условиям и, в лучшем случае, противодействует, восстанавливая условия до оптимальных растениям. И в этом случае динамика физико-химических свойств почвы может служить показателем скорости и направленности процессов измененяющих факторы плодородия при текущей системе земледелия. Например, разложение органических веществ изменяет сорбционные свойства поверхности органо-минеральных почвенных частиц, которые определяют буферную емкость питательных элементов и скорость их высвобождения, каталитическую активность ферментов и экологический защитный потенциал в отношении токсичных веществ. Моделирование динамики свойств поверхности почвенных частиц, изотермы сорбции, почвенной ОГХ, может позволить понять направление процессов трансформации органического вещества (приближение к критической точке начала деградации или его восстановление), направление изменения водоудерживающей способности, водопроницаемости и водопрочности агрегатной структуры, обеспечивающих оптимальную плотность и воздухоносную пористость для развития корней. Эти факторы являются факторами плодородия и их динамика очень информативна. Моделирование зависящей от них, в свою очередь, динамики почвенного дыхания, как связующего разные блоки системы процесса, позволяет получать временные серии с различными сценариями

[9] *Evans S.E, Dieckmann U., Franklin O. and Kaiser C. Synergistic effects of diffusion and microbial physiology reproduce the Birch effect in a micro-scale model // Soil Biology and Biochemistry 2016. V.93, pp.28–37*

климатического, погодного и антропогенного воздействия для разработки системы раннего обнаружения признаков смены режимов функционирования экосистемы. Валидация временных серий модели предполагается посредством стационарного полевого непрерывного мониторинга потока почвенного дыхания и его изотопного состава.

Общая концепция моделирования

Разрабатываемая система раннего обнаружения признаков критических изменений в режиме функционирования почвенного покрова содержит в основе комплексную физически обоснованную математическую модель механистического описания почвенных процессов, дающую динамику их показателей на разном масштабе времени (от суток до сотен лет). Модель основана на модели почвенного агрегата[10], с разделением процессов транспорта по профилю, приводящих к перераспределению физико-химических параметров среды, и трансформации органического вещества в результате микробного роста. Последнее изменяет состав почвенных грануло-денсиметрических фракций, определяющих локальные воздухо- и водопроводящие свойства почвы (плотность, пористость, коэффициенты влагопроводности и диффузии), обеспечивая самосогласованность модели почвы посредством множества обратных связей. Разрабатываемая модель связывает:

a) процесс роста микроорганизмов и трансформации фракций органического вещества;

b) процесс роста растения и потребление питательных веществ, выделение эксудатов;

c) зависимости (экспресс-методы) для локальных свойств почвы от легко измеряемых мониторинговых данных:

физических (константы основной гидрофизической характеристики (ОГХ) и реологические пределы, профиль плотности, удельная поверхность, виды пористости, воздухопроницаемость, агрегатный и микроагрегатный состав, водоустойчивость структуры); химических (емкость катионного обмена, степень гумификации, гидрофобность органического вещества, содержание некоторых питательных элементов, их подвижных форм); биологических (некоторые показатели биологической активности, аммонифицирующая активность, равномерность разложения спектра субстратов и тд.);

- в случае естественной эволюции почвы эти свойства почвы эволюционируют вместе с процессами a) и b);

- в случае сельско-хозяйственного использования эти свойства каждый раз обновляются вычислением из мониторинговых данных;

d) процесс транспорта, дающие пространственное перераспределение физических и химических показателей среды (содержание кислорода, воды, температуры, питательных веществ, почвенной массы);

Входные параметры модели:

1) Мониторинговые данные: погодные (осадки, ФАР, снежность зимы); морфологические (даты фаз роста, состояние фитоценоза); физические (профили температуры, влажности, электропроводности, твердости, воздухопроницаемости), карты рельефа, фаз развития, индекса зелености биомассы NDWI, распределения снежного покрова

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[10] *Vasilyeva N. A., Ingtem J. G. and Silaev, D. A. Nonlinear Dynamical Model of Microorganism Growth in Soil // Computational Mathematics and Modeling. Springer Verlag, 2016. V. 27 № 2. P. 172–180*

2) Базовые параметры для адаптации модели к другому типу почвы, региону применения: климатические, агрофизические (ОГХ, изотерма адсорбции, водоустойчивость структуры, содержание грануло-денсиметрических фракций); Химические (данные агрохим обследования, диапазон измерений содержания основных питательных элементов и подвижных форм, элементный состав фракций), состав органического вещества контрольного образца);

Выходные данные модели

Прогноз динамики почвенных показателей:

— Сравнение текущих величин с оптимальными диапазонами значений, корректировка диапазонов оптимальности, выявление сильно отклоняющихся

— Долгосрочный прогноз значений почвенных показателей, скоростей круговорота, скоростей трансформации между разными формами

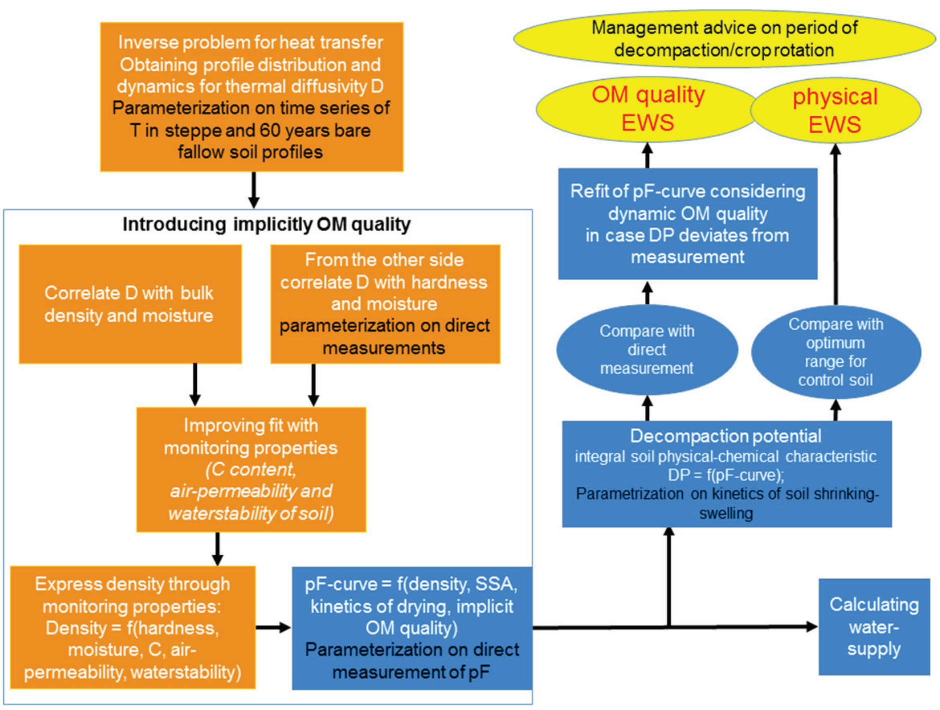
— Приемы регулирования показателей: севообороты, расчет оптимальных доз внесения удобрений

Прогноз продуктивности экосистемы:

— Краткосрочный и долгосрочный прогноз продуктивности

— Оценка рисков потери урожая в текущем сезоне

Раннее обнаружение признаков изменения многолетнего режима функционирования экосистемы



План-схема исследований по получению ранних признаков смены режима из физико-химических свойства почвы

Морская часть: Популяция атлантической трески

Для популяции рыб основным интегральным показателем является биомасса рыб, идущих на нерест (spawning stock biomass — SSB). Этот показатель определяется количеством рыб, средней массой особей различных возрастов и долей рыб в популяции, которые дают потомство в данном возрасте. В теории, биомасса достигает максимального значения, равного вместимости экологической ниши для данного вида, при котором скорость прироста равна нулю. Для каждой популяции существует, зависящие от особенностей биологического цикла рыб, значение SSB при котором прирост биомассы популяции максимален. Это значение (MSY) важно для промышленного рыболовства, поскольку поддержание популяции на этом уровне позволяет получать максимальный возможный улов в долгосрочной перспективе.

Олли эффект описывает положительно-обратную связь между приростом популяции в расчете на одну особь и численностью популяции. Таким образом, в отличие от случая компенсационного роста популяции (наибольший прирост при малой численности), интенсивный вылов может привести к снижению численности ниже критического значения, ниже которого популяция не восстанавливается даже при полном прекращении вылова. Для предотвращения подобной ситуации необходимо знать минимальную численность популяции, при которой еще возможен положительный прирост численности.

Непосредственный мониторинг численности и возрастного состава популяции рыб, а также важнейших параметров их биологического цикла (естественная смертность, доля рыб, идущих на нерест и средняя масса особи в зависимости от возраста) является трудоемкой задачей и на практике осуществляется только в небольшом объеме. Для оценки полной биомассы и SSB популяции применяются различные модели возрастной структуры, которые используют данные о вылове за длительный период в сочетании с ограниченными данными непосредственного мониторинга. В таких моделях количество неизвестных и параметров обычно превышает количество доступных данных, поэтому требуются дополнительные предположения, например, в, используемой в настоящее время для оценки популяции и выдачи квот на вылов атлантической трески, модели основным предположением является требование максимума временной корреляции параметров модели. Подобные модели хороши для оценки запасов рыбы и вычисления реперных точек MSY, но не способны давать долгосрочный прогноз, поскольку они полностью зависимы от данных мониторинга.

Общая концепция моделирования

Для разработки методов раннего обнаружения смены режима динамики популяции рыб необходима математическая модель популяции, которая более полно учитывает известные биологические механизмы, влияющие на рождаемость, смертность и рост особей, и при этом требует мониторинговых данных только для параметризации, позволяя генерировать длинные временные серии различных интегральных параметров популяции (например, SSB, отношение рождаемость/смертность и т.д.) в зависимости от стратегии вылова и климатических сценариев. В модели учитываются следующие нелинейные эффекты: замедление воспроизводства при низкой плотности популяции (Олли эффект) и увеличение смертности при большой плотности (конкуренция за ресурсы). Модель связывает между собой различные характеристики популяции:

1) Численность особей всех возрастов во все годы — основная «внутренняя» величина, вычисляемая в модели.

2) Доля особей, идущих на нерест: В исторический период известна в каждый год, при прогнозировании используется среднее за исторический период.

3) Смертность известна в исторический период, при прогнозировании используется функция общей биомассы, учитывающая ограниченные ресурсы.

4) Средний вес одной особи в зависимости от года и возраста: в исторический период

известен, при прогнозировании генерируется скоррелированным алгоритмом случайного блуждания, параметризованным на исторических данных.

5) SSB — вычисляется, при параметризации сравнивается с историческими данными.

6) Функция рекрутмента (количество мальков, доживших до возраста 1 год в зависимости от SSB) — выбирается с учетом биологических механизмов, параметризуется на исторических данных результирующего (SSB). Предложенная нами функция рекрутмента, по сравнению с описанными ранее в литературе позволяет точнее описать исторические данные и имеет два устойчивых состояния с высокой и низкой численностью популяции. Предполагается, что биологические особенности различных популяций рыб учитываются в общей структуре модели, а различия в свойствах окружающей среды могут быть настроены коэффициентами предлагаемой функции рекрутмента.

7) Вероятность вылова одной особи в зависимости от года и возраста — известна в исторический период, определяется стратегией вылова при прогнозировании.

Входные параметры модели:

1)Информация о физических факторах среды (температуре океана, солености, кислотности), количестве фито- и зоопланктона, погодные и климатические данные, информация о планах вылова на будущее или стратегия формирования этих планов.

2)Входные параметры для адаптации модели к другой популяции или виду рыб: Информация о количестве выловленной рыбы разных возрастов в исторический период наблюдений, данные об особенностях биологического цикла рыб, полученные в результате наблюдений или моделирования, информация о трофических цепях, в которых участвует популяция рыб, функция рекрутмента.

Выходные данные модели

Прогноз динамики популяции:

— Сравнение текущего состояния популяции с реперными точками, оценка рисков критического падения популяции при заданной стратегии вылова, минимально допустимая численность популяции.

— Долгосрочный прогноз динамики популяции, время восстановления после коллапса

— Регулирования популяции рыб: квоты на вылов как рассматриваемого вида рыб, так и других, морских организмов, связанных с ним трофической цепью

Прогноз продуктивности экосистемы:

— Краткосрочный и долгосрочный прогноз продуктивности, максимальный стабильный улов.

Раннее обнаружение признаков изменения многолетнего режима функционирования экосистемы

Концепция раннего обнаружения признаков смены режимов в экосистемах (EWS):

Основные цели:

1. Предсказание коллапсов популяции.
2. Вычисление порогового значения биомассы при котором коллапса популяции можно из бежать путем изменения стратегии вылова.
3. Вычисление пороговых значений (реперных точек) из динамического неравновесного процесса в отличие от статических значений, полученных из анализа равновесных со-

стояний модели при постоянных внешних условиях.
4. Анализ влияния стратегии вылова на предсказуемость коллапсов (EWS) и динамические реперные точки.

Часть I. Моделирование различных типов коллапсов, их категоризация вместе с соответствующими стратегиями, выявление похожих характеристик в каждой категории стратегий

a) алгоритм случайного блуждания, генерирующий все возможные стратегии вылова, состоящие из множества планов

b) алгоритм разбиения временной серии на участки коллапса, восстановления, и стабильного состояния популяции; категоризация коллапсов

c) получение обобщенной методологии EWS посредством:

i) анализа временных серий популяции и соответствующих стратегий, которые привели к отсутствию коллапса, коллапсу с восстановлением или коллапсу без восстановления

ii) выявления похожих характеристик временных серий и соответствующих стратегий в разных категориях

iii) сравнение результатов полученных при использовании разных функций рекрутмента (с различным Олли-эффектом)

v) сравнение результатов при различных коэффициентах в предлагаемой функции рекрутмента (имитация различных популяций трески)

Часть II. Определение пороговых значений параметров стратегии

1. Получение частоты коллапсов как функции параметра стратегии вылова, определение порогового значения
2. Анализ временных серий без коллапсов (выше порогового значения) на предмет EWS. Оценка возможности обнаружения порогового значения при приближении к нему в за висимости от расстояния.
3. Анализ характеристик коллапсов и соответствующих стратегий (частота коллапсов, распределение по категориям, время восстановления и т.д.) при приближении к пороговому значению.
4. Сравнение результатов, полученных для различных функций рекрутмента и различных значений коэффициента Олли-эффекта в предложенной функции рекрутмента.

Предположение: Сигналы раннего обнаружения будут работать, если модель правильно описывает общие биологические механизмы, даже если значения коэффициентов в модели сильно отличаются от реальных или некоторые процессы не учитываются, если это не влияет на общие свойства динамики SSB, которые используются при построении методологии EWS.

Часть III. Стратегия управления

Предлагается методика выбора безопасных и экономически выгодных параметров стратегии вылова на основе полученной информации о риске и возможности предсказания коллапсов в зависимости от состояния популяции, которая может быть использования для построения планов вылова.

В случае, если модель правильно описывает общие механизмы (возрастная структура, функция рекрутмента и конкуренция за ресурсы) она может быть применена к различным популяциям.

Workshop Program

7 of August, Monday — Participants arrival, arranged taxi to Metropol Hotel (Teatralnyi proezd, 2)

8 of August, Tuesday — «Modeling complex dynamic systems»
9.00 – 9.30 Welcome talk (Director in charge Igor Y. Savin). General excursion in the institute bout research activity.
9.30–10.15 A multi-objective calibration of RothC within the GLUE framework: an example of the equifinality inherent to first-order SOC model structures (Dr. Lorenzo Manichetti, Swidish University of Agricultural Sciences)
Coffee-break
10.45–11.30 Review on modeling approaches to estimate soil carbon fluxes and stocks and risks of regime shifts induced by climate change (Dr. Fernando Moyano, Georg-August University of Goettingen)
11.30–12.15 Mathematical modeling of regime shifts in soils (Dr. Nadezda Vasilyeva, Interdisciplinary Laboratory for Mathematical Modeling of Soil Systems, Dokuchaev Soil Science Institute)
Lunch (at Grabli, 10 min walk)
13.30–14.15 Regime shifts in fish populations (Anna-Marie Winter, Center for Ecological and Evolutionary Synthesis, University of Oslo and Economics and Natural Resources Group, Wageningen University)
Coffee-break
14.45–15.30 Review on modeling complexity in ecosystems (Prof. Bai-Lian Larry Li, Ecological complexity and modeling, University of California)
Coffee/snacks
(optional) 18.00–19.30 River boat (Radisson) with a dinner and city sightseeing overview

9 of August, Wednesday — «Early warning signals of regime shifts in ecosystems»
9.00–9.45 Early warning signals of regime shifts in time series of data from financial markets (Dr. Elena Rovenskaya, Advanced Systems Analysis, International Institute for Applied Systems Analysis)
9.45–10.30 Applicability of time series of soil monitoring data for development of early warning signals methodology for prediction of critical changes in soils (Taras Vasiliev, Interdisciplinary Laboratory for Mathematical Modeling of Soil Systems, Dokuchaev Soil Science Institute)
Coffee-break
11.00–11.45 Analysis of modelled time series of fish population under different scenarios of commercial exploitation and development of methodology for detection of early warning signals of regime shifts (Dr. Artem Vladimirov, Interdisciplinary Laboratory for Mathematical Modeling of Soil Systems, Dokuchaev Soil Science Institute)
Lunch (at Varenichnaya, 10 m walk)
13.30–14.15 Solving optimal control problems for commercially exploited ecosystems on example of fish population (Dr. Ludmila Artemyeva, Optimal Control Department, Faculty of Computational Mathematics and Cybernetics, Lomonosov Moscow State University).
14.15–15.00 Review on drought risks in ecological systems (Prof. Ana Maria Tarquis, Complex systems group, Educational Innovation Group RiskMetrics, Research Center for the Management of Agricultural and Environmental Risks, Department of Applied Mathematics, Universidad Politécnica de Madrid).

15.00–16.00 Round table 1. Discussion of existing EWS methods (statistical approaches, their applicability and limitation). Potential applications of mechanistic dynamic models of complexity in ecosystems for development of early warning signal methodology.
Coffee/Snacks
16.30–18.00 Excursion to Tretyakovskaya gallery with official English speaking guide. (5 min walk from the workshop)
19.00 Social dinner at Restaurant

10 of August, Thursday — Feedbacks and summary.
9.00–10.30 Round table 2. Conclusions, feedback and ideas for development of early warning signal methodology to predict regime shifts in ecosystems using mathematical modeling of complex dynamics.
Coffee-break
11.00–12.30 Round table. Actual questions in ecosystem modeling. Formulation of scientific research topics interesting for joint international collaborations.
12.30–13.00 Workshop together photographing and short interviews (2–3 minutes).
Lunch
14.00 Drive to Lomonosov Moscow State University
15.00–16.30 Excursion to Lomonosov Moscow State University Earth Museum and the viewing point from Rotonda.
19.00 Ballet «Sleeping beauty» of Summer Ballet Seasons in Russian Academic Youth Theatre (RAMT), Theatre square, 2 (next to the Bolshoi theatre). Tickets booked and provided to interested participants.

11 of August, Friday. Participants departure. Arranged taxi from the Hotel to airport.

Participants

Project leader of marine group Prof. Nils Christian Stenseth, Head of CEES: «Review on complexity and nonlinearities in marine ecosystems»

Research interests

Population biology (ecology and genetic structuring); large-scale ecological and evolutionary patterns; effects (ecology and evolution) of climate variation; terrestrial, marine and freshwater systems, including vector-borne infectious diseases with an environmental reservoir. Above all I am, in various settings, working on merging ecological and evolutionary thinking as well as better understanding the feedback-loop between ecology and evolution: ecology causes evolution through ecologically-based selective pressure, and when evolution occurs, the ecological interactions within the ecosystem may change — potentially leading to a modified ecologically-based selective pressure.

Background

I am a Core Member, Research Professor and the Chair of CEES at the University of Oslo. In addition, I am Professor II at both the University of Agder and the Norwegian University of Science and Technology (NTNU).

My research interests span a broad spectrum of ecological and evolutionary topics, most of which are rooted in population biology. Before the early 1990s, much of my work was purely theoretical. Later, I adopted the research strategy of «asking» available data what the underlying ecological or evolutionary process might most likely be — all within a theoretical perspective. I strongly favour comparative studies — by comparing similar features between different (but comparable) systems, we typically learn more than we otherwise would have done. Variations in population densities in time and space — and the underlying demographic processes — have been a main interest of mine over the years. An important example is the interdependent relationship between density-dependent and density-independent processes, where the ecological effect of climate is an important example of the latter.

Most of my work relates to basic issues. (I have never claimed that my research is of any immediate use, although I do hope it will be in the long run.) However, I find great pleasure in working on more applied issues as well; I have never been ashamed of my research being of practical use here and now. These applied interests have brought me into work on pest control (e.g., rodents in Africa), harvesting (marine and terrestrial), bio-economics (e.g., the ecological dynamics of dryland pastoral systems) and epidemiology (Plague).

I am convinced that it is helpful to try to understand what has happened in the past, in preparing for what might happen in the future, e.g., ecological and evolutionary effects of climate change. For this reason, I value the existence of long-term time series — and the analysis of them.
I love interacting with colleagues, and find great pleasure in building and maintaining teams. I am an ISI highly cited researcher.

Besides being an active scientist I am also a public advocate for science, actively participating in the discussions on how best to structure and strengthen the scientific community. I am an elected member of The Norwegian Academy of Science and Letters (DNVA); I was the vice-president/president of that Academy 2009–2014. I am also an elected member/fellow of several other academies, including the National Academy of Sciences (Washington, US), French Académie des Sciences, the Russian Academy of Sciences, Finnish Society of Sciences and Letters, Academia Europaea, the Royal Norwegian Society of Science and Letters and Agder Academy of Science and Letters. I have been awarded honorary doctorates (Doctor Honoris Causa) at the University of Antwerpen, Belgium (2001) and at the École Normale Supéreure, Lyon, France (2011), and I am honorary Professor at Addis Ababa University in Ethiopia. I am a Chevalier (Knight) in the French National Order of the Legion of Honour.
During the period 2012 to 2015 I served as the President of the International Biological Union (IUBS). Currently I am a member of the Scientific Council of the European Research Council (ERC) as well as the Editor-in-Chief of Climate Research.

Project leader: Dr. Anne Maria Eikeset, researcher at CEES, TerMARisk

My main interests are modeling in the interface between ecology, evolution and economics on how natural resources, as common pool resources embedded in social-ecological systems, adapt to exploitation and climate change. In particular I have focused on marine ecosystems and fish, from individual level to population level, to communities. I develop models to study how eco-evolutionary dynamics and economics interact in a changing environment; like under climate change, or under more abrupt perturbations, oil spills. For example, I use these models to study multiple scenarios for (optimal) harvest rules under different objectives and regulations (like harvest control rules in commercial fisheries). I am also working on time-series modeling, like state-space models, to study the mechanisms and how uncertainty affects the fish species adaptive capacity. Most of my work has been done for the Barents Sea, in the Arctic region.

I have since 2012 been a member of the Levin Lab at Princeton University and is currently a Visiting Associate Research Scholar, Department of Ecology and Evolutionary Biology, Princeton University.

Invited external expert: Prof. Ana Maria Tarquis Alfonso: «Review on drought risks in ecological systems»

She is a professor in Applied Mathematics at Universidad Politécnica de Madrid (UPM) and General Secretary of CEIGRAM (Research Center for the Management of Agricultural and Environmental Risks). She has been teaching Mathematics at UPM under different graduate programs, as well as PhD courses and recently Master's courses once that the Bologna plan was implemented in Spain. Her research interests have been applying powerful mathematical tools in agriculture and environmental research to address problems in a different way and see what progress can be made. In this sense, beside the application of classical Statistics and Modeling analysis, she has been using Lindenmayer systems (L-systems) in plant growth, fractal/multifractal and wavelet analysis in soils and time series studies, Barabasi networks and heterogeneous preferential attachment networks to several systems, artificial networks and fractal filters in image analysis.

ABSTRACT

Ecological systems are generally considered among the most complex because they are characterized by a large number of diverse components, nonlinear interactions, scale multiplicity, and temporal/spatial heterogeneity. Hierarchy theory, as well as empirical evidence, suggests that complexity often takes the form of modularity in structure and functionality. Therefore, powerful tools should be applied to understanding complex ecological systems.

Drought is, by itself, a complex phenomenon, which is difficult to define. The term is used to refer to deficiency in rainfall, soil moisture, vegetation greenness, ecological conditions or socio economic conditions, and different drought types can be inferred. It is considered as one of the major natural hazards in south Europe with a significant impact on agriculture, environment, society and economy. Droughts affect sustainability of agriculture and may result in environmental degradation of a region, which is one of the factors contributing to the vulnerability of agriculture.

Risk management is part of a farmers» business strategy since production is subject to many uncertainties that could threaten returns or even the viability of farms. The sources of risk in agro-ecosystems are numerous and diverse. The prevalence of sources of risk that affect many farmers at once, such as weather-related hazards, is specific to agriculture. Some weather related risks such as drought have a systemic component in that they affect most farmers within an entire region or country. There is no doubt that agriculture, as an economic sector, is therefore most vulnerable and most exposed to climate extremes.

In this talk, we will show different drought cases studied pointing out the need to apply complex systems concepts to understand the dynamic of such agro-ecosystems. The design of drought insurance will be a direct application of this approach.

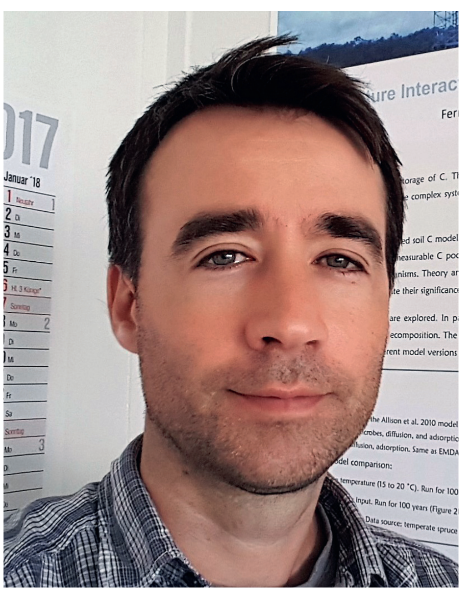
Invited external expert: Prof. Bai-Lian Larry Li: «Review on modeling complexity in ecosystems»

Much of the effort in 20th-century biological research has been aimed at reducing biological phenomena to the behavior of molecules. Despite the enormous success of this approach, a discrete biological function can only rarely be attributed to an individual molecule. Most biological functions arise from complex interactions among many components. Our increasing understanding of complex systems demands that 21st century biological research advances beyond reductionism.

Using this holistic mechanistic view and a highly-quantitative, modeling approach to biological and ecological systems, research conducted in Dr. Li's laboratory addresses questions that include but are not limited to: How do biological and ecological systems self-organize? What are the origins and mechanisms of emergence of scaling from individual to landscape levels (especially on emergence of dynamic scaling)? And what are the physical bases of non-equilibrium biological and ecological systems? We use mathematical, statistical, and computational modeling approaches as a way of exploring and answering these questions. These modeling approaches help identify general principles and basic mechanisms governing emerging properties of biological and ecological systems at multiple temporal and spatial scales based on energetic, thermodynamic and information considerations.

We also apply complex systems theories and modeling approaches to very applied ecological problems in conservation biology, biological invasion, restoration ecology, ecological monitoring and assessment, global change, and sustainable development.
Recently, I have some interests on the development of multi-scale modeling to incorporate genomic, proteomic and metabolomic data, along with information on the associated biochemical and physiological mechanisms and pathways that control and influence biological and ecological processes. Basically, it's kind of model hopefully to link genes to ecosystems. I have been looking into some minimal models for complex dynamics in cellular processes, genetic regulatory networks, noise in gene expression and its consequence for cellular behavior, etc.

Nonlinear dynamics and chaotic and complex systems constitute some of the most fascinating developments of late twentieth century mathematics and physics. The implications have changed our understanding of important phenomena in almost every field of science, including ecology. This talk will introduce some of our recent work on complexity and chaos in the Spatio-temporal dynamics of marine ecosystems. The dynamics of these biological communities exhibit an interplay between processes acting on a scale from hundreds of meters to kilometers, controlled by biology, and processes acting on a scale from dozens to hundreds of kilometers, dominated by the heterogeneity of hydrophysical fields. We focus on how biological processes affect spatio-temporal pattern formation and explain why the heterogeneity of the species spatial distribution can not always be reduced to the heterogeneity of the aquatic environment.



Invited external expert: Dr. Fernando Moyano: «Review on modeling approaches to estimate soil carbon fluxes and stocks and risks of regime shifts induced by climate change»

Dr. Fernando Moyano is a researcher and lecturer in the Bioclimatology group of the University of Göttingen. He is interested in the interactions between ecosystems, land-use, climate change and society. More specifically, his research focuses on understanding the response of soil organic matter to environmental change in diverse ecosystems. After studying Biology at the University of Cordoba, Argentina, Dr. Moyano obtained a PhD degree (Dr. rer. nat) working at the Max Planck Institute for Biogeochemistry in Jena, Germany, where he explored the factors affecting soil respiration fluxes in cropland and forested areas and quantified their connection with above ground CO2 assimilation and temperature variability. He later moved to France where he was employed by the Centre national de la recherche scientifique (CNRS) and later by the Laboratoire des Sciences du Climat et de l'Environnement (LSCE). His work in France involved research and modeling of the response of soil organic matter decomposition to variations in temperature and moisture, relying on combined statistical and theoretical approaches. At the LSCE he contributed to developing the Orchidee land surface model. In addition to teaching, his current work at the University of Goettingen focuses on the development of mechanistic models simulating processes of soil C dynamics combined with understanding the effects of land use change at various biogeochemical levels. Dr. Moyano is a collaborator within EFForTS, a multidisciplinary project that looks at the effects of oil palm plantations replacing primary forests in Indonesia.

Abstract
The carbon cycle and climate are tightly connected, not only by human emissions of fossil carbon, but also by C sinks and sources over various types of planetary surfaces. In average, land use change results in large amounts of CO2 emitted to the atmosphere, but land vegetation can also takes up CO2, partially offsetting the overall increases in atmospheric concentrations. The role of soils in determining past and future changes in flows and stocks is still highly uncertain as a result of their complex nature, strong spatial variability and difficulty in directly measuring soil processes. Thus, most soil C models rely on highly simplified representations of decomposition processes driving soil C accumulation and turnover, since more realistic but more complex models cannot be properly validated. However, a significant amount of research is being done to improve soil models by making them more mechanistic, i.e. more closely based on established theory. These models tend to be non-linear and result in complex responses of soil C to different drivers. While many simulations lead to highly improbable outcomes, others show behaviors that are more consistent with field or laboratory observations. Recent meta-analysis of field observations have shown that the response of soil C to increases in temperature depends on the ecosystem type. This behavior is also reflected in newer models that incorporate microbial and enzymatic dynamics. Interactions have also been observed between temperature and moisture effects. These have been successfully simulated by explicitly including diffusion in soils, resulting in future predictions that again contrast with conventional model predictions. A better understanding of the mechanisms responsible for soil C stabilization will require a combination of theory development, further observations and modelling tools that allow an integration of both. The continued development of models combined with an increasing availability of data will lead to better validated models, helping reduce the uncertainties still associated with the long term response of soils to climate and land use change.

Invited external expert: Dr. Lorenzo Manichetti: «A multi-objective calibration of RothC within the GLUE framework: an example of the equifinality inherent to first-order SOC model structures»

Dr. Lorenzo Menichetti is a researcher in the group of Ecosystem Ecology in SLU University in Uppsala (Sweden). He is interested in understanding soil ecosystems as a whole, and this interest evolved naturally toward modelling in recent years. His knowledge base developed around the carbon cycle and its interactions with biotic and abiotic components. A parallel fascination for epistemology brought in an interest for models as hypotheses, and between noise and signal he got particularly attracted by the former.

He graduated in 2006 in Tropical Agriculture at the University of Florence (Italy) with a thesis on the influence of termites on soil biogeochemical cycles. After a period working in private sector, first as agronomist and then as project manager, he started to study for a PhD in soil science in SLU University (Uppsala), where he received it in 2014. The studies were mainly focused on C isotopes, but there he started developing there a side interest for modelling and uncertainty analysis. He then had one really short experience as postdoc in Cranfield University (UK), working with signal processing in soil proximal sensing. This was followed by a second postdoc at the Climate and Air Pollution group in Agroscope Zürich (Switzerland), more specifically on soil organic carbon (SOC) modelling where he sharpened the tools he developed during the PhD studies. He recently headed back to Sweden, in the same institution and partially same group as during the PhD studies, but this time with more clear ideas about his interest and more specifically working on soil models. He is at the moment following two project, one more experimental about modelling the influence of wild deer on nutrient fluxes between ecosystems, and another focused on maintaining and extending the SOC model developed in SLU Uppsala, ICBM.
His modelling style, probably influenced by his teachers, is oriented toward minimalism and characterized by a pretty liberal use of Occam's razor.
Abstract
Authors: Lorenzo Menichetti1[11], Claudia Cagnarini[12]
The vast majority of current soil organic carbon (SOC) models or modules are based on similar structures all implementing first-order kinetics. In order to represent the paradigm of chemical SOC recalcitrance within these structures, most of these models utilize a set of relatively arbitrary C «pools», each with a different decay constant. These structures are far from being minimalistic, and they usually lead to many interactions between the parameters (mostly decay constants with input and humification rates). The effect of these interactions on model parameterization is defined in the literature as equifinality, a word expressing the rather intuitive concept that one particular predicted value by a particular model structure can be generated by many combinations of parameters (parameter sets) which, due to the interactions, can differ substantially the one from the other.

This has the consequence of widening the uncertainty bounds of model predictions, or, in case of calibrations still based on the search of a single optimum, unrealistic predictions depending on local conditions.

In this study we selected RothC, one of the most widely used SOC models, as a target for an exploration based on the GLUE framework[13] based on multi-decadal data from a Swiss long term experiment (ZOFE, located in Zürich). In an attempt to reduce model uncertainty and overcome the expected equifinality, we introduced a multi-objective calibration based on several variable, cali-

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[11] *SLU University, Uppsala, Sweden*

[12] *Bangor University, Bangor, UK*

[13] *Beven, K., & Binley, A. (2014). GLUE: 20 years on. Hydrological Processes, 28(24), 5897–5918. https://doi.org/10.1002/hyp.10082*

brating 1) against SOC time series, 2) against SOC time series and soil respiration measurements from the literature, 3) against SOC time series and biomass measurements from the literature 4) against SOC time series and a Zimmerman's fractionation results from the literature.

All these criteria defined several multidimensional model spaces (where the dimensions where defined by parameters and fitness indicators), within which results were analyzed and presented.

In general the model resulted quite undetermined, and the impact of the additional criteria on the parameterization uncertainty was really low if detectable at all, confirming some limitations inherent to representing SOC decay with structures based on first-order kinetics.

Invited external expert: Prof. Grabarnik Pavel Yakovlevich

Laboratory head of Ecosystems Modeling, Institute of physical-chemical and biological problems of soil science Russian Academy of Science, Puschino

д.ф.— м.н., заведующий лабораторией моделирования экосистем Института физико-химических и биологических проблем почвоведения РАН, Пущино, Россия

Биография

1979 — закончил факультет прикладной математики-процессов управления Ленинградского государственного университета

1992 — защитил кандидатскую диссертацию на тему «Оценивание параметров пространственных точечных процессов марковского типа»

2013 — защитил докторскую диссертацию на тему «Моделирование и методы статистического анализа пространственной структуры древостоев на основе случайных точечных полей»

с 1979 — сотрудник Института физико-химических и биологических проблем почвоведения РАН

Научные интересы

Математическое моделирование лесных экосистем, моделирование пространственно распределенных систем взаимодействующих объектов; пространственная статистика, стохастическая геометрия, обработка изображений, байесовские методы анализа стохастичесих моделей, анализ чувствительности и неопределенности модельных систем

Dr. Elena Rovenskaya: «Early warning signals of regime shifts in time series of data from financial markets»

Elena Rovenskaya is the Program Director of the Advanced Systems Analysis (ASA) Program at the International Institute for Applied Systems Analysis. She is also a Research Scholar at the Optimal Control Department of the Faculty of Computational Mathematics and Cybernetics, Lomonosov Moscow State University, Russia. Her scientific interests lie in the fields of theory of optimal control, ill-posed problems and economic-environmental modeling.

Dr. Rovenskaya graduated in 2003 from the Faculty of Physics, Lomonosov Moscow State University, Russia. She received her PhD in 2006 from the Faculty of Computational Mathematics and Cybernetics, Lomonosov Moscow State University, Russia. The title of her PhD thesis was «On solving the problem of finding the optimal compatibility parameter value for a class of equations in a normalized space.» In 2005, Dr. Rovenskaya participated in IIASA's Young Scientists Summer Program and since 2006, she has been collaborating with the Dynamic Systems Program and later with its successor, Advanced Systems Analysis Program. In 2013, she was appointed Acting Program Leader for the ASA Program and in 2014, she became the Director of the ASA Program.

Dr. Rovenskaya's current research is focusing on modeling of optimal forest management, exploring systemic risks in ecological networks, modeling economic growth with environmental constraints and agent-based modeling of regional development.

Abstract
With this approach based on machine learning and pattern recognition, we investigate whether pre-cursors of certain events can be identified in time series. The developed algorithm must be calibrated («trained») based on past data when an event of interest occurred. The algorithm relies on a random process describing the occurrence of positive and negative signals in a time series preceding the event in question. After calibration, it is able to «see» patterns in the times series, which indicate the probability of the event to occur over a specified time horizon. We demonstrate the applicability of the algorithm for the case study of financial crises over last 40 years.

Dr. Ludmila Artemyeva: «Solving optimal control problems for commercially exploited ecosystems on example of fish population»

Liudmila Artemyeva is an assistant professor at the Optimal Control Department of the Faculty of Computational Mathematics and Cybernetics, Lomonosov Moscow State University, Russia. Her main fields of scientific interest include optimization methods, optimal control theory. She teaches optimization methods, linear optimal control theory, multicriteria optimization theory, optimal control of heating rod. Liudmila Artemyeva also supervise bachelor and master students.

Dr. Artemyeva graduated from the Faculty of Computational Mathematics and Cybernetics, Lomonosov Moscow State University, Russia. In 2013, she received her PhD in mathematics. The title of her thesis is «Searching for an equilibrium point in two-person saddle point games».

Her current scientific work is focused on optimization problems with dynamics, described by partial differential equations, especially on multicriteria optimization in ecological systems.

Артемьева Людмила Анатольевна работает в должности ассистента на кафедре Оптимального управления факультета Вычислительной математики и кибернетики Московского государственного университета имени М. В. Ломоносова. В область научных интересов Артемьевой Л. А. входят методы оптимизации, оптимальное управление. На факультете ассистент Артемьева преподает такие предметы как «Методы оптимизации», «Линейная теория оптимального управления», «Многокритериальная оптимизация», «Оптимальное управление нагревом стержня». Также ассистент Артемьева руководит выпускными работами студентов бакалавриата и магистратуры.

Артемьева Л. А. с отличием закончила факультет вычислительной математики и кибернетики. В 2013 году успешно защитила диссертацию на тему «Методы поиска точки равновесия в седловых играх двух лиц».

В настоящее время исследования Артемьевой Л. А. посвящены разработке методов решения задач оптимального управления процессами, описываемыми уравнениями в частных производных, и, в частности, задач многокритериальной оптимизации экологических процессов.

Abstract

Optimal harvesting of biological renewable population (such as fish and trees) is one of the classic problems of resource economics[14][15]. While trying to solve this problem an important question is the level of biological detail and complexity of the chosen model that are sufficient for various purposes. Today exist a range of population models such as exponential population growth, logistic equation as model of population dynamics and recently there has been a growing interest in extending classic fishery models to cover multiple species and metapopulations and to include the age-structure of the population.

In a present work, the age-structured population model[16] described by the linear partial differential equation is considered. This model consists of the evolutionary equation, the boundary condition which is known as fertility equation and the initial condition. The goal is to find the control function that satisfies the model and optimizes several utility functions (economic and ecological utility functions). The presence of several functions is since fishery management handles typically with multiple objectives, in most cases conflicting (maximizing fishing yields, minimizing ecological impacts). In this case we cannot find the optimal solution in a common way. We need to find specific equilibrium solutions.

To solve the problem, we can use the following scheme. First of all it is needed to formulate the problem in a form which is mostly convenient for applying analytical methods. Than it is needed to propose a step-by-step scheme how to find the Pareto frontier. Also, it is needed to propose a difference scheme to solve numerically the dynamic equation. In the method mentioned above can arise next challenges. First of all, it is the possibility to find the analytical solution in dynamic model? How should we value employment, fish stock in the water, etc. What to do if we receive inaccurate input data? Do we need to use in this case specific regularization methods?

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14 *G. C. Plourde. A simple model of replenishable resource expoitation. Am. Econom. Rev. 60, 518–522.1970.*

15 *C. Koen. Optimal harvesting of renewable resources. JOTA. 58, 83–91. 1988*

16 *Olli Tahvonen. Economics of harvesting age-structured fish population. Journal of environmental economics and management. 2009. 58. pp. 281–299.*

Задачи оптимального управления для коммерчески эксплуатируемых экологических систем, на примере рыбных популяций.

Вопрос оптимального потребления биологически возобновляемых ресурсов, таких как, рыбные или лесные ресурсы, является одной из классических задач экономики ресурсов[17][18]. При решении таких задач важным является вопрос выбора должного уровня детализации биологического процесса, или иначе говоря, биологической модели, которая будет в достаточной для конкретной задачи степени описывать процесс. На сегодняшний день существует целый ряд популяционных моделей, среди которых, экспоненциальная модель роста, логистическое уравнение, в последнее время наблюдается большой интерес к развитию классических моделей с целью учесть многовидовую структуру, а также включить структурированность популяций по возрасту.

В настоящей работе рассматривается структурированная по возрасту модель[19], которая описывается уравнением в частных производных первого порядка с нелокальным краевым условием. Необходимо найти оптимальное управление — вылов, который удовлетворяет модели, и при это оптимизирует ряд функционалов (экономические и экологические критерии качества). Наличие нескольких функционалов обуславливается необходимостью оптимизации нескольких функционалов, часто противоречащих друг другу (максимизировать прибыль, минимизировать экологические потери). При такой постановке задачи оптимальное решение в обычном смысле может и не существовать, и в этом случае необходимо искать решение в определенном смысле.

Для решения поставленной задачи предлагается воспользоваться следующей схемой. Сначала необходимо сформулировать задачу в наиболее удобном для применения аналитических методов виде. Далее необходимо выработать пошаговую схему поиска точек Парето исходной задачи. Также необходимо предложить численную схему решения уравнения в частных производных. При подобном подходе могут возникнуть следующие сложности. Возможно ли найти решение уравнения аналитически? Как в модели учитывать рабочую силу, исходное количество рыбы в воде и подобные параметры. Что делать с неточно заданными входными данными? Необходимо ли использовать методы регуляризации?

Anna-Marie Winter: «Regime shifts in a fish population model»

I am a PhD student at the Centre for Ecological and Evolutionary Synthesis (CEES) at the University of Oslo, with Professor Nils Christian Stenseth (CEES), Dr. Anne Maria Eikeset (CEES) and Dr. Andries Peter Richter (Environmental Economics and Natural Resources Group, Wageningen Research Centre and University, Netherlands) as my supervisors.

My scientific interest lies in feedback effects between anthropogenic activity and natural resource dynamics in aquatic systems and I am especially intrigued by those interactions that lead to a collapse of the resource.

In my PhD research, I focus on how climatic drivers (e.g. increase in sea surface temperature or acidification of the ocean) interact with harvesting pressure (e.g. by fishing pressure, gear selectivity or open access of a fishery) and erode the resilience of a fish population and its ability to recover from collapse. Recovery potential is particularly reduced if the fish population's recruitment is

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[17] *G. C. Plourde. A simple model of replenishable resource expoitation. Am. Econom. Rev. 60, 518–522.1970.*

[18] *C. Koen. Optimal harvesting of renewable resources. JOTA. 58, 83–91. 1988*

[19] *Olli Tahvonen. Economics of harvesting age-structured fish population. Journal of environmental economics and management. 2009. 58. pp. 281–299.*

impaired by e.g. an Allee effect: Below a certain biomass threshold individual growth rate and thus the population's potential to replenish is decreased, even when fishing pressure is reduced. Reversion of such a regime shift pose a major challenge for fisheries management. With theoretical population models I aim to study the system's behavior precedent such a regime shift, to then identify indicators signaling the proximity of a possible collapse. The project TerMARisk was found to bring together mathematicians and natural scientists to study this challenge of regime shift anticipation.

TerMARisk also reflects my joy to work together with scientists from different nationalities and disciplines. I believe in inclusiveness and accessibility of research and appreciate when reaching an audience beyond.

Abstract
Regime shifts in fish population

Regime shifts in marine systems are often discussed on an ecosystem level, where an unbalance in species interactions often caused by fishing, leads to the persistent ecosystem change.
Here I focus on regime shifts in fish communities and populations, which lead to a low abundance or collapsed state as an alternative regime that is stabilized by different feed-back mechanisms. In particular, I focus on size-selective feeding and density-dependence as an underlying feed-back mechanism. For example, in the Baltic Sea, the fishing of Atlantic cod and the resultant lack of top-down control of its prey population dynamics lead in a different prey size structure, with less individuals suitable to predation. Thus, Atlantic cod is remained at small population size owing to food shortage.

Besides the prey-size preference, the negative density dependence of the cod's prey hampers its recovery. The prey fish released from top-down control replenishes fast and outcompetes the juvenile cod.

The Allee effect is a case of a positive density dependence at small population size. Individual growth rate and thus also the population's renewal capacity is reduced below a certain biomass threshold. If the population is reduced below the Allee threshold, it will degrade towards collapse even if the fishing pressure is removed.

Preventing and reverting such a regime-shift is a major challenge for fisheries management, because fish population are exposed to a multitude of stressors, which interact and are not stable in time. Climate and fishing pressure are rising and likely to increase the occurrence of unwanted regime shifts. This poses an additional challenge for rebuilding strategies of fisheries, which are already vulnerable due to e.g. fishing induced body size-truncation and demographic instability.

Project leader of terrestrial group: Dr. Nadezda A. Vasilyeva: «Mathematical modeling of regime shifts in soils»

My research interests are in the area of nonlinear dynamics in complex self-organizing systems and feedbacks in biospheric processes. I have been working on modeling mechanisms of macroscale soil structure genesis and degradation driven by soil organic matter transformations by microorganisms. I am very interested two broaden my ecosystems research vision. This excellent opportunity is provided now by NordForsk supported Nordic-Russian collaboration project «Multidisciplinary approach two anticipate critical regime shifts in terrestrial and marine systems at risk» (TerMARisk). The project was initiated by Anna-Marie Winter between CEES and our Interdisciplinary Laboratory for Mathematical Modeling of Soil Systems That Dokuchaev Soil Science Institute in Moscow, Russia (ILMMSS).

As a postdoc I have experienced teamwork in international research projects at the French National Center for Scientific Research (CNRS) with a research project on soil organic carbon stabilization process and sensitivity two climate change. As well, as a visiting postdoc in the University of Zurich with research on black carbon stabilization of soil organic matter, and the University of Pennsylvania, Philadelphia with soil organic matter study using thermal analysis.
As educational background I have obtained PhD at the Lomonosov Moscow State University, Russia, Department of Soil Physics and Reclamation, together with MS in Soil Science Department and BS in Applied Mathematics and Informatics, specializing in mathematical modeling and numerical methods at the Department of Mathematical Physics.
Within TerMARisk project I am supervising a master student Maria Zaitzeva from ILMMSS. I work together with Dr. Artem Vladimirov from ILMMSS and Anna-Marie Winter from CEES on developing early-warning signals of predicting critical regime shifts in ecosystems under supervision of Prof. Nils Stenseth and Dr. Anne Maria Eikeset.

Abstract
To describe soil aggregate structure formation and organic matter (OM) transformation processes resulting from soil microbial activity it is necessary to model competition in microbial community for various substrates considering priming-effects and other nonlinear processes. Especially interesting is self-organization of microbial community and its habitat[20], now as well in the context of considering competition and physical environmental factors while upscaling to model macroscopic fluxes of carbon dioxide from soils with changing climate[21]. Earlier we have developed a multiscale 1D dynamic model of microbial growth and C cycle, applied to a spherically-symmetrical soil aggregate and soil profile[22], where we showed the emergence of pore-space structure as a

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[20] *Young I. M. and Crawford J. W. Interactions and Self-Organization in the Soil-Microbe Complex // Science 2004. V.304, Issue 5677, pp. 1634–1637*

[21] *Evans S.E, Dieckmann U., Franklin O. and Kaiser C. Synergistic effects of diffusion and microbial physiology reproduce the Birch effect in a micro-scale model // Soil Biology and Biochemistry 2016. V.93, pp.28–37*

[22] *Vasilyeva N. A., Ingtem J. G. and Silaev, D. A. Nonlinear Dynamical Model of Microorganism Growth in Soil // Computational Mathematics and Model-*

result of interactions between microbes, OM, temperature, water and oxygen. In the present study we propose the development of the model for a 2D case, needed for modelling effects of landscape heterogeneity, phytocenosis and rhizosphere boundaries on evolution of soil cover heterogeneity. We are looking for solutions in which at the same time are realized different dynamic regimes in different spatial domains. Proposed is a multiscale modeling of spatial patterns in dynamic regimes of microbial competition in soil and formation of soil structure as a result of microbial transformation of OM. Previous concept of OM states cycling is extended on the basement of experimental data about physical soil fractionation (with minimal disturbance of chemical structure), i.e. granulo-densimetric fractions (on particle density and size), long-term field experiments to obtain stable OM pool and laboratory incubation experiments of soil respiration in series of moisture and temperature. Thus, OM transformation is modelled in a particulate/free state and organo-mineral/adsorbed state onto mineral, each comprised of labile and stable pools, with age-structure and feedbacks between fractions and their rates of decomposition (density-dependence/priming-effect). Model solutions are found in which simultaneously in different parts of space realized are chaotic oscillations, stationary domains and regular waves of microbial population and OM.
Since soil microbes are driving changes in their environment then if complex self-organized structure of microbe community realizes that lasts enough long then the trace there are leaving with their life cycle can be a mechanism, responsible for formation of soil physical structure at different space-time scales.

Абстракт.
Математическое моделирование смены режимов в почвах
Для описания процессов агрегатообразования и трансформации органического вещества (ОВ), являющихся результатом активности почвенных микроорганизмов необходимо моделирование конкуренции различных видов микроорганизмов за различные виды субстратов с учетом прайминга и других нелинейных процессов. Особый интерес представляет самоорганизация жизнедеятельности микробоценоза и его среды обитания[23], теперь уже и в контексте учета конкуренции и физических факторов среды при переходе к моделированию макроскопических потоков углекислого газа из почвы с изменением климата[24]. Ранее нами была разработана одномерная многомасштабная динамическая модель роста почвенных микроорганизмов и круговорота углерода, применимая к сферически-симметричному почвенному агрегату или почвенному профилю[25], где была получена самоорганизация порового пространства почвы в результате взаимодействия почвенных микроорганизмов, ОВ, температуры, воды и кислорода. В настоящей работе предложено развитие модели на двумерный случай, необходимое для моделирования влияния неоднородности ландшафта, границ растительных сообществ и ризосферных границ на формирование пестроты почвенного покрова. Мы ищем решения, в которых одновременно реализуются разные динамические режимы в разных областях пространства. Представлено многомасштабное моделирование пространственных паттернов динамических режимов конкурен-

ing. Springer Verlag, 2016. V. 27 № 2. P. 172–180

23 *Young I. M. and Crawford J. W. Interactions and Self-Organization in the Soil-Microbe Complex // Science 2004. V.304, Issue 5677, pp. 1634–1637*

24 *Evans S.E, Dieckmann U., Franklin O. and Kaiser C. Synergistic effects of diffusion and microbial physiology reproduce the Birch effect in a micro-scale model // Soil Biology and Biochemistry 2016. V.93, pp.28–37*

25 *Vasilyeva N. A., Ingtem J. G. and Silaev, D. A. Nonlinear Dynamical Model of Microorganism Growth in Soil // Computational Mathematics and Modeling. Springer Verlag, 2016. V. 27 № 2. P. 172–180*

ции микроорганизмов в почве и формирования почвенной структуры в результате трансформации микробами почвенного ОВ. Прежняя концепция круговорота состояний ОВ расширена на основано на экспериментальных данных о физическом фракционировании почвы (с минимальным нарушением химического строения), т.е. грануло-денсиметрическими фракциями (по плотности и размеру частиц), многолетних полевых экспериментах по получению стабильного ОВ и лабораторных инкубациях почвенного дыхания в сериях температуры и влажности. Таким образов, трансформация ОВ моделируется в свободном и адсорбированном на минералах состоянии, включая легко- и труднодоступные пулы, с возрастной структурой и учетом взаимного влияния фракций на скорость их разложения (прайминг-эффект). Найдены решения модели в которых одновременно в разных областях пространства реализуются хаотические колебания, стационарные области и регулярные волны популяций микроорганизмов и органического вещества.
Поскольку микроорганизмы в почве способны менять свойства своего окружения, то если реализуется сложная самоорганизация микроорганизмов в структуры, которые существуют достаточно долго, то оставляемый ими след в процессе жизнедеятельности может быть механизмом, отвечающим за формирование физической структуры почвы на разных пространственно-временных масштабах.

Dr. Artem Vladimirov: «Analysis of modelled time series of fish population under different scenarios of commercial exploitation and development of methodology for detection of early warning signals of regime shifts»

As a researcher in Dokuchaev Soil Science Institute, Interdisciplinary Laboratory for Mathematical Modeling of Soil Systems I participate in the project TerMARisk: a multidisciplinary approach to anticipate critical regime shifts in ecosystems — deriving management guidance for terrestrial and marine systems at risk. The goals of this project include developing methodology for predicting collapse in ecosystems under harvesting pressure and finding similarities in behavior of marine and terrestrial ecosystems.
My research interests include mathematical modeling and analysis of complex behavior and self-organization in ecosystems alongside with condensed matter theory, magnetism and general problems of numerical and mathematical modeling. I got my PhD in theoretical physics in 2010 from Joint Institute for Nuclear Research, Dubna, Russia. Since then I work on theory of condensed matter, in particular, magnetism and spin fluctuations in strongly correlated electronic systems. In 2015 I started to work on mathematical modeling of soil organic matter transformation and microbial growth in collaboration with Dr. Nadezda Vasilyeva from Dokuchaev Soil Science Institute, Moscow, Russia, and in 2016 I joined Interdisciplinary Laboratory for Mathematical Modeling of Soil Systems (ILMMSS) under supervision of Dr. Nadezda Vasilyeva, as it was created.

Abstract
Marine fish populations are part of ecosystems with many complex non-linear feedbacks, which may prohibit population recovery after it is declined below certain threshold due do commercial

fishing, as it happened with north-western (Canadian) population of Atlantic cod[1]. Nature of such feedbacks and population level at which recovery is inhibited are unknown. Even direct measurement of current population state and precise control of fishing rates are often not possible. To avoid collapses of other fish population in the future, it is important to predict them in advance, so necessary action can be taken to avoid collapse. This is a challenging task, because mechanisms, that will lead to collapse of the particular population have not yet been observed, thus methodology of collapse prediction should be based on general properties of population dynamics. Pure statistical approach to reveal early warning signals cannot be applied here, because there is not enough historical data available. We propose to supplement statistical approach with quite general model of fish population dynamics, which can be parameterized on historical data and then used to generate time series for all possible range of unknown parameters, so collapse probability can be estimated. Age structured model for Atlantic cod population dynamics with non-linear effects is proposed for this purpose. Model features new stock-recruitment function which is chosen considering biological mechanisms of fish spawning process, and allows to describe historical population dynamics and population collapses better then commonly used functions. Also, density dependence for natural mortality and correlated random process for fish weight are proposed for predictions. Long time series of fish population are generated, using different fishing strategies and analyzed for population collapses. Collapse probability, recovery time, steepness of decline and recovery, growth rate and birth/death ratio, age structure of population are analyzed as functions of fishing strategy parameters. Individual collapses and their corresponding fishing strategies are extracted from time series. We categorize fishing strategies according to resulting population dynamics: does not lead to a collapse, leads to a collapse with recovery, leads to a collapse without recovery, and look for common features of each category.

Taras Vasiliev: «Applicability of time series of soil monitoring data for development of early warning signals methodology for prediction of critical changes in soils»

I am a research associate in the V. V. Dokuchaev Soil Science Institute, Interdisciplinary Laboratory for Mathematical Modeling of Soil Systems, where I take part in the development of integrated architecture «field to laboratory» for soil field and experimental data mining and analysis system, currently being tested and implemented in the Institute. I am responsible for the development of cartographic data base and its integration with soil data system in the Soil Data Center of the Institute. My professional expertise is in simulation and experimental data analysis in high-energy physics.

I also started working on a project «Monitoring soil fertility factors and analysis of organic matter transformations» in the newly formed (2017) «Laboratory of Agroinformation analysis» (specialized department of Skoltech in our Institute), where I participate in soil data analysis and developing of a physical properties block for mathematical model of soil fertility.

My research interested are in the development of control-and-measurement systems for studying such complex systems as soil, soil data analysis for automation and raising efficiency of the experimental research.

Я являюсь научным сотрудником в междисциплинарной лаборатории математического моделирования почвенных систем Почвенного института им. В. В. Докучаева. Участвую в разработке интегрированной архитектуры «от поля до лаборатории» для системы сбора и анализа полевых и экспериментальных почвенных данных SoilDrive, находящаяся в настоящий момент на этапе тестирования и внедрения в Институте. Веду разработку картографической базы данных и ее интегрирование с системой почвенных данных SoilDrive в Центре Почвенных Данных Института. Мой профессиональный опыт в области экспериментальной физике элементарных частиц.
Также я начал работать на созданной в 2017 году базовой кафедре «Агроинформационного анализа» Сколтех в нашем Интитуте над проектом «Мониторинг факторов почвенного плодородия и анализ трансформации почвенного органического вещества», где я участвую в анализе почвенных данных и разработке блока физических свойств модели плодородия.
Мои научные интересы в разработке подходов для целостного изучения сложных природных систем и самих контрольно-измерительных комплексов, развитии почвенного анализа данных для автоматизации и повышения эффективности экспериментальных исследований.

Abstract
Under heavy agricultural land use soil bulk density is a highly dynamic soil property since it is forced externally by multiple heavy wheel pressure. Bulk density affects basic soil hydrological properties influencing soil respiration[26] and thus is needed for the soil respiration model to update physical environment parameters in a profile. Compaction is the most rapid change in physical properties of heavily used agricultural soils. It alone can be the driver of changes in the whole ecosystem. We suggest that decompaction potential of the soil should be monitored to anticipate critical (irreversible) change in soil properties.
Although in the framework of a soil respiration model (Terrestrial part Soil: General modelling framework) soil organic matter quality is addressed, currently in only physical fractions (granulo-densimetric fractions, i.e. in size and density) are considered for organic matter states in organic matter transformations part of the model. In the research plan for deriving early-warning signals in soils (scheme 2 in the General modelling framework) we propose the approach to extract information on organic matter transformations in terms of its quality using such an integral characteristic of physical-chemical soil properties as decompaction potential (DP). Decompaction potential is proposed to be modelled from monitoring data of soil physical properties for which fast measuring methods are available in three steps: i) modelling soil bulk density as a function of (profiles of temperature, moisture, resistance to penetration, air-permeability and water-stability) and total organic carbon (TOC) content (monitored every 3–5 years). Model is based on solving inverse problem for heat transfer and further introducing correlations of thermal conductivity with bulk density and above-listed properties; ii) modelling pF-curve (basic soil hydrological characteristic) from bulk density, specific surface area (SSA) and soil drying kinetics with parametrization on direct measurements of soil pF-curve. pF-curve is useful directly for calculating available for plants water budget; iii) modelling decompaction potential from pF-curve with parametrization

[26] *The moisture response of soil heterotrophic respiration: interaction with soil properties FE Moyano, NA Vasilyeva, L Bouckaert, F Cook, JM Craine, A Don, … Biogeosciences 9 (3), 1173–1182*

on kinetics of soil shrinking-swelling. In this way, the resulting model of decompaction potential implicitly contains in its coefficients of correlation with soil water-stability, SSA, drying and shrinking-swelling kinetics.

DP values can be compared to the typical value for soil DP range and thus give an early-warning signal for physical condition — approaching irreversible compaction state of soil. Time period for decompaction can be continuously estimated providing advice on crop-rotation length for management to avoid critical regime shift.

From the other side, comparing simulated DP with direct measurements by simple shrinking-swelling analysis in case of deviation will give information of the change in soil quality coefficients, and its dynamics can be followed by refit of pF-curve.

To develop the concept we used temperature, moisture, water-permeability and compaction profiles of undisturbed steppe soil and highly compacted 60 years bare fallow soil. Currently, this concept is being tested in the ongoing project on «Monitoring soil fertility and soil organic matter transformation» along with spatial variability of agrochemical report data as EWS.

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I am a junior research associate in the V. V. Dokuchaev Soil Science Institute, Interdisciplinary Laboratory for Mathematical Modeling of Soil Systems. I got my master's education in 2017 at the Faculty of Computational Mathematics and Cybernetics of Moscow State University. My scientific interest lies in studying chaotic dynamics in systems of differential equations. Exploring chaotic behavior, scenario of transition to chaos, cascades of bifurcations, singular attractors is what I am focused on in scientific research. The most interesting part of TerMARisk project for me is to study terrestrial and marine systems resilience and collapse detectability.

Я младший научный сотрудник междисциплинарной лаборатории математического моделирования почвенных систем Почвенного института имени В. В. Докучаева. В 2017 году окончила магистратуру факультета вычислительной математики и кибернетики МГУ. Мои научные интересы связаны с изучением хаотической динамики в системах дифференциальных уравнений. Самая интересная часть проекта TerMARisk для меня — изучение подходов к обнаружению признаков критических изменений в экосистемах.

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