ODD+D for LimnoSES

(after the ODD+D protocol for describing human decisions in agent-based models (Müller et al. 2013))

Overview

I.i.a What is the purpose of the study?

The main purpose of the model is to simulate social-ecological feedbacks in lake use and management systems where ecological regime shifts can occur between the turbid and the clear water state. We further aim to extend the regime shift evaluation to include social responses and regulation mechanisms of important drivers in the lake. In particular, the issues of cooperation between different interest groups and time lags of social responses to changes of the lake state play an important role.

I.i.b For whom is the model designed?

For scientists of different disciplinary backgrounds who contribute to research on lake management and look for a deeper understanding of the interplay between social and ecological dynamics.

I.ii.a What kinds of entities are in the model?

The model consists of a social and an ecological submodel. The following descriptions describe both submodels separately (see for an graphical overview **Fehler! Verweisquelle konnte nicht gefunden werden.**).

Ecological entities: The ecological submodel represents the lake that includes the stocks for a predator and a prey fish species (pike – *Esox Lucius* and bream – *Abramis brama* respectively). The density of macrophytes is estimated as a function from bream.

Social entities: One agent represents the municipality and its function to regulate sewage treatment and potentially enforce the upgrade of sewage treatment systems from private house owners. Hundred agents represent private house owners that release nutrients to the lake and decide on potential upgrade of their sewage treatment system.

I.ii.b By what attributes (i.e. state variables and parameters) are these entities characterized?

Ecological entities: The two fish species are represented as stock densities and characterized by growth, mortality and interaction rates. (see for details and numbers section III.iv.b)

Social entities:
The municipalities legislation activity can be triggered by monitoring that the pike density drops below a threshold. The house owners have an onsite sewage system (OSS) that can be upgraded. House owners are characterized by a willingness-to-upgrade that can be increased by information through neighbors who upgraded their sewage system (‘social engagement’) or through regular checks by the municipality (‘central enforcement’).

I.ii.c What are the exogenous factors/drivers of the model?

Ecological submodel: The food web in the lake is driven by the amount of nutrients which can be a time series for nutrient increase/decrease scenarios. In the coupled model, the amount of nutrients is subject to the number of households that release insufficiently treated sewage water into the lake.

Social submodel: The abundance of pike is monitored by the municipality to estimate the necessity to regulate private sewage treatment. As soon as the pike level drops below a threshold, this triggers regulation and informing the private house owners about the need to upgrade their sewage system.

I.ii.d If applicable, how is space included in the model?

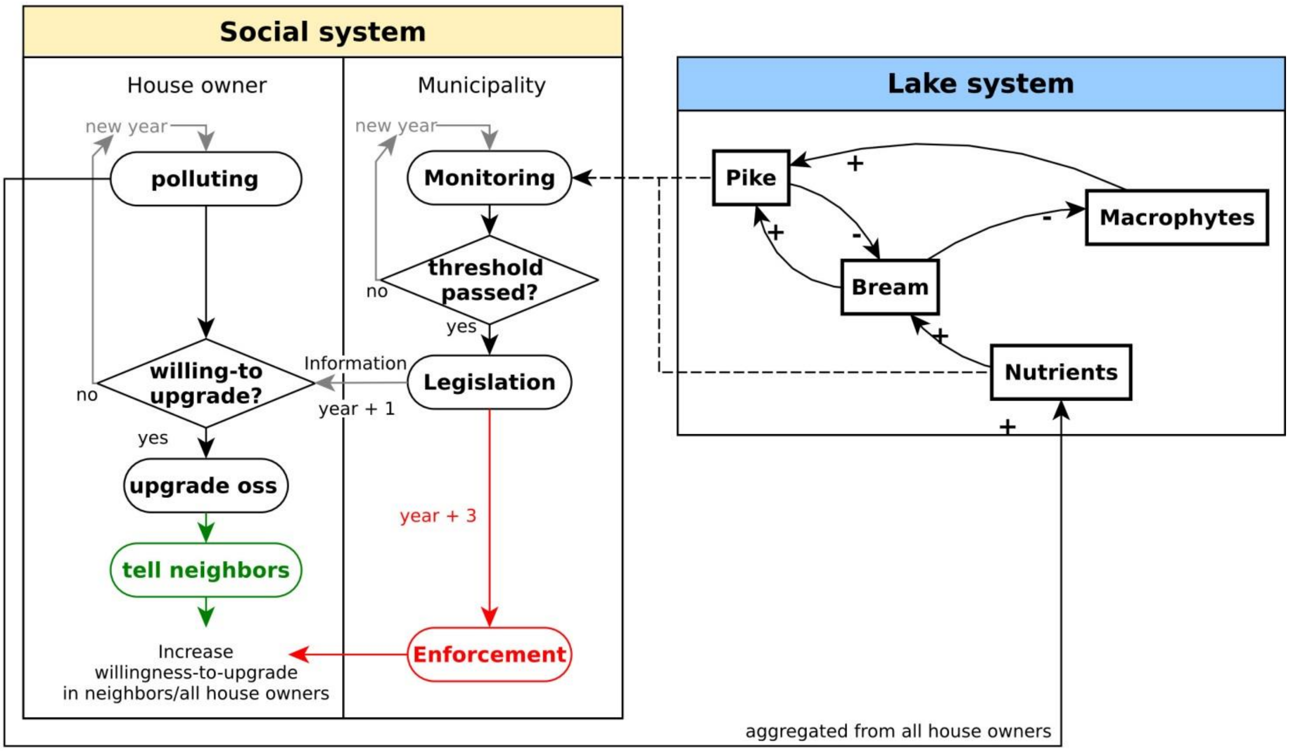
Not included within functions. Lake area and coastal area is only differentiated for visualization purposes.

I.ii.e What are the temporal and spatial resolutions and extents of the model?

The ecological submodel runs on daily time steps, the social submodel on annual time steps. Thus, the processes of monitoring/legislation and house owner decisions about upgrading the private sewage system are made once per year.

I.iii.a What entity does what, and in what order?

1. Pollution: House owners release nutrients through their oss and in case they were informed about the need to upgrade the oss, they decide whether they do this investment (can be done only once). If they upgrade their oss in the 'social engagement' scenario, they inform their neighbors about their modernization which increases their willingness to upgrade.
2. Ecosystem dynamics: Nutrients affect the system dynamics of lake: fish and macrophytes
3. Regulation: The Municipality evaluates monitoring results and starts the legislation for private sewage treatment when the threshold level of pike is passed. As a consequence, house owners are informed about the new law and the need to modernize their oss. For the 'central enforcement' scenario, municipal inspectors are sent out to check on the installed oss and they motivate house owners which increases their willingness to upgrade.



Design concepts

II.i.a Which general concepts, theories or hypotheses are underlying the model's design at the system level or at the level(s) of the submodel(s) (apart from the decision model)? What is the link to complexity and the purpose of the model?

The model addresses social-ecological interactions and therefore includes a social and an ecological submodel that describe the specific subsystem characteristics. The main interactions are monitoring of the lake's state and potential pollution of the lake by applying insufficient sewage treatment installations.

The ecological submodel is a reimplementation of a minimum model that enables regime shifts between the clear and the turbid state of the lake (Scheffer 1989). The social submodel is based on assumptions on social norms that in some situations might overwrite the purely economic reasons for a certain behavior. The case is in general informed by current lake management practices in Sweden and regulation of on-site sewage (OSS) treatment systems (Wallin et al. 2013).

II.i.b On what assumptions is/are the agents' decision model(s) based?

The municipalities decision on regulating private sewage treatment is based on simple thresholds assumed to trigger their response. House owners agents instead are assumed to take individual decisions when requested to upgrade their sewage system. They find themselves in a high-cost low-benefit situation and tend to avoid timely upgrade of their OSS (expressed by the variable willingness-to-upgrade).

II.i.c Why is/are certain decision model(s) chosen?

Due to a lack of empirical evidence, only the simplest assumptions are used here: a probability called willingness-to-upgrade that determines when house owners upgrade their OSS.

II.i.d If the model/submodel (e.g. the decision model) is based on empirical data, where do the data come from?

Not applicable yet.

II.i.e At which level of aggregation were the data available?

Not applicable.

II.ii.a What are the subjects and objects of the decision-making? On which level of aggregation is decision-making modelled? Are multiple levels of decision making included?

Subjects are individual house owner agents.

II.ii.b What is the basic rationality behind agent decision-making in the model? Do agents pursue an explicit objective or have other success criteria?

Not applicable.

II.ii.c How do agents make their decisions?

Decision making is triggered by the information about sewage regulations from the municipality.

Then current value for the willingness-to-upgrade is the probability with which they decide about the OSS update.

II.ii.d Do the agents adapt their behaviour to changing endogenous and exogenous state variables? And if yes, how?

The willingness-to-update can be changing through interventions, either through horizontal information from neighbors that recently updated their OSS or vertical through the municipality that sends out inspectors to check for the current state of the installed OSS. In both scenarios, the willingness-to-upgrade is increased by 50% but it cannot exceed 1.

II.ii.e Do social norms or cultural values play a role in the decision-making process?

In some cases, inspectors were sent by municipalities to check the current installation and support upgrading ('central enforcement'

II.ii.f Do spatial aspects play a role in the decision process?

No

II.ii.g Do temporal aspects play a role in the decision process?

Yes, the willingness-to-upgrade is increased either through stochastic interaction with neighbors or by central enforcement (inspector checks) from the municipality. So, with increasing values for the willingness-to-upgrade, the probability for upgrades increases over the course of one simulation.

II.ii.h To which extent and how is uncertainty included in the agents' decision rules?

Not applicable.

II.iii.a Is individual learning included in the decision process? How do individuals change their decision rules over time as consequence of their experience?

Not applicable.

II.iii.b Is collective learning implemented in the model?

Not applicable.

II.iv.a What endogenous and exogenous state variables are individuals assumed to sense and consider in their decisions? Is the sensing process erroneous?

Not applicable.

II.iv.b What state variables of which other individuals can an individual perceive? Is the sensing process erroneous?

Not applicable.

II.iv.c What is the spatial scale of sensing?

Not applicable.

II.iv.d Are the mechanisms by which agents obtain information modelled explicitly, or are individuals simply assumed to know these variables?

The municipality receives annual updates on the current nutrient content in the lake, it does not read daily variations.

II.iv.e Are the costs for cognition and the costs for gathering information explicitly included in the model?

No.

II.v.a Which data do the agents use to predict future conditions?

Not applicable.

II.v.b What internal models are agents assumed to use to estimate future conditions or consequences of their decisions?

Not applicable.

II.v.c Might agents be erroneous in the prediction process, and how is it implemented?

Not applicable.

II.vi.a Are interactions among agents and entities assumed as direct or indirect?

In the scenario of 'social engagement', the horizontal information exchange about OSS update is considered to be direct.

II.vi.b On what do the interactions depend?

On the spatial distance, we assumed a neighborhood radius of three units.

II.vi.c If the interactions involve communication, how are such communications represented?

No communication is modelled.

II.vi.d If a coordination network exists, how does it affect the agent behaviour? Is the structure of the network imposed or emergent?

Not applicable.

II.vii.a Do the individuals form or belong to aggregations that affect and are affected by the individuals? Are these aggregations imposed by the modeller or do they emerge during the simulation?

No

II.vii.b How are collectives represented?

Not relevant

II.viii.a Are the agents heterogeneous? If yes, which state variables and/or processes differ between the agents?

The willingness-to-upgrade can vary during the 'social engagement' scenario.

II.viii.b Are the agents heterogeneous in their decision-making? If yes, which decision models

or decision objects differ between the agents?

No.

II.ix.a What processes (including initialisation) are modelled by assuming they are random or partly random?

Not applicable.

II.x.a What data are collected from the ABM for testing, understanding and analysing it, and how and when are they collected?

Not applicable.

II.x.b What key results, outputs or characteristics of the model are emerging from the individuals? (Emergence)

The aggregated pollution from private house owners is calculated from the number of not-updated OSS. Further, the time that is needed from the year house owners are informed to the year when all house owners updated their OSS is recorded.

Details

III.i.a How has the model been implemented?

The ecological submodel was first implemented in Matlab Grind to identify suitable value ranges for the alternative stable states. The coupled model was then implemented in NetLogo where the ecological submodel was reproduced within the system dynamics editor. The social submodel was implemented with the common NetLogo interface.

III.i.b Is the model accessible, and if so where?

In the future, it is intended to publish LimnoSES through openabm.org after a thorough review process of the documentation and the code (Rollins et al. 2014). Current model versions are available under https://bitbucket.org/rominama/limnoses.

III.ii.a) What is the initial state of the model world, i.e. at time t = 0 of a simulation run? b) Is the initialization always the same, or is it allowed to vary among simulations? c) Are the initial values chosen arbitrarily or based on data?

For the ecological submodel test, we initialized the lake variables either for the turbid or the clear state:

State	**Nutrients**	**Pike [$g \cdot m^{-2}$]**	**Bream [$g \cdot m^{-2}$]**
Clear	0.5	2.6	25.8
turbid	2.5	0.04	84

The values stem from two independent implementations, one in Matlab where we identified stable states numerically and one from a reimplementation NetLogo.

III.iii.a Does the model use input from external sources such as data files or other models to represent processes that change over time?

No

III.iv.a What, in detail, are the submodels that represent the processes listed in 'Process overview and scheduling'?

1. House owners release nutrients

Assumptions: We have a total number of households (h) that may contribute to eutrophication of the lake through untreated sewage leaking into the catchment.

- A minimum threshold of polluting households is tolerated (tl) that does not lead to increases in nutrients in the lake
- The number of affectors above this threshold tl translates linearly into an amount of sewage-water with a maximum value 0.1
- If less than the threshold tl is polluting, the difference is contributing in the same way (linearly) to reduction of nutrients until the initial nutrient level is reached. This means that at a tl of 50% and 80% of households upgraded the oss, 30% of the maximal change value of nutrients is applied to reduce the current nutrient level in the lake. Tolerance values lower than 50% would indicate that a slower maximum decrease in nutrients is possible than increases.

$$f(affectors) = -\frac{tl \cdot sewage_{max}}{h-tl} + \frac{sewage_{max}}{h-tl} \cdot affectors$$

Parameter	comment	Value [per year]
$sewage_{max}$		0.1
tl	Tolerance level of polluting households	50 [%]
h	Total number of households	100

2. System dynamics at the lake

$$\frac{dbream}{dt} = ib + r \cdot \left(\frac{nutr}{nutr + H_1}\right) \cdot bream - cb \cdot bream^2 - \frac{bream^2}{bream^2 + H_4^2} \cdot pike \cdot predation_{rate}$$

$$\frac{dpike}{dt} = ip + pike \cdot predation_{rate} \cdot predation_{efficiency} \cdot \left(\frac{bream^2}{bream^2 + H_4^2}\right) \cdot \left(\frac{V}{V + H_2}\right) - pike \cdot mortality - cp \cdot pike^2$$

3. Municipality regulation

0) baseline: immediate response to pike threshold means that houseowners are directly informed and they have a uniformly distributed willingness-to-upgrade

a) 'central enforcement': we assume centralized, regular monitoring activities of the lake water quality. When it is perceived as necessary, new rules are developed, such as "Lex Ringsjön". This asks houseowners to install particular private sewage systems and they are regularly checked whether their installation works sufficiently or not. So all houseowners receive the information about the new law at the same time but their compliance rate is low.

b) ‘social engagement’: individual houseowners perceive the state of the lake through swimming or fishing activities. Since they are educated, they also see the necessity to upgrade their sewage system but this 'mind shift' may happen at certain events and not for all houseowner at once. But as soon as they see their neighbor doing it, the compliance rate is high.

III.iv.b What are the model parameters, their dimensions and reference values?

Table 1Ecological parameters and values from an ecological minimal model (Scheffer 1989)

Parameter	comment	Value [per year]	Value [per day]
r_bream		2.74 g/year	7.5*10^-3 day^-1
Predation_rate	maximum predation rate of pike	18.25 year^-1	prmax: 0.05 day^-1
Predation_efficiency	pike conversion efficiency to growth	0.1	0.1
Mortality pike		0.82	2.25*10^-3 day^-1
Cb [cp]	Intraspecific competition constant for bream [pike]	0.0274 m^2 g^-1 year^-1, [0.1]	7.5*10^-5 day^-1 [2.75*10^-4 day^-1]
Im	Immigration	0.009 g m^-2 day^-1	0.00002
H1 H2 H3 H4	Half saturation constants on how - nutrients supports bream growing - vegetation hampers pike reproduce - bream disturbs vegetation as total - bream predation supports pike growth	0.5 (dimension less) 10 % 20 g/m^2 15 g/m^2	0.5 (dimension less) 10 % 20 g/m^2 15 g/m^2

III.iv.c How were the submodels designed or chosen, and how were they parameterized and then tested?

1. Find out whether submodels exhibit multiple stable states, determine initial conditions that lead to stable state (Python script 1 to check via isoclines?!)

2. Check: How do parameter changes affect equilibrium? Which parameters allow for large or only small changes while keeping the characteristics of the system? (Python script 2 to analyze NetLogo outcome)

3. How do links/interrelations between different minimal models change the system stability?

4. Extend this test (2./3.) to include social processes, variables.

Table 1: Implemented experiments in the NetLogo BehaviorSpace to test and validate model assumptions, analyze the sensitivity of patterns towards input variation, and to explore model behavior in extended experiments.

Test or experiment	Hypothesis and assumptions	Observed effects	Follow up question

I: “Rtipping” – Transient nutrient in-/decrease	Hysteresis	Sudden shifts in bream and pike abundance appear, but it is dependent on the rate of nutrient change.	Why is the rate only affecting eutrophication and not restoration?
II: “TurbidityResponse” a) start with turbid state	Social pressure between houseowners works faster than top-down rule enforcement	Yes, but only in conditions were the initial willingness-to-upgrade is greater than 0.2	In what way would results differ in a fully coupled system?
III: “FullRestoration”	Social response lags may cause even larger lags in restoring the pike level	Pike restoration time increases non-linearly with the social time lag	Where does the variability between runs originate?

References

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