BEVIS II Report

Internal loading of phosphorus
Model modifications to the bottom loads and scenario calculations

Tuula Kohonen, Päivi Korpinen, Arto Inkala & Anders Engqvist

HUSÖ BIOLOGICAL STATION
Åbo Akademi University 2008

Internal loading of phosphorus

Tuula Kohonen
Åbo Akademi University

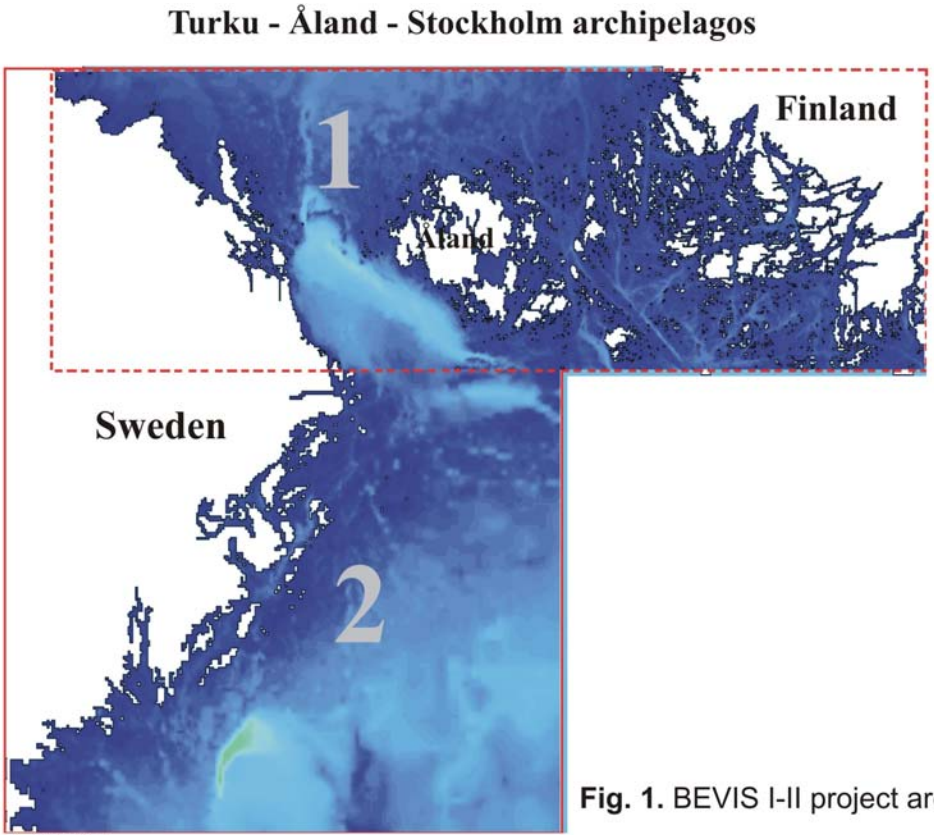
Background

Tools for planning joint protective measures for water quality have been produced in a multinational project BEVIS for the three archipelago areas of Turku, Åland and Stockholm (Fig.1). Effective protection plans are needed to achieve a good ecological status of EU waters by year 2015 as stated by the EU Water Framework Directive. Additionally, recent ecological concerns of the present state of the Baltic Proper also generate a need for new, more effective measures to stop the deterioration of the Baltic Sea waters. The latest research results show that anthropogenic nutrient emissions and internal loading from anoxic sediments have had severe adverse effects on the Baltic Sea ecosystem in spite of a significant reduction of nutrient discharges during the past decades.

The BEVIS project has been financed by EU's Interreg IIIA Skärgården programme and four national financiers: Government of Åland, The Office of Regional Planning and Urban Transportation/Stockholm County Council, Southwest Finland Regional Environment Centre, and Svealands Coastal Water Management Association. The first phase of BEVIS took place in 2004-2006. The aim of the project was to plan water quality models for the archipelago areas Turku-Åland-Stockholm (the northern part) and to estimate the effects and importance of different local and regional water protection measures.

Two different 3D water quality models have been applied to the BEVIS I project area (area 1 in Fig. 1). The “Swedish” model has been developed at Stockholm University (project partner during 2004-2006) and the other ”Finnish” model by a consortium of the Finnish Environment Institute (SYKE) and Environmental Impact Assessment Centre of Finland Ltd (EIA). In both models the horizontal grid resolution is 0.25’ (ca 463 m), and the Finnish model includes even a fine-tuned model for the Föglö area on Åland with a resolution of 0.0625’ (circa 116 m). The Finnish model is an ecosystem model that can simulate the amount of phytoplankton.

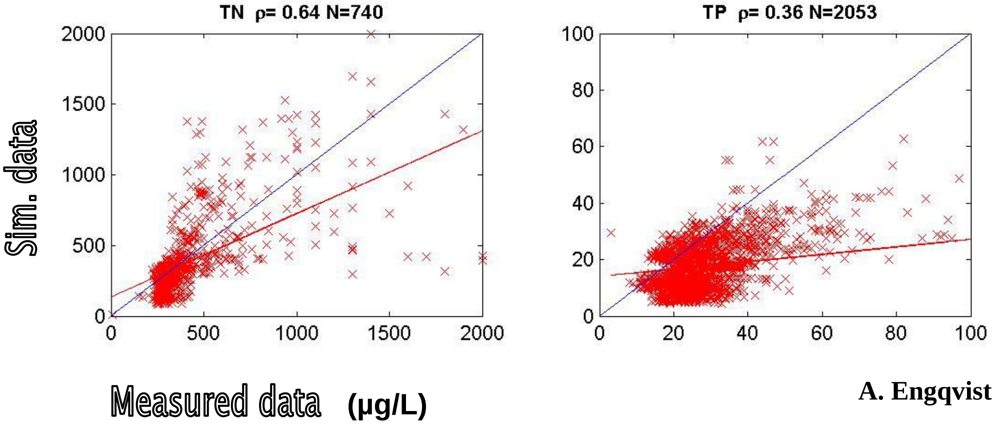
The nutrient loading data from diffuse and point sources have been collected to the regional BEVIS database from the entire project area. The models use the loading data from the 12 months of the year 2004, except for the initial nutrient loading from December 2003. Nitrogen and phosphorus data have been arranged into different categories according to the nutrient loading sources: initial values in the beginning of the modeling period (INI), inflow from the model borders (BOR), inflow via rivers (RIV), loading from fish farms (FIF), loading from industries (IND), loading from sewage treatment plants (STP), diffuse loading, other than from rivers (DIF), airborne nitrogen loading (AIR), and benthic flux of nutrients (BOT).



A. Engqvist

Fig. 1. BEVIS I-II project areas.

Results of the BEVIS model validations and simulations showed that the models function well in relation to the complex model area, but they seem to underestimate the leakage of phosphorus from the bottom sediments (Kohonen & Mattila 2007). The models could simulate the nitrogen concentrations in the water acceptably well (Fig. 2).



A. Engqvist

Fig. 2. Model validation in BEVIS I. Comparison of measured and simulated concentrations of total nitrogen (TN) and total phosphorus (TP) in the water.

The BEVIS project continued in 2007. In BEVIS II the project area was extended further to the south (area 2 in Fig. 1). The main objectives of BEVIS II were to build a water quality model for the Svealand coast (including the main Stockholm archipelago) and to assess the magnitude of the internal loading of phosphorus (P) for modelling purposes.

Sediment work shop

A sediment work shop was arranged at Husö Biological Station on Åland 22-24.5.2007 to specify guidelines for the assessment of the internal P loading. Altogether six Baltic Sea scientists from the Geological Surveys of Sweden (SGU), Finland (GTK) and Denmark (GEUS), Swedish Environmental Protection Agency, Finnish Institute of Marine Research (FIMR) and Åbo Akademi University participated in the work shop.

During the work shop the published and unpublished data useful for the P flux calculations from the sediments of the BEVIS project area were discussed. Information was available e.g. from anoxia studies in the Stockholm archipelago (Jonsson, Ed. 2003) and in the archipelago Sea (Virtasalo et al. 2005), sediment distribution maps from the EU's BALANCE project, early results from the Finnish SEGUE project and unpublished sediment data from SGU's field research on the Swedish coast. It also became clear that important information was not available, e.g. data of concentrations of different P fractions in sediments, data of P fluxes from different sediment units and so on. However, it was assumed that the new calculations with the available data would result in better estimations of BOT loading for the models than the model module method used in BEVIS I modeling.

Sediment map

The sediment map from EU's BALANCE project (Al-Hamdani et al. 2007) was used for the spatial distribution of different sediment types in the project area. The original digital data was transferred with ArcGIS to the project area 1 with some minor corrections for sediment types in the Åland area and in the Archipelago Sea. The corrective information was acquired from the Government of Åland (observations of fishermen in the Åland area) and from our earlier research cruises in the Turku archipelago.

The BALANCE map used the following classification of sediment types:
I. Bedrock
II. Hard bottom complex, includes patchy hard surfaces and coarse sand (sometimes also clay) to boulders
III. Sand including fine to coarse sand (with gravel exposures)
IV. Hard clay sometimes/often/possibly exposed or covered with a thin layer of sand/gravel
V. Mud including gyttja-clay to gyttja-silt

The internal P loading was calculated for the sediment classes II-V.

Calculation methods for internal P loads

For all the calculations of the internal P loading only the potentially mobile P fraction pools (measured or estimated) in sediments were used. At first the yearly amount of potential P fluxes were calculated.

MUD:
For the estimation it was assumed that the P release takes place only from the loose, watery top 5 mm sediment layer in the mud areas. The linear accumulation of 5-6 mm/year corresponds to the accumulation rate of 900 mg/cm2/year in the Archipelago Sea (Mattila et al. 2006). The same rate was used for all mud areas. The potentially mobile P pools in the recent mud sediments has been quantified using sequential extraction in the Archipelago Sea areas (Virtasalo et al. 2005, Leivuori et al. 2007). Unpublished total P data was obtained for the mud areas in the Swedish coast from SGU. According to the results of the SEGUE project we assumed that 45 % of total P is potentially mobile (Kaarina Lukkari FIMR, pers. comm.). In the Åland area no data of P concentrations in sediments were available and the median value of the potentially mobile P fractions in the accumulation areas from the research of Virtasalo et al. (2005) was used.

HARD CLAY & HARD BOTTOM COMPLEX:
As these sediment types (e.g. glacial clay and till) occur in the erosion areas, it was assumed that the potential yearly P fluxes correspond to the fluxes from the top 3 mm. The linear erosion of 3 mm equals the present land-uplift (3-4 mm/year) in the project area. Dry bulk density for glacial clay (Virtasalo et al. 2005) was used to calculate the erosion rate and the measured potentially mobile P fraction in glacial clay of the study of Virtasalo & Kotilainen (2006) was used to calculate the potential P fluxes for all glacial clay and till bottoms in the project area 1.

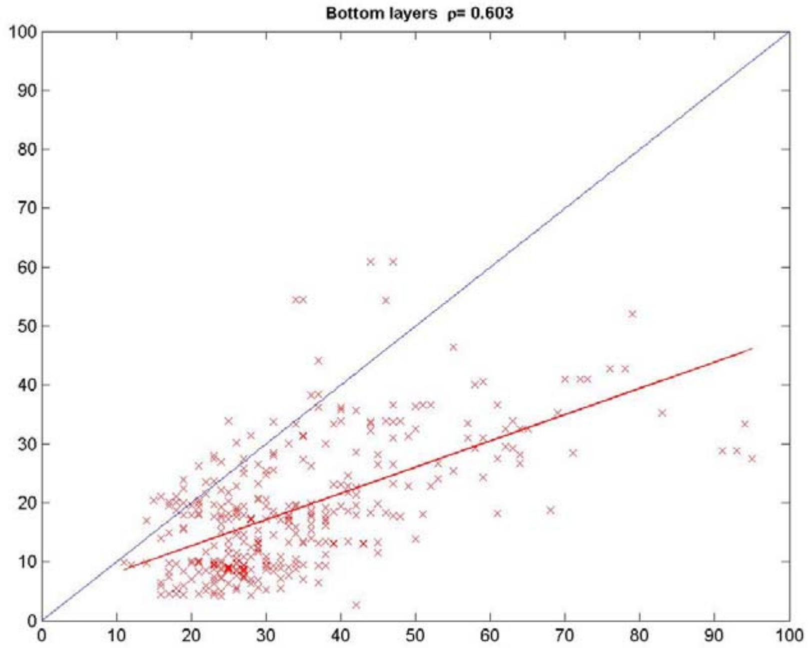
SAND:
As sand bottoms also occur in the erosion areas, it was assumed that the P fluxes from sand areas come from the top 3 mm sediment layer. Potentially mobile P fraction pools have been measured from littoral sand bottoms in the Archipelago Sea (Kohonen et al. 2004) at five sites from 6-9 different water depths. The calculated potential P fluxes for different depths were used for all the sand bottoms in the project area 1.

Finally, it was assumed that 10 % of the calculated potential P fractions will be released into the water. The estimated yearly P fluxes were divided into monthly fluxes for the modeling purposes. The major P leakage from sediments would occur in the mud areas during the summer months June, July and August. Natural erosion of bottom sediments is caused by waves and currents. To estimate the monthly P fluxes from sand, clay and till bottoms wind data were obtained from the Finnish Meteorological Institute. The number of days in 2004 with the wind velocity ≥10 m/s in Utö (Archipelago Sea) was used in monthly estimations. As the ice cover dampens or prevents the wind-induced waves, ice data from the Swedish Meteorological and Hydrological Institute (SMHI) was used to correct the effects of wind data during winter months. Also ice data were from the year 2004, i.e. the comparison year in the scenario modeling.

Results and discussion

If 10 % of the potentially mobile P fraction will be released into the overlaying water from the 5 mm top sediment layer in mud areas and from 3 mm top sediment layer in sand, glacial clay and till areas the total internal loading of phosphorus is circa 900 ton P/project area 1/year. This is more than the total P loading from land based sources, 676 ton P/project area 1 in 2004.

The Swedish model gives better correlation results for P with the new BOT data (Fig. 3) than the same model with “old” BOT data (Fig. 2).



A. Engqvist 13.12.2007

Fig. 3. Model validation in BEVIS II. Comparison of measured (x) and simulated (y) concentrations of total phosphorus (µg TP/L) in the bottom near water.

The assessed yearly internal P load was divided into monthly and daily P fluxes (Fig. 4), and the data were delivered for the modelling purposes in GIS-format.

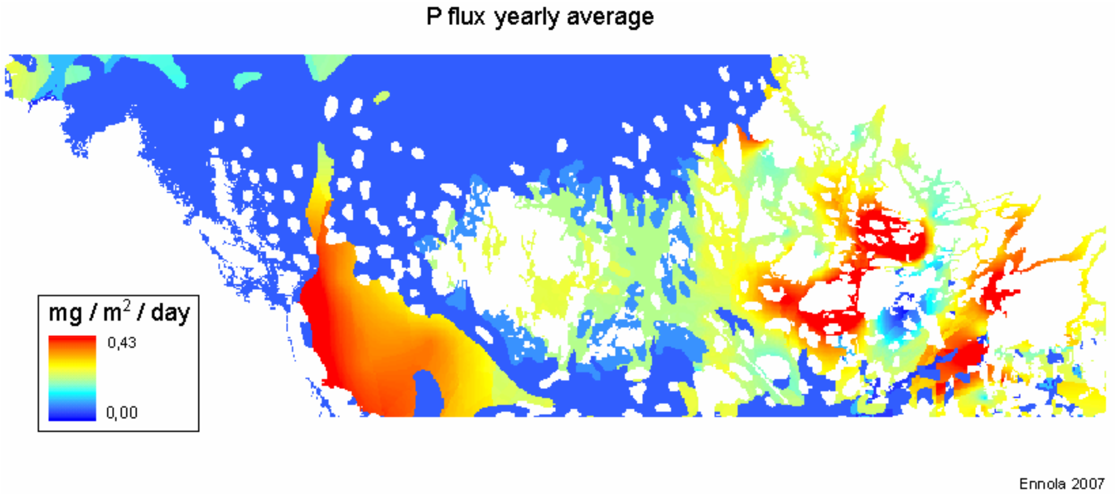


Fig. 4. The estimated mean daily phosphorus efflux from surface sediments to the water in the BEVIS project area 1. (The white areas are either dry land or submarine bedrock void of loose sediment cover).

The calculated maximum P flux is 0.5 mg P/m^2/day from mud bottom during summer months. This is less than the measured benthic P fluxes from the fine grained sediments into overlaying water during the flux studies in the Archipelago of Åland (0.6–6.7 mg/ m^2/day, mean 2.2 mg/m^2/day, Lehtoranta et al. 2007) and in the littoral zone in the Arhipelago Sea (mean flux 2 mg P/m^2/day, Suomela et al. 2005). Good oxygen conditions prevailed during the flux measurements. Higher benthic P flux values have been observed from anoxic sediments e.g. in the study of Pitkänen et al. (2003) in the Gulf of Finland: separate cruises during 1999-2000, men P flux 13 mg P/m^2/day, maximum >30 mg P/m^2/day. Phosphorus could be released easily from Fe-compounds, when oxidized sediments turn reduced. Anoxic “dead bottoms” prevail in the large, deep basins of the Baltic Sea (Jonsson et al. 1990) and in the deep accumulation areas in the Gulf of Finland (Perttilä et al. 2003). In the coastal and archipelago areas hypoxia occurs at shallower water depths where organic material settles in shallow basins in shelter of islands and skerries. In the Archipelago Sea the basins with water depths 20-60 m have been most severely affected by the oxygen deficiency, but in the deeper areas the oxygen conditions are generally good. In the deep elongated canyons strong bottom currents prevent accumulation of fine grained and organic rich matter. (Virtasalo et al. 2005.) Similar hypoxic conditions might prevail in the Åland archipelago, but no investigations of oxygen depletion have been done in the area.

Even if the calculated internal P load gives more reliable results in model simulations for the project area 1 than the earlier load values, the P load from bottom seems still to be rather an underestimate than an overestimate. This assumption is also confirmed by the model validations (see Korpinen & Inkala this report).

Conclusions

Sea floor sediments seem to be a significant loading source for phosphorus even in coastal and archipelago areas.

There are substantial gaps in spatial and temporal sediment data - more research is needed on this important issue.

References

Al-Hamdani, Z. and Reker, J. (editors), Alanen. U., Andersen, J.H., Bendtsen, J., Bergstrm, U., Dahl, K., Dinesen, G., Erichsen, A., Elhammer, A., Geitner, K., Hermansen, B., Holmberg, J., Kotilainen, A., Leth, J., Lindberg, T., Lindeberg, G., Nyberg, J., Reijonen, A., Ryabchuk, D., Sparrevohn, C., Sørensen, T., Söderkvist, J., Thougaard, L., Vestergaard, O., Zetterlund, S., 2007. Towards marine landscapes in the Baltic Sea. BALANCE Interim Report No 10.

Jonsson, P., Carman, R. & Wulff, F., 1990. Laminated sediments in the Baltic - A tool for evaluating nutrient mass balances. Ambio, 19 (3):152-158.

Jonsson, P. (Ed.), Persson, J. och Holmberg, P., 2003. Skärgårdens bottnar. Naturvårdsverket Rapport 5212, Stockholm, ISBN 91-620-5212-8, ISSN 0282-7298, 112 sid. English summary.

Kohonen, T., Vahteri, P., Helminen, U., Sihvonen, M. & Vuorinen, I. 2004. Loppuraportti tutkimushankkeesta (KOR) Kalojen lisääntymisalueet Saaristomerellä. SEILI Archipelago Research Institute Publications 2. 109 s., 31 liites.)

Kohonen, T. & J. Mattila (Eds.) 2007: Mesoskaliga vattenkvalitetsmodeller som stöd för beslutsfattande i skärgårdsregionerna Åboland-Åland-Stockholm, BEVIS-slutrapport. *(Mesoscale water quality models as support for decision making in the archipelagos of Turku, Åland and Stockholm, BEVIS final report; Mesoskaalan vedenlaatumallit päätöksenteon tukena Turun, Ahvenanmaan ja Tukholman saaristoalueilla, BEVIS loppuraportti).* Forskningsrapporter från Husö biologiska station No 118 (2007). Åbo Akademis tryckeri, Åbo 2007. 146 s., 3 appendix. Available on the BEVIS home page http://web.abo.fi/fak/mnf/biol/huso/bevis/

Lehtoranta, J., Knuuttila, S., Väänänen, P. & Nöjd, A. 2007. Sediment studies in the Archipelago of Åland. Data report. 2004. *In*: Kohonen, T. & J. Mattila (Eds.) 2007: Mesoskaliga vattenkvalitetsmodeller som stöd för beslutsfattande i skärgårdsregionerna Åboland-Åland-Stockholm, BEVIS- slutrapport. *(Mesoscale water quality models as support for decision making in the archipelagos of Turku, Åland and Stockholm, BEVIS final report; Mesoskaalan vedenlaatumallit päätöksenteon tukena Turun, Ahvenanmaan ja Tukholman saaristoalueilla, BEVIS loppuraportti).* Forskningsrapporter från Husö biologiska station No 118 (2007), Appendix 3.

Leivuori, M., Lukkari, K., Räike, A. & Tallberg, P. 2007. Phosphorus and silicon dynamics in sediments. *In*: Pitkänen, H., Tallberg, P. (Eds.). Searching efficient protection strategies for the eutrophied Gulf of Finland: the integrated use of experimental and modelling tools (SEGUE)., Helsinki, Finnish Environment Institute. P. 16-19. *The Finnish Environment* ; 2007, 35-43.
http://www.ymparisto.fi/default.asp?contentid=234813&lan=en

Mattila, J., Kankaanpää, H. & Ilus, E. 2006. Estimation of recent sediment accumulation in the Baltic Sea using artificial radionuclides 137Cs and 239,240Pu as time markers. BOREAL ENVIRONMENT RESEARCH 11,:95-107.

Perttilä, M., Jonsson, P., Larsen, B., Niemistö, L., Winterhalter, B. & Axelsson, V., 2003. The 1993 HELCOM/ICES Baltic Sea Sediment Baseline Study. *In*: Perttilä, M. (Ed.). Contaminants in the Baltic Sea Sediments. Results of the 1993 HELCOM/ICES Baltic Sea Sediment Baseline Study. No. 50 2003, MERI, Report Series of the Finnish Institute of Marine Research, 9-20.

Pitkänen, H., Lehtoranta, J., Peltonen, H., Laine, A., Kotta, J., Kotta, I., Moskalenko, P., Mäkinen, A., Kangas, P., Perttilä, M. & Kiirikki, M. 2003. Benthis release of phosphorus and its relation to environmental conditions in the esturial Gulf of Finland, Baltic Sea, in the early 2000's. Proc. Estonian Acad. Sci. Biol. Ecol., 2003, 52, 3, 173-192.

Suomela, J., Gran, V., Helminen, H., Lagus, A., Lehtoranta, J. & Sipura, J. 2005. Effects of sediment and nutrient enrichment on water quality in the Archipelago Sea, nirthern Baltic: An enclosure experiment in shollow water. Estuarine, Coastal and Shelf Science 65 (2005), 337-350.

Virtasalo, J., Kohonen, T., Vuorinen, I. & Huttula, T. 2005. Sea bottom anoxia in the Archipelago Sea, northern Baltic Sea - Implications for phosphorus remineralization at the sediment surface. Marine Geology 224 (2005), 103– 122.

Virtasalo, J. J., Kotilainen, A. T. & Räsänen, M. E. 2005: Holocene stratigraphy of the Archipelago Sea, northern Baltic Sea: the definitions and descriptions of the Dragsfjärd, Korppoo and Nauvo Alloformations. *Baltica* 18 (2), 83-97.

Virtasalo, J.J., Kotilainen, A.T. 2006. Phosphorus forms and reactive iron in Holocene sediments of the Archipelago Sea, northern Baltic Sea: from glacial to direct climatic depositional influences. *In*: Virtasalo, J.J. 2006. Late-Weichselian - Flandrian Depositional History of the Archipelago Sea, northern Baltic Sea. TURUN YLIOPISTON JULKAISUJA. ANNALES UNIVERSITATIS TURKUENSIS. *SARJA - SER. AII OSA - TOM. 196*. BIOLOGICA - GEOGRAPHICA – GEOLOGICA. TURUN YLIOPISTO. (Article IV in a doctoral thesis.)

Scenarios

BEVIS phase II (2007)
Scenarios 8-10

Scenario 8

Reduction of nutrient loading from agriculture according to the current regional water protection plans in Finland, Sweden and Åland. Nutrient loading from other sources remains unchanged, i.e. on the same level as in 2004. Scenario 8 results in decrease of the diffuse and river loading.

Scenario 9

Waste waters from sparsely populated areas will be led to the nearest waste water treatment plant in the area. Cleaning effectiveness will be the same as in 2004. Nutrient loading from other sources remains unchanged, i.e. on the same level as in 2004. Scenario 9 results in decrease of the diffuse and river loads and increase of the load from waste water treatment plants.

Scenario 10

Simulation of the effects of climate change on nutrient loading when frequency of rains will increase during winter and early spring. Scenario 10 results in increase of the diffuse and river loads, the atmospheric fallout and the nutrient flows coming across the borders.

BEVIS phase I (2004-2006)
Scenarios 1-7

Results in the final report:

Kohonen, T. & J. Mattila (red.) 2007: Mesoskaliga vattenkvalitetsmodeller som stöd för beslutsfattande i skärgårdsregionerna Åboland-Åland-Stockholm, BEVIS- slutrapport. *(Mesoscale water quality models as support for decision making in the archipelagos of Turku, Åland and Stockholm, BEVIS final report; Mesoskaalan vedenlaatumallit päätöksenteon tukena Turun, Ahvenanmaan ja Tukholman saaristoalueilla, BEVIS loppuraportti).* Forskningsrapporter från Husö biologiska station No 118 (2007). Åbo Akademis tryckeri, Åbo 2007. 146 s., 3 appendix.
http://web.abo.fi/fak/mnf/biol/huso/bevis/

BEVIS II – Model modifications to the bottom loads and scenario calculations

Päivi Korpinen* and Arto Inkala**

*Suomen ympäristökeskus SYKE (firstname.lastname@ymparisto.fi)
** Environmental Impact Assessment Center of Finland (EIA) ltd (firstname.lastname@eia.fi)

Model modifications

Substantial uncertainty was related to the bottom phosphorus loads in the simulations of BEVIS I-project. In 2007 new assessments of internal nutrient loads were completed and the results were available for the improvement of the BEVIS-model. The amount of phosphorus reflux from different sediments were provided by Åbo Akademi University. The monthly nutrient load was assessed for every grid square in the bottom.

SYKE-EIA ecosystem model does have a sediment module, which calculates sedimentation, internal loading and resuspension. This module has been developed for the Gulf of Finland (Kiirikki et al 2006) and did not work reliably in the BEVIS I-project in the Archipelago Sea area. For the BEVIS II-simulations the model was reprogrammed according to the new data. The new version of the model calculates only sedimentation as a phosphorus interaction between the water and the sediment. The phosphorus flux from the sediments was given as an input file (load). The nitrogen cycle and bottom interactions were not changed between the BEVIS I and II simulations. Basically the ecosystem model parameters were not altered. During the model calibration the half saturation coefficient of radiation for both plankton groups was readjusted to be the same as in the SYKE-EIA model for the whole Baltic Sea (Kiirikki et al 2001) and the model for Pietari-Neva area (Korpinen et al 2003). Previously the calibrated values from local model application HESPO were used (Korpinen et al 2002).

Validation

The new modified version of BEVIS-model was validated against the measurements from the area (Figures 1-6). Compared to the previous version with sediment module the new version with bottom load input file improved both DIN and DIP values, especially at the end of the year. In the high resolution area (Föglöfjärden) the nutrient dynamics is more natural than in the BEVIS I-model. There is still too high phosphorus values in the open sea points (Mariehamn, Utö, Nötö), but the values are lower than in the first version of the model. The spring bloom is approximately 4 weeks late in the model, but the duration of the bloom is shorter than in previous version. The algae dynamics could still be improved in the model.

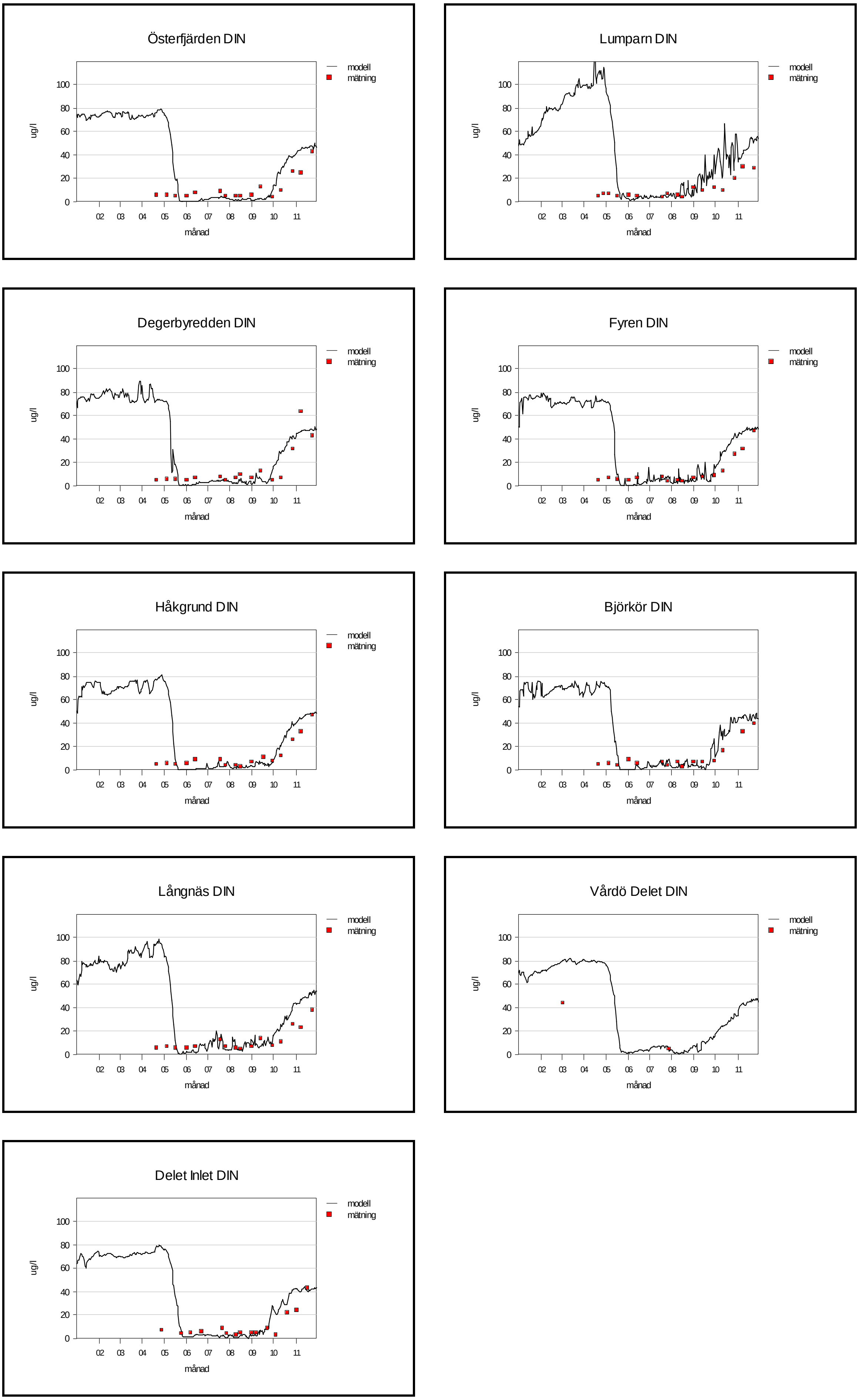


Figure 1. Modeled and measured DIN (µg/l) in 9 points in 2004, calculated with the BEVIS II-model version.

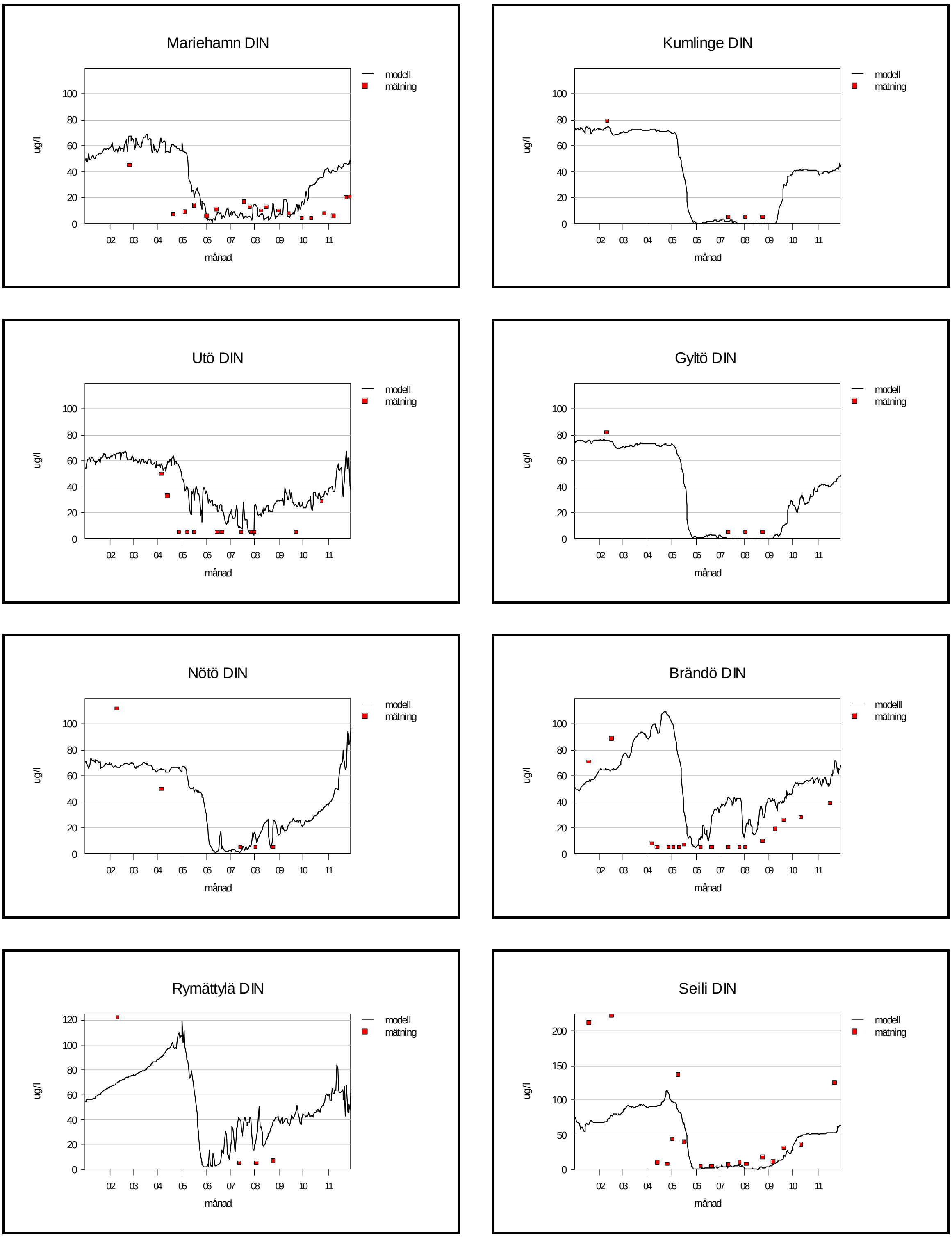


Figure 2. Modeled and measured DIN (µg/l) in 8 points in 2004, calculated with the BEVIS II-model version.

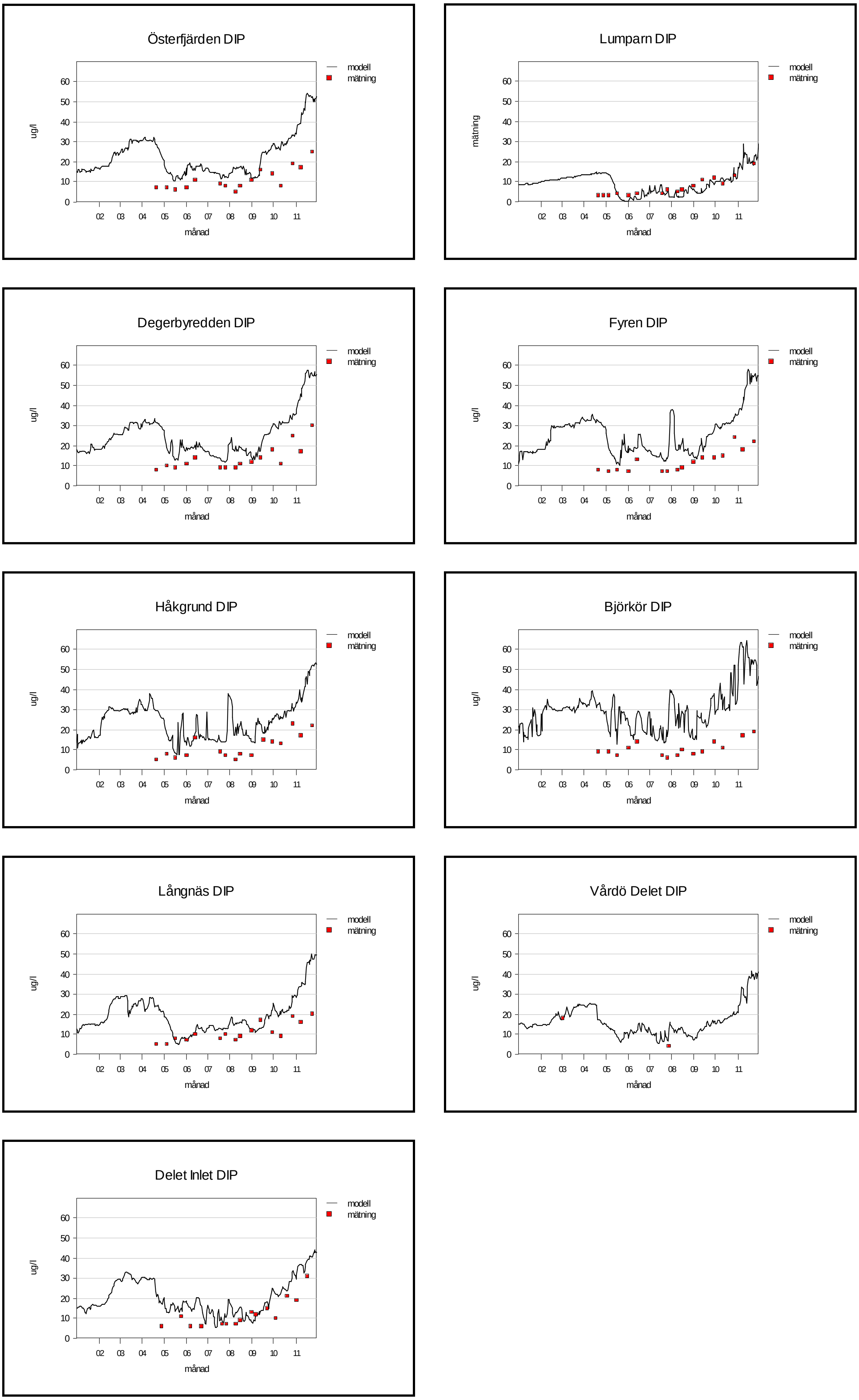


Figure 3. Modeled and measured DIP (µg/l) in 9 points in 2004, calculated with the BEVIS II-model version.

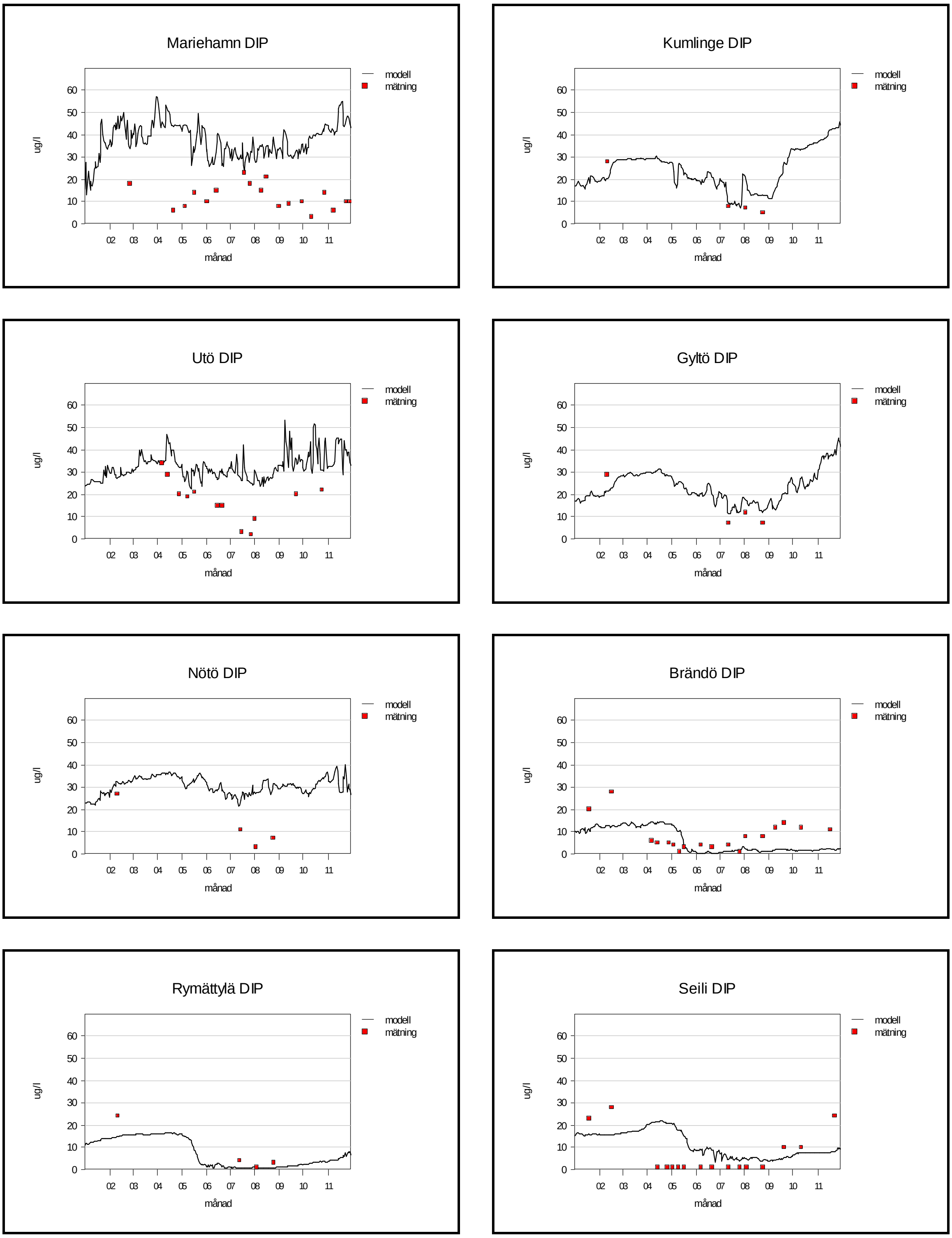


Figure 4. Modeled and measured DIP (µg/l) in 8 points in 2004, calculated with the BEVIS II-model version.

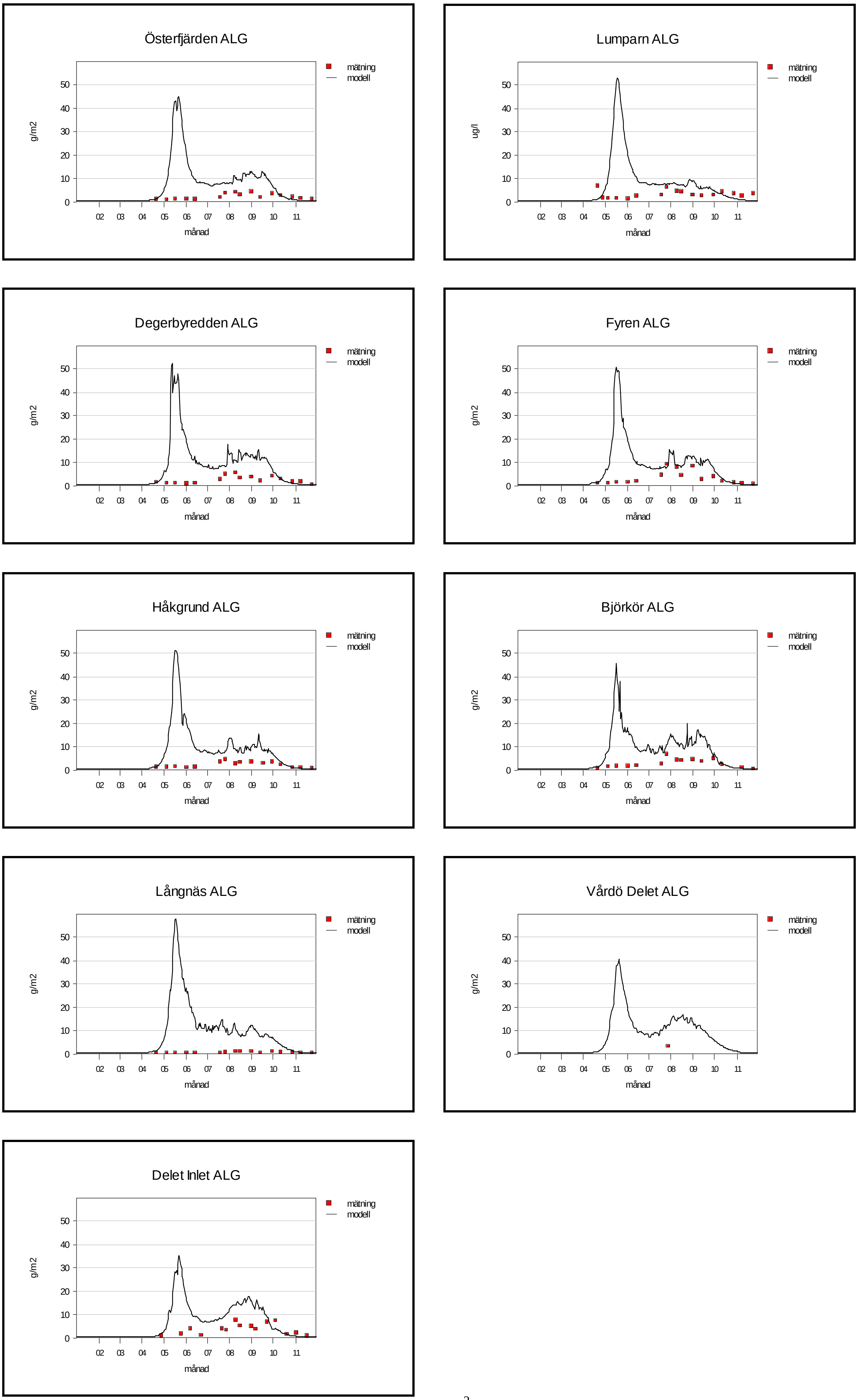


Figure 5. Modeled and measured total phytoplankton (g/m^2) in 9 points in 2004, calculated with the BEVIS II-model.

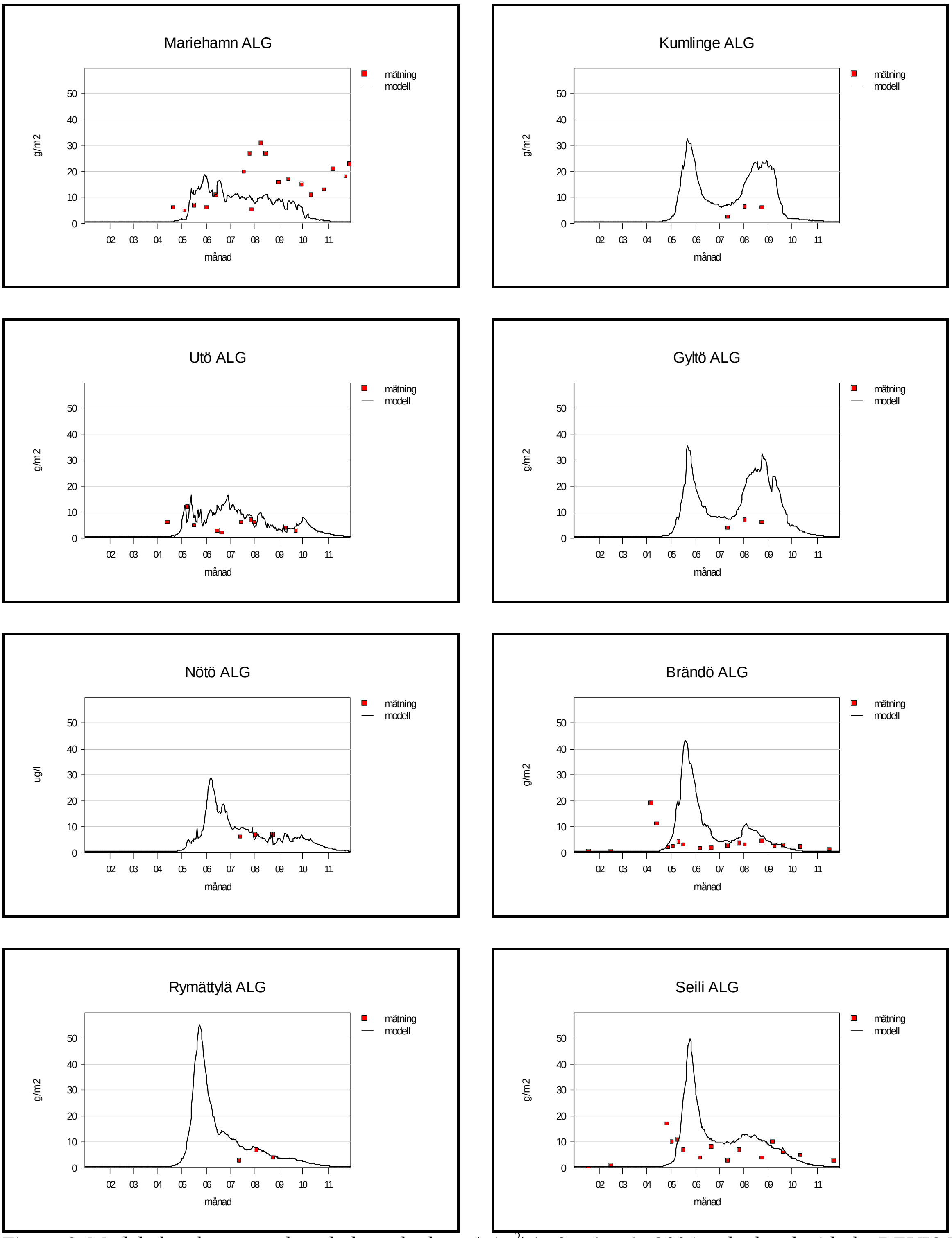


Figure 6. Modeled and measured total phytoplankton (g/m^2) in 8 points in 2004, calculated with the BEVIS II-model.

Scenario calculations

The new scenarios 8, 9 and 10 were decided by the steering group. Åbo Akademi University calculated the effect of the scenario to the different types of loading. The effect of the scenario was provided as a factor by which the "present state" load was multiplied with. Year 2004 was decided to be the reference year. In scenarios 8 and 9 the factor was the same for one load type (for example river loading) for the whole year. In scenario 10 the factor changed monthly.

The model was run over one growing season for the direct impacts on water quality and algal biomass. The calculation was started at the beginning of the calendar year and was stopped at the end of September. The simulations of the scenarios were first run with the present (2004) load. The model was run also with changed scenario loads. The average biomasses of the ALG1 (mainly spring bloom species) and ALG2 (nitrogen fixing cyanobacteria) were recorded for January-September (growth period) in all the scenarios. The biomasses of each scenario were compared to the biomasses from the present state calculations. The results are presented as relative changes (%) in phytoplankton biomasses, both total phytoplankton biomasses (ALG1+ALG2) and cyanobacteria biomasses (ALG2). The results are shown in ten catagories, between -30%-+25% change in the biomass. Changes lower than ±5% were neglected.

Scenario 8

Scenario 8 results in decrease of the diffuse loading and river loading in the model. The results can be seen around the Åland islands, the total phytoplankton biomass decreases 5-10%. In the Finnish archipelago area the decrease can be up to 25% but in small areas. Mainly the effects stay under 10% (Figure 7).

Figure 7. The effects (%) of the decrease in the load from agriculture (scenario 8) on total phytoplankton biomass. Comparison year 2004.

Some increase (5-10%) in cyanobacteria biomass takes place in Lumparn in Åland, but the areas are really small (Figure 8). Some decrease in the cyanobacteria biomassa occurs in the North-Western Åland. In the Finnish archipelago the effects are also quite local, even though stronger than in the Åland side.

Figure 8. The effects (%) of the decrease in the load from agriculture (scenario 8) on cyanobacteria biomass. Comparison year 2004.

No changes were made to the Swedish loads, therefore there are no effects on the Swedish coast.

Scenario 9

Scenario 9 results in decrease of the diffuse and river loads and increase in the load of the load from waste water treatment plants in the model. This will affect quite large areas in the archipelago both in Åland and Finland side. The decrease is quite mild, 5-10% from the total phytoplankton biomass (Figure 9). No increase occurs due to the increased load from the treatment plants.

Figure 9. The effects (%) of the scattered settlement scenario (scenario 9) on total phytoplankton biomass. Comparison year 2004.

This scenario decreases also the cyanobacteria biomass 5-10% in the Finnish archipelago (Figure 10). The effect area is smaller and more local.

Figure 10. The effects (%) of the scattered settlement scenario (scenario 9) on cyanobacteria biomass. Comparison year 2004.

In this scenario only the loads from Finland and Åland were changed. The Swedish loads were kept the same.

Scenario 10

Scenario 10 results in increase of diffuse loading, river loading, atmospheric fallout and the border values in the model. Loads in Finland, Åland and Sweden were changed according to the scenario. The effects of this scenario are significant both in total phytoplankton and cyanobacteria biomass (Figures 11 and 12).

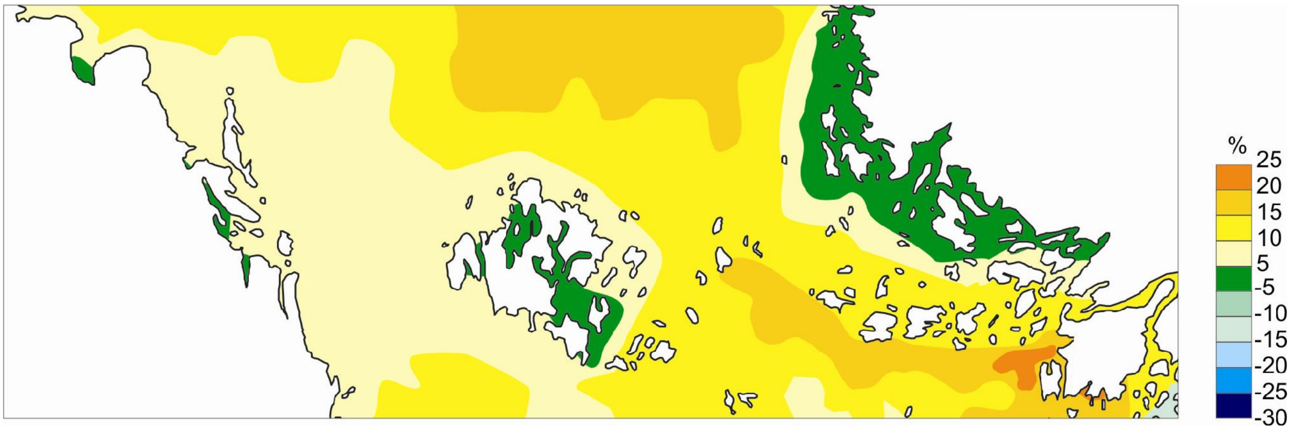


Figure 11. The effects (%) of the climate change (scenario 10) on total phytoplankton biomass. Comparison year 2004.

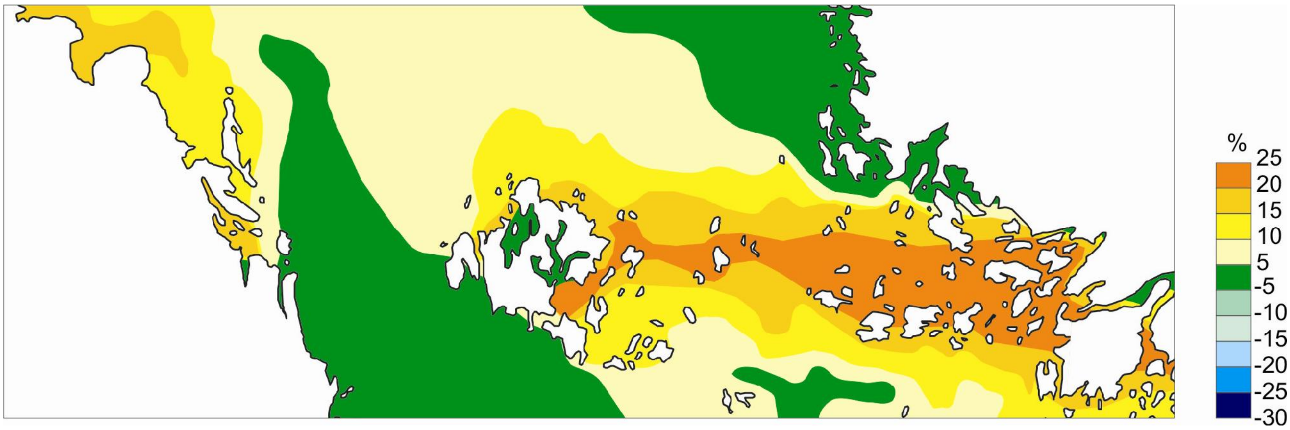


Figure 12. The effects (%) of the climate change (scenario 9) on cyanobacteria biomass. Comparison year 2004.

The increased rain fallout and early spring increase the growth of phytoplankton up to 25%. The effects on total phytoplankton can be seen in the open sea areas and do not reach the inner archipelago areas. However, the effects on cyanobacteria concentrate more to the coastal areas and even to the innermost areas.

References

Kiirikki, M., Inkala, A., Kuosa, H., Kuusisto, M. & Sarkkula, J. 2001. Evaluating the effects of nutrient load reductions on the biomass of toxic nitrogen-fixing cyanobacteria in the Gulf of Finland, the Baltic Sea. Boreal Environment Research 6: 131–146.

Kiirikki, M., Lehtoranta, J., Inkala, A., Pitkänen, H., Hietanen, S., Hall, P. O. J., Tengberg, A., Koponen, J. and Sarkkula, J. 2006. A simple sediment process description suitable for 3D-ecosystem modelling – Development and testing in the Gulf of Finland. Journal of Marine Systems 61(1-2):55-66.

Korpinen, P., Koponen, J., Kiirikki, M., Sarkkula, J., Peltoniemi, H., Väänänen, P. & GästgifvarsM. 2002. Vattendragsmodellen HESPO: Approximering av miljöriskerna och eutrofieringsutvecklingen i havsområdet Helsingfors-Esbo-Tallinn. Miljö i Finland 559:1-46.

Korpinen, P., Kiirikki, M., Rantanen, P., Inkala, A., Sarkkula, J. 2003. High resolution 3D-ecosystem model for the Neva Bay and Estuary - model validation and future scenarios. Oceanologia 2003, no 45(1), pp. 67-80.

Calculation of three complementary scenarios (8 through 10)

Anders Engqvist, Åbo Akademi

The following complementary scenarios (8 through 10) -in addition to the seven presented earlier- have all been calculated using so-called loading coefficients that were implemented in the AX-model in order to make it possible to perform scenario comparison in an efficient way. These coefficients are subdivided first into those that apply to total concentration of nitrogen (TN) and total phosphorus (TP), and second to the three geographical regions into which the model area is partitioned (Fig. 1). There are eight loading categories:

1. BOR – those that enter across the northern and southern model boundaries.
2. RIV – those that are associated with river discharge (no rivers in Åland area)
3. FIF – loading from fish farming
4. IND – discharges from industries (no industries are found in the Åland area)
5. STP – loading from sewage treatment plants
6. DIF – diffuse loading that cannot be attributed to discrete watersheds
7. AIR – air-deposited TN (TP deposited by air is regarded negligible)
8. BOT – TN and TP released from bottom sediments

The nominal loading of all these eight categories has been estimated. The TP loading of the BOT category has been revised compared to the earlier scenario runs 1 through 7 as have some of the riverine source category, which excludes direct comparison of this earlier computed group with the present scenarios 8 through 10. All the results presented are presently computed by first rerunning the nominal case (Scenario 1) with all loading coefficients set to 1.00 and with the revised BOT-loading data. For each month the average concentrations are computed for each grid cell. The various scenario runs are then also performed with adjusted loading coefficients values and the monthly TN and TP averages are computed analogously as for the nominal run. Finally, the concentrations of the nominal run are subtracted from the three new scenarios and the ensuing relative concentration differences compared to the new Scenario 1 are depicted in the form of diagrams for the surface layer (0 – 2.5 m depth) and an intermediary layer (12.5 – 17.5 m depth) for the three months, January, April and July. Of course, the intervening months must be computed by the 3D-model.

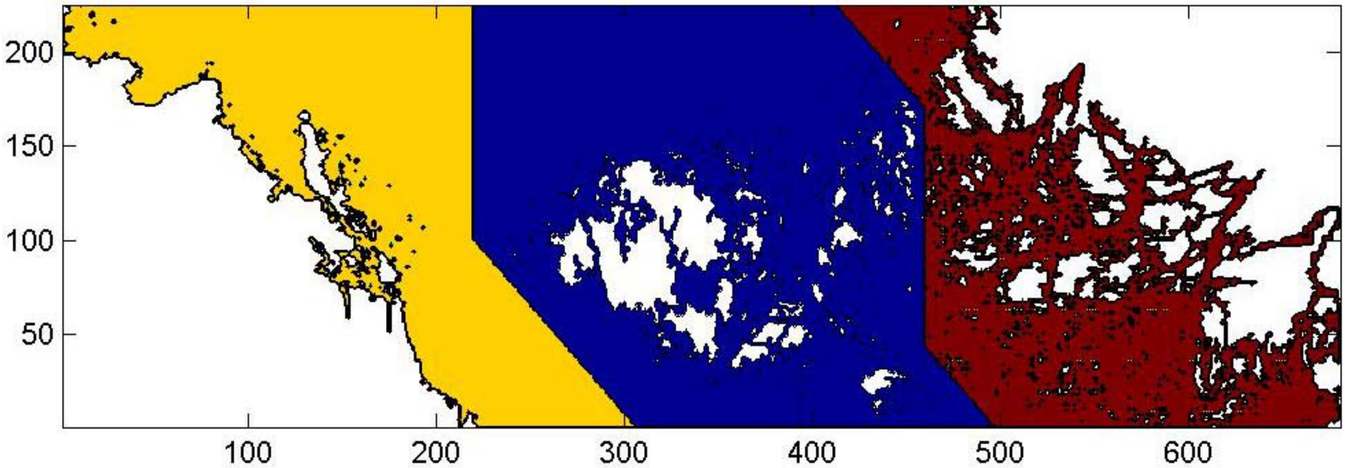


Fig. 1 Area partitioning concerning manipulation of the different source categories with the assigned loading coefficients that are listed in a parameter file that modify the source strength of the TN and TP nutrients loading of a particular scenario. The yellow area corresponds to measures performed on the Swedish side, red area to the Finnish administration and the section in between (blue area) denote measures taken in the Åland area. This also applies to the source category (BOR) that pertains to nutrients entering across the northern and southern borders although what is entering across these boundaries is not dependant on local policy measures within the model domain. The numbers along the axis denote grid coordinates.

Scenario 8

Scenario 8 concerns implementation of planned nutrient reduction programs. The model calculation is a straightforward application of the indicated decreased loading coefficients (Table 1). These reductions concern nutrient discharge from rivers on the Finnish mainland coast and reduced diffuse loading for both Finland and Åland regions. The corresponding reductions on the Swedish side are considered as already done. See figures 2-3 for modeling results.

Table 1. The loading coefficients of scenario 8 are the maintained for all months. The stars denote entries that are not applicable.

	TN			TP		
	Sweden	Åland	Finland	Sweden	Åland	Finland
BOR	1.00	1.00	1.00	1.00	1.00	1.00
RIV	1.00	****	0.86	1.00	****	0.84
FIF	1.00	1.00	1.00	1.00	1.00	1.00
IND	1.00	****	1.00	1.00	****	1.00
STP	1.00	1.00	1.00	1.00	1.00	1.00
DIF	1.00	0.88	0.87	1.00	0.93	0.85
AIR	1.00	1.00	1.00	****	****	****
BOT	1.00	1.00	1.00	1.00	1.00	1.00

For TN the effect of these reductions is mostly visible and significant for the surface water at the river mouths and adjacent embayments on the Finnish mainland side. Around the Åland mainland there is a slight but mainly insignificant decrease of the TN concentration which also intermittently spreads to the Swedish coast. These effects are slightly enhanced towards the summer months because of the accumulated effect of the reduction.

For TP mainly the same results as for TN apply, with somewhat more enhanced influence areas but not lowered concentrations, mostly manifested as increased areas delimited by the contour-lines.

Scenario 9

This scenario is intended to simulate the effect of channeling separate household wastewater discharges to sewage treatment plants. This is modeled by decreasing the diffuse loading coefficients and increasing the ones corresponding to STP (Table 2). The net action should result in an overall loading reduction. For the Swedish side no estimates have been made about the diffuse loading for the nominal run (i.e. Scenario 1), which means that reduction of the DIF loading by altering the loading coefficient cannot be made. Instead, an inventory of these separate loading sources reveals that they are mainly located in the same areas as the river mouths on the Swedish coast. Therefore the intended reduction has been implemented as a corresponding reduction of the RIV loading coefficient, as to withhold the same amount of TP that consequently does not enter into the sea. The corresponding amount of TN is negligible. The dominating loading contribution of the major river Dalälven on the Swedish side has been exempted from this reduction, since at its discharge location there are too few separate households that are not connected to sewage treatment plants. See figures 4-5 for modeling results.

Table 2. The loading coefficients of scenario 9 are the maintained for all months. The loading coefficients of scenario 8 are the maintained for all months. The stars denote items that are not applicable.

	TN			TP		
	Sweden	Åland	Finland	Sweden	Åland	Finland
BOR	1.00	1.00	1.00	1.00	1.00	1.00
RIV	1.00	****	0.98	0.98	****	0.94
FIF	1.00	1.00	1.00	1.00	1.00	1.00
IND	1.00	****	1.00	1.00	****	1.00
STP	1.00	1.30	1.01	1.00	1.80	1.01
DIF	1.00	0.93	0.97	1.00	0.66	0.89
AIR	1.00	1.00	1.00	****	****	****
BOT	1.00	1.00	1.00	1.00	1.00	1.00

The resulting relative changes in TN concentrations are the comparatively small expected reductions (less than 2%) on the Finnish and the Åland sides with a seemingly heterogenic mixing zone towards the mainly unaffected waters on the Swedish side. The grainy mixing zone is mainly an expression of the averaging process. These effects of the reduced loading are somewhat enhanced with regard to the extent of the influenced area towards the summer month of July.

For the relative change of TP concentrations there is also a slight but noticeable effect on the Swedish side, as expected. The area influenced around Åland reaches its maximal extent during the spring month of April, not in the summer as for TN.

Scenario 10

This scenario is designed to mimic expected large-scale changes in the weather pattern with a changed redistribution of precipitation and wind over the months. The precipitation data have been assessed from Sweclim (a MISTRA-project) estimates and the increased expected through-flow of the model area has been introduced as increased loading coefficients of the border (Table 3).

The resulting relative changes are decisively significant both for the TN and the TP concentrations. In particular, it is obvious that the incoming nutrient flows across the borders have the expected vast impact. The varying precipitation yields patches of relatively decreased concentration due to decreased precipitation during the spring and summer months and also includes the changed loading during the intervening months. This is noticeable for April when the nutrient front has reached the influence area near the river mouths which then experience a relatively lower concentration due to the assumed decreased concentration of the rivers. A patch with negative relative concentrations (most likely due to numerical averaging effects) has been set to zero for the January diagrams. For the spring and summer months the occurring negative relative concentrations seem realistic and at locations where these are beneath the 10% level, the contouring program show such areas in white colour. The increased nutrient flux across the borders makes little difference with regard to the depth: both the depicted surface and intermediary strata display the same general pattern of change. See figures 6-7 for modeling results.

Table 3. The loading coefficients of scenario 10 with regard to the different months. The RIV, DIF and the AIR loading coefficients reflect the anticipated redistribution of precipitation over the year as predicted by Sweclim. The abbreviations (S) for Sweden, (Å) for Åland and (F) for Finland are used in the column headings. The loading coefficients of scenario 8 are the maintained for all months. The stars denote entries that are not applicable.

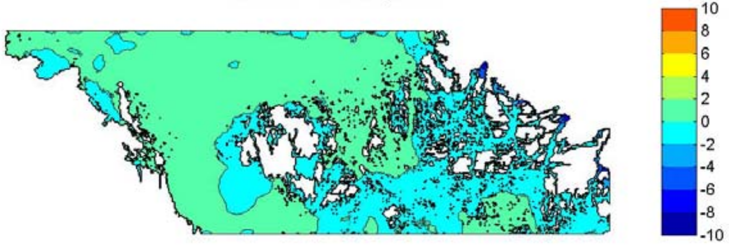
	Jan						**Feb**						**Mar**					
	TN			**TP**			**TN**			**TP**			**TN**			**TP**		
	S	Å	F	S	Å	F	S	Å	F	S	Å	F	S	Å	F	S	Å	F
BOR	**1.40**	**1.40**	**1.40**	**1.40**	**1.40**	**1.40**	**1.40**	**1.40**	**1.40**	**1.40**	**1.40**	**1.40**	**1.35**	**1.35**	**1.35**	**1.35**	**1.35**	**1.35**
RIV	**1.40**	********	**1.40**	**1.40**	********	**1.40**	**1.40**	********	**1.40**	**1.40**	********	**1.40**	**1.60**	********	**1.60**	**1.60**	********	**1.60**
FIF	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
IND	**1.00**	********	**1.00**	**1.00**	********	**1.00**	**1.00**	********	**1.00**	**1.00**	********	**1.00**	**1.00**	********	**1.00**	**1.00**	********	**1.00**
STP	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
DIF	**1.40**	**1.40**	**1.40**	**1.40**	**1.40**	**1.40**	**1.40**	**1.40**	**1.40**	**1.40**	**1.40**	**1.40**	**1.60**	**1.60**	**1.60**	**1.60**	**1.60**	**1.60**
AIR	**1.33**	**1.33**	**1.33**	********	********	********	**1.33**	**1.33**	**1.33**	********	********	********	**1.33**	**1.33**	**1.33**	********	********	********
BOT	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

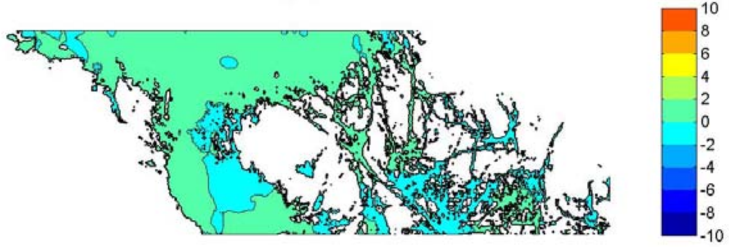
	Apr						**May**						**Jun**					
	TN			**TP**			**TN**			**TP**			**TN**			**TP**		
	S	Å	F	S	Å	F	S	Å	F	S	Å	F	S	Å	F	S	Å	F
BOR	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.20**	**1.20**	**1.20**	**1.20**	**1.20**	**1.20**
RIV	**1.00**	********	**1.00**	**1.00**	********	**1.00**	**0.80**	********	**0.80**	**0.80**	********	**0.80**	**0.67**	********	**0.67**	**0.67**	********	**0.67**
FIF	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
IND	**1.00**	********	**1.00**	**1.00**	********	**1.00**	**1.00**	********	**1.00**	**1.00**	********	**1.00**	**1.00**	********	**1.00**	**1.00**	********	**1.00**
STP	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
DIF	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**0.80**	**0.80**	**0.80**	**0.80**	**0.80**	**0.80**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**
AIR	**1.00**	**1.00**	**1.00**	********	********	********	**0.87**	**0.87**	**0.87**	********	********	********	**0.80**	**0.80**	**0.80**	********	********	********
BOT	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

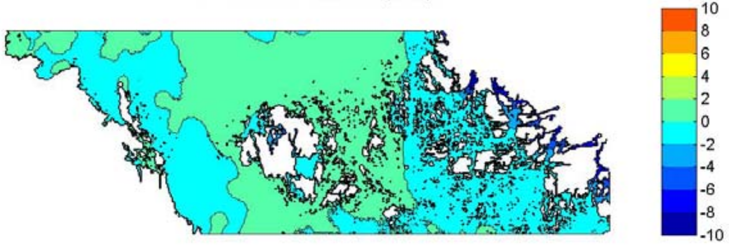
	Jul						**Aug**						**Sep**					
	TN			**TP**			**TN**			**TP**			**TN**			**TP**		
	S	Å	F	S	Å	F	S	Å	F	S	Å	F	S	Å	F	S	Å	F
BOR	**1.10**	**1.10**	**1.10**	**1.10**	**1.10**	**1.10**	**1.10**	**1.10**	**1.10**	**1.10**	**1.10**	**1.10**	**1.20**	**1.20**	**1.20**	**1.20**	**1.20**	**1.20**
RIV	**0.67**	********	**0.67**	**0.67**	********	**0.67**	**0.67**	********	**0.67**	**0.67**	********	**0.67**	**0.80**	********	**0.80**	**0.80**	********	**0.80**
FIF	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
IND	**1.00**	********	**1.00**	**1.00**	********	**1.00**	**1.00**	********	**1.00**	**1.00**	********	**1.00**	**1.00**	********	**1.00**	**1.00**	********	**1.00**
STP	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
DIF	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.80**	**0.80**	**0.80**	**0.80**	**0.80**	**0.80**
AIR	**0.80**	**0.80**	**0.80**	********	********	********	**0.80**	**0.80**	**0.80**	********	********	********	**0.87**	**0.87**	**0.87**	********	********	********
BOT	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

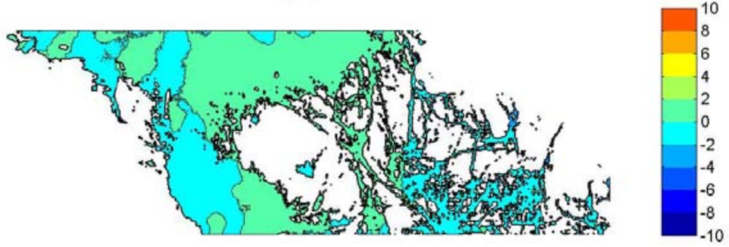
	Oct						**Nov**						**Dec**					
	TN			**TP**			**TN**			**TP**			**TN**			**TP**		
	S	Å	F	S	Å	F	S	Å	F	S	Å	F	S	Å	F	S	Å	F
BOR	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.30**	**1.35**	**1.35**	**1.35**	**1.35**	**1.35**	**1.35**
RIV	**0.90**	********	**0.90**	**0.90**	********	**0.90**	**1.07**	********	**1.07**	**1.07**	********	**1.07**	**1.17**	********	**1.17**	**1.17**	********	**1.17**
FIF	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
IND	**1.00**	********	**1.00**	**1.00**	********	**1.00**	**1.00**	********	**1.00**	**1.00**	********	**1.00**	**1.00**	********	**1.00**	**1.00**	********	**1.00**
STP	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
DIF	**0.90**	**0.90**	**0.90**	**0.90**	**0.90**	**0.90**	**1.07**	**1.07**	**1.07**	**1.07**	**1.07**	**1.07**	**1.17**	**1.17**	**1.17**	**1.17**	**1.17**	**1.17**
AIR	**1.00**	**1.00**	**1.00**	********	********	********	**1.33**	**1.33**	**1.33**	********	********	********	**1.33**	**1.33**	**1.33**	********	********	********
BOT	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

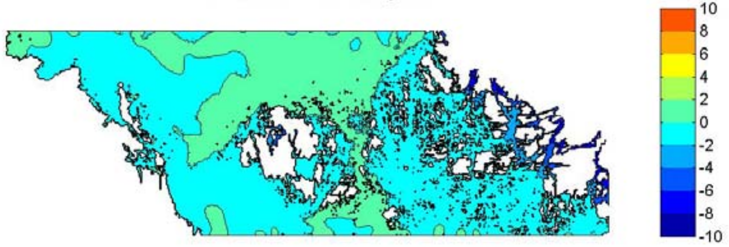
Fig.2. Effects of scenario 8 in total nitrogen concentrations (%) in the water. Comparison year: 2004.


TN - Scenario 8 -Surface layer Jan


Intermediary layer 12.5 - 17.5 m


TN - Scenario 8 -Surface layer Apr


Intermediary layer 12.5 - 17.5 m


TN - Scenario 8 -Surface layer Jul

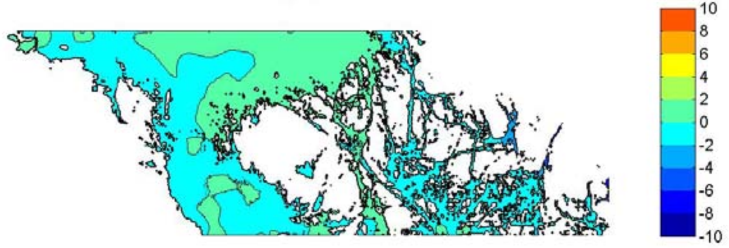

Intermediary layer 12.5 - 17.5 m

Fig.3. Effects of scenario 8 in total phosphorus concentrations (%) in the water. Comparison year: 2004.

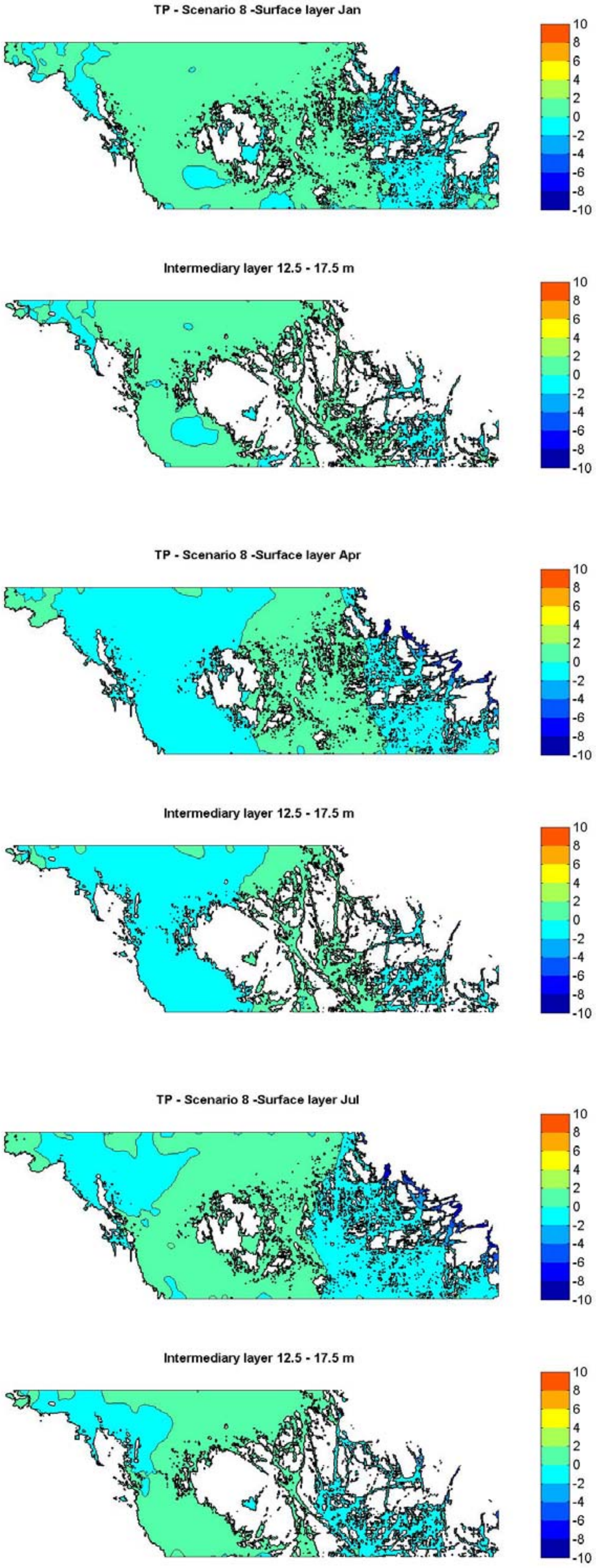
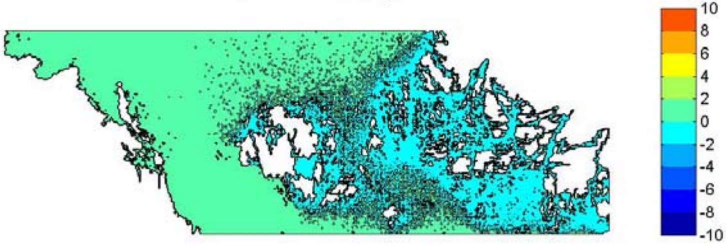
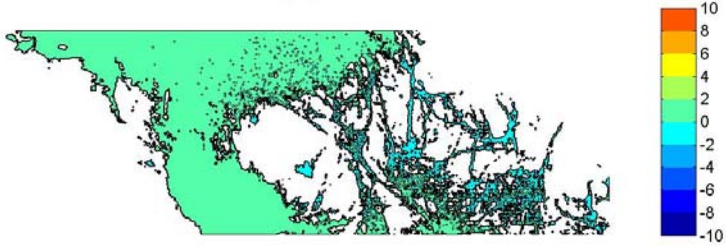


Fig.4. Effects of scenario 9 in total nitrogen concentrations (%) in the water. Comparison year: 2004.

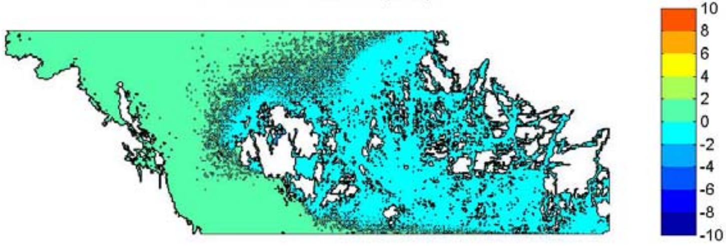
TN - Scenario 9 -Surface layer Jan



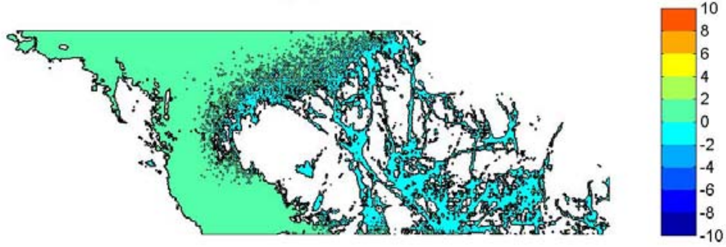
Intermediary layer 12.5 - 17.5 m



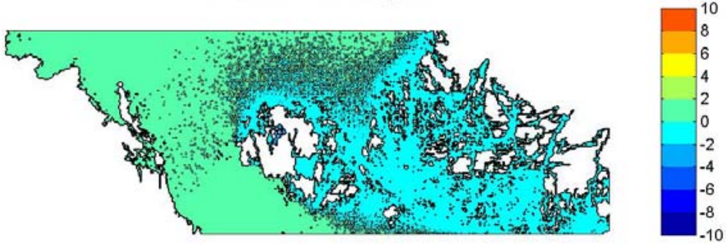
TN - Scenario 9 -Surface layer Apr



Intermediary layer 12.5 - 17.5 m



TN - Scenario 9 -Surface layer Jul



Intermediary layer 12.5 - 17.5 m

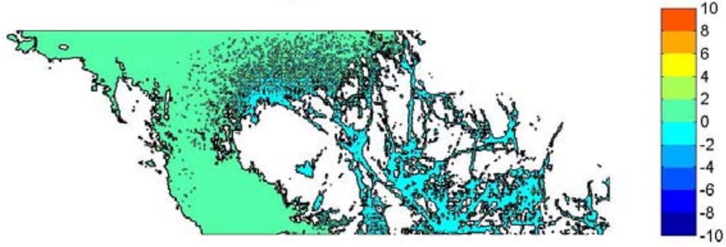


Fig.5. Effects of scenario 9 in total phosphorus concentrations (%) in the water. Comparison year: 2004.

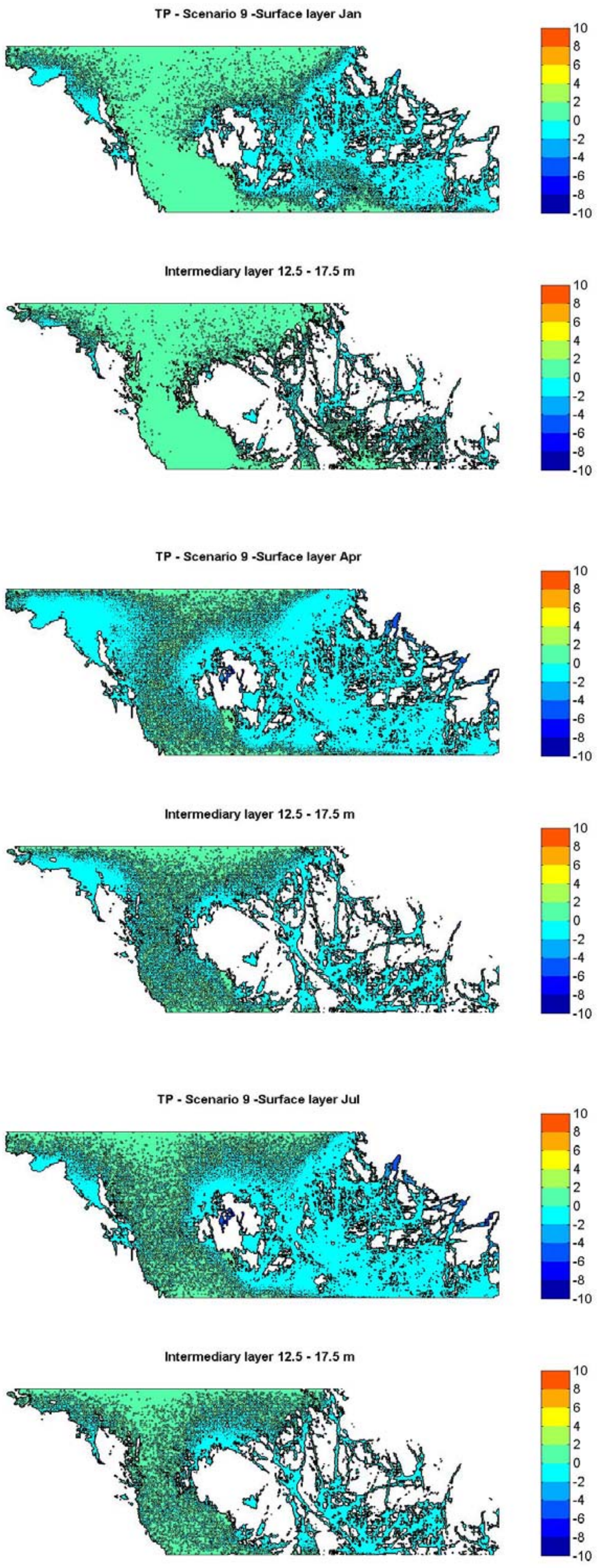


Fig.6. Effects of scenario 10 in total nitrogen concentrations (%) in the water. Comparison year: 2004.

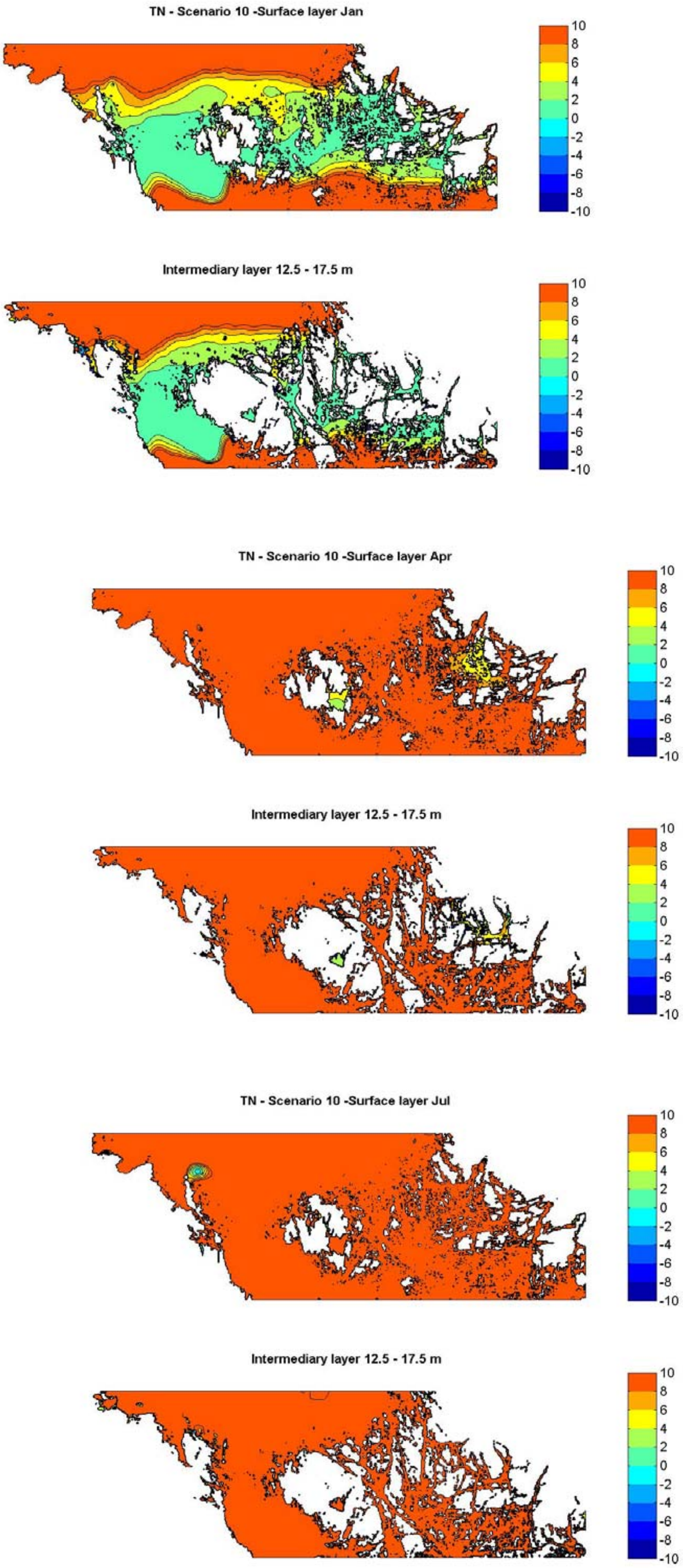
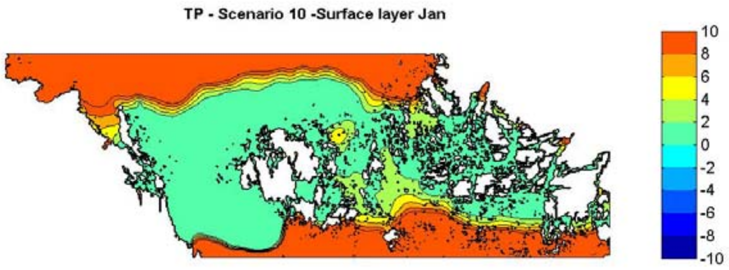
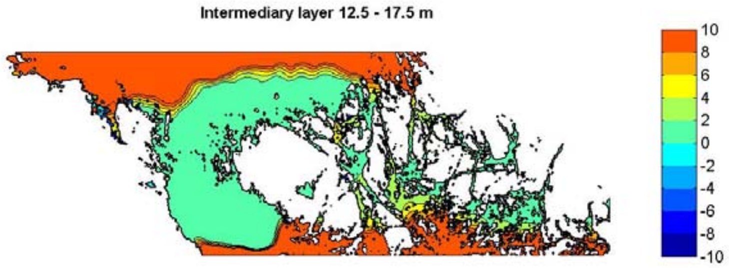
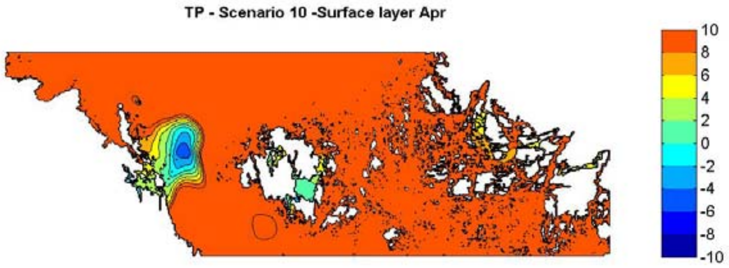
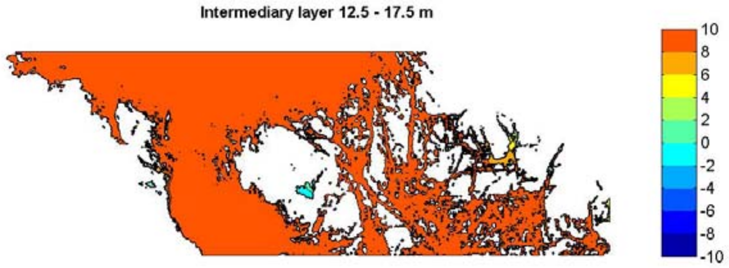


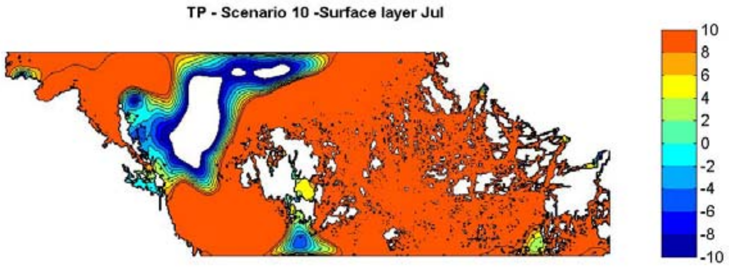
Fig.7. Effects of scenario 10 in total phosphorus concentrations (%) in the water. Comparison year: 2004.

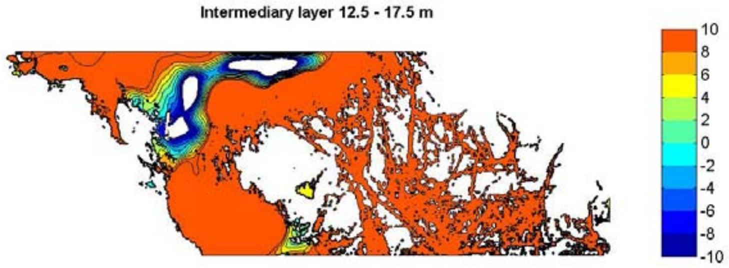

TP - Scenario 10 -Surface layer Jan


Intermediary layer 12.5 - 17.5 m


TP - Scenario 10 -Surface layer Apr


Intermediary layer 12.5 - 17.5 m


TP - Scenario 10 -Surface layer Jul


Intermediary layer 12.5 - 17.5 m