

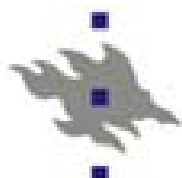
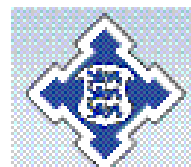
EVAGULF

Protection of aquatic communities in the Gulf of Finland: risk-based policymaking

Final report

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Contents

Summary	3
Tiivistelmä	4
Kokkuvõte	5
Project objectives	6
Project activities	6
Bayesian networks	6
Use of Bayesian networks in the EVAGULF model	7
Areal division	9
Scenarios and nutrient loading forecasts	9
Risk approaches	11
EU Water Framework Directive (WFD) approach	12
International conservation status classification (IUCN) approach ...	13
Key environmental correlates	14
Physical variables	15
Bayesian MCMC population models	16
Species	16
Methods	17
Priors	18
Data	23
Posteriors	23
Population Bayesian networks in Hugin	24
Future development	24
Prediction models for the Estonian WFD variables	25
Data availability and analyses	25
ZKI Index of macrozoobenthos community	27
Valuation	30
Decision support tool – EVAGULF RADSS	31
System architecture	31
Graphical user interface	33
Results	35
Sensitivity of the Gulf of Finland food web to nutrient reductions	39
Background	39
Materials and methods	39
Results	44
Discussion	50
Impact of the project	51
Financing and participants	52
Dissemination	53
Press releases	53
Www-pages	54
Newspaper articles	54
Presentations	54
Articles	56
Acknowledgements	56
References	56
Appendixes	

Summary

The water quality and the state of the ecosystem in the Gulf of Finland have deteriorated with an accelerating pace during the last years. This has happened despite considerable investments on environmental protection, research, and international protection programmes and agreements. The largest problem is still eutrophication, primarily caused by nutrient loading from the catchment area. The main objective of the project EVAGULF was to design and construct a meta-analysis tool which would enable linking together different data and model results to create a more complete general view of the eutrophication chain, its consequences in the ecosystem of the Gulf of Finland and related uncertainties. This kind of tool was expected to increase the information value of existing data and knowledge. An important aim was also to develop a probabilistic approach for risk assessment and management purposes of ecosystems.

The model developed during the project is based on Bayesian networks, which integrate results of several models. It enables the assessment of the utilities gained and risks posed by some general country-specific nutrient loading scenarios. The model also makes possible to evaluate the likely role of increased precipitation caused by the global climate change in respect to the magnitude of nutrient loading. In the model, the Gulf of Finland is divided into 9 sub-areas, each of them being modelled and evaluated separately, which enables the assessment of country-specific significance for each of them. The first version of the EVAGULF model is based on two different valuation approaches: the criteria of the international conservation status classification and the coastal water classification system of the EU Water Framework Directive. Both aim to secure the biological diversity and a good environmental status of the Gulf of Finland, but their emphasis and indicators vary.

With the EVAGULF Risk Analysis and Decision Support System (RADSS), population and ecosystem level risks can be calculated for different nutrient loading scenarios with the conditions defined by the user. The Bayesian network calculates the probability distributions for the amount of external nutrient loading to the water area in question from the catchment area, conditional to the options selected by the user. This information is further processed in the ecosystem model part, where the conditional probability distributions for the predicted environmental variables due to changes in primary production are modelled. The output distributions of the ecosystem model serve as input data for the population analyses, which model the probable response and the survival of the species in the conditions in question.

In addition, a food web model using Ecopath with Ecosim software was developed within the project. This model describes the species interactions as well as the effect of changing environmental conditions, including changes in nutrient levels. This kind of information can be combined in the EVAGULF model in the future. The model covers the Gulf of Finland with both temporal and spatial resolution. This area has been described as a part of the entire Baltic Sea area, as well as separately in order to reach higher spatial resolution. This model takes into consideration the variation in major external forces, such as the salinity gradient, bottom hypoxia and fishing effort.

The project EVAGULF (fimos 113560) was carried out as a part of the INTERREG III A Southern Finland and Estonia –programme from September 1st 2006 to December 31st 2007. The project was financed by the European Regional Development Fund, South-East Finland Regional Environment Centre, Estonian Ministry of the Interior and University of Tartu.

Tiivistelmä

Suomenlahden vedenlaatu ja ekosysteemin tila ovat viime vuosina heikentyneet kiihtyvällä tahdilla. Tämä on tapahtunut huolimatta huomattavista investoinneista luonnonsuojeluun, tutkimuksesta sekä kansainvälisistä suojeluohjelmista ja -sopimuksista. Suurin ongelma on edelleen rehevöityminen, joka johtuu pääasiallisesti valuma-alueelta tulevasta ravinnekuormituksesta. EVAGULF-hankkeen päätavoite oli suunnitella ja rakentaa meta-analyysityökalu, joka mahdollistaisi erilaisten aineistojen ja mallitulosten yhdistämisen, jotta voitaisiin luoda parempi kokonaiskuva rehevöitymisketjusta, sen seurauksista Suomenlahden ekosysteemissä ja siihen liittyvistä epävarmuuksista. Tämän kaltaisen työkalun odotettiin lisäävän olemassa olevien aineistojen ja tiedon informaatioarvoa. Tärkeä tavoite oli myös kehittää todennäköisyyspohjainen lähestymistapa ekosysteemien riskinarviointi- ja ohjaustarkoituksiin.

Hankkeen aikana kehitetty malli perustuu Bayes-verkkoihin, jotka yhdistävät useiden mallien tuloksia. Malli mahdollistaa yleisten, maakohtaisten ravinnekuormitusskenaarioiden tuottaman hyödyn ja riskin arvioinnin. Mallin avulla on myös mahdollista tarkastella ilmastomuutoksen todennäköisesti aiheuttaman lisääntyneen sadannan todennäköistä roolia suhteessa ravinnekuormituksen suuruuteen. Mallissa Suomenlahti on jaettu yhdeksään alueeseen, joista jokaista mallinnetaan ja arvioidaan erikseen, mikä mahdollistaa niihin kohdistuvan maakohtaisen vaikutuksen merkityksen arvioimisen. EVAGULF-mallin ensimmäinen versio perustuu kahteen erilaiseen arvotusperiaatteeseen: kansainvälisen uhanalaisuusluokituksen kriteereihin ja EUn Vesiputedirektiivin rannikkovesien luokitusjärjestelmään. Molempien tavoitteena on varmistaa Suomenlahden biologinen monimuotoisuus ja hyvä ympäristön tila, mutta niiden painotukset ja indikaattorit ovat erilaisia.

EVAGULF riskianalyysi- ja päätöstyökalulla (Risk Analysis and Decision Support System; RADSS) voidaan laskea eri ravinnekuormitusskenaarioiden aiheuttamia riskejä populaatio- ja ekosysteemitasoilla käyttäjän määrittelemillä ehdoilla. Bayes-verkko laskee todennäköisyysjakaumat kyseessä olevalle vesialueelle kohdistuvan ulkoisen ravinnekuormituksen määrälle valuma-alueelta käyttäjän valitsemien vaihtoehtojen mukaisesti. Tätä informaatiota käsitellään edelleen ekosysteemimalliosuudessa, jossa mallinnetaan perustuotannon muutosten aiheuttamat ehdolliset todennäköisyysjakaumat ennustetuille ympäristömuuttujille. Ekosysteemimallin tulosjakaumat toimivat sisäänsyöttöaineistona populaatioanalyysille, jotka mallintavat lajin todennäköistä vastetta ja selviytymistä kyseessä olevissa olosuhteissa.

Lisäksi hankkeessa kehitettiin ravintoverkkomalli käyttäen Ecopath with Ecosim -ohjelmistoa. Tämä malli kuvaa lajien välisiä vuorovaikutussuhteita sekä muuttuvien ympäristöolosuhteiden, kuten ravinnepitoisuuksien muutosten, vaikutuksia. Tämänkaltaista informaatiota voidaan jatkossa yhdistää EVAGULF-malliin. Malli kattaa Suomenlahden sekä ajallisesti että paikallisesti. Alue on kuvattu sekä koko Itämeren alueen osana että erikseen tarkemman paikallisen erottelukyvyn tavoittamiseksi. Malli huomioi vaihtelun merkittävässä ulkoisissa tekijöissä, kuten suolapitoisuusgradientti, pohjan vähähappisuus ja kalastuspaine.

EVAGULF-hanke (fimos 113560) toteutettiin osana Etelä-Suomen ja Viron INTERREG III A -ohjelmaa ajalla 1.9.2006–31.12.2007. Hanketta rahoittivat Euroopan Aluekehitysrahasto, Kaakkois-Suomen Ympäristökeskus, Viron sisäministeriö ja Tartun yliopisto.

Kokkuvõte

Soome lahe vee kvaliteet ja ökosüsteemi seisund on viimaste aastate jooksul halvenenud kiires tempos. Halvenemine on toimunud vaatamata märkimisväärsetele investeeringutele keskkonnakaitse, uuringute, rahvusvahelistesse toetusprogrammidesse ja lepingutesse. Suurimaks probleemiks on endiselt eutrofeerumine, mis on peamiselt põhjustatud toitainete lahustumisest veekogumisaladel. EVAGULF projekti peamiseks eesmärgiks oli välja töötada ja konstrueerida analüüsi vahend, mis võimaldaks siduda erinevaid tulemuste andmeid ja mudeleid loomaks täiuslikumat põhiülevaadet eutrofikatsioonihetke ahelast, selle tähtsusest ja mõjust Soome lahe ökosüsteemile. Tähtsaks ideeks oli ka arendada välja võimalik lähenemine riski hindamisele ja haldamisele ökosüsteemi ülalannetel.

Projekti käigus väljatöötatud mudel baseerub Bayesian võrgustikul, mis integreerib mitmeid mudeleid. See võimaldab määrata saadud kasu ja riskid mis puudutavad riigi-spetsiifiliste toitainete lahustumise stsenaariumitega. See mudel teeb ka võimalikuks hinnata suurenenud sademete rolli, mis on tekkinud globaalsetest kliimamuutustest, seoses toitainete lahustumise magnituudiga. Mudelis on Soome laht jaotatud 9 alaks, igat neist on kujutatud ja hinnatud eraldi, mis võimaldab määrata riigi-spetsiifilise tähenduse igale neist. EVAGULFi esimene mudel baseerus kahel erineval väärtushinnangul: rahvusvahelise alalhoiu staatuse klassifikatsioonil ja rannavete klassifikatsiooni süsteemil vastavalt EU veepoliitika raamdirektiivile. Mõlema ideeks oli kaitsta Soome lahe bioloogilist mitmekesisust ja keskkonna seisukorda, aga nende rõhuasetus ja näitajad on varieeruvad.

EVAGULF riskianalüüsi ja otsuste toetamise süsteemiga (Risk Analysis and Decision Support System; RADSS), saab kalkuleerida populatsiooni ja ökosüsteemi taseme riskid erinevatele toitainete lahustumise stsenaariumitele kasutaja poolt määratletud tingimuste järgi. Bayesian võrgustik kalkuleerib tõenäolise jaotuse väliste toitainete lahustumisele vees veekogumise piirkonnas sõltuvalt kasutaja valitud valikutele. Antud informatsiooni töödeldakse edaspidi ökosüsteemi mudeli osas, kus sõltuvalt tõenäolisest jaotusest keskkonna muutuste prognoosandmetele, mis on seotud modelleeritud primaarsete produktsiooni muutustega, on kujutatud. Väljatoodud ökosüsteemi mudeli jaotused toimivad populatsiooni analüüside sisendandmetena, mis kujundavad võimaliku vastutoime ja liikide püsima jäämise küsimuse all olevates tingimustes.

Lisaks on välja töötatud projekti raames web-mudel kasutades Ecopathi koos Ecosim tarkvaraga. Antud mudel kirjeldab liikide integreerumist, samuti ka keskkonna tingimuste muutuste mõju kaasa arvatud toitainete taseme muutusi. Sellist informatsiooni on võimalik ühildada ka tulevikus EVAGULF mudeliga. Mudel katab Soome lahe ajalist ja ruumilist resolutsiooni. Antud ala kirjeldatakse kogu Läänemere ala osana, samuti eraldi osana, et saavutada suurem ruumiline resolutsioon. Antud mudel võtab arvesse peamiste välisjõudude muutused nagu soolasisalduse kõrvalekalded, põhjakihtide hapnikuvaeguse ja kalapüügi.

EVAGULF projekt (fimos 113560) on osa INTERREG IIIA Lõuna-Soome ja Eesti programmist 1.septembrist 2006 kuni 31. detsembrini 2007. Projekti finantseerib Euroopa Regionaalarengu Fond, Kagu-Soome Regionaalne Keskkonnakeskus, Eesti Siseministerium ja Tartu Ülikool.

Project objectives

The water quality and the state of the ecosystem in the Gulf of Finland have deteriorated with an accelerating pace during the last years. This has happened despite considerable investments on environmental protection, research, and international protection programmes and agreements. The largest problem is still eutrophication, primarily caused by nutrient loading from the catchment area (e.g., HELCOM 2005).

The Gulf of Finland has been widely studied, and several long-term monitoring data sets exist (e.g., Elken et al. 2003). Traditionally, each of the possessors of data sets has analyzed their own data separately from the others. In addition, there are hundreds of single studies, whose results have been left totally unutilized after their publication. Because the resources to protect the Gulf of Finland are limited in all the surrounding countries, they should be used in the most cost-effective way possible to improve the state of the water area.

The main objective of the project EVAGULF was to design and construct a meta-analysis tool which would enable linking together different data and model results to create more complete general view of the eutrophication chain, its consequences in the ecosystem of the Gulf of Finland and related uncertainties. This kind of tool was expected to increase the information value of existing data and knowledge. An important aim was also to develop a probabilistic approach for risk assessment and management purposes of ecosystems.

One of the project goals was to search means for studying the country-specific responsibilities within the Gulf of Finland as well as to dissect the role of the global climate change. The aim was to find a way to evaluate the importance of the nutrient loading from each surrounding country for the status of the ecosystem in different parts of the Gulf of Finland. This kind of knowledge would be of great advantage in searching for cost-effective protection measures and evaluating the influence of national and international policies and legislation.

The project also aimed to promote the development of active and transparent cooperation network between both national and international research institutions. Common tools were hoped to promote a common view about the state of the Gulf of Finland and the actions needed to improve it. Bringing out the project and the idea of the produced analysis tool prototype through media and conferences was hoped to arouse discussion about the approach and the need for it among the researchers and decision makers as well as to increase public awareness of the ecosystem level risks related to the eutrophication of the Gulf of Finland.

Project activities

Bayesian networks

Bayesian networks (BNs, e.g., Charniak 1991), based on conditional probabilities and known cause-effect chains, are methodological tools used to combine results from separate loading, ecosystem and population models. They enable the combination of data sets of different forms and with different precision to a single analysis, and the assessment of the origin, type and magnitude of the uncertainties related to the cause-effect relationships and decisions.

Decision support system (DSS) is a term for a method that provides a quantitative means to study different alternative decisions (Clemen 1996). They ease the work of decision-makers by helping to make consistent and justifiable choices. Through Bayesian networks enhanced with decision and utility variables, the management scenarios and their consequences can be evaluated, taking uncertainty fully into account. Thus, BNs are flexible tools what comes to the construction of different kinds of decision support and analysis systems being applied in many environmental issues (see e.g. Borsuk et al. 2004, Marcot et al. 2001, Varis 1997).

A Bayesian network is a way to analyze and visualize, what we think of some phenomenon. It consists of discretized variables, each having a defined number of possible outcomes (discrete classes of variables). The links between the variables have been defined based on how the variables are thought to be related in the light of current knowledge. For each variable having incoming links from parent variables, a conditional probability is determined for every possible level on the condition of all combined levels of the parents. Afterwards, the Bayesian network can be used to evaluate the functioning of the system by manipulating the state of some variables and calculating the effects on others. The network algorithm calculates probability distributions for the variables based on how the conditional probabilities have been defined. In the EVAGULF model, the conditional probabilities are estimated computationally with the help of the models described below.

Bayesian networks have been used to help in the search for optimal decision strategies under uncertainties (Varis 1997). More lately, they have been used in modelling complex environmental questions and interactions containing significant uncertainties (e.g. Reckhow 1999, Marcot et al. 2001, Borsuk et al. 2004). Bayesian networks are especially suitable for questions where uncertainty plays an important role, but, at the same time, the processes and cause-effect relationships are relatively well known (Uusitalo 2007).

Another important benefit is also the easy updating of a Bayesian network: the network updates itself based on a change made in a certain part of it (change means that knowledge related to one or more variables is updated). The new knowledge affects the shape of the probability distribution either by narrowing or spreading it, depending on whether the new observation is in line with earlier results or not. The Bayesian networks and the analysis of the scenarios were carried out in the EVAGULF project by the Hugin software (Madsen et al. 2005). In the Risk Analysis and Decision Support System (RADSS), the Bayesian Networks for Java software (Hsu 2003) were used.

Use of Bayesian networks in the EVAGULF model

The model developed during the project is based on Bayesian networks, which integrate results of several models. It enables the assessment of the utilities gained and risks posed by some general country-specific nutrient loading scenarios. Model also makes possible to evaluate the likely role of increased precipitation caused by climate warming what comes to the magnitude of nutrient loading. In the model, the Gulf of Finland is divided into 9 sub-areas, each of them being modelled and evaluated separately which enables the assessment of country-specific significance for each of them.

With the EVAGULF model, utilities gained with different policy scenarios on population and ecosystem level can be calculated. The user can test different country-specific scenario combinations and the effect of climate warming on the precipitation and dissect the differences

between them. The BN calculates probability distributions for environmental conditions due to changes in primary production basing on the predicted nutrient loads modelled for each scenario.

The output distributions of the ecosystem model results serve as input data for the population analyses, which model the probable response and the survival of the species in the conditions in question. The results are evaluated in the light of two different classification systems. The total benefit gained with the scenario under study is calculated through the valuation system according to the approach (Fig. 1). In the user interface the results are compared to the current situation which is handled as a zero-level.

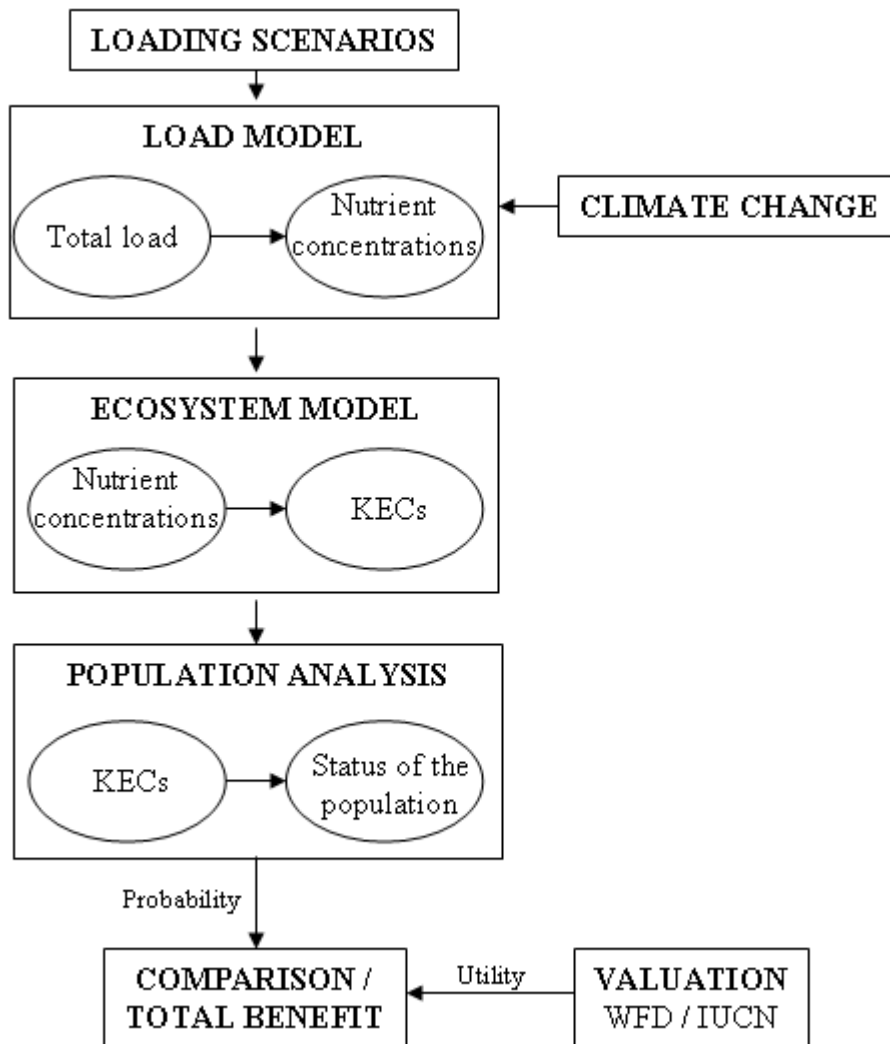


Fig. 1. The simplified structure of the EVAGULF model. KECs = key environmental correlates, WFD = EU Water Framework Directive, IUCN = international conservation status classification.

The model enables studying either the probability distributions of separate variables or classifications as such or comparing the total benefit gained with the scenario compared to current situation. The predictions of EVAGULF model describe the situation in year 2015 (the landmark of the EU Water Framework Directive) assuming that the scenarios have been running at least five years before that.

Areal division

In the EVAGULF decision support model, the coastal areas of Finland and Estonia in the Gulf of Finland are divided according to the division that is made for the implementation of the EU Water Framework Directive (European Commission 2000): the Finnish coast to eastern and western inner and outer archipelago zones, and the Estonian coast to eastern and western coastal zones. The pelagic area is divided into three parts (Fig. 2). This division is based on a similarity analysis conducted in the Finnish Institute of Marine Research.

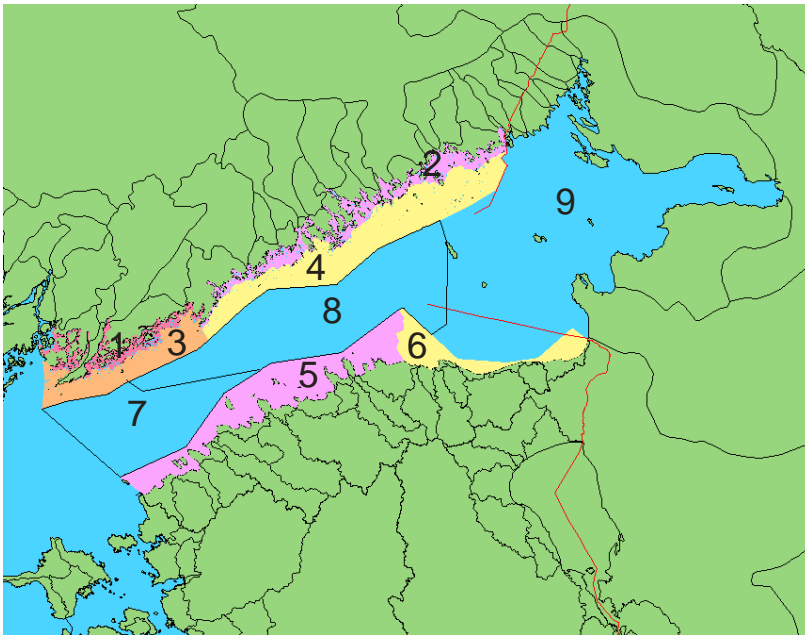


Fig. 2. Regional division of the Gulf of Finland in the EVAGULF tool. Finnish coastal areas: 1. Western inner archipelago, 2. Eastern inner archipelago, 3. Western outer archipelago and 4. Eastern outer archipelago. Estonian coastal areas: 5. Western coast and 6. Eastern coast. Open sea-areas: 7. Western open sea, 8. Central open sea and 9. Eastern open sea.

Scenarios and nutrient loading forecasts

There were four independent nutrient loading scenarios for Finland, three for Russia and two for Estonia. Additionally, one assessment for the climate change (increased precipitation) was formed. Thus the total number of load scenario combinations was 48. The Finnish Environment Institute (SYKE) planned and calculated the scenarios and made test runs with the ecosystem model.

Nutrient (nitrogen, phosphorus) loads were collected from various sources. River loads and loads for municipal and industrial sources in Finland were taken from the data bases of SYKE. Monthly mean values for 2000-2006 were calculated for riverine discharges and direct coastal point sources. This basic data set describes the "present loading", and was considered to be the basic scenario. Basic loading data for the Estonian scenarios were provided by the Estonian Marine Institute, University of Tartu. Mean monthly values for the period 2000-2003 were calculated to represent "present loading". For the Russian load the SEGUE data (Pitkänen & Tallberg 2007) representing the year 2000 (for St. Petersburg 2004) was used.

In addition to the current state, three different water protection scenarios were used for Finland, taken from the Guidelines for water protection towards 2015 (Rekolainen et al. 2006). The decrease

of the discharges in the alternatives varied from -16 to -47 % for total phosphorus and from -15 to -42 % for total nitrogen (Tables 1 and 2).

Table 1. Expected percentile sector-specific nutrient loading reduction in three possible future scenarios in Finland. Scenario 1: "Business as usual"; scenario 2: "Realistic"; scenario 3: "Optimistic".

	Phosphorus (reduction %)			Nitrogen (reduction %)		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Paper industry	-5	-20	-50	0	-15	-30
Communities	-20	-40	-60	-30	-40	-50
Fish farming	-15	-30	-40	0	-20	-30
Fur farming	-20	-40	-50			
Peat industry	-10	-25	-30	-5	-20	-25
Agriculture	-10	-30	-50	-10	-20	-50
Scattered settlement	-50	-65	-80	-30	-45	-65
Forestry	20	-5	-30	-15	-25	-30

Table 2. Predicted total loads of phosphorus (P) and nitrogen (N) from Finland to the Gulf of Finland for different scenarios.

Loading scenario	Climate change scenario	P (t year ⁻¹)	N (t year ⁻¹)
Current	No	625	16618
Current	Yes	782	20146
"Business as usual": -15%	No	539	14407
"Business as usual": -15%	Yes	696	17934
"Realistic": -30%	No	438	13531
"Realistic": -30%	Yes	595	17058
"Optimistic": -40-50%	No	357	11142
"Optimistic": -40-50%	Yes	514	14669

For Russia, two water protection scenarios were applied (Table 3): 1. All waste waters of St. Petersburg region are purified with 80% efficiency regarding phosphorus and with 75% efficiency regarding nitrogen. 2. The purification efficiency is increased in the existing treatment plants to 80% regarding phosphorus alone.

Table 3. Predicted total loads of phosphorus (P) and nitrogen (N) from Russia to the Gulf of Finland for different scenarios.

Loading scenario	Climate change scenario	P (t year ⁻¹)	N (t year ⁻¹)
Current	No	4637	77262
Current	Yes	5654	92285
-80% P, current wwtp	No	4337	77262
-80% P, current wwtp	Yes	5354	92285
-75%N, -80%P, all treated	No	3442	71341
-75%N, -80%P, all treated	Yes	4459	86364

For Estonia, there was one future scenario, the effect of intensified agriculture (Pitkänen & Tallberg, 2007). The scenario indicates the future agricultural development for the time period of 2020-2024. The catchment model PolFlow was applied to approximate the future load to the Gulf of Finland. The PolFlow model (De Wit 1999, 2001) describes sources, transport and loads of nutrients in large drainage basins. It comprises a hydrological part, description of nutrient sources (emissions), their pathways to surface waters and transport of nutrients to the river mouth. In SEGUE project, the economic changes were assessed through two plausible scenarios, the "Low

loading" scenario with environmental friendly political and economic processes, and the "High loading" scenario which led to intensified agriculture in Estonia. The "High loading" scenario was used in the EVAGULF project (Table 4). The phosphorus load was, however, 47 tons/year lower in this scenario than in the basic scenario, whereas nitrogen load was increased by 6575 ton/year. The decrease in phosphorus load is resulting from improvements in manure handling. Environmental requirements will be fulfilled even in the bad scenario in this sector in the future (K. Piirimäe, pers. com.).

Table 4. Predicted total loads of phosphorus (P) and nitrogen (N) from Estonia to the Gulf of Finland for different scenarios.

Loading scenario	Climate change scenario	P (t year ⁻¹)	N (t year ⁻¹)
Current	No	1106	17244
Current	Yes	1441	18970
Agric. load +10 %	No	1059	23819
Agric. load +10 %	Yes	1394	25545

For the climate warming scenario, riverine fluxes from 2000 were used for Finland, representing high run-off and river loads especially in winter. In Estonia riverine fluxes were from 2005, while in Russia high water flows of 2005 (HELCOM/PLC data base) was applied together with concentration data of the year 2000. Climate change was simulated by running the model with the loads from the combined wet years five times in a row.

Risk approaches

The concept of risk contains the probability of a certain event and the magnitude of harm caused if it becomes true. Because the national loading scenarios evaluated in the project were almost all better compared to recent situation, we used the inverse of risk: product of probability and the utility gained with the improvements to evaluate their effects in the ecosystem of Gulf of Finland. The magnitude of harm or utility is always somewhat subjective a question (Burgman 2005). The approach of the EVAGULF model is not designed to reflect the views and values of its creators, but to produce assessments that are commonly acceptable and follow the current concerns and decisions of the society. Therefore, the valuation of utility or harm is based on recommendations and threshold values defined in international agreements, classification systems and legislation.

What comes to the biodiversity and ecological quality of the Gulf of Finland ecosystem, even the commonly accepted definitions of targets, indicators and criteria vary greatly depending on the context. During the project, University of Helsinki made an extensive review of legislation, conventions and classification systems concerning the conservation of the Baltic Sea and the species living in the marine or coastal ecosystems of the Gulf of Finland. The review included the principles of the international conservation status classification system of the World Conservation Union (IUCN 2001), the coastal water classification system of the EU Water Framework Directive (European Commission 2000), the regulations of the EU Nature Directive (92/43/ETY), the guidelines of the Finnish Nature Conservation Act (Ministry of Environment, 1096/1996) and the visions and objectives of the Helsinki Commission (HELCOM) as well as the principles of the planned EU Marine Strategy (European Commission 2006).

The first version of EVAGULF model is based on two different approaches: the criteria of the international conservation status classification (IUCN 2001) and the coastal water classification system of the EU Water Framework Directive (European Commission 2000). Both aim to secure

the biological diversity and a good environmental status of the Gulf of Finland, but their emphasis and indicators vary. These two approaches were chosen because the classification systems they are based on are well-defined and computationally feasible. They also are internationally used and accepted. Principles of both systems are turned into the computational form as precisely as possible.

Methods of the WFD implementation vary slightly between Finland and Estonia. Partners decided to apply the guidelines of both countries within their own coastal areas. One of the future plans is to compare the results and predictions of these two classification systems by modelling. WFD classification has been applied only to the coastal areas of the Gulf of Finland because the system and boundaries are not meaningful to the open sea areas.

EU Water Framework Directive (WFD) approach

For Finnish coastal areas (inner and outer archipelago), the WFD model includes the following indicator variables: winter concentrations of total phosphorus (only for the outer archipelago areas) and total nitrogen, summer values for the secchi-depth and for chlorophyll-a as well as the maximum growth depth of *F. vesiculosus* on sheltered and exposed shores. Benthic index (BBI) is left out at this stage.

For Estonian coastal areas, the indicator variables used for the WFD classification are phytoplankton, macrovegetation and benthic index. Nutrients as such are not used because the class boundaries in Estonian system are calculated for summer values and did not thus match correctly with the results of the EIA-SYKE ecosystem model.

To enable the user to dissect the likely WFD classification status of each variable separately, the discretization class intervals (already based on the class boundaries of the WFD classification) in the BNs of the Finnish areas are first turned into a labelled form according to the verbal classes, i.e. “High”, “Good”, “Moderate”, “Poor” and “Bad”.

To define the general status of an area, the classes are averaged by first giving each class a common factor (CF). In other words, each status class has given “points” so that “High” status gets 100 % (CF 1), “Good” gets 80 % (CF 0.8), “Moderate” 50 % (CF 0.5), “Poor” 30 % (CF 0.3) and “Bad” 10 % (CF 0.1). An average is taken over the CFs of each indicator variable included in the model. Since autumn 2007, when the BNs were constructed, the CF point proportions have been slightly changed (see classification guidelines: Ohje pintavesien ekologisen luokittelun toteuttamiseksi 5.12.2007). The model will be modified accordingly at a later stage.

The general status of an area is defined by the average of the CFs according to following intervals: if average is higher than 0.8, the general status is classified to be “High”, for the average ≤ 0.8 general status is “Good”, ≤ 0.6 is “Moderate”, ≤ 0.4 is “Poor” and ≤ 0.2 is “Bad”. All these calculations are performed in the conditional probability tables of the variables so that the probability distributions remain through the process. Thus, the final result of the general status of an area is still given as a probability.

In the Estonian WFD classification system, the general status of the water area follows the “One out – all out” -rule. According to this principle, the state of the area under consideration is determined by the indicator variable(s) classified to be in the worst state. Thus, in a case that one variable is in “Poor” status and the others are classified as “Good”, the general status of the area will still be “Poor”. The calculation method is totally different from the averaging rule of the Finnish

classification system and the final distributions of these 2 systems are not comparable. While using "One out, all out" -method, the probability distribution of the general status is skewed towards the worst state already from the beginning.

International conservation status classification (IUCN) approach

The BNs of the IUCN approach utilize so far the same WFD-inspired discretizing classes of the environmental variables than the WFD models. In other words, the upper parts of the area-specific networks are identical between these two approaches. So far only two species are included in the model: *M. affinis* for all nine areas and *F. vesiculosus* for the coastal areas.

The end product of the EVAGULF population models, called here "population viability", is the state of the population parameter under consideration (density for *M. affinis* and growth depth for *F. vesiculosus*) in proportion to its historical reference value. International classification of the conservation status of species is primarily based on quantitative criteria like changes in population size or area of distribution. Additional criteria used are e.g. number and fragmentariness of the occurrence. Any of the criteria being fulfilled is a sufficient argument for the inclusion of a species in a conservation status class.

In the IUCN approach of EVAGULF model, the definition of the conservation status class is based on the definitions of the classification criteria A concerning observed, evaluated, concluded or predicted reduction of the population size ("Critically Endangered" if > 80 %, "Endangered" if > 50 %, "Vulnerable" if > 20 % and "Near Threatened" if > 10 %). The maximum growth depth of *F. vesiculosus* and the population density of *M. affinis* in relation to their historical reference values are assumed to be proportional to the changes in population sizes. In case that the population is growing or stable (predicted reduction is less than 10 %), it is simply defined to have a status "Ok" in the model.

Although it is not reasonable to calculate or evaluate any "general conservation status" (which is a species-specific qualifier) for a water area, the probabilities of the species to belong to a certain IUCN class are averaged within each area for the later risk-benefit –evaluation purposes. Common factors used for the classes are 0, 20, 50, 80 and 100, the class "Ok" having the highest and "Critically Endangered" the lowest point value. The CFs are inverses of the criteria intervals' upper limits. The class intervals for the probability distributions of averages are 0-20-50-80-100, thus corresponding the original criteria intervals (although conversely).

It should be taken into account that the data behind the EVAGULF population models for *F. vesiculosus* and *M. affinis* are at the moment collected only from the Finnish coastal areas. Model applicability to the other areas is not verified yet. However, they are still applied in the BNs to test the models and the user interface.

In real terms, both WFD and IUCN classifications are to some extent case-specific. For example, when defining the ecological status of a water area according to the WFD, in addition to the state calculated by using computational standard values also a status evaluated by the experts will be determined. Therefore, also the reliability and representativeness of the monitoring data used are evaluated and considered (Ohje pintavesien ekologisen luokittelun toteuttamiseksi 5.12.2007). When evaluating an areal conservation status of a species in turn, the occurrence in nearby areas (e.g. the other areas within the Gulf of Finland, the rest of the Baltic Sea or the inland waters of the

surrounding countries) should also be taken into account. What comes to the species that are migrating long distances, the valuation should be rationalized as well.

A model is, even at its best, only a description of how we think that the system works and a way to dissect our thinking logically. Although all details and exceptions cannot be taken into account in a model or turned into a computational form at all, we can gain at least a suggestive picture of the likely situation under alternative circumstances. Still, it must be underlined that the EVAGULF model is not designed to be a true classification tool, but more like an aid for the conceptualization of alternative visions of the future.

Key environmental correlates

The basic loading data set as well as the Finnish scenarios were calculated at SYKE to test the functioning of the ecosystem model. The needed code adjustments to the model and the final scenario runs were performed at the Environmental Impact Assessment Centre of Finland (EIA Ltd, Arto Inkala) working as sub-contractor for SYKE. EIA Ltd made the adequate modifications to the model code so that the results could be produced in the agreed format suitable for the Bayesian networks of the EVAGULF. None of the parameters needed in the BNs were produced directly by the model (total nutrients, amount of chlorophyll-a, near-bottom oxygen, secchi depth), but different coefficients based on available monitoring data from the Gulf of Finland were applied to transfer the model output variables into the variables needed in the Bayesian work.

The results had to be calculated according to the areal division of Gulf of Finland used in the EVAGULF tool, of which mean values for every variable were produced with the different loading scenario combinations (48 in total). The results were delivered to the Helsinki University as files which consisted of the data as mean values for each needed variable in each 5x5 km grid cell inside each sub-area of the Gulf of Finland for the agreed season (summer or winter, varying according to the variable).

The EIA-SYKE ecological model (Kiirikki et al. 2001, 2006) was used as a tool for scenario assessments. The model was run for the same 5 year period (1995-1999), that it has been calibrated and validated for. It was assumed that the present years can be similar as years in the late 90's and also it was assumed, that the effects of the load scenarios in the fifth year of simulation describe close enough the situation in the 2015, if the load reductions will be done now.

The EIA-SYKE model simulates dissolved nutrient and algal biomass as carbon. However, the environmental variables used in the EVAGULF BNs for further simulations and classifications were total nutrients of surface water layer at spring time, chlorophyll-a and secchi depth at late summer and oxygen conditions in the bottom sediment. Apart from the oxygen, all of these variables are indicators of the ecological status of the water area in the EU WFD classification system (Rekolainen et al. 2006). In addition, all of them are either as such or correlated with the key environmental factors of several species and thus can be utilized in population models.

The total nutrients at the spring time were assessed from the modelled dissolved nutrient at the end of March. There was no clear correlation between dissolved and total nutrients during spring time in the measurements. The coefficient in the transformation from the modelled dissolved nutrients and the total nutrients was selected so, that the average result was in the same level as the measured ones.

The chlorophyll a was calculated from the average biomass during 1.7.-7.9. The coefficient from algal biomass to chlorophyll a was 0.005, which was little bit lower than usual coefficient for whole growth season 0.0067. However, the average results with the lower coefficient give better results because the model might overestimate cyanobacteria blooms and chlorophyll concentration can also vary during seasons. The secchi depth was calculated from the algal biomass and the average value of period 1.7-7.9 was saved. This value is yet an underestimate, because it does not take suspended solids into account.

The EIA-SYKE model does not simulate oxygen, but the oxygen conditions in the sediment surface are assessed from the CO₂ flux, produced by the detritus carbon. If the CO₂ flux increase over critical value, the sediment surface is anoxic. The Boolean value, if critical value was achieved in the grid square or not, was saved during simulation and also the average value of detritus carbon in the sediment.

The probability distributions of the environmental variables were produced by using the spatial variability in the results. Each value of 5*5 km squares within the area in consideration was used as a one possible prediction or “observation”. The distributions were formed by using the EM-learning function of the Hugin-software which is based on EM (Estimation-Maximization) algorithm. The algorithm calculates the probability distributions of the network from the data (in this case from the model results of EIA-SYKE ecosystem model).

Because the use of BNs as modelling tools requires the discretization of all the variables, the class intervals of numeric nodes should always be thought through carefully. At worst, wrong class boundaries may “block” information from the model. On the other hand, the amount of the classes should be kept moderate because each additional class makes the model runs harder and more time-consuming. This is why discretization should not be done randomly but by basing it on some justifiable limits or the share of the observations within the scale.

In the EVAGULF BNs class boundaries specified in the preliminary Finnish and Estonian WFD classification guidelines (in the autumn 2007) were used for the nutrient concentrations, chlorophyll and secchi depth. These have been defined by using statistic distributions and expert opinions so that round the boundary values the deviation of the variable from its reference value can be read to phase from state to another. Each area has the class boundaries of its own based on their different natural conditions and reference values.

In the WFD classification systems – as well as in the first prototype of the EVAGULF model - Finnish inner and outer archipelago areas have different environmental variable class boundaries. Both areas of the Estonian coast have limit values of their own as well. For the areas of open Gulf of Finland the classes of Finnish outer archipelago were used. Probably those of Estonian coastal areas would have been more suitable, but because Estonian class boundaries for the nutrient concentrations are defined by using summer observations and the predictions produced by EIA-SYKE ecosystem model was for the winter nutrients (used in the Finnish system), it was seen to be more reasonable to use the values of Finnish outer archipelago areas for now. Areal discretization of the variables is presented in Appendix 1.

Physical variables

In the time period from present to 2015, the global climate change was not assumed to have permanent effects on the water salinity or temperature of the Gulf of Finland. Thus the distributions

were produced to reflect the current situation. The University of Helsinki collected large monitoring data sets from different sources. For the four Finnish coastal areas, data was obtained from the HERTTA-database of the Finnish Environmental Administration. For the two Estonian coastal areas, the monitoring data of the Estonian Marine Institute was used. Data series for the three open sea areas was provided by the Finnish Institute of Marine Research. Data from years 1998-2007 was used.

In the coastal areas, probability distributions for salinity of the surface water layer were calculated by using annual averages of 0-5 m the water layer. For the near-bottom distributions, annual averages of 0.5-1 m from the sediment surface were used. Corresponding temperature distributions were calculated by using the averages of the July-August period for the same depths. Only the monitoring sites with minimum depth of 15 m were included.

In the open sea areas, annual averages of the surface water salinity, as well as the July-August temperature were calculated for the water layer of 1-20 m. Corresponding bottom values were calculated for the water layer of 0-5 m from the sediment surface. The depths of the monitoring sites varied between 37-82 m.

Averages were calculated annually for each monitoring site. Probability distributions of salinity and summer time temperature in the surface and bottom layers were produced to reflect the spatiotemporal variability within each water area. Observations were read in to the BNs by using the EM-learning algorithm as with the other environmental variables.

Discretization of salinity is based on the phasing of the freshwater, brackish water and marine species in the ecosystem in relation to salinity gradient (Wetzel 2001). The class intervals are 0 – 3 – 5 – 7 – >7 psu. Summer temperature in the surface water and near bottom layers was divided into 5 classes evenly. Class intervals for the near bottom layer are 0 – 4 – 8 – 12 – 16 – 20 °C and for the surface water layer 6 – 10 – 14 – 18 – 22 – 26 °C.

Bayesian MCMC population models

The objective was to summarize the knowledge about the species threatened by eutrophication of the Gulf of Finland and also to develop new methodology that would enable modelling the effects of eutrophication on them. We wanted to create models that would take into account the large amount of uncertainties related to the subject and to increase the information value of existing studies and data series by combining all the available information into the same model.

Species

During the project, we compiled a list of the species living in the aquatic or coastal ecosystems of the Gulf of Finland and that are somehow classified to be threatened or especially remarkable for the ecosystem: species classified as threatened according to criteria of the international conservation status classification (IUCN 2001, Rassi et al. 2001), those specified as threatened or declining by HELCOM (HELCOM 2007), the species mentioned in the EU Nature Directive (92/43/ETY: append. II, IV and V) as well as those defined as endangered in the Finnish nature conservation decree (Ministry of Environment, 1096/1996).

The first example species to be modelled were the benthic amphipod *Monoporeia affinis* and the bladder wrack *Fucus vesiculosus*. Both species have been monitored in the Gulf of Finland for decades and there were data available. This enables comparing the results modelled with the data and those based only on the prior knowledge and expert interviews which in the future helps in designing models for data poor species. Both species were also listed by HELCOM. In addition, *F. vesiculosus* is the only individual species considered in the ecological classification system of the EU Water Framework Directive. It is also often mentioned as an important keystone species, forming a habitat for numerous of other species. Thus, the model could also be used as a part of other models predicting the status of the species dependent on *F. vesiculosus*.

Methods

Most ecological studies and models include prior information only implicitly, usually in their design or the discussion of results (McCarthy & Masters 2005). One of the main differences in the Bayesian approach compared with the traditional statistics is that knowledge derived from previous studies is used explicitly and quantitatively. True Bayesian analyses consist of four basic elements: the prior distribution that reflects any prior belief in possible values of parameters; data; a model that relates the data to the parameters; and the posterior distribution that reflects the updated belief in the parameter values given the data and the model. The uncertainties in the parameter values are expressed as probability distributions.

Ecological data from the Gulf of Finland is usually heterogeneous and scattered. The amount of existing knowledge and separate studies is high but the availability of uniform data is very restricted. In Bayesian modelling, the observational studies as well as laboratory experiments on one piece of the system under examination can be used as valuable prior information when e.g. assessing the impacts of habitat changes on a population.

In Bayesian analyses, both the prior information and the data influence the results. Their contribution depends on their relative precision so that the most precise have the greatest weight. Thus the posterior distribution is a weighted average of the prior and the data (McCarthy & Masters 2005). Prior information, if presented in a transparent, coherent and logical way, can be cost-effective in adding certainty to ecological studies, in which expected values of most parameters can, at their best, be specified as probability distributions rather than as precise values.

For both species, several articles and reports were used as the prior information about the most important factors affecting the populations in the Gulf of Finland. For *F. vesiculosus*, these were light attenuation in the water, availability of suitable substrates and salinity. For *M. affinis*, these were oxygen concentration, salinity and temperature. There were also some other factors that are known to affect these species, e.g. the amount of annual filamentous algae for *F. vesiculosus* and the amount and composition of the phytoplankton community for *M. affinis*. To keep the first model versions simple, these were left out at this stage. In the case of *M. affinis*, we also used expert knowledge for the formulation of the priors (see below).

Available monitoring data on the species were collected together with water quality data from the corresponding time and location. Each species observation was connected to the water quality observations of the nearest possible site and time. For *F. vesiculosus*, the maximum growth depth observed was listed. Each observation was connected to the average secchi depth during the same growing season and to the average salinity of the surface water layer during the whole year. For the *M. affinis*, density (individuals m⁻²) was the variable in focus. The observations were linked with

data on salinity, temperature and oxygen concentration in the near bottom water layer at the closest possible site and sampling time.

Posterior joint distributions for model parameters were modelled by using Bayesian MCMC (Multiple Chain Monte Carlo) simulations of the WinBUGS software (Bayesian Inference Using Gibbs Sampling, Spiegelhalter et al. 2005). MCMC works by randomly sampling parameter values of the model from the joint posterior distribution. In the future, these posterior distributions for parameters will be used in modelling the states of the *M. affinis* and *F. vesiculosus* populations in the year 2015 in different policy scenarios. These model runs will be based on the predictions of the state of the environmental variables produced in this project and the results can be linked to the EVAGULF RADSS networks.

Priors

Here we use the term viability to describe the predicted magnitude of the population parameter comparable to the state of the population in year 2015. Therefore, we are not assessing the productivity or evaluating the trends in the population size but just studying what the direct impacts of the key environmental variables on the population are.

The criteria for population viability vary depending on the context. Ludwig (1996) and McCarthy et al. (2003) criticize the use of complete extinction as a threshold, because the random environmental factors make predicting to moment of total extinction (when the last individual has died) difficult, which increases uncertainty. Thus Ludwig (1996) recommends the use of the probability that the population size becomes so small, that it is in danger to disappear, as the criteria. McCarthy et al. (2003) also find this kind of a minimum population approach to work better for e.g. populations, which have a very low probability for total extinction, and for populations which are already very small. In this project, we used the commonly accepted classification criteria of the international conservation status classification (World Conservation Union, IUCN 2001) and the EU WFD classification reference values derived from historical data and observations.

When the population model is used for risk analysis purposes, the absolute population density or distribution area is not in focus, but the relative values in comparison with a certain reference level. Despite the huge uncertainties of the DSS recommendations based on absolute assessments, decision rankings produced by corresponding relative analyses have been found to be quite robust to uncertainty (McCarthy et al. 2003). In the EVAGULF population models, the studied variable is proportioned either to the site-specific maximum observations in the data (for *M. affinis*) or to the reference value defined in the guidelines for the Finnish WFD classification (Ohje pintavesien ekologisen luokittelun toteuttamiseksi 5.12.2007) (for *F. vesiculosus*).

Monoporeia affinis

The model assesses the acute effects of salinity, temperature and oxygen concentration on the species viability. Viability is determined as the population density on a site in proportion to the maximum values historically observed on that site. The population density at a certain moment is assumed to be determined by the key environmental factors (salinity, temperature and oxygen) and a random variable illustrating the site-specific “quality” or carrying capacity. The prior information is given for the parameters that define the shape of the interdependence curve between the environmental variables and viability.

First, the assumed viability dependence was outlined separately for each environmental variable based on literature and expert interviews (pers. comm., Ari Laine, Metsähallitus). *M. affinis* favours cold freshwater conditions and is quite sensitive to low oxygen concentrations. The tolerance limits for these factors are more or less known but the development of the correlation curve between them is more uncertain.

The prior correlations were transformed to a numerical form. According to the prior knowledge, the impacts of salinity and oxygen concentration follow the form of a sigmoidal equation with four parameters formulated as:

$$y = y_0 + \frac{a}{1 + e^{-\left(\frac{x-x_0}{b}\right)}} \quad (\text{Eq. 1})$$

For salinity, the prior parameters (expectation value μ) and their deviations (σ) are (all the uncertain parameters are assumed to be normally distributed):

Parameter	μ	σ
a	1	0
b	-1.5	2
x₀	9	6
y₀	0	0

For oxygen concentration, the prior parameters (expectation value μ) and their deviations (σ) are (all the uncertain parameters are assumed to be normally distributed):

Parameter	μ	σ
a	1	0
b	1	1
x₀	6	4
y₀	0	0

Figure 3 shows an example of the possible correlation curves gained with the prior parameters in the case of salinity. In the equation, the parameter a defines the upper limit of the curve. In this case it is 1, because the variable under consideration is a relative value with a maximum of 100 %. The negativeness or positiveness of the parameter b gives the trend and its magnitude the slope of the curve. The parameter x₀, in turn, tells the location of the inflection point on the x-axis while the parameter y₀ is the lower limit of the curve on the y-axis.

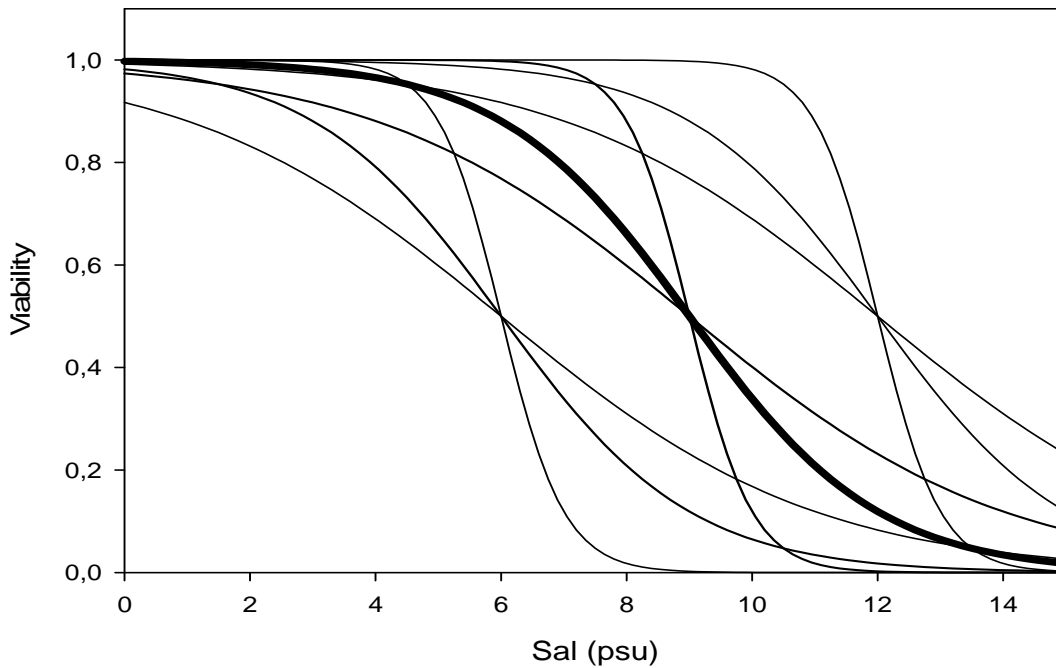


Fig. 3. Possible curves for the dependency of the *M. affinis* viability on salinity (psu) gained by mixing the parameter expectation values and the upper and lower limit values of the assumed deviation with all possible combinations. The curve with all the parameters equalling the expectation value, i.e. the alternative that is thought to be most likely, is thickened.

The dependence of viability on the temperature was found to follow a modified Gaussian curve with 4 parameters:

$$y = ae \left[-0,5 \left(\frac{|x-x_0|}{b} \right)^c \right] \quad (\text{Eq. 2})$$

For temperature, the prior parameters (expectation value μ) and their deviations (σ) are (all the uncertain parameters are assumed to be normally distributed):

Parameter	μ	σ
a	1	0
b	5	4
c	3	3
x_0	9	6

In the equation, the parameter a defines the top of the peaked curve, b controls the width, whereas x_0 is the position of the centre of the peak on the x-axis. The fourth parameter, c, affects the width of the top of the peak and the steepness of the sides of the curve.

Fucus vesiculosus

Viability of *F. vesiculosus* was considered through the maximum growth depth observed on a site in different years. It is also one of the ecological indicator variables in the implementation of the EU

Water Framework Directive in both Finland and Estonia. The model assesses the effects of salinity and secchi-depth on the species viability. Also the availability of suitable substrate is taken into account.

Like all plants, *F. vesiculosus* growth is dependent on light (e.g. Bäck & Ruuskanen 2000). Secchi-depth is a commonly observed variable that is highly comparable with the light attenuation in water. The reproduction of *F. vesiculosus* can succeed only in salinities over 4 psu (Serrão et. al 1996); thus, salinity can be seen as the primary factor controlling its occurrence. *F. vesiculosus* also needs clean and solid surfaces as a substrate. Of these three factors, secchi-depth and the amount of substrate are correlated with the eutrophication via increased phytoplankton production that increases light attenuation and the amount of sedimenting material. Also, filamentous algae may sometimes compete for the same substrates or even smother *F. vesiculosus*.

The wave exposure of the habitat has effects on *F. vesiculosus* (Ruuskanen et al. 1999). The surf and currents clean the substrates by removing sedimenting material. Also, the light conditions are better on exposed sites because of less turbidity. E.g. the width and the lower edge of the *F. vesiculosus* belt correlate with different exposure indexes. As a result of eutrophication, the narrowing of *F. vesiculosus* belts has been most significant on exposed shores (Bäck & Ruuskanen 2000). On a sheltered shore, the maximum growth depth is usually primarily dependent on the availability of solid substrate, the usual depth being only about 1-2 m.

The above mentioned prior information was transformed to the model code language. We first assumed that the minimum amount of light needed for *F. vesiculosus* growth would prevail in the secchi-depth, thus being more or less linearly correlated with it. Then, a clause that defines the salinity of about 4 psu being a limiting factor was added to the code.

Although no data on the depth of the suitable substrate was collected when the growth depth observations were made, the Bayesian methodology and the use of prior information enables including it in the model. Because the substrate restriction cuts the linear regression of the *F. vesiculosus* maximum growth depth and secchi-depth in some point, the dependency curve is identical with a so called “hockey stick” function usually used for modelling the reproducing stock size - fecundity –relationship:

$$y = \begin{cases} (a/b)*x & \text{If } x \leq b \\ a & \text{If } x > b \end{cases} \quad (\text{Eq. 3})$$

The parameter x is secchi-depth, a is the bottom limiting depth and b is the crossing point of the light and bottom restrictions on the x-axis; thus, a/b defines the slope of the light correlation. Therefore, if secchi-depth is predicted to be higher than the bottom restriction depth, the bottom restriction will adjust the maximum growth depth of *F. vesiculosus* and vice versa. Figure 4 illustrates the situation.

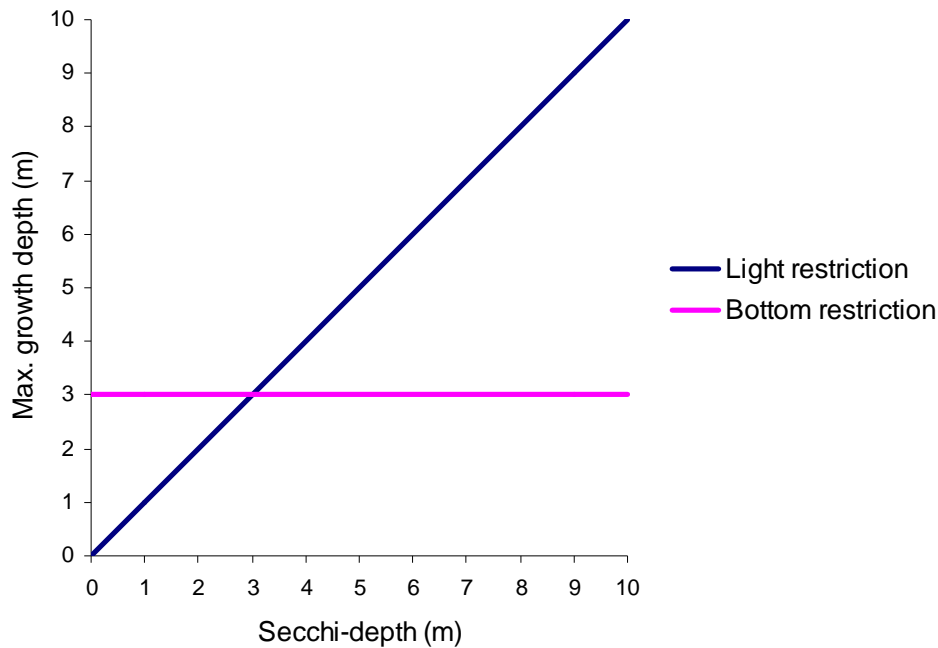


Fig. 4. The principle of the “hockey stick” model. The maximum growth depth (m) on the y-axis is dependent on the secchi-depth (m) on the x-axis until the bottom restriction (availability of solid substrate) becomes the limiting factor.

In literature concerning *F. vesiculosus*, the most commonly used method to evaluate the wave exposure is the Baardseth index (Baardseth 1970), which is calculated by placing the centre of a circle with a radius of 7.5 km on the site under examination. The circle is divided into 40 sectors (9° each) and the number of the sectors free of land areas is summed up. Thus, a value of 0 indicates extreme shelter, whereas 40 represents ultimate exposure (Ruuskanen et al. 1999).

The exposure index values are not comparable between the inner and outer archipelagos (Ruuskanen et al. 1999): the same Baardseth index value results in a greater growth depth in the outer archipelago than close to the mainland because of the different current and wave conditions affected by neighbouring islands, skerries and rocks. In the outer archipelago, even the shores with a low Baardseth index are exposed to strong currents and wave action resulting from the continuing water circulation around the islands in the absence of a dense network of current-blocking elements typical for the inner archipelago.

In the guidelines for the Finnish WFD classification (Ohje pintavesien ekologisen luokittelun toteuttamiseksi 5.12.2007), the maximum growth depth of *F. vesiculosus* has different class boundaries and reference values for the inner and outer archipelagos of the Gulf of Finland. Ruuskanen and Bäck (1999) have defined sites having a Baardseth index higher than 17 to be ranked as exposed and the sites with an index below 4 as sheltered. According to the latest guidelines for the Finnish WFD classification (Ohje pintavesien ekologisen luokittelun toteuttamiseksi 5.12.2007), the sampling sites should have a Baardseth index of 0-6 in the inner and intermediate archipelago and 15-24 in the outer archipelago to ensure the spatiotemporal comparability of the results.

In the *F. vesiculosus* model developed during the project, the influence of the Baardseth index is taken into account by assuming that it would have an effect on the bottom restriction depth. The

prior parameters (expectation value μ) and their deviations (σ) are (all the parameters are assumed to be normally distributed):

Parameter	μ	σ
Salinity restriction	4	0.4
a/b	1	0.4
a	$r_a * \text{baard} + x0_a$	2
r_a	0.2	0.4
x0_a	2	4

The parameter of the bottom restriction a is dependent on the Baardseth index (baard, observed from the data) with the slope r_a and a datum level x0_a. The slope is assumed to be quite small (0.2) having quite large deviation because according to the literature, the correlation is not very clear and quite few studies have been conducted in the Gulf of Finland. The datum level of the bottom restriction is assumed to be between 0-4 m with the expected value of 2. The deviation is high because this first model is designed to fit for both inner and outer archipelago. In the future, we can modify the code for separate runs of each zone.

At this stage, it is not studied, whether these model assumptions fit the Estonian coastal system as well. At least the prior parameters should be modified to describe the local conditions. Local data should also be used. On the other hand, the benefit of Bayesian MCMC simulation is that it is also possible to produce a quite robust model totally without data. We can first learn from this model and then create new priors exploiting the results and our knowledge of the likely parameters on the Estonian coast although the data naturally improves the confidence of the results.

Data

Data on *M. affinis* was gathered from the monitoring data of the Finnish Radiation and Nuclear Safety Authority (FRNSA), City of Helsinki Environment Centre and from the HERTTA-database of Finnish Environmental Administration. Data was collected from the years 1975-2006. Corresponding water quality data was compiled from the reports of FRNSA and the HERTTA-database.

Data on *F. vesiculosus* was gathered from the monitoring data of FRNSA and Finnish Environment Institute (SYKE) and collected from the years 1977-2005. Corresponding water quality data was compiled from the reports of FRNSA and the HERTTA-database. Baardseth exposure indexes were calculated for the *F. vesiculosus* observation sites on the map.

Posteriors

By running the population models with the prior information and the data represented above, the posterior distributions of the correlation parameters for the species and their key environmental factors will be produced in the future. These posterior parameters will be used for modelling the likely area-specific viabilities of the species under the states of their key environmental variables within the area predicted by the EIA-SYKE ecosystem model. Salinity and temperature levels are taken from the average distributions of the last 10 years. The same prior model structure can be used also for the posterior runs.

Population Bayesian networks in Hugin

Final MCMC simulation results for the dependencies of the species viability on their key environmental variables will be read into the species-specific Bayesian networks (BNs). The BNs as such are quite simple and they are included into the areal BNs as submodels which have input nodes from the main network with identical conditional probability tables.

The BN of *M. affinis* consists of the three key environmental variables (salinity, temperature and oxygen) as input nodes and population viability as an output node (Appendix 2). It is used only for the IUCN approach modelling because the species is not considered in the WFD. This submodel supplies the results gained from either the raw data or the MCMC simulation to the main BN of the area. Resulting population viability is discretized according to the percentual class boundaries of the IUCN classification criteria A so that it can be directly transformed to an IUCN class in the main model.

The submodel of *F. vesiculosus* is included both in the IUCN and the WFD approach BNs. The submodel structure and the calculation between these two approaches vary a little (Appendixes 2 and 3). The upper part of the BNs, into which the data or the MCMC simulation results are read, is identical between the approaches. It consists of the input nodes (secchi depth and salinity) and the two maximum growth depth nodes: one for exposed conditions and another for sheltered shores (assessed separately in the WFD). These two are discretized according to their class intervals in the guidelines for the Finnish WFD classification (Ohje pintavesien ekologisen luokittelun toteuttamiseksi 5.12.2007).

In the WFD approach model, both predicted growth depths are first turned into their qualitative WFD classes to enable users to assess them separately for a certain scenario. After that, they are given the common factors according to the point system described earlier, which are the output nodes of the *F. vesiculosus* WFD model. The main model of the area will receive their information and by averaging their common factor distributions calculate the probability distribution for the WFD class of the *F. vesiculosus* maximum growth depth.

In the IUCN model, the maximum growth depths are transformed to the viability of *F. vesiculosus* (this is not included in the MCMC simulations because the variable in the WFD approach is just the growth depth) by proportioning the median values of the predicted maximum growth depth distribution classes to the area-specific historical reference value (defined according to the Finnish and Estonian WFD classification systems). The total viability is gained by averaging these ratios of the sheltered and exposed sites. Like in the *M. affinis* BN, the output node “*Fucus* viability” is discretized according to the percentual class boundaries of the IUCN classification criteria A and further transformed to an IUCN class in the main model.

Future development

The MCMC model testing and final runs were not finished in the timeframe of the project and therefore the data collected for simulation purposes were read into the BNs by using the EM-algorithm. When prior information is not used, Bayesian analyses and likelihood-based frequentist analyses produce numerically equivalent results, although implementing many models in a Bayesian framework is often easier (Clark 2005).

By using this kind of simplification we lose the benefits gained with the use of existing prior information. Without the prior information, the Hugin software does not extrapolate the effects of the combinations of different environmental variables not observed in the dataset but gives a uniform distribution for all possible states of the population, i.e. all the possible states are equally likely.

Because the oxygen predictions are currently in boolean form (i.e. oxygen depletion is likely to appear within the area or not), the modification of the collected data set of *M. affinis* needs to be considered. In regard to *Fucus*, the addition of some kind of dependency between the sedimenting material or chlorophyll-a and substrate restriction could be worth testing. Also, linking the observation sites of both species with the model grid of the EIA-SYKE could produce more realistic results.

A new kind of application for the formulation of priors was developed, which can easily be exploited in the future. Final MCMC simulation results will be read into the BNs in the future. Also, by comparing the resulting probability distributions with the distributions produced now by the EM-algorithm, the significance and information value of prior knowledge in this kind of population risk assessment models can be examined.

Prediction models for the Estonian WFD variables

Large Estonian biological and water quality datasets were analyzed by the Estonian Marine Institute (EMI) during the project. As a result of these analyses, predictions for the status of three WFD classification variables: benthic index, phytoplankton and phytobenthos (macrovegetation) were modelled corresponding to the conditions of the nutrient and chlorophyll-a concentrations for different scenarios (the predictions produced by the EIA-SYKE model). These models were based on the statistical analyses and correlations observed, the predictions being produced for each square of the EIA-SYKE model grid separately. The results were read into the WFD approach BNs of the Estonian coastal areas by using the EM-algorithm (Appendix 4). Thus, the probability distributions illustrate the spatial variability within each of the two areas.

In this report only the analyses behind the benthic index is considered, the methodology being similar for the other indicators as well.

Data availability and analyses

Macrozoobenthos community data was obtained from the databases of the Estonian Marine Institute. The historical data covered all Estonian water bodies except for Hara Bay and Väike Väin (Figure 5, Table 5). These two water bodies are very small compared with the other water bodies and it is likely that information from adjacent sea is adequate for the description of the reference condition of these water bodies. Only truly quantitative samples were used in the data analysis. The studied depth range was from 1.5 to 35 m in all water bodies where applicable.

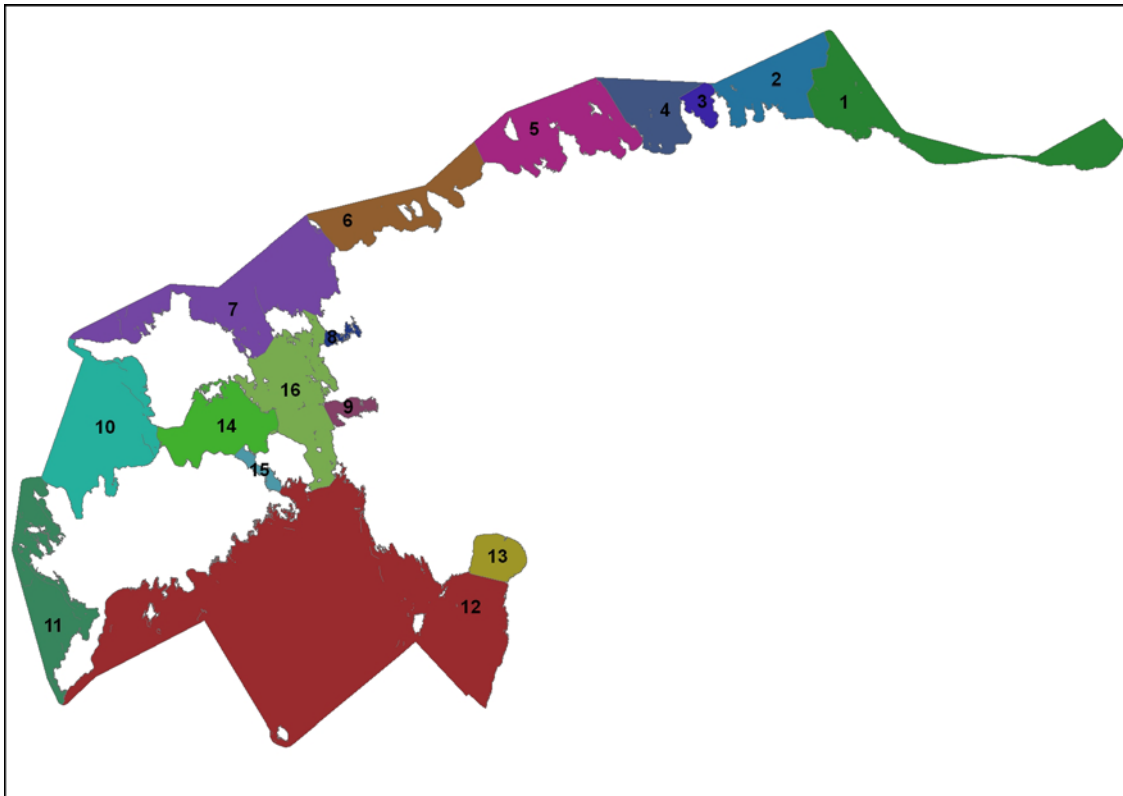


Fig. 5. Water bodies around the Estonian coastal sea.

Table 5. Names of the water bodies.

1 Narva laht	Narva Bay
2 Käsnu-Kunda	Käsnu-Kunda
3 Hara laht	Hara Bay
4 Kolga laht	Kolga Bay
5 Tallinna piirkond	Tallinn sea area
6 Soome lahe lääneosa	Western Gulf of Finland
7 Läänesaarte põhjaosa	North of West Estonian Archipelago Sea
8 Haapsalu laht	Haapsalu Bay
9 Matsalu laht	Matsalu Bay
10 Soela	Soela Strait
11 Saaremaa läänerannik	West of Saaremaa Island
12 Liivi laht	Gulf of Riga
13 Pärnu laht	Pärnu Bay
14 Kassari laht	Kassari Bay
15 Väike väin	Väike Strait
16 Väinameri	West Estonian Archipelago Sea

Multivariate data analyses were performed by the statistical program “PRIMER” version 6.1.5 (Clarke & Gorley 2006). Invertebrate abundance and biomass data were not transformed. Similarities between each pair of samples were calculated separately for abundances and biomasses using a zero-adjusted Bray Curtis coefficient. The coefficient is known to outperform most other similarity measures and enables samples containing no organisms at all to be included (Clarke et al.

2006). ANOSIM analysis was used to seek the statistical significance in the structure of benthic communities between historical and recent conditions by different water bodies. Simper analysis was used to seek the contribution of different species to these differences.

The main findings of the analyses were as follows:

1. Total invertebrate abundances did not change systematically in all water bodies.
2. Total invertebrate biomass increased in all water bodies.
3. There were only a few species that significantly increased both their biomass and biomass share within invertebrate communities together with increasing eutrophication. These species were *Mytilus trossulus*, *Macoma balthica*, *Mya arenaria*, *Cerastoderma glaucum*, *Theodoxus fluviatilis* and *Dreissena polymorpha*. *M. trossulus* increased its biomass in western water bodies, i.e. all regions in the Baltic Proper and Kassari Bay (more saline, characterised as frontal areas) whereas the increase in other species was mainly observed in more sheltered water bodies. The increase in the biomass of *M. trossulus* exceeded manifolds the other invertebrate species.
4. Only *Monoporeia affinis* systematically declined its biomass in course of eutrophication. However, this decline was minor compared to the increasing trends of species named above. There were no species that has disappeared in the study area from 1950s onwards. There were a few invasive species that established the Estonian coastal sea since 1970s. Most important species were *Marenzelleria neglecta*, *Gammarus tigrinus*, *Chelicorophium curvispinum* and *Pontogammarus robustoides*. Those species were not considered indicative for eutrophication.

Based on the results above the following conclusions were drawn and the following decisions were made:

1. Invertebrate biomass rather than abundance was considered as a better proxy for the assessment of water quality in the Estonian coastal sea. This is supported by earlier studies demonstrating that there were stronger linkage between nutrient load and invertebrate biomass than between nutrient load and invertebrate abundance in the Estonian coastal sea. The usage of biomasses is also justified by higher stability of biomasses (both temporal and spatial perspective) compared with abundances. These studies also demonstrated that benthic invertebrates inhabiting frontal areas behave differently from those communities inhabiting water bodies with longer residence time. Besides, the community composition of invertebrates varied along the eutrophication gradient reflecting that invertebrate sensitivity varies among species (Kotta 2000, Lauringson & Kotta 2006, Kotta et al. 2007ab).
2. Historical data was used to compute the reference values of invertebrate dry weights.
3. The invertebrate species were divided into three groups reflecting their sensitivity to eutrophication (i.e. difference between past and present conditions). Besides, the indicative value of invertebrate species was verified using regression analysis relating nutrient loads to the biomass of species.
4. The sensitivity of species to eutrophication was not considered to vary among water bodies of the Estonian coastal sea. The indicative value of invasive species (those established later than the 1960s) were obtained either from literature and/or functional relationships between nutrient load and species biomass data collected in 1990s and 2000s.

ZKI Index of macrozoobenthos community

The values of ZKI index (Table 6) vary between 0 and 1, 1 representing the reference communities and 0 representing the most deteriorated communities. The index can be used for soft bottom

communities including mixed sand sediments. Either accumulation or erosion processes may prevail in the area. Depth should exceed 2 m.

Table 6. Established type-specific water quality classification system for Estonian coastal waters: Class boundaries of ZKI index. Ref = Reference condition, AD = Acceptable deviation, H/G = class boundary between “HIGH” and “GOOD” water quality class, G/M = class boundary between “GOOD” and “MODERATE” water quality class, M/P = class boundary between “MODERATE” and “POOR” water quality class, P/B = class boundary between “POOR” and “BAD” water quality class.

Metric	Ref	AD	H/G	G/M	M/P	P/B
ZKI	1	50%	0.8	0.5	0.3	0.1

The equation of ZKI index is as follows:

$$ZKI = \frac{3 \times \text{Klass 3} + 2 \times \text{Klass 2} + \text{Klass 1}}{3 \times (\log_{10}(\text{SampleDW} + 1) + 1) / (\log_{10}(\text{ReferenceDW} + 1) + 1)} \quad (\text{Eq. 4})$$

where:

- Klass *i* is a ratio of sum of dry weight of the species belonging to class *i* to total invertebrate biomass at station
- SampleDW is total invertebrate dry weight in a sample
- ReferenceDW is the reference value of total invertebrate dry weight defined for each water body.

When ReferenceDW exceeds SampleDW then the index becomes as follows:

$$ZKI = \frac{3 \times \text{Klass 3} + 2 \times \text{Klass 2} + \text{Klass 1}}{3} \quad (\text{Eq. 5})$$

Current water quality in the different water bodies around the Estonian coastal sea assessed by benthic invertebrates

Estonian water quality classification system for surface waters is based on type-specific reference conditions and fulfils the requirements of WFD. The established classification system includes biological and supporting physico-chemical quality elements shown below.

Biological quality elements:

- Species composition, abundance and biomass of phytoplankton
- Species composition and biomass of benthic macrovegetation
- Species composition and biomass of benthic macroinvertebrates

Physico-chemical quality elements supporting biological elements

- Water transparency
- Temperature conditions
- Oxygen concentration
- Salinity
- Nutrient concentration

The established methodology requires that at least three stations should be sampled in triplicate to assess the water quality status in a water body. The selected sampling sites should cover the most important soft bottom habitats in a water body.

Available macrozoobenthos community data collected in 2006–2007 was used to assess the water quality of Estonian water bodies. The analysis shows that the water quality of the most Estonian water bodies can be classified as good. However, the average values of ZKI index hardly exceed 0.55 and the maximum value of the index is estimated at 0.61 in the water body 6. Therefore, even a slight deterioration of environment is expected to shift the water bodies from good to moderate quality class. The water quality is moderate in water body 7.

Validation of ZKI index: Relation between nutrient loads and index value

The data on total nitrogen and phosphorus loading were obtained from the Estonian Environment Information Centre and databases of the Estonian Marine Institute. The data on benthic invertebrate assemblages were obtained from databases of the Estonian Marine Institute.

Annual nutrient loading to a water body correlated relatively well to the value of ZKI index. Stronger correlations were observed in sheltered sites compared with more exposed sites; this result can be primarily explained by longer residence time in sheltered sites (Fig. 6). Total phosphorus loads explained a large part in the variability of ZKI index in the western Gulf of Finland whereas total nitrogen loads explained better the variability of ZKI index in the eastern Gulf of Finland. This difference is likely explained by spatial variability in the type of nutrient limitation in the Estonian coastal sea.

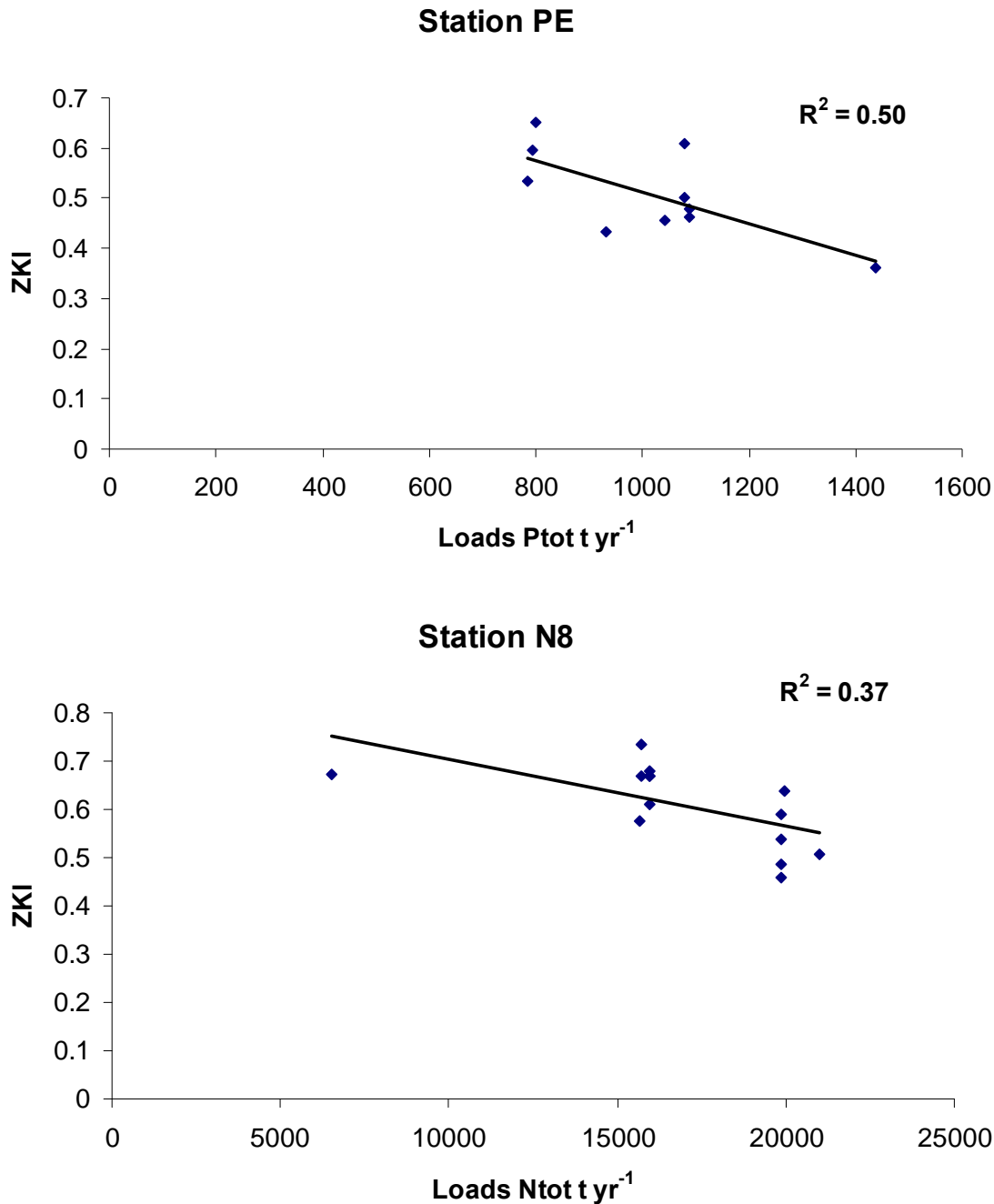


Fig. 6. Relationship between nutrient loading and ZKI index in moderately exposed (PE) and exposed sites (N8) in the Gulf of Finland.

Valuation

The assessment of the total risk or benefit enables summarizing the model information into one value and comparing the predicted end results of different scenarios. In addition to the probability gained from the upper parts of the BN, it is necessary to feed in the knowledge of how we value different end result alternatives. Thus, total benefit (the inverse of risk) gained is a function of the probability of a certain end result and the value that illustrates how much this result is appreciated in relation to the other possible results.

The magnitude of the utility value as such does not matter but the relationships between the utility values given for different end-results. The utility functions as an emphasis factor for the probability. The probability of each class from the resulting end-product distribution is multiplied with the utility factor given for that particular class to produce the total benefit value. In the user interface (described below), the differences in total benefits (or risks if the result is negative) between the current state (datum level, value is transformed to null) and the predictions for year 2015 can be examined.

In the IUCN approach of the EVAGULF tool, the different conservation status classes are valued using the same relationships than the upper limits of the percentual decrease classes functioning as criteria for each status. The class “OK” (0-10 % decrease in population size) makes an exception as it is valued to be 100 (Table 7). The utility values for the WFD classes, in turn, follow a point system similar to the one used in the case of common factors and specified in the guidelines for the Finnish WFD classification (Ohje pintavesien ekologisen luokittelun toteuttamiseksi 5.12.2007).

Table 7. Classification states of the EU Water Framework Directive (WFD), international conservation status of the World Conservation Union (IUCN) and the utility values (scale 0-100) they are given in the EVAGULF valuation. IUCN classes: OK = vital, NT = near threatened, VU = vulnerable, EN = endangered and CR = critically endangered.

WFD classes:	High	Good	Moderate	Poor	Bad
Utility	100	80	50	30	10
IUCN classes:	OK	NT	VU	EN	CR
Utility	100	80	50	20	0

Decision support tool – EVAGULF RADSS

The software system was developed at the Helsinki University of Technology within the project EVAGULF. This report describes the current, version 1.0 finished, state of the software. The software is named EVAGULF RADSS (Risk Analysis and Decision Support System). At this state the software implements the basic requirements but is not implemented or tested in real use. It is expected that the software will be developed further in response to better analysis of the actual decision making workflows and new Bayesian networks for analyzing the decision situation. This has been taken into account in the design of the software and in the writing of this document.

The overall system design and architecture is described. The current system is set up in a certain architectural style, but the design allows modifications. The current workflows for configuring the system and preparing data are also described. The data the system requires is maps and Bayesian networks. Further, the graphical user interface (GUI) of the system is described. The GUI belongs to a Java program and this chapter is the main user’s manual of the EVAGULF RADSS. The file formats are discussed and described. The system introduces an XML configuration file format, but it also contains a translator for Bayesian network formats.

System architecture

The system architecture is depicted in Figure 7. The system consists of an application and documents. The master document makes references to actual data documents. Currently the documents are stored as files inside the applications JAR file, but it is expected that in the future the

system will be configured in such a way that the application may also download them from a server or servers, or open them from a local file and that this can also be initiated by the user.

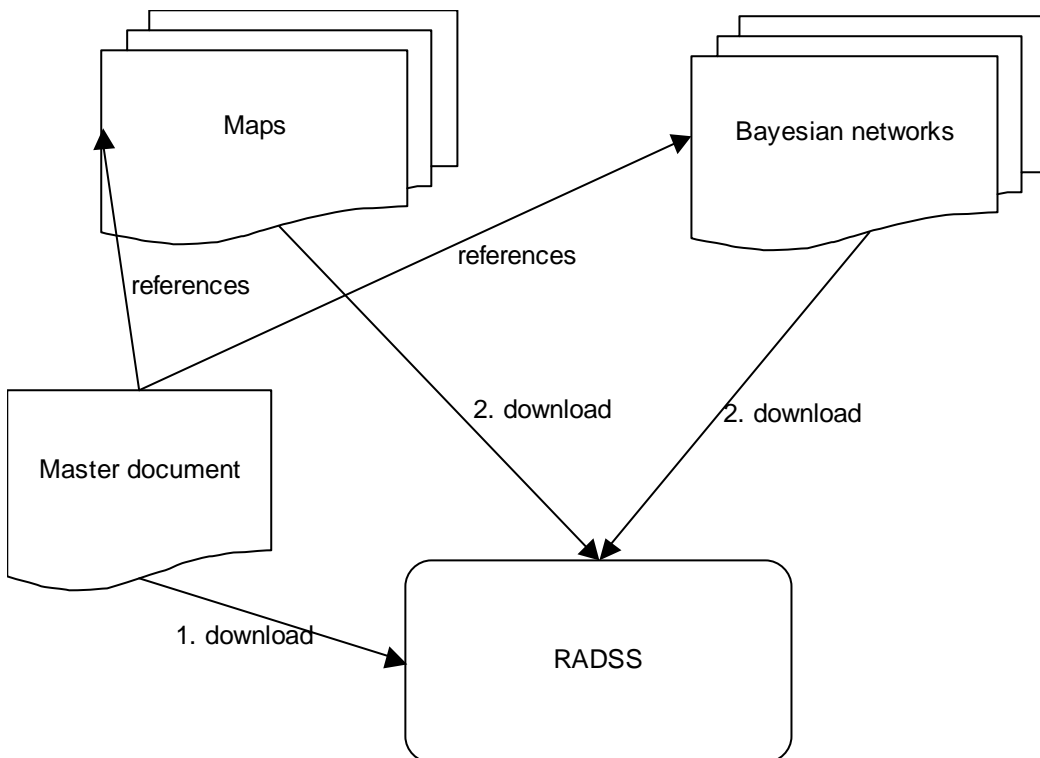


Fig. 7. The architecture of the system. The application opens first the master document, which refers to maps and Bayesian networks, which can be downloaded in the second step.

The internal architecture of the application is such that each Bayesian network is duplicated internally. This is done in order to have a network, which contains the current situation, and a network, which contains the planned situation.

The second network contains always the planned situation, except when a more elaborate analysis is initiated. Such analysis is done for example when a track is selected to the “The effect of” control. Then the network is run for all possible options that exist in that track.

Configuring and preparing data for the system

The main file to configure and prepare for the application is the master document. The document is an XML file. The master document consists of sections for maps, authorities, areas, scenarios, and models. Many of these sections and their details are expected to be developed further in the future. The Bayesian networks must be converted to the XMLBIF format. A converter from the Hugin format to XMLBIF has been developed in the project.

The maps section of the master document

As the mapping functionality is not yet developed from the basic stage this section should contain only the main map that is shown in the map panel on the front page of the application.

The authorities section of the master document

This section names the authorities (also called approaches), whose system is used to evaluate the ecological status of the areas. Currently these are IUCN (International Union of Conservation Networks) and WFD (European Union's Water Framework Directive). The codes that are given here are used as references in other sections.

The areas section of the master document

In this section the areas for which Bayesian networks have been developed are introduced and declared. The areas should form a tree-like structure, where areas are always a part of a bigger area, except the whole area, which is not a part of any area. The areas should not overlap in any other way. The names of the areas are used in the user interface.

The scenarios section of the master document

In this section the scenarios, which are the basis of the analysis are introduced. Each scenario is a combination of several subscenarios or tracks. The tracks in the current application are the climate change and the scenarios or strategic decisions or policies that are adopted in countries: Finland, Russia, and Estonia. For each track there are two or more possible futures, whose impacts the user can study. The track names and the alternative future names are used to build the user interface.

The models section of the master document

In this section the Bayesian networks that have been developed for use with the application are introduced. Each model must be linked to one and only one authority and one and only one area. The nodes in each model, which contain data for the report section of the user interface, must be defined here. For each node the name must be given and the class for which the node gives information, the entity of which the information is about, and whether the information is numeric. The various classes are currently: *indicator*, *species*, *variable*, *load*, and *concentration*. The entities may be whatever there are in the networks. A numeric node is a node, whose domain values are numeric.

Graphical user interface

The EVAGULF RADSS is a graphical application, which is available at the system's web page at <http://map.hut.fi/EVAGULF/EVAGULF-RADSS.html>. The user interface provides a main panel or page, from which the user may define the scenario and study the main impacts of the scenario on various areas. The second page of the application gives the user a look into the Bayesian networks, their structure, the nodes, the domains of the nodes, and the descriptions of the nodes and the domain values. A third page for studying the problem not using the *what-if* paradigm, but using a *what-is-needed-in-order-to* paradigm instead has been planned but not implemented at this stage.

The main page

The main page is shown in Figure 8. The main page consists of (from top to bottom and left to right): page tabs, authority control, scenario and area control, reports on each information class, the map, the status text and disclaimer and log buttons. The controls are input tools. The user has controls for selecting the authority, the area of focus, and the scenario. The report (impacts) panels contain selected information retrieved from the Bayesian networks and processes it for the user. The map may be panned and zoomed but currently the application does not retrieve finer scale maps when zoomed in, and there is only the overview map available.

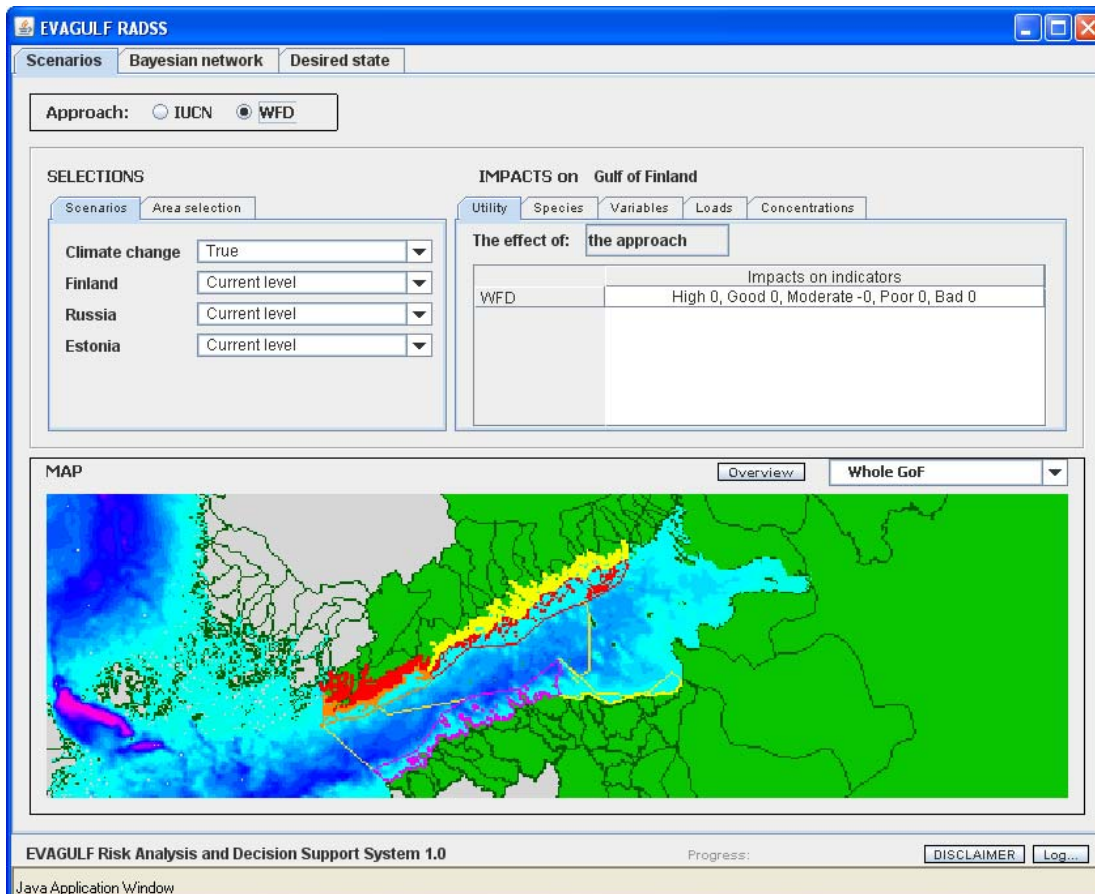


Fig. 8. The main page of the application. The components of the interface are described in the text.

The impact information is presented to the user in panels and tables according to the classes and entities. The classes are currently fixed to those mentioned in previous chapter and also depicted in Figure 8, but the entities are dynamically retrieved from the configuration files. Each panel in the impact section presents the impacts on a different class of entities (topic and things in that topic). The impacts are always shown for the selected approach and for the selected area. If the area consists of subareas, then the impact is averaged over the subareas.

The impact information is presented to the user either as a single number or as a vector (per class and entity). The vectors are composed of domain values and numbers. The number or the numbers in the vector are the changes in the studied future situation compared to the current situation. The number is the change in the expected value and the numbers in the vectors are changes in the probability values in percentages.

The Bayesian network page

This page is depicted in Figure 9. This page is for browsing the Bayesian networks used by the application. Currently the application is configured in such a way that the user can only browse the networks: Editing the prior probabilities or inputting evidence is not possible. This may however be changed in the future versions rather easily. The components on the page are partially the same as on the first page, but there are no controls for changing the decision. The area control is the same as on the first page. It must be noted that not all areas contain models.

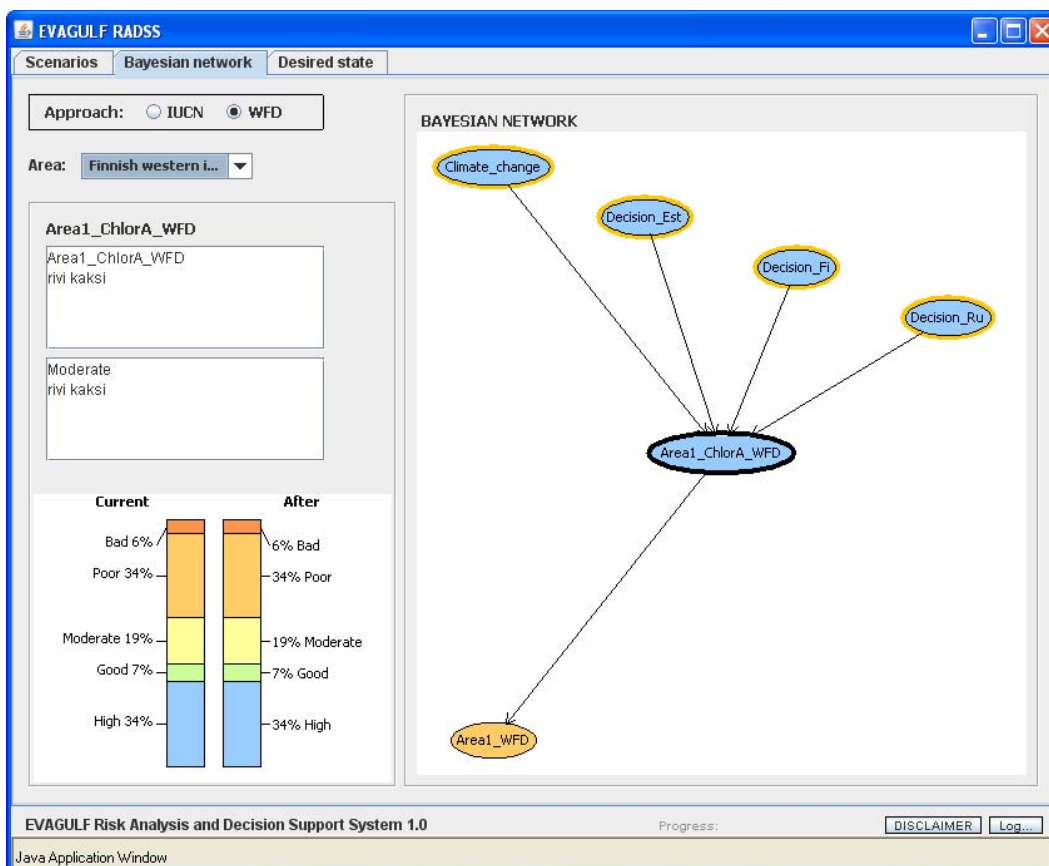


Fig. 9. The Bayesian network page.

The page contains two main panels for information: the network panel and the node panel. The network panel allows browsing the network by clicking on the nodes. Only the parents and children of the selected node are shown. The node panel contains two information panels: the upper one contains the description of the node and the lower one contains the description of the selected domain value. A domain value is selected by clicking on it (left one) in the lowest panel. The lowest panel shows the probability distribution of the domain values in the current situation contrasted to those predicted for the future under the selected scenario.

Results

The final meta-analysis BN produced in the EVAGULF project enables the study of the predicted state of the Gulf of Finland ecosystem in year 2015 for different loading and climate change assumptions. The user can assess any of the model components separately if wished. Results are calculated and shown in probability format, which makes it possible to evaluate also the amount of

variability and uncertainty related to different parts of the system (Figure 10). This is possible also in the EVAGULF RADSS user interface (Fig. 9).

The total benefits or risks gained with different scenarios can be compared with the current state (Tables 8 and 9). On the basis of the four-scenario WFD approach comparison shown in tables 8 and 9 it seems that the effect of the climate change is quite remarkable (scenario pairs A-B and C-D are identical besides the different climate alternatives). The effect of the Russian loading scenario can be seen clearly especially in the Finnish outer archipelago and Estonian coast. Results of the Estonian eastern coast are probably not realistic because of the unsuitable model calibration of the ecosystem model used for predicting the state of the environmental variables.

Table 8. Area-specific comparison of total benefit gained with four different scenarios in the WFD approach. The value is percentual change in the total benefit value compared with the current state. Area 1: Finnish western inner archipelago; Area 2: Finnish eastern inner archipelago; Area 3: Finnish western outer archipelago; Area 4: Finnish eastern outer archipelago; Area 5: Estonian western coast; Area 6: Estonian eastern coast. Scenario components are specified in Table 9.

Scenario	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6
A	2	26	4	28	30	2
B	-3	17	2	14	18	-3
C	0	3	2	1	4	0
D	-6	-3	-3	-3	-4	-10

Table 9. Components of the scenarios used in the analysis shown in Table 8.

Scenario	Climate	Finland	Estonia	Russia
A	Current	Optimistic scen.	Current level	Current facilities -80%P
B	Warmer	Optimistic scen.	Current level	Current facilities -80%P
C	Current	Realistic scen.	Increase 10%	Current level
D	Warmer	Realistic scen.	Increase 10%	Current level

Similar comparisons made with the IUCN approach model give only results close to zero. That is not because of the unsuitability of the IUCN classification for this kind of analyses but because of the discretization system used for the environmental variables. The change in the total benefit value in the IUCN approach is created only via the changes in the status of the populations.

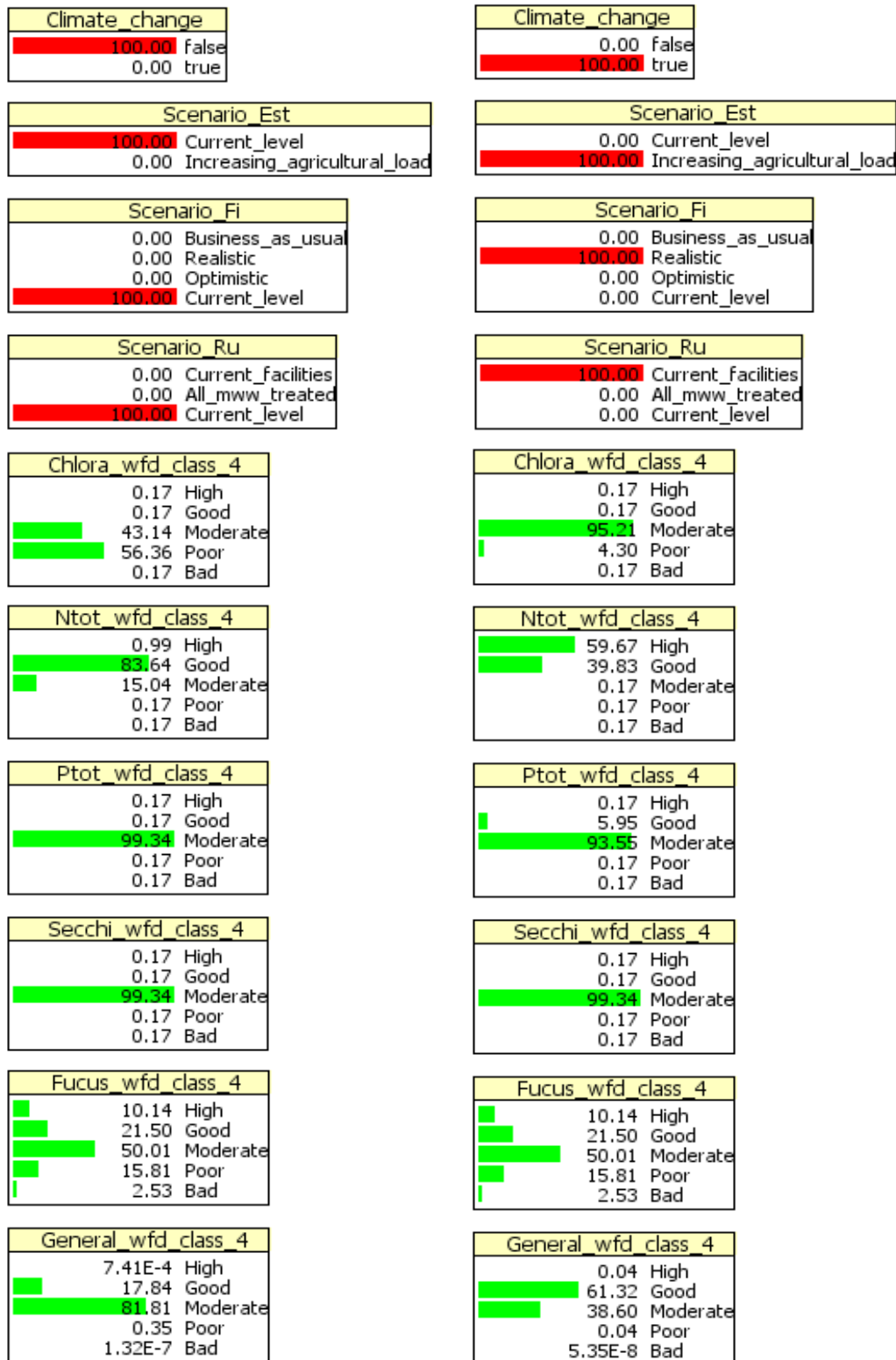


Fig. 10. Comparison of the probability distributions for the state of different WFD classification variables and the areal classification they would produce with different scenarios in area 4 (Finnish eastern outer archipelago). The values are percentual probabilities. The ecosystem model results for secchi-depth are in both cases distributed within the class boundaries of “Moderate” (1.3-3.7 m). In this case the classification system “blocks” the information about the differences between the two scenarios. This affects further the *F. vesiculosus* classification because the secchi-depth is the most important factor affecting its growth depth.

With the discretization system created for the WFD approach purposes, the class division prohibits some information from moving forward in the BNs. For example, the secchi-depth that is the only input variable in the *F. vesiculosus* model affected by the loading scenarios has one class interval in which a large proportion of the predicted values are located in every scenario. This supplies the *F. vesiculosus* model information that nothing happens no matter how large the loading is. Based on these results, we can conclude that the WFD inspired discretization of the key environmental variables is not suitable for population modelling (the same problem occurs also in the *F. vesiculosus* model of the WFD approach) and a different system, probably with more narrow class intervals should be used. Although the total benefit comparisons of the IUCN approach model is not meaningful in its present form, the EVAGULF tool still enables studying other parts of the BNs as for the WFD approach. Thus, also the predicted changes in the open sea areas under different scenarios can be evaluated.

It is also interesting to examine the effects of the different scenario factors separately on each area (Fig 11). This can be done for all the variables included in the model, not only for the resulting classifications. With this kind of approach, it is also possible to consider the significance of the country-specific loading in different parts of the Gulf of Finland and also the differences in the main forces affecting the state of an area.

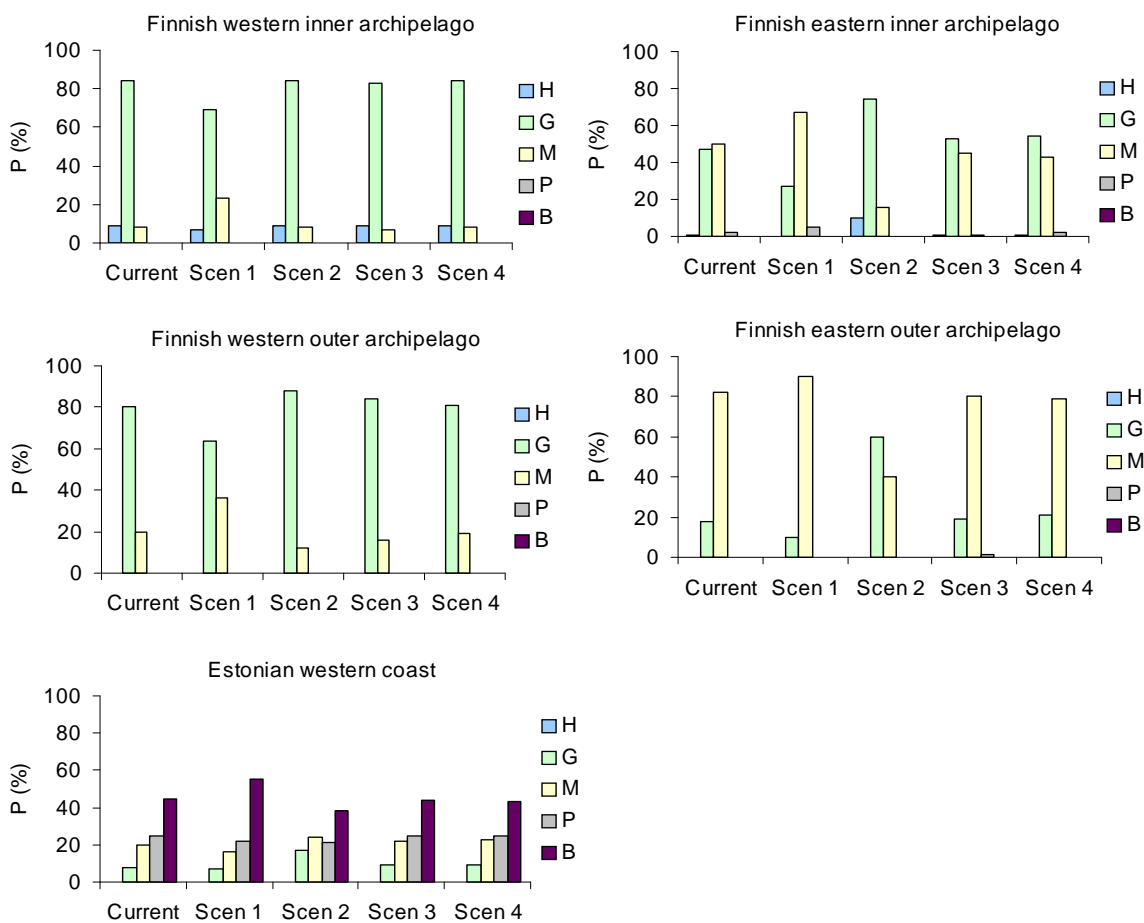


Fig. 11. Influence of four different factors on the probability distribution of the predicted area-specific WFD classification. P = Probability. Current = current level situation, Scen 1 = current loading levels and climate change scenario, Scen 2 = Russian scenario “Current facilities with 80% remove of phosphorus”, Scen 3 = Finnish scenario “Realistic”, Scen 4 = Estonian scenario “Increasing agricultural load 10%”. H = high, G = good, M = moderate, P = poor, B = bad. Note: the Estonian “One out – all out” classification is not comparable with the Finnish averaging system, although the scenarios can still be compared to each other.

Sensitivity of the Gulf of Finland food web to nutrient reductions

Background

Eutrophication is stated as the most serious challenge faced by the Baltic Sea environmental policy (HELCOM BSAP); however its impact on the Gulf of Finland, as well as the whole Baltic Sea, food web is currently not well understood. Thus the Finnish Institute of Marine Research has created a food web model using Ecopath with Ecosim software (EwE; c.f. Niiranen et al. in prep.). This model describes the species-species interaction, as well as the effect of changing environmental conditions, including changes in nutrient levels. This is the kind of information that would be very useful if the Bayesian EVAGULF model, created within the framework of this project, is to be developed further.

The model covers the Gulf of Finland with, both, temporal and spatial resolution. This area has been described as a part of the entire Baltic Sea area, as well as separately in order to reach higher spatial resolution. This model takes into consideration the variation in major external forces, such as the salinity gradient, bottom hypoxia and fishing effort.

Nitrogen (N) and phosphorus (P) are the main drivers in our model. Nitrogen is the limiting nutrient in most of the Baltic Sea, including the Gulf of Finland. Phosphorus, on the other hand, has a significant role in determining the formation and intensity of toxic cyanobacterial blooms that are currently a major concern, especially on the Gulf of Finland. The modelled food web contains 27 species or functional groups and four detritus groups (including N and P) that all have significant roles within the Baltic Sea ecosystem. The lowest trophic levels are represented by phytoplankton and cyanobacteria, with seals as top predators. Other groups belong to bacteria, zooplankton, zoobenthos, pelagic invertebrates and fish. The most important commercial fish species, cod (*Gadus morhua*), herring (*Clupea harengus*) and sprat (*Sprattus sprattus*) (ICES 2007) are included in the model.

There have been previous studies carried out using an Ecopath-approach on the Baltic Sea. In 2003 Harvey et al. published an Ecopath-study that was concentrated on the Baltic Sea fisheries. Also Sandberg (2007) has used an Ecopath-approach when studying the Baltic Sea carbon budgets. The main difference between this model and the previous models is that in this model nutrients are included as part of the food web, making this an end-to end model.

Materials and methods

Ecopath with Ecosim (EwE)

Ecopath with Ecosim (EwE) (Christensen et al. 2005) is a freely distributed (www.ecopath.org) ecosystem modelling software delivered by the Fisheries Centre of the University of British Columbia (Canada). The basis of this software lies in an Ecopath mass-balance equation (Eq. 6) first introduced by Polovina (1984) and further developed by Christensen and Pauly (1992).

$$P_i = Y_i + B_i + M2_i + E_i + BA_i + P_i * (1 - EE_i) \quad (\text{Eq. 6})$$

where P_i stands for the total production rate, Y_i for the total fishery catch rate, $M2_i$ for the total predation rate, E_i for the net migration rate, BA_i for the biomass accumulation rate and $P_i * (1 - EE_i)$ is the other mortality rate for group i .

In EwE, different sources and their interactions are described as trophically linked biomass pools and further the mass-balanced state of an ecosystem is handled by a set of simultaneous linear equations (Christensen & Pauly 1992). The minimum input required for each biomass pool is biomass/area (B), production/biomass (P/B), consumption/biomass (C/B) and diet composition. The impact of fishery can be included into an Ecopath mass-balance model.

In addition to the Ecopath mass-balance core, EwE contains two extensions. Ecosim is a time dynamic simulation model, which inherits its key parameters from the Ecopath core (Christensen et al. 2005) and incorporates differential equations that express biomass flux rates between different pools as a function of time varying biomass and harvest rates (Walters et al. 1997). In Ecosim, predator-prey interactions can be moderated by prey behaviour in order to vary exposure to predation. Thus, biomass flux patterns can show either bottom-up or top-down control. External forces can be introduced into the simulation as specific forcing functions. Ecospace is a spatial extension of EwE that inherits parameters and functions from Ecopath and Ecosim. In Ecospace, user defines a grid map across which biomass is distributed. Onto this map one can define several different habitat types, which are either preferential or non-preferred by biomass pools subjected to them. The level of preference is defined by altering the group specific predation pressure, feeding rates and level of movement. The movement of biomass in Ecospace is always symmetrical from the cell of origin (Christensen et al. 2005). Marine protected areas (MPAs) and spatially varying fishery pressure can be defined in Ecospace. External forcing with spatial resolution can, also, be incorporated into an Ecospace model.

Detailed information on EwE-software is available on the Ecopath with Ecosim user's guide by Christensen et al. (2005) or on www.ecopath.org.

Software improvements

Finnish Institute of Marine Research has worked in co-operation with the Fisheries Centre of the University of British Columbia (Canada) in order to improve the Ecopath-software, so that it would serve the aims of this project in a best possible way. The most important result of this co-operation has been the inclusion of salinity into Ecosim and Ecospace.

Ecopath-model of the Baltic Sea and the Gulf of Finland

We created a new Ecopath-model, consisting of 31 species/functional groups common to the Gulf of Finland and the entire Baltic Sea. This includes groups with large total biomasses, as well as keystone species.

In our model, phytoplankton (spring and summer) and cyanobacteria as primary producers represent the lowest trophic levels of the food web, with seals as top predators. Other groups included belong to bacteria (2), zooplankton (8), zoobenthos (6), pelagic invertebrates (1) and fish (6). All living groups are described by biomass (t/km^2 wet weight), production/biomass (P/B (a^{-1})) and consumption/biomass (C/B (a^{-1})) (Table 10). The diet composition of each group is expressed as the proportion of each prey out of the total diet of the consumer (Table 11). Ecopath calculates the ecotrophic efficiency (EE, which describes the proportion of the produced biomass (of a certain group) that flows to predators) and trophic level (TL) of each group according to the aforementioned input. Biomass is the only input required to determine detritus groups in the mass-balanced model.

Nutrients (N and P) and organic matter (DOM and POM) are described as four separate detritus groups: Redfield, Poverl, DOM and POM, where Redfield represents the amount of nitrogen and phosphorus available for the primary production, based on the common Redfield ratio 16 N : 1 P (calculated using the chemical properties of N), and Poverl stands for the amount of phosphorus overleft from this ratio. Nutrients are not automatically included as components of an Ecopath-model; hence we had to modify the basic model. This required determining phytoplankton groups as heterotrophic organisms, so that 98 % (99 % for cyanobacteria) of their biomass was defined to be produced by primary production and the remaining 2 % (1 % for cyanobacteria) by predation on the Redfield-nutrient (phosphorus (Poverl) in the case of cyanobacteria).

Table 10. The basic input parameters of Ecopath. B = biomass, P/B = production/biomass, C/B = consumption/biomass, EE = ecotrophic efficiency and P/C = production/consumption.

Group	B (t/km-2)	P/B (a-1)	C/B (a-1)	EE	P/C
seals	0.004	0.1	12.77	0	0.008
cod (adult)	0.379	1.21	2.59	0.847	0.467
herring (adult)	2.381	0.555	7.96	0.755	0.07
sprat (adult)	5.143	0.604	7.5	0.829	0.081
cod (juvenile)	0.59	0.8	5.306	0.766	0.151
herring (juvenile)	1.376	0.442	12.21	0.718	0.036
sprat (juvenile)	1.218	0.474	12.968	0.744	0.037
mysids	1.5	5.5	17	0.554	0.324
<i>Acartia</i> sp.	3.05	20	45	0.275	0.444
<i>Pseudocalanus</i> sp.	1.65	20	45	0.551	0.444
<i>Temora longicornis</i>	2.066	20	45	0.69	0.444
<i>Eurytemora</i> sp.	3.813	20	45	0.139	0.444
<i>Limnocalanus macrurus</i>	2.12	20	45	0.237	0.444
<i>Centropages hamatus</i>	0.276	25	50	0.768	0.5
cladocerans	0.855	20	45	0.59	0.444
ciliates	2	120	400	0.594	0.3
<i>S. entomon</i>	1	3	15	0.136	0.2
<i>H. sarsi</i>	0.139	1.3	10	0.637	0.13
<i>M. baltica</i>	8.117	0.9	13	0.161	0.069
<i>P. femorata</i>	2.875	5.91	35	0.168	0.169
<i>M. affinis</i>	2.504	8.13	35	0.217	0.232
meiobenthos	3	18	45	0.718	0.4
bacteria (water)	4.112	150	350	0.611	0.429
bacteria (sediment)	5	150	350	0.679	0.429
spring PP	15	90	1.89	0.013	47.619
phytoplankton	10	110	2.27	0.454	48.458
cyanobacteria	10	110	1.12	0.013	98.214
Redfield	3.286	-	-	0.992	-
Poverl.	1.738	-	-	0.502	-
POM	100	-	-	0.126	-
DOM	100	-	-	0.771	-

The biomass data for most groups is derived from the FIMR database. The final biomass-value for each group is calculated as the surface area weighed mean of the mean biomasses of all sub-areas. The sub-area-specific biomass means were calculated as mean values from representative sampling stations. A representative station here is a station with rather undisturbed/representative environmental conditions and frequent measurement data (at least once a year records). The exception here is the biomass data for water column bacteria, which is recalculated from Heinänen (1992) and for sediment bacteria. The fish biomass data is from multispecies virtual population analysis (MSVPA) by ICES (2007). Data on production, consumption and diet are from literature (e.g. Harvey et al. 2003); also, some expertise judgement has been used. All the biomass, production and consumption values are calculated as yearly averages.

Table 11. The prey of each group expressed as the proportion of the total diet.

	seals	cod (ad)	herring (ad)	sprat (ad)	cod (juv)	herring (juv)	sprat (juv)	mysids	Acartia sp.	Pseudocalanus sp.	T. longicornis	Eurytemora sp.	L. macrurus	C. hamatus	cladocerans	ciliates	S. entomon	H. sarsi	M. baltica	P. femorata	M. affinis	meiobenthos	bacteria (w)	bacteria (s)	spring PP	phytoplankton	cyanobacteria
Seals																											
cod (ad)	0.05																										
herring (ad)	0.15	0.15			0.07																						
sprat (ad)	0.25	0.35			0.30																						
cod (juv)	0.01	0.01																									
herring (juv)		0.08	0.00		0.05																						
sprat (juv)		0.05	0.00		0.05	0.01																					
mysids			0.20		0.10	0.03																					
Acartia sp.			0.01	0.20	0.10	0.22	0.15																				
Pseudocalanus sp.			0.25	0.14	0.11	0.22	0.11																				
T. longicornis			0.09	0.35	0.35	0.35	0.07																				
Eurytemora sp.			0.06	0.09	0.10	0.05	0.14																				
L. macrurus			0.03	0.09	0.10	0.05	0.14																				
C. hamatus			0.01	0.03	0.08	0.05	0.07																				
cladocerans			0.03	0.11	0.13	0.07	0.08																				
ciliates								0.25	0.25	0.25	0.25	0.20	0.32														
S. entomon	0.09	0.08	0.01		0.08																						
H. sarsi		0.01	0.01		0.01																						
M. baltica		0.04	0.01		0.05													0.05	0.10								
P. femorata		0.03	0.01		0.05	0.00												0.15	0.20								
M. affinis		0.03	0.01		0.05	0.00												0.25	0.25								
meiobenthos																				0.10	0.15	0.15					
bacteria (w)												0.10															
bacteria (s)																											
spring PP								0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01		
phytoplankton								0.20	0.73	0.73	0.73	0.51	0.78	0.61	0.99	0.08											
cyanobacteria								0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01											
Redfield																									1.00	1.00	
Poverl.																											1.00
POM												0.12		0.05		0.11	0.45	0.25	0.30	0.34	0.34	0.40					
DOM																							1.00	1.00			
Import	0.45	0.20	0.28	0.00	0.20	0.00	0.01					0.00															

Temporal and spatial dynamics

We simulated temporal and spatial dynamics of the food web created for years 1996-2006. The temporal changes (Ecosim) in environmental conditions were represented by yearly changes in nutrient conditions, as well as yearly varying fishing pressure for cod, herring and sprat. Also, in the cases of juvenile cod and benthic fauna, periods of anoxia were taken into consideration.

When studying the spatial resolution (Ecospace) we created two grid maps, one for the entire Baltic Sea (end co-ordinates: 66N, 53.5N, 13E and 31E) (Fig. 12) and one for the Gulf of Finland (end co-ordinates: 60.75N, 59.3N, 24E and 30.75E) (Fig. 13). A separate grid map was created for the Gulf of Finland in order to reach higher resolution for the area. The grid sizes were 20 km x 20 km and 10 km x 10 km, respectively. Within both maps we determined different habitats according to varying salinity, bottom oxygen concentrations and species-specific fish nursery grounds (Fig. 12 and Fig. 13). All habitats were either determined as preferential or non-preferential for the species studied.

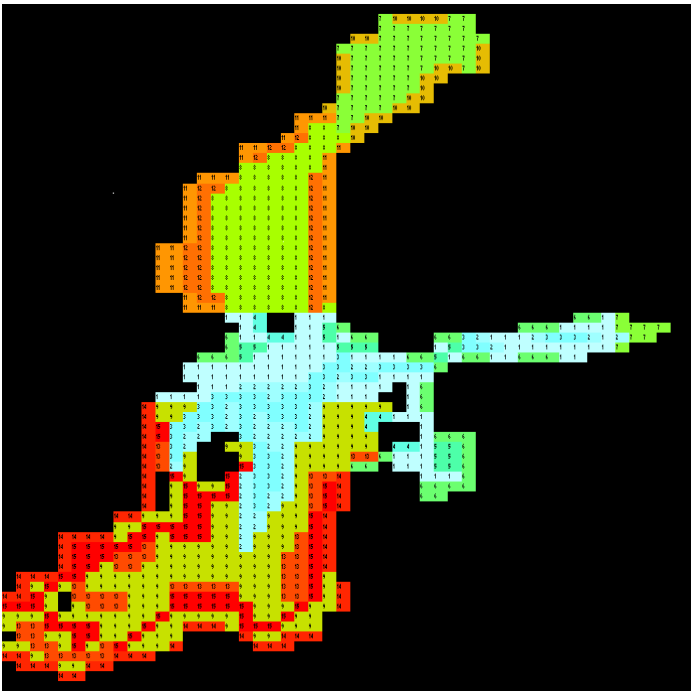


Fig. 12. Baltic Sea base map, where 1 = regular, 2 = < 2 ml l⁻¹ O₂, 3 = < 0 ml l⁻¹ O₂, 4 = cod nursery, 5 = sprat nursery, 6 = herring nursery, 7 = salinity < 4, 8 = salinity < 6, 9 = salinity > 8, 10 = herring nursery (salinity < 4), 11 = herring nursery (salinity < 6), 12 = sprat nursery (salinity < 6), 13 = sprat nursery (salinity > 8), 14 = herring nursery (salinity > 8), 15 = cod nursery (salinity > 8).

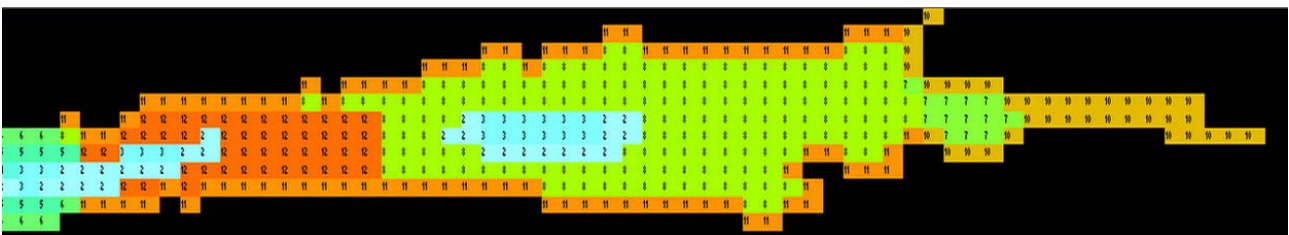


Fig. 13. Gulf of Finland base map, where 1 = regular, 2 = < 2 ml l⁻¹ O₂, 3 = < 0 ml l⁻¹ O₂, 4 = cod nursery, 5 = sprat nursery, 6 = herring nursery, 7 = salinity < 4, 8 = salinity < 6, 9 = salinity > 8, 10 = herring nursery (salinity < 4), 11 = herring nursery (salinity < 6), 12 = sprat nursery (salinity < 6), 13 = sprat nursery (salinity > 8), 14 = herring nursery (salinity > 8), 15 = cod nursery (salinity > 8).

Results

The mass-balance flowchart for our food web is shown in Figure 14. From this chart one can see that the production at the top of the food web modelled is only a fraction of the production at the base of the web. Also, the extensive linking between different species is obvious.

When the ecotrophic efficiency (EE)-values are studied (Table 10), it is shown that zooplankton such as *Pseudocalanus* sp. (EE = 0.551), *Temora* sp. (EE = 0.690) and *Centropages hamatus* (EE = 0.768) are efficiently grazed on. This makes sense, as all these copepod species are important prey for Baltic sprat and herring (Möllmann et al. 2004, Arrhenius & Hansson 1993). Our model, also, indicates that the Baltic Sea microbial loop is efficient as the EE-values for water and sediment bacteria are 0.611 and 0.679, respectively. In addition, the EE-values for all commercial fish are rather high; however this is mainly due to fishery actions. The EE for the redfield-nutrient is close to 1.

The mixed trophic impact (Ulanowich & Pucia 1990) of each group is presented in Figure 15. The mixed trophic impact of all four detritus groups (including both nutrient groups) is high, especially within the lower and medium trophic levels of the food web. The effect of the Redfield-nutrient seems to cascade also to the higher levels, even though it does dampen down along the way. The effect of summer phytoplankton corresponds well with the one of Redfield. When the impact of fishery actions is observed with this model it seems that the impact of single countries is not that significant, however, the total impact of all fisheries is rather high, especially in the case of the Baltic cod. Further, the mixed trophic impact analysis of Ecopath tells us that if the biomass of the Redfield-nutrient is increased within the food web at its steady-state, this will have highest impact on the two phytoplankton groups. The effect on the biomass of most zooplankton groups is half of this and further the effect on fish is from one tenth to one fifth of the effect on the phytoplankton.

Our ten-year Ecosim-simulation (1996-2005) of the biomass of the Baltic Sea herring stock does correlate rather well with the ICES MSVPA-results (Fig. 16), when yearly nutrient forcing and fishing pressure are imposed on the group. This correlation is not as good in the case of sprat as with herring, as the decline of the stock in our model is not as deep as in the ICES MSVPA-simulation (1998 and 2001-2004). Although the development of fish stocks is not our particular interest, we have found it very useful to compare the simulation data from our model and the simulation data from ICES, as this helps us to identify possible strengths and weaknesses in our simulation. The reference data from lower trophic levels is more scattered and the measurement data, as well as the simulation, show more fluctuation.

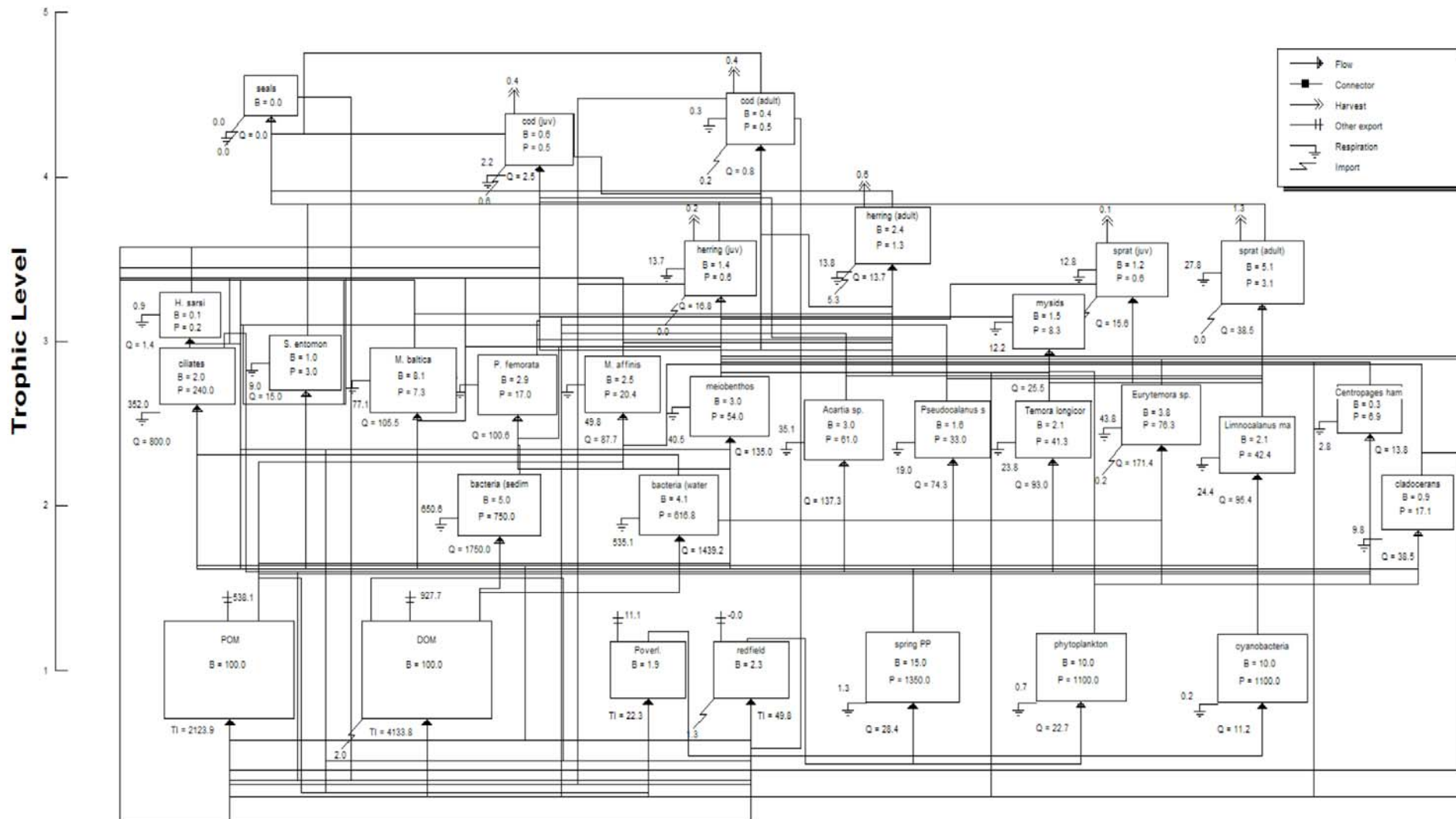


Fig. 14. The flowchart of the Baltic Sea food web, where B = biomass and P = production.

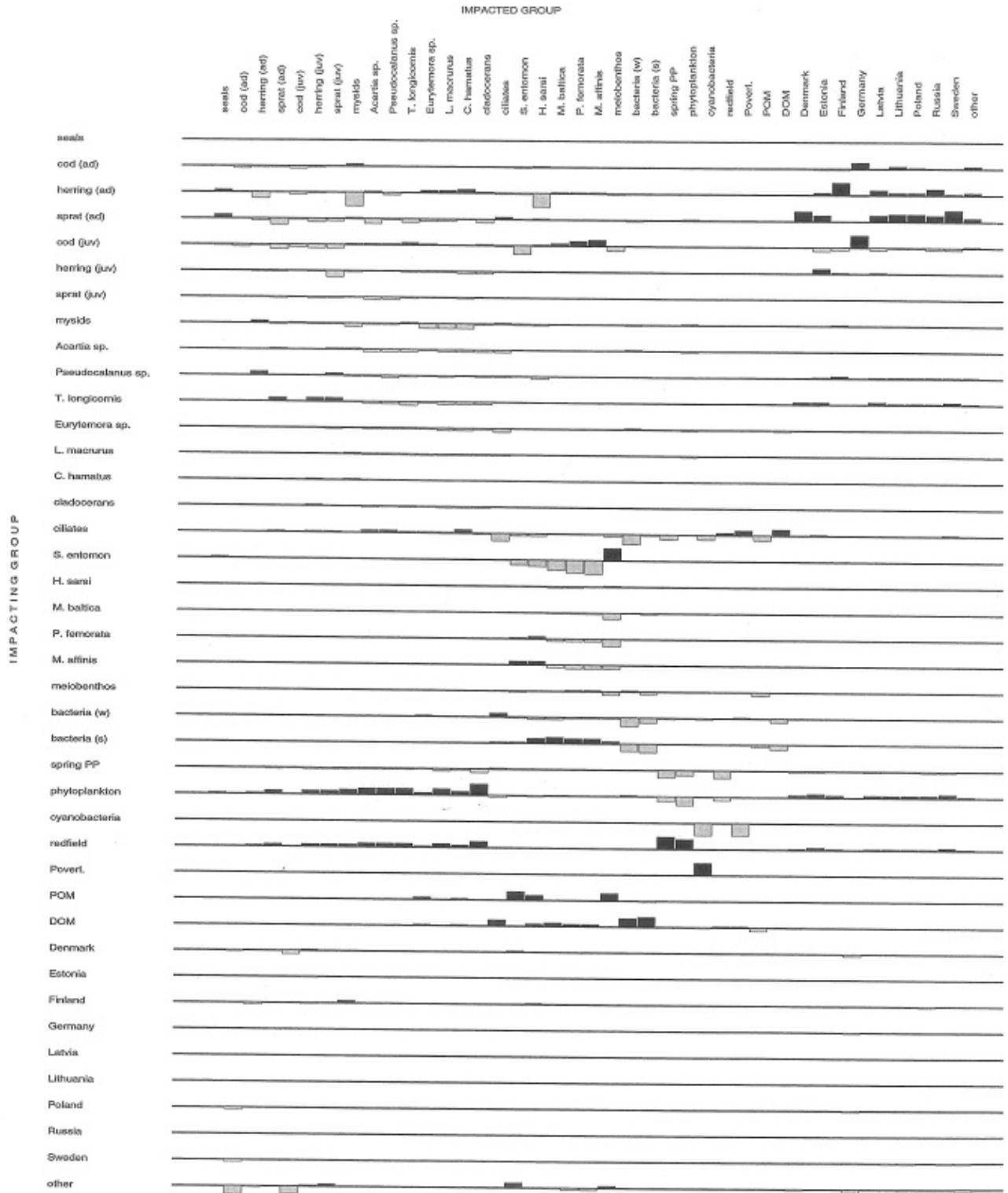


Fig. 15. The mixed trophic impact, including the impact of fisheries. The impacting groups are on the left hand side and the impacted groups are named at the top. The downward bars represent negative impact and the upward bars positive impact.

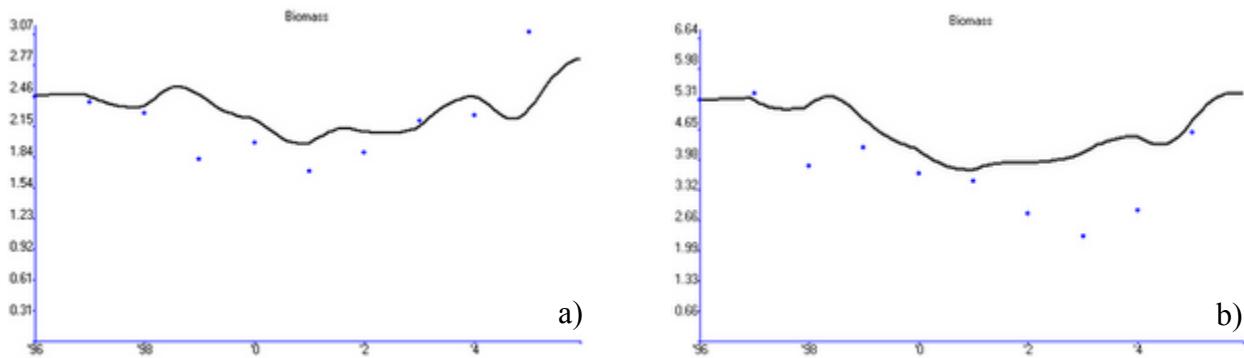


Fig. 16. The biomass development (1996-2006) simulated by our model is represented by the black solid line and the ICES MSVPA-results are represented as blue dots; a) herring, b) sprat.

We studied the effects of 5 and 10 percent Redfield-nutrient decrease on the food web model using Ecosim. No other forcing functions than reduction in nutrient levels were implemented within this study. The results (Table 12) from the ten-year Ecosim-run were rather different from the results of the mixed trophic impact analysis. The most significant difference is that in the simulation the summer phytoplankton biomass seems to increase when the Redfield-nutrient is decreased. The spring phytoplankton biomass on the other hand, experiences a relative decrease as big as the Redfield-nutrient. One possible explanation for this is that within the model both phytoplankton groups compete for the same resources and thus as spring phytoplankton is more affected by the nutrient decrease than summer phytoplankton, will this further aid the growth of summer phytoplankton. However, in nature, these two groups don't exist simultaneously and this decreases the force of their interaction. The increase in the summer phytoplankton does explain many of the responses at higher levels of our food web model.

When the biomass simulation graphs are studied it looks like both the phytoplankton and zooplankton groups react rather strongly to the change in nutrients rather immediately. However they do find a new biomass balance after a couple of years. It also seems that the initial reaction of these groups to the nutrient change displays behaviour somewhat similar to overcorrection. The groups higher up in the food web, like fish, don't seem to display such overcorrection (Fig. 17).

The spatial simulation (Ecospace) was run for both the Gulf of Finland and the whole Baltic Proper. The results from these two runs were not identical; however, they did display similarities. The end results of a ten-year run (1996-2005), for selected groups, are shown in Figure 18. According to these model runs, the sprat biomass is distributed along the Gulf of Finland salinity gradient in a way that they are more abundant at the mouth of the gulf than farther east. *Pseudocalanus* sp. also prefers higher salinities, which is also observed from both of our models. However, at the mouth of the Gulf of Finland *Pseudocalanus* sp. biomass seems to have decreased. This is most likely caused by the high abundance of sprat at the same area in our model. A benthic animal *P. femorata* seems to have disappeared from the Gulf of Finland in the area specific simulation, the likely causes being low salinity and frequent bottom anoxia. However, the simulation of the entire Baltic Sea displays different results and here the *P. femorata* is only absent from the very eastern part of the gulf. Cyanobacteria and leftover phosphorus do seem much interrelated, as during the cyanobacterial bloom the overleft phosphorus is consumed from the growth area. Within the area specific models run, the Redfield-nutrient shows a general decrease in the course of the past 10 years, but the distribution of nutrient biomass seems to be somewhat heterogeneous. The entire Baltic Sea model show rather opposite results, and indicates that the nutrient concentrations have increased in the Gulf of Finland during the same time period. The reason why the

entire Baltic Sea model show in many cases higher biomass values than the regional model, can be due to lower resolution and consequently worse chances for organisms to leave the area (as the narrow gulf is surrounded by so many land cells into which the organisms cannot move).

Table 12. The results from the 5 and 10 % Redfield-nutrient reductions in Ecosim (start = year zero, end = year 10).

		-5 %		-10 %	
	B(start)	B(end)	B(end/start)	B(end)	B(end/start)
seals	0.004	0.004	0.99	0.004	0.98
cod (adult)	0.379	0.37	0.98	0.359	0.95
herring (adult)	2.393	2.369	0.99	2.317	0.97
Sprat (adult)	5.16	5.114	0.99	5.025	0.97
cod (juvenile)	0.59	0.573	0.97	0.556	0.94
herring (juvenile)	1.376	1.372	1	1.346	0.98
Sprat (juvenile)	1.218	1.21	0.99	1.187	0.97
Mysids	1.501	1.458	0.97	1.438	0.96
<i>Acartia</i> sp.	3.052	3.08	1.01	3.023	0.99
<i>Pseudocalanus</i> sp.	1.651	1.634	0.99	1.623	0.98
<i>T. longicornis</i>	2.068	2.002	0.97	2.024	0.98
<i>Eurytemora</i> sp.	3.815	3.797	1	3.702	0.97
<i>L. macrurus</i>	2.121	2.156	1.02	2.111	0.99
<i>C. hamatus</i>	0.276	0.286	1.03	0.277	1
Cladocerans	0.856	0.839	0.98	0.849	0.99
Ciliates	2.001	2.012	1.01	1.971	0.99
<i>S. entomon</i>	1	0.952	0.95	0.911	0.91
<i>H. sarsi</i>	0.139	0.134	0.97	0.13	0.94
<i>M. baltica</i>	8.118	8.023	0.99	7.768	0.96
<i>P. femorata</i>	2.876	2.82	0.98	2.733	0.95
<i>M. affinis</i>	2.506	2.475	0.99	2.388	0.95
Meiobenthos	3.002	2.953	0.98	2.891	0.96
bacteria (w)	4.114	4.063	0.99	4.046	0.98
bacteria (s)	5.002	5.028	1.01	4.957	0.99
spring PP	15.009	14.223	0.95	13.634	0.91
Phytoplankton	10.003	10.258	1.03	10.263	1.03
Cyanobacteria	10.005	9.981	1	9.71	0.97
Redfield	3.286	3.12	0.95	2.96	0.9
Poverl.	1.738	1.74	1	1.717	0.99
POM	100.036	97.108	0.97	94.311	0.94
DOM	100.039	100.273	1	99.406	0.99

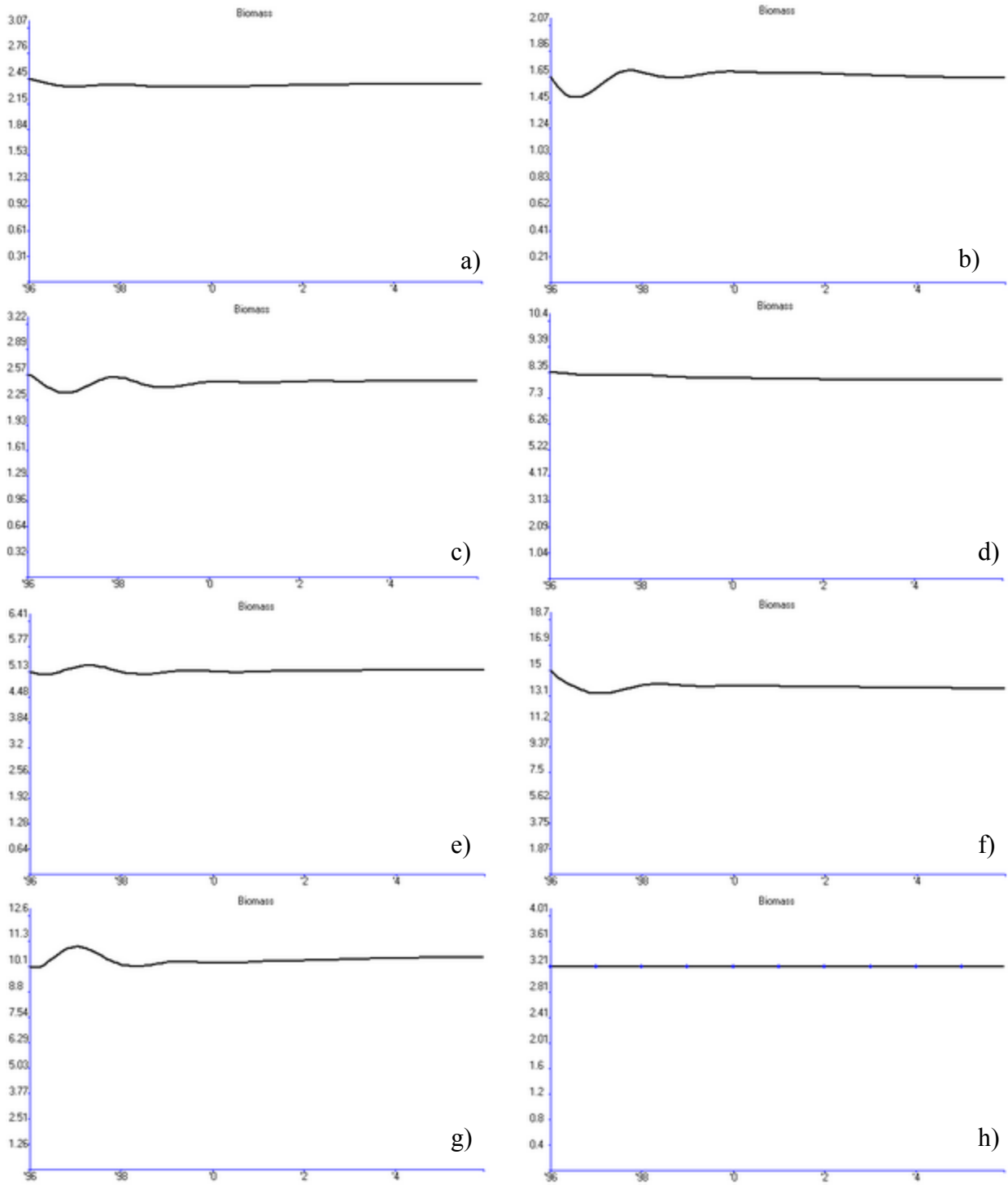


Fig. 17. The biomass simulations of selected groups after 5 % decrease in Redfield-nutrient: a) herring, b) *Pseudocalanus* sp., c) *M. affinis*, d) *M. baltica*, e) sediment bacteria, f) spring phytoplankton, g) summer phytoplankton and h) Redfield-nutrient. Note that the graphs have differing scaling.

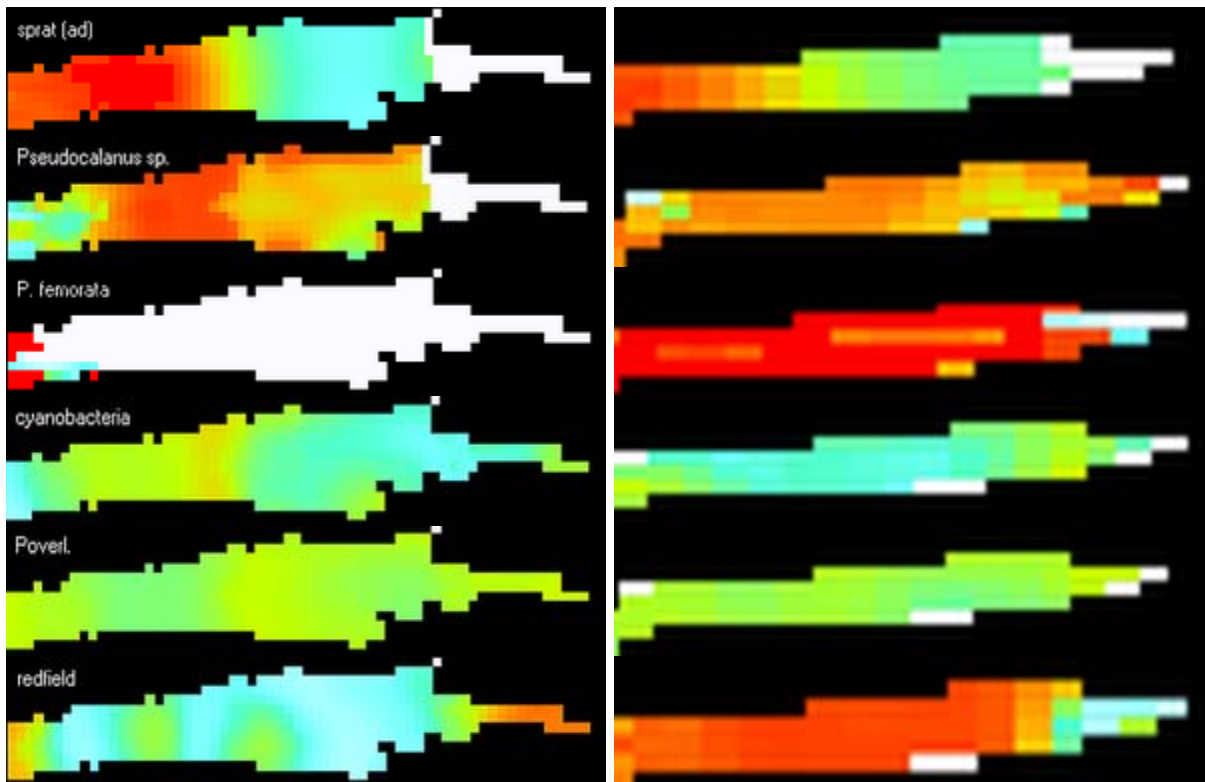


Fig. 18. The end results of a 10-year Ecospace run from the Gulf of Finland run (left) and the entire Baltic Sea run (right), for sprat, mysids, *Eurytemora* sp., ciliates, *P. femorata*, sediment bacteria, Redfield-nutrient and cyanobacteria. Areas where the biomass has increased are indicated with a red colour and areas where the biomass has decreased are indicated with a blue colour. Green indicates that there has been no change in biomass. White areas don't contain the organism in question.

Discussion

Our food web model seems to produce rather similar results with the ICES MSVPA simulation data (1997-2006) for fish biomasses, which is encouraging. This is especially so as we have now included nutrients as separate groups within this model, which is something that has not been done previously within the context of Baltic Sea Ecopath-studies. In addition, the results from the mixed trophic impact analysis are mostly within the lines what we expected, as well as the high EE-values do coincide with the species and groups that we know are under intensive predation pressure. It was also an interesting observation that the model didn't response similarly to the changes in nutrients in its mass-balanced state and in the case of the simulation, and this is something we need to look further into in the future. One of the very important aspects within the Baltic Sea food web is the efficient functioning of the microbial loop and we are happy that this is represented, at least at some level, within this model.

There are still ways in which we can improve this model. The improvements will in the future concern especially the Ecospace-feature, into which our aim is to include at least spatial nutrient forcing (in the form of nutrient maps) and to explore if more physical forces (e.g. seasonal changes in temperature and light conditions) could be included into the model. Also, we do have to look into the simulation model more carefully, and most likely include temperature and light forcing functions into this feature as well,

so that potential problems like the simultaneous growth of spring and summer phytoplankton species could be avoided in the future.

We consider that the sensitivity information is one of the most useful tools that can be created by our model. Thus in the future we aim to improve the technical features of EwE, in a way that bottom-up sensitivities can be easily withdrawn from the models created. Now EwE produces only the top-down sensitivities automatically. This is a very important aspect, as information on species-species interaction within the Baltic Sea and the Gulf of Finland food webs is rather scarce at the moment.

Impact of the project

Because biological processes are complex and include a lot of stochasticity, a probabilistic approach has many advantages when studying those (Borsuk et al. 2004). During the project, new methodology for this was successfully developed. The developed model and user interface are yet introductory prototypes but they still appear very promising tools for the comparison of different scenarios from the ecosystem point of view.

One of project objectives was to start developing a tool that would help decision makers in their work. In the first place, this kind of tool is an excellent aid for combining large entities. No human mind alone can compare the impacts of 48 scenarios within 9 areas. In addition, the presentation of predictions as probability distributions gives the decision-maker a more realistic picture of the uncertainties related to the ecological processes and the effects of the conservation measures. The comparison of the magnitude of different scenarios and separate factors within and between different parts of the Gulf of Finland gives interesting information about the country-specific areal roles. Of course, at this moment the alternative scenarios are so large-scaled that no true decision ranking is possible.

Although the differences in the total risks and benefits predicted to be gained with different loading scenarios are in some cases small due to the large uncertainties or problems in the discretizing of variables, the methodology still clearly points out the measures which would most likely maximize the probability for a good state of the ecosystem. Moreover, the analysis network in itself is a valuable tool for evaluating the importance of different factors for the robustness of the scenario ranking, thus helping to steer monitoring to produce information relevant for the control of the eutrophication process. This kind of knowledge could in the future serve as a basis for the design of a common monitoring system between the countries surrounding the Gulf of Finland.

By linking together several model results and separate datasets from different monitoring programs and studies, the EVAGULF tool is able to produce a quite clear general view of the eutrophication chain in the ecosystem of the Gulf of Finland. The different parts of the model increase the information value of each other as well as the use of prior information and multiple monitoring datasets in the Bayesian MCMC models do. The use of different commonly accepted approaches for analysing the same results and datasets enables the assessment of the approach-driven uncertainty and help to realize what those approaches in fact are telling us.

User of the EVAGULF RADSS 1.0 should notice that despite the interesting data and modelling work behind it, it is yet a prototype. It was created within a relatively short time period and the main purpose

of the project was to develop and test the methodology – not to create a finalized decision analysis tool. The results or the functioning of the user interface are not examined closer or revised yet.

An important challenge in the future is related to the clear, understandable presentation of the probabilistic thinking and uncertainty in the user interface. If the user is not familiar with this kind of an approach, there may be some erroneous interpretations. At their best, results presented as probability distributions are considerably more informative than traditional point estimates and confidence intervals, and they give excellent support both for discussion and decision-making in the society (Uusitalo 2007). The potential end-users will be interviewed for the continuation development work of the EVAGULF RADSS.

The cooperation between the Estonian and Finnish partners during the project was highly interactive and productive. Plenty of good ideas and future plans arose and cooperation is hoped to be continued in the future. The project received considerable attention e.g. from media, management authorities and international research community.

Financing and participants

The project EVAGULF (fimos 113560) was carried out as a part of the INTERREG III A Southern Finland and Estonia –programme. The project budget was 391 433 € and the implementation period was September 1st 2006 – December 31st 2008. The project was financed by the European Regional Development Fund, South-East Finland Regional Environment Centre, Estonian Ministry of the Interior and University of Tartu. Project financing is presented in Table 13 and realized budget is presented in Table 14.

The lead partner and coordinator was University of Helsinki, Department of Biological and Environmental Sciences, Kotka unit (UHel). Other partners were Estonian Marine Institute (University of Tartu) (EMI), Finnish Environment Institute (SYKE), Finnish Institute of Marine Research (FIMR) and Helsinki University of Technology, Laboratory of Geoinformation and Positioning Technology (TKK).

UHel was responsible for the design and construction of the risk and scenario assessment model and development of new methodology for the construction of Bayesian population risk assessment models. EMI was responsible for creating Bayesian networks for the Estonian coastal areas. SYKE was responsible for the loading models and ecosystem modelling. FIMR was responsible for the areal division and the sensitivity analyses of the Gulf of Finland food web. TKK was responsible for the creation of the risk analysis and decision support system and its user interface.

Partners in co-operation were Kotka Maritime Research Centre (Merikotka ry), South-East Finland Regional Environment Centre, Estonian Ministry of the Environment, EuroUniversity of Tallinn and Estonian Environment Information Centre.

Table 13. Project financing. ERDF = European Regional Development Fund, KAS = South-East Finland Regional Environment Centre.

Financing	€	%
ERDF	208 966	53.38
KAS	169 217	43.23
Estonian Ministry of the Interior	5 300	1.35
University of Tartu	7 950	2.03
Altogether	391 433	100
Realized financing*		
ERDF	164 642.71	53.12
KAS	135 634.98	43.76
Estonian Ministry of the Interior	3 867.70	1.25
University of Tartu	5 801.55	1.87
Altogether	309 946.94	100

* Situation in February 2008

Table 14. The realized project budget.

Cost category	Budget €	Expenses €* €	Left €* €
Office and rent	23 748 €	10 100.84	13 647.16
Personnel	302 696 €	244 730.38	57 965.62
Travel	16 246 €	9 657.86	6 588.14
Purchased services	41 890 €	42 977.90	- 1 087.90
Computers	5 353 €	1 755.88	3 597.12
Other	1 500 €	724.08	775.92
Altogether	391 433 €	309 946.94	81 486.06

* Situation in February 2008

Dissemination

Press releases

The press release "Suomalais-virolainen tutkimus selvittää Suomenlahden rehevöitymistä" was published on December 4th 2006 together with the information officer at the University of Helsinki about the launching of the project. At least the following institutes published the press release in their web news: Verkkouutiset (www.verkkouutiset.fi), Finnish Institute of Marine Research (www.fimr.fi) and Finland's environmental administration (www.ymparisto.fi).

University of Tartu, Estonian Marine Institute published January 21st 2008 the press release "TÜ EESTI MEREINSTITUUT OSALEB PARTNERINA SOOME LAHE SEISUNDI UURIMISE PROJEKTIS", highlighting the results of the project.

The press release "Uusi analyysityökalu Suomenlahden tilan kehityksen arviointiin", highlighting the results of the project, was published February 8th 2008 together with the information officer of the University of Helsinki.

Www-pages

Www-pages <http://www.evagulf.fi> were created for the project in Finnish, English and Estonian together with Riku Lumiaro and Maiju Koivula, information officers at the Finnish Institute of Marine Research. The pages were updated regularly.

Newspaper articles

The newspaper Etelä-Saimaa published an article on December 5th 2007 about the project with title "Suomenlahden rehevöitymistä selvitetään".

The newspaper Kymen Sanomat published an article on January 21st 2007 about the project, where Sakari Kuikka, Annukka Lehikoinen and Eveliina Lindén were interviewed. Reporter Timo Uusiniitty's article "Työkalu suojelutoimien hyötyjen ja riskien arviointiin" was published on page 2, and it was advertised on page 1 with title "Miten suojelutoimista saadaan suurin hyöty?"

The article "Sanoista tekoihin meriluonnon hyväksi", written by Annukka Lehikoinen and Eveliina Lindén, was published July 14th 2007 in the newspaper Helsingin Sanomat, in section Mielipide.

The newspaper Kymen Sanomat published July 21st 2007 the article "Riskit epäonnistumiseen suuret pohjan hapettamisessa" on the project EVAGULF, written by reporter Timo Uusiniitty.

The newspaper Viikko eteenpäin published July 26th 2007 the article "Luonnon monimuotoisuus jäänyt sinilevän varjoon" on the project EVAGULF, written by reporter Reijo Hämäläinen.

The newspaper Kymen Sanomat published February 9th 2008 and the newspaper Kouvolan Sanomat published February 10th 2008 the article "Uusi työkalu Suomenlahden tilan arviointiin" on the project EVAGULF, written by reporter Timo Uusiniitty.

Presentations

Annukka Lehikoinen gave a presentation on September 28th 2006 with title "EVAGULF – Suomenlahden vesiluonnon suojelu: riskipohjainen päätöksenteko" at a meeting of the Fisheries and Environmental Management Group of the Department of Biological and Environmental Sciences of the University of Helsinki, held at the Department of Applied Sciences of Education of the University of Helsinki.

Annukka Lehikoinen gave a presentation on November 16th 2006 with title "EVAGULF – Suomenlahden vesiluonnon suojele: riskipohjainen päätöksenteko" at a meeting of the scientist network of the Kotka Maritime Research Centre Merikotka, held in Kotka Maretarium.

Annukka Lehikoinen presented the tool to be developed in the project and methods used in doing so, in a joint meeting with the scientist of the project OILECO on February 23rd 2007 held in Palmenia, Kotka.

Robert Aps gave a presentation with title "Protection of ecological values of the Gulf of Finland" in the Estonian Marine Science 2007 conference April 10th 2007 in Tallink Hotel, Tallinn.

Eveliina Lindén presented the project EVAGULF June 1st 2007 in the press conference of The Tall Ships' Races in restaurant Duetto, Kotka.

Anna Kiiski (coordinator, project OILECO) presented the project EVAGULF June 6th 2007 for the personnel of the Tacis project "People, Nature and Harbours" in the Kymenlaakso University of Applied Sciences, Kotka.

Annukka Lehikoinen presented the project EVAGULF June 13th 2007 for the personnel of the office of the Faculty of Biosciences, University of Helsinki, in Maretarium, Kotka.

The main event of the summer 2007 was the seminar "Riskipeliä meidän merellämme? – Seminaari ympäristöriskien hallinnasta Suomenlahdella" during The Tall Ships' Races on July 20th 2007. The seminar was held on STS Sedov in Kotka, and there were ca. 100 participants. Sakari Kuikka gave a presentation with title "Luonnontieteilijä ja päätösanalyysi – eriskummallinen parivaljakko?", Annukka Lehikoinen gave a presentation with title "Rehevöitymisen riskien äärellä" and Eveliina Lindén gave a presentation with title "Rehevöityvä Suomenlahti – vaarassa muutakin kuin uimaretket". The seminar was widely acknowledged in the media, both in newspapers and in the television (YLE1 Aamu-tv, A-studio).

Eveliina Lindén gave on September 17th 2007 a presentation with title "EVAGULF – Protection of aquatic communities in the Gulf of Finland: risk-based policymaking" in the Annual Science Conference of the International Council for the Exploration of the Sea (ICES), held in Helsinki. The presentation was situated in the session "Developing the ecosystem approach to the management of human activities for the Baltic Sea". The session conveners (Andris Andrushaitis (Latvia), Eero Aro (Finland) and Christian Möllmann (Germany)) included in their report a thematic figure describing the EVAGULF RADSS tool as an example of risk analysis. The presentation received wide interest also from the general conference audience.

Susa Niiranen gave a presentation with title "An Ecopath model of the Baltic Sea food web" in the 6th European Conference on Ecological modelling (ECEM'07), held in Trieste, Italy November 26th – 30th 2007.

Articles

The project wrote an article E. Lindén, A. Lehtikoinen, S. Kuikka, R. Aps, J. Kotta, G. Martin, T. Saat, H. Pitkänen, A. Räsänen, P. Korpinen, T. Stipa, S. Kaitala and A. Jolma: EVAGULF – Protection of aquatic communities in the Gulf of Finland: risk-based policymaking. – ICES CM 2007/C:07. The article was published on a cd, which was distributed to all participants of the ICES Annual Science Conference and in the internet: <http://www.ices.dk/products/CMdocs/CM-2007/C/C0707.pdf>.

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Appendix 1. Class boundaries of the EU WFD classification system, used as a base for the areal discretization of the variables in the EVAGULF BNs. H = high, G = good, M = moderate, P = poor, B = bad.

Finnish western and eastern inner archipelago areas*

Variable	Unit	Class boundaries			
		H/G	G/M	M/P	P/B
Total phosphorus	µg/l	26	33	65	87
Total nitrogen	µg/l	468	585	1170	1560
Secchi-depth	m	4,5	3	1,1	0,5
Chlorophyll-a	µg/l	3,2	4,7	13	26
<i>Fucus</i> max depth sheltered	m	2,5	1,5	0,7	0,5
<i>Fucus</i> max depth exposed	m	4	2,5	1	0,7

Finnish western and eastern outer archipelago areas and the open sea areas

Variable	Unit	Class boundaries			
		H/G	G/M	M/P	P/B
Total phosphorus	µg/l	23	29	57	76
Total nitrogen	µg/l	408	510	1020	1360
Secchi-depth	m	5,6	3,7	1,3	0,7
Chlorophyll-a	µg/l	2,8	4,1	12	23
<i>Fucus</i> max depth sheltered	m	3,5	2,5	1	0,5
<i>Fucus</i> max depth exposed	m	6	4	1,5	1

Estonian western coast**

Variable	Unit	Class boundaries			
		H/G	G/M	M/P	P/B
Total phosphorus	µg/l	52	66	74	83
Total nitrogen	µg/l	406	508	576	644
Secchi-depth	m	5	4,1	3	1,7
Chlorophyll-a	µg/l	2,6	3,3	3,7	4,2
<i>Fucus</i> max depth	m	5,6	3,5	2,1	0,7

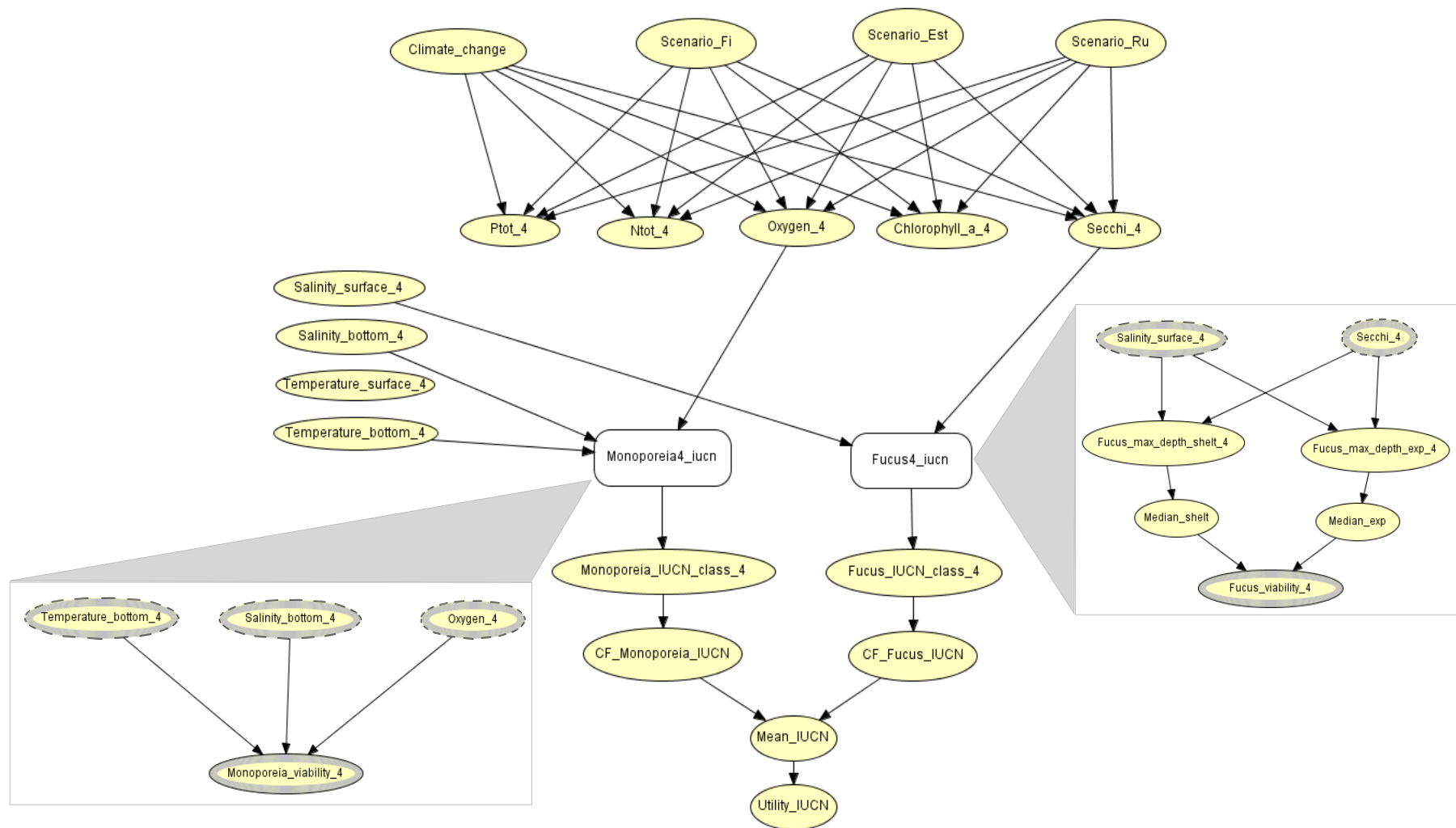
Estonian eastern coast**

Variable	Unit	Class boundaries			
		H/G	G/M	M/P	P/B
Total phosphorus	µg/l	67	84	95	106
Total nitrogen	µg/l	548	685	776	867
Secchi-depth	m	4	3,4	2,5	1,4
Chlorophyll-a	µg/l	4	5	5,6	6,3
<i>Fucus</i> max depth	m	3,2	2	1,2	0,4

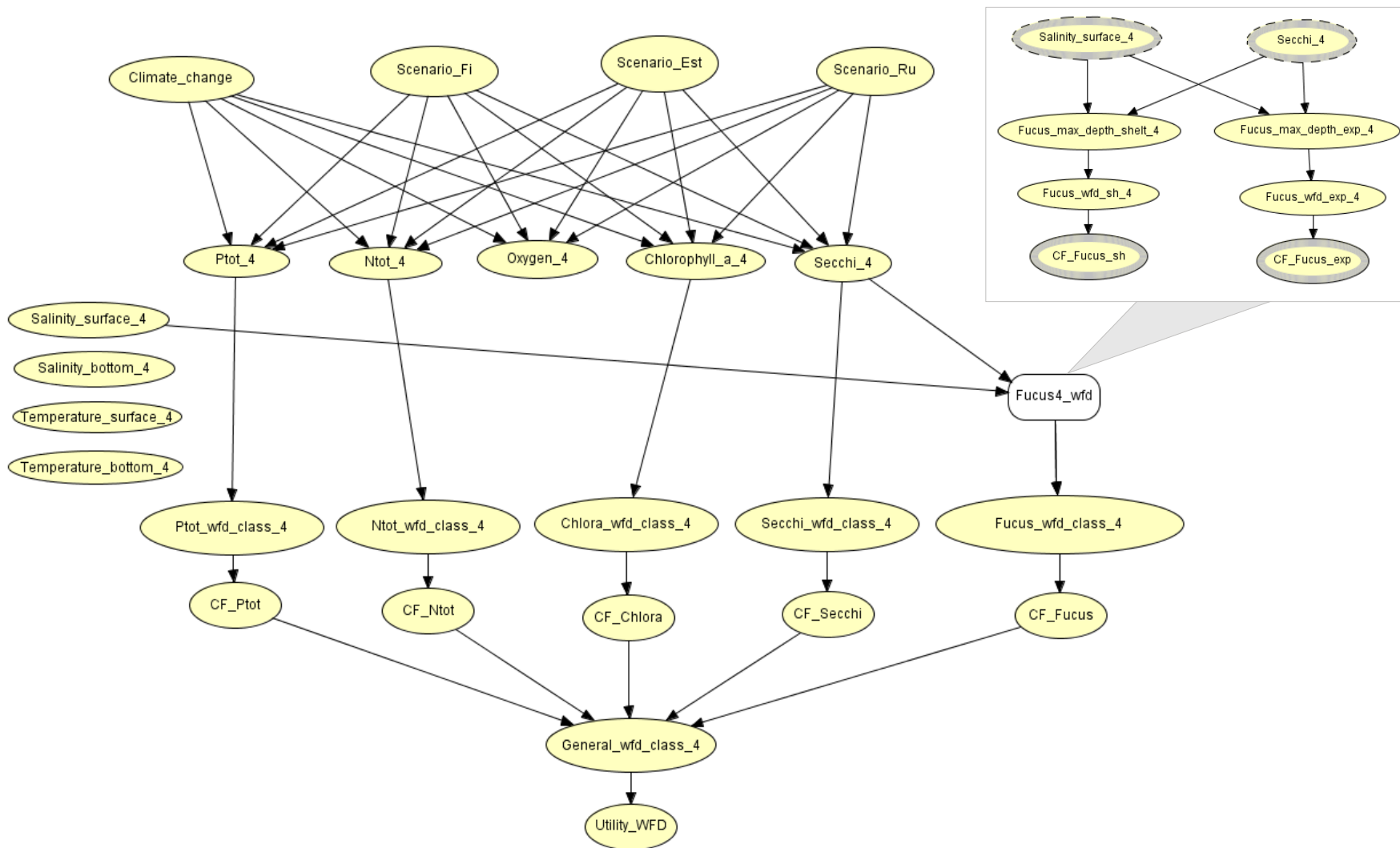
*In WFD classification of Finnish inner archipelago areas, total phosphorus is not included because of the great amount of internal loading. The discretization class boundaries for phosphorus are calculated by using total nitrogen WFD class boundaries for inner archipelago and the same N_{tot}/P_{tot}-relation than in outer archipelago WFD class boundaries.

**The Estonian WFD classes for the nutrient concentrations are calculated for summer values whereas in Finnish system the winter concentrations are evaluated.

Appendix 2. Structure of the areal networks in the IUCN approach.



Appendix 3. Structure of the areal networks in the WFD approach.



Appendix 4. Structure of the Estonian WFD classification network. In this network salinity and temperature are not linked, but they are still included as independent variables to enable the user to dissect their distribution within the area.

