Norwegian Financial Mechanism and Republic of Lithuania

Coastal Research and Planning Institute, Klaipėda University

Project: A system for the sustainable management of Lithuanian marine resources using novel surveillance, modeling tools and ecosystem approach

Technical Report 3

Water quality modelling system

Project indicator:
1. Water quality model developed (sensitivity analysis, calibration and validation)

Prepared by: P. Zemlys[1]
Contributors: R. Paškauskas[1]
G. Umgiesser[2]
Ch. Ferrarin[2]

1 Coastal Research and Planning Institute, Klaipeda University
2 Venice Marine Research Institute - CNR-ISMAR

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ABBREVIATIONS

DOC – dissolved organic carbon
POC – particulate organic carbon
TP – total phosphorus
TN – total nitrogen
CNR-ISMAR – Venice Marine Research Institute (Italy)

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INTRODUCTION

Curonian lagoon is shallow and large estuarine lagoon with complex interactions between biotic and abiotic components that depends on water exchange between the lagoon and the Baltic Sea. The effective management of such a complex systems can not be limited to the results based on observations and measurements. It requires also more sophisticated tools such as mathematical models that provide scientists with a more holistic view of the physical, chemical and biological processes and are suitable as decision support tools.

This project workpackage was focused on the development of the water quality modelling system, based on numerical simulation of the hydraulic transport and ecological processes. System simulates interaction between the Curonian lagoon and the Baltic Sea coastal waters and reflects spatio-temporal dynamics of a lagoon waters in the coastal zone of the Baltic Sea and marine waters in the Curonian lagoon providing information on main water quality characteristics (temperature, salinity, nutrient concentrations, organic matter, phytoplankton biomass). Modeling system is developed with partners from ISMAR-CNR and calibrated/validated using existing data, measurements obtained from field expeditions and data from installed automatic water quality surveillance system.

Water quality forecast system is based on the finite element program package SHYFEM which can be used to resolve the hydrodynamic equations in lagoons, coastal seas, estuaries and lakes. The program uses finite elements for the resolution of the hydrodynamic equations. These finite elements, together with an effective semi-implicit time resolution algorithm, make this program especially suitable for application to a complicated geometry and bathymetry.

Water quality forecast system consists of two subsystems: 1)hydrodynamic model; 2)water quality model AQUABC. Both subsystems are connected into one program and run together as one executable under Linux operation system. All calculations necessary for model testing and scenarios runs were done on 16 core server that was purchased in this project.

1. DATA ACQUISITION AND SAMPLING

General description

The data used for model development can be divided into several groups:

1) Geographical data for model grid development (bathymetry, coastal lines).
2) Data for open boundaries (river discharges, open sea boundary data).
3) Meteorological forcing data.
4) Data for model calibration and validation.

Lithuania nautical maps developed by Lithuania Hydrographical service were used for model grid development. 1 nautical mile spatial resolution forecasts of operational hydrodynamic model HIROMB (Swedish Meteorological and Hydrological Institute) were used for open sea boundary conditions. River discharges were obtained from Hydrological and Meteorological Service of Lithuania monitoring data. 8 km. horizontal spatial resolution forecasts of operational meteorological model HIRLAM (Hydrological and Meteorological Service of Lithuania) were used for meteorological forcing. State monitoring stations data (fig. 1.3) were used for preliminary water quality model calibration and Baltic Sea boundary conditions.

Additional field surveys in the Curonian Lagoon and in the Baltic Sea coastal waters were carried out by the project workgroup in 2009 to obtain more data not available in permanent monitoring databases for the water quality modelling.

Selection of sampling sites

Because estuarine lagoons and plume impact zones are generally more complex than inland waters due to combined effect of the land and the sea several different zones for data collection were chosen. It includes three points in the lagoon itself, one in the Nemunas River and three in the sea (fig. 1.1).

The dominant bottom substrates are sand, silt, and shell deposits. Mud only prevails in the southern-western part of the Curonian Lagoon, i.e. in the zone of intensive sedimentation. Twelve sampling sites were chosen in four different zones in accordance with distribution of most characteristic bottom sediments (Fig. 1.2).

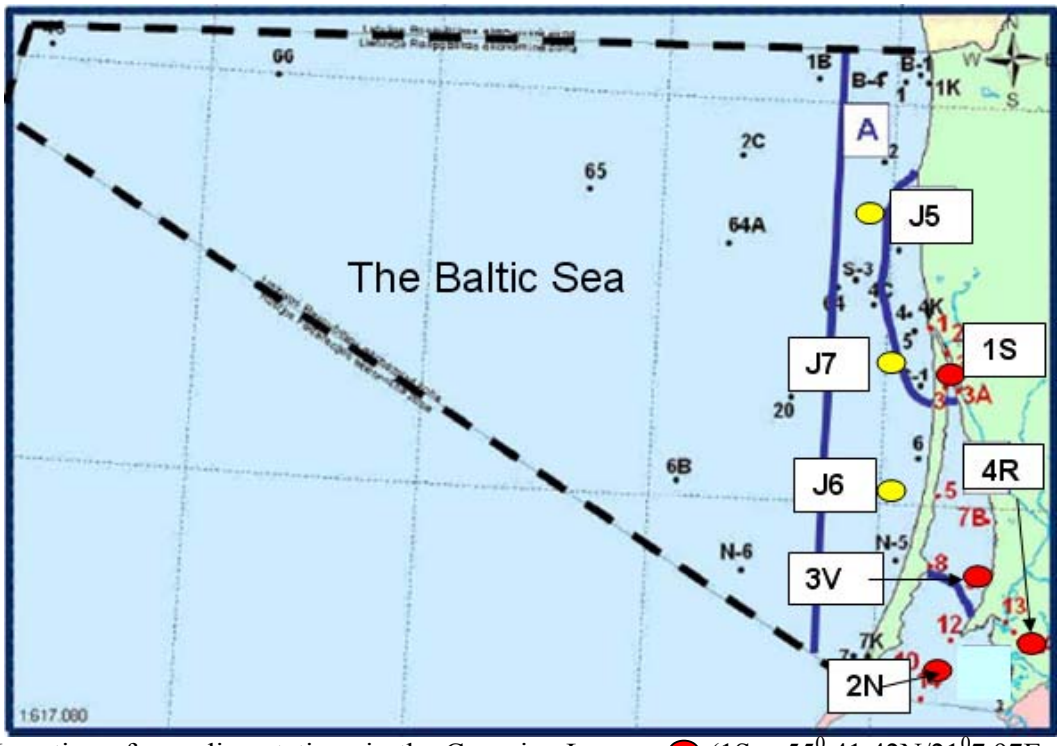
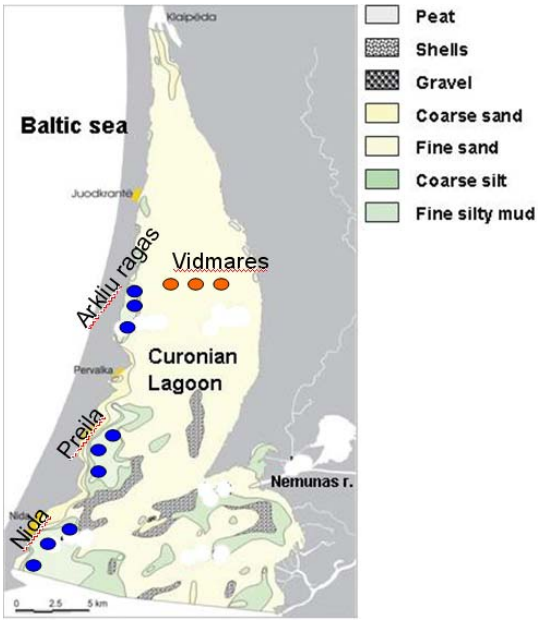


Fig.1.1. Location of sampling stations in the Curonian Lagoon (1S – 55^0 41,42N/$21^0$7,97E; 2N – 55^0 16, 95' N / 21^0 03,34'E; 3V – 55^0 21,29'N/21^0 10,76'E; 4R – 55^0 21, 73'N/21^0 23,03'E) and the Baltic Sea (J-5 – 55^0 46,91‘N/21^0 0,7‘E; J-7 – 55^0 43,1‘N/21^0 3,69‘E; J-6 – 55^0 38,99‘N/$21^0$4,53‘E)



Zone	station	Latitude	Longitude
Nida	ND_1	55^o18‘03‘‘	21^o02‘05‘‘‘
	ND_2	55° 17‘09“	21^o01‘02“
	ND_3	55° 17‘00“	21^o00‘15“
Preila	PD_1	55° 21‘15“	21^o03‘16“
	PD_2	55° 22‘03“	21^o04‘08“
	PD_3	55° 20‘07“	21° 03‘08“
Arkliu ragas	ARD_1	55° 27‘52“	21° 09‘14“
	ARD_2	55° 27‘52“	21° 11‘10“
	ARD_3	55° 27‘52“	21° 13‘06“
Vidmares	S_1	55° 27‘00“	21° 06‘00“
	S_2	55° 27‘30“	21° 06‘30“
	S_3	55° 27‘50“	21° 07‘00“

Fig. 1.2. Location of bottom sediments sampling stations in the Curonian Lagoon in bare sands zone and in muddy zones; (coordinates specified in table above)

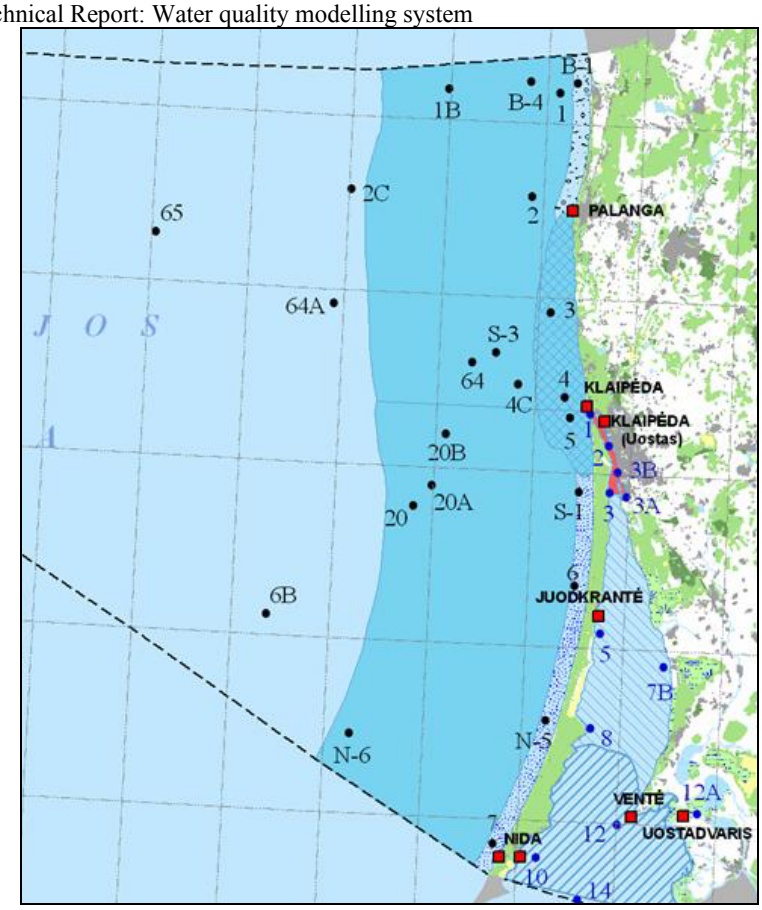


Fig. 1.3. Location of state motoring stations in the Curonian Lagoon and Lithuania coastal waters of the Baltic Sea.

Sampling design and analytical methods

8 sampling sessions (in March – October) were accomplished in the Curonian Lagoon in 2009. For the sea and bottom sediments sampling less frequency was chosen. A Van Veen grab was used for sediment sampling (Fig.1.2). Surface and near-bottom water was sampled using a 2 L Ruttner sampler.

The following parameters were measured with a portable universal MultiLine F/Set-3 meter (WTW) in situ at the upper water layers: temperature, pH, oxygen concentration, salinity. Samples for other hydrochemical parameters and for bioecological variables were collected in special plastic vessels for transportation to laboratory for further analysis. In the upper sediment layer, median grain size, concentrations of organic carbon, total nitrogen and phosphorus, oxygen consumption rates, organic matter mineralization rates and redox conditions (Eh) were also routinely determined.

Dissolved oxygen concentration was determined by Winkler's method. Dissolved nutrient (phosphate and nitrate) analyses were performed according to Merkiene & Ceponyte (1994): phosphate-P was assessed by the molybdate ascorbic acid method after digestion with sulphuric acid. The total phosphorus (TP) concentration was measured using persulphate-H_2SO_4 digestion and the molybdate ascorbic acid method. Nitrate-N was determined using potassium persulphate- $K_2S_2O_8$ followed by Cd reduction to NO_2 and photometric analysis. Total nitrogen (TN) was analyzed by the Kjeldahl method (Jirka et al. 1976). TN and TP concentrations in the upper sediment samples were estimated using the spectrophotometric phenol-hypochlorite method. For TN analysis the organic and inorganic nitrogen was converted into ammonium by digestion with concentrated sulphuric acid, followed by treatment with sodium salicylate and hypochlorite. TP was measured after perchlorate- H_2SO_4 digestion with analysis as above. Organic carbon ($C_{org.}$) was measured by the dichromate oxidation method (Potapova, 1980). The rate of sediment oxygen consumption and organic matter mineralization were determined by the isolated columns method (Kuznecov & Dubinina 1980).

2. HYDRODYNAMIC MODEL

General description

The hydrodynamic model SHYFEM (Shallow water HYdrodynamic Finit Element Model) used in this work is a finite element model developed at the CNR-ISMAR of Venice and successfully applied to some coastal environments. The model is freely available on the SHYFEM web page: https://sites.google.com/site/shyfem/.

The model uses a semi-implicit algorithm for integration in time, which combines the advantages of the explicit and the implicit scheme. The terms treated implicitly are the divergence terms in the continuity equation and the Coriolis term, the pressure gradient, and the bottom friction in the momentum equation. All other terms are treated explicitly. Algorithm is unconditionally stable for any time step chosen and allows the transport variables to be solved explicitly without solving a linear system. Compared to a fully implicit solution of the shallow water equations the dimensions of the matrix are reduced to one-third. The spatial discretization of the unknowns is carried out with the finite element method, partially modified from the classic formulation. This approach gives the possibility to avoid high numerical damping and mass conservation problems, due to the combination of the semi-implicit method with the finite element scheme (Galerkin method). With respect to the original formulation, here the water level and the velocities (transports) are described by using form functions of different order, the standard linear form function for the water level but stepwise constant form function for the transports. This result in a grid that resembles more a staggered grid often used in finite difference discretization.

Model can be used in 2D and 3D mode. In case of 2D for each element of the grid one value for the whole water column is computed. All the variables are computed in the center of the layer, halfway down the total depth. The 3D computation is performed on the basis of z layers. In this representation each layer horizontally has constant depth over the whole basin, but vertically the layer thickness may vary between different layers. However, the first layer (surface layer) is of varying thickness because of the water level variation, and the last layer of an element might be only partially present due to the bathymetry. The introduction of layers requires also defining the values of vertical eddy viscosity and eddy diffusivity. This could be done by setting a constant value of the vertical viscosity and vertical diffusivity or by computation the vertical eddy coefficients through a turbulence closure scheme. GOTM k-ε model is used for this purpose.

Modelling domain and grid

Three model grids were developed (fig. 2.1) and used for different purpose in this study. The first grid (fig 2.1, No 1) covers only the Curonian lagoon and Klaipeda strait. It has small open boundary with the Baltic Sea, requires few computing resources and was used for the preliminary calibration of water quality module. The second grid (fig 2.1 No 2) covers coastal area of the Baltic Sea until

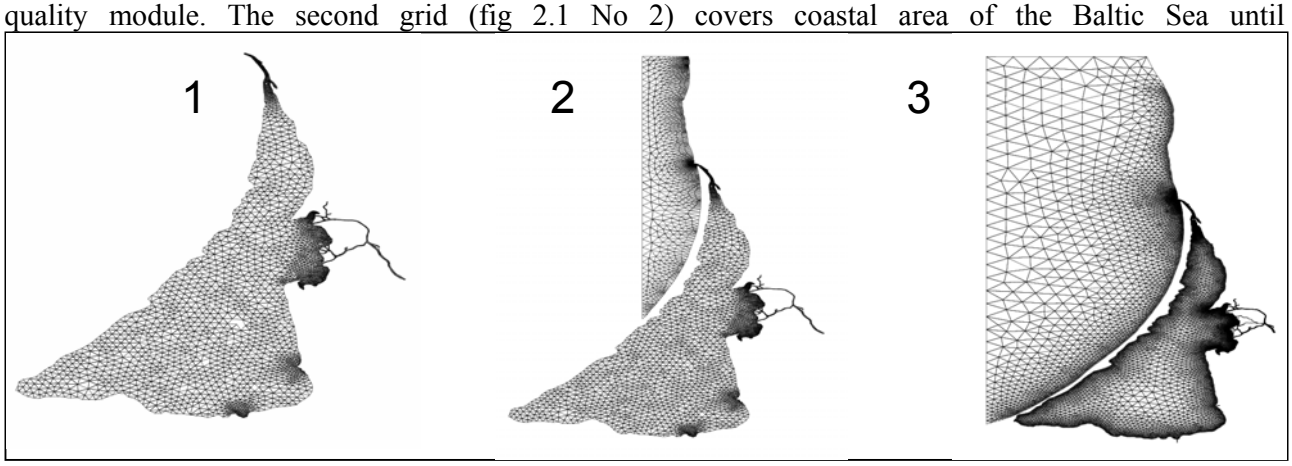


Fig. 2.1. Model grids:

30m depths and was used for 2D water quality modelling that needs to reproduce the water exchange between the Curonian lagoon and the Baltic Sea. The third grid covers the Baltic Sea coastal area until 70m. depth and was used to investigate of 3D effects on water currents and salinity. Bathymetry of the modelling area is shown in fig. 2.2.

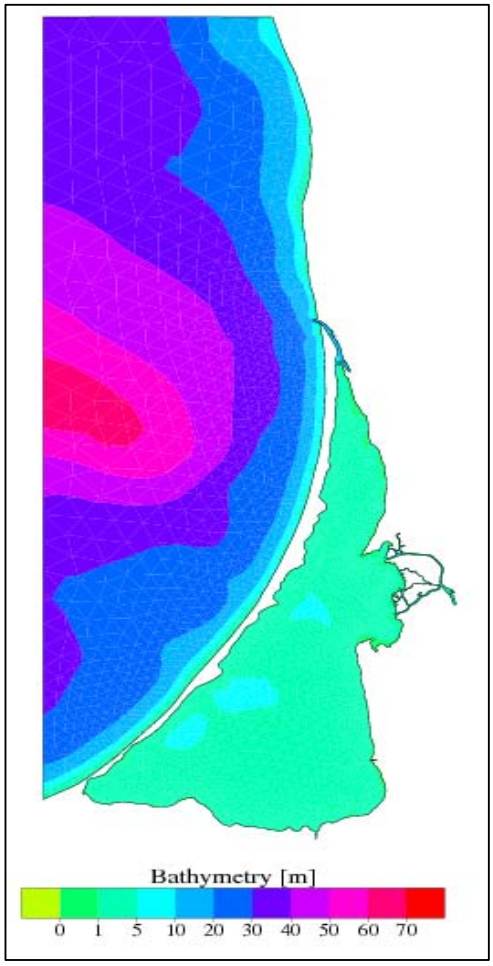


Fig. 2.2. Bathymetry of the modelling domain.

Model performance

Hydrodynamic model was tested on reproduction of measured values of water levels, surface water temperature and salinity. The 3D model performance with the grid No 3 is presented in fig. 2.3 - 2.7. Model shows good performance for water levels and temperature. The weaker but still satisfactory performance was on salinity which is very variable in northern part of the Curonian lagoon and in the Baltic Sea in the vicinity of the outlet of the Curonian lagoon. The weakest performance on salinity was shown for Juodkrante station (fig. 2.7), but it was caused also by law quality of data especially in winter time.

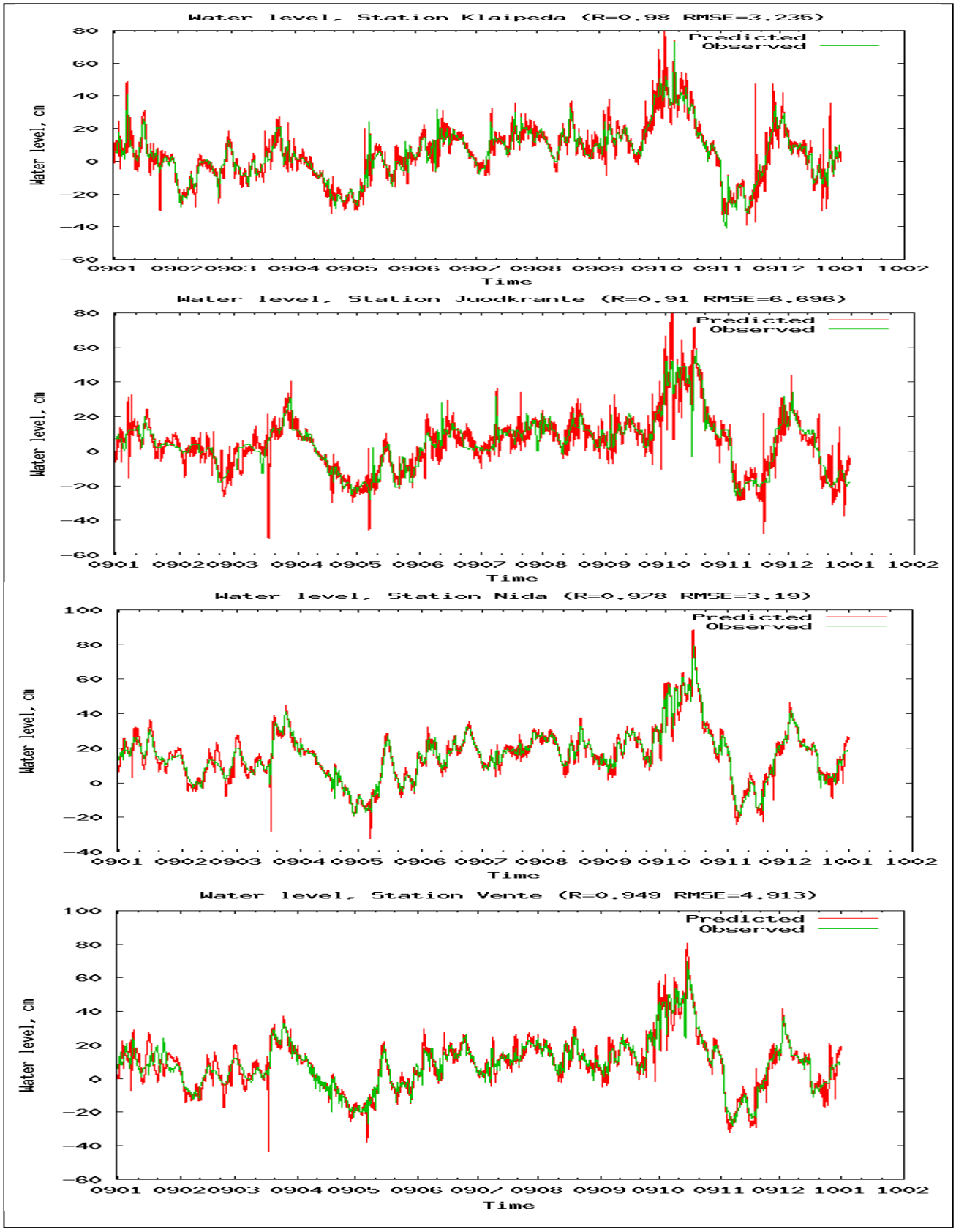


Fig. 2.3. Hydrodynamic model performance on water levels in Klaipeda strait and the Curonian lagoon coastal stations Juodkrante, Nida and Vente for 2009.

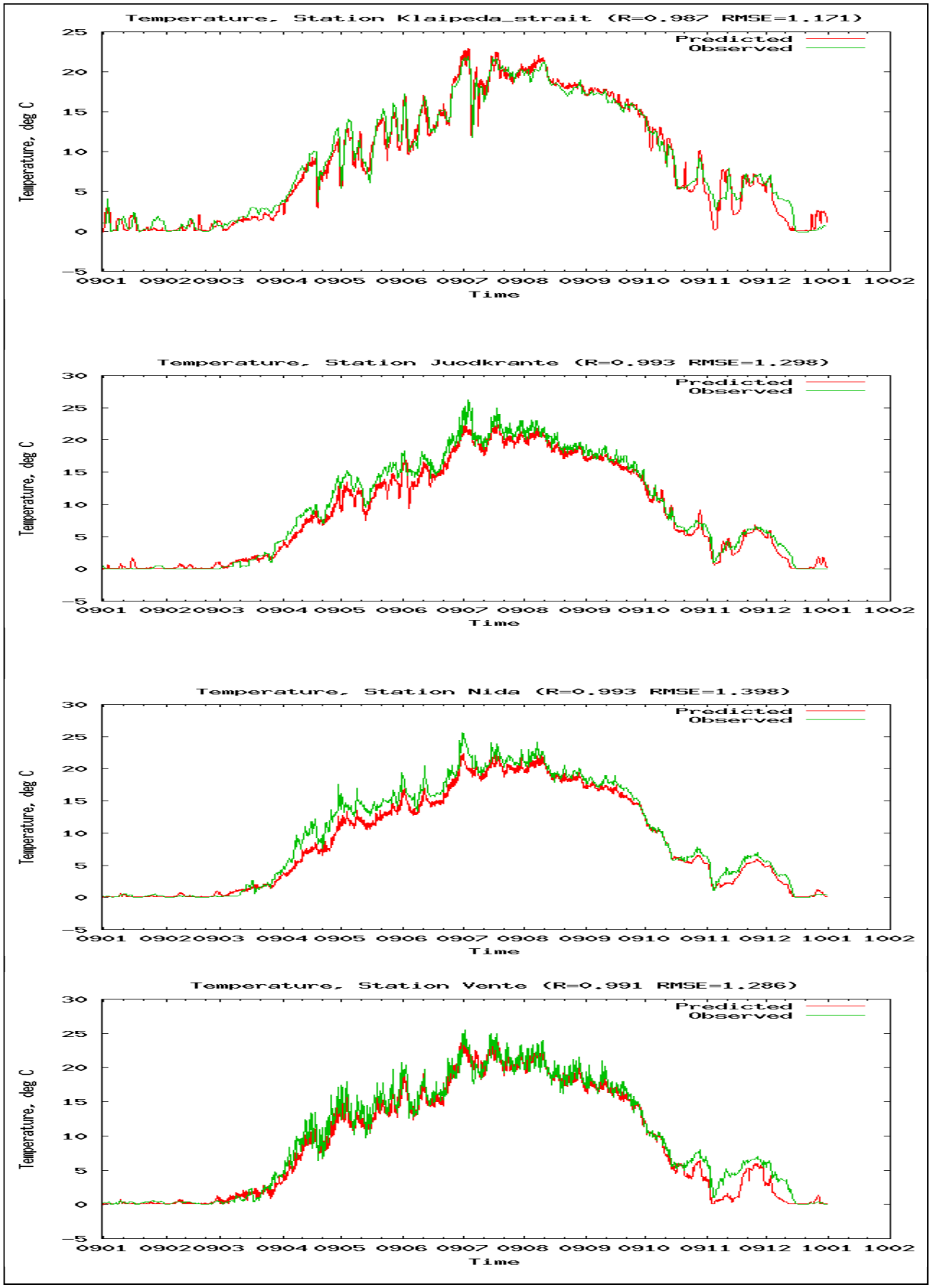


Fig. 2.4. Hydrodynamic model performance on surface water temperature in Klaipeda strait and the Curonian lagoon coastal stations Juodkrante, Nida and Vente for 2009.

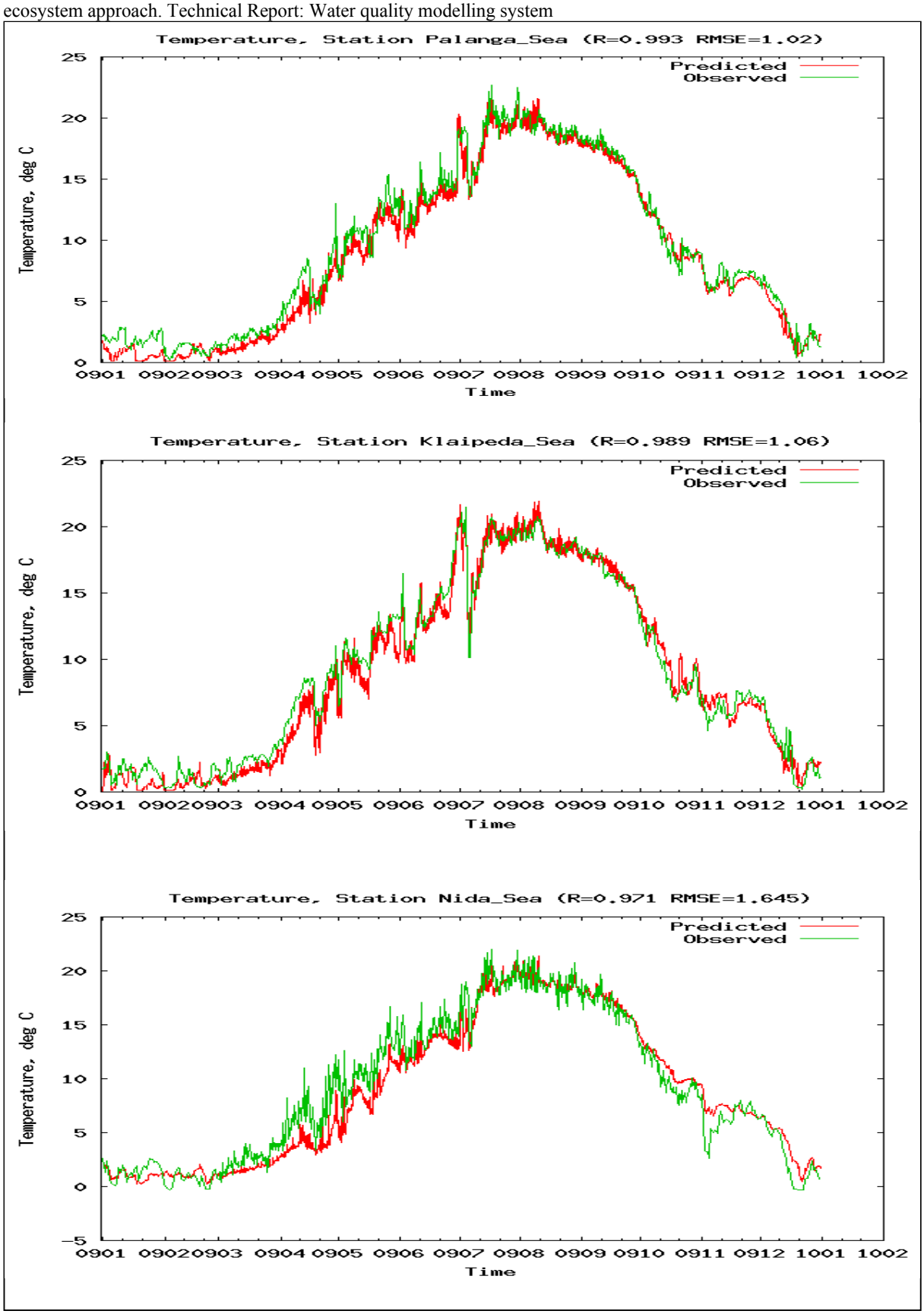


Fig. 2.5. Hydrodynamic model performance on surface water temperature in the Baltic Sea coastal stations Palanga, Klaipeda and Nida for 2009.

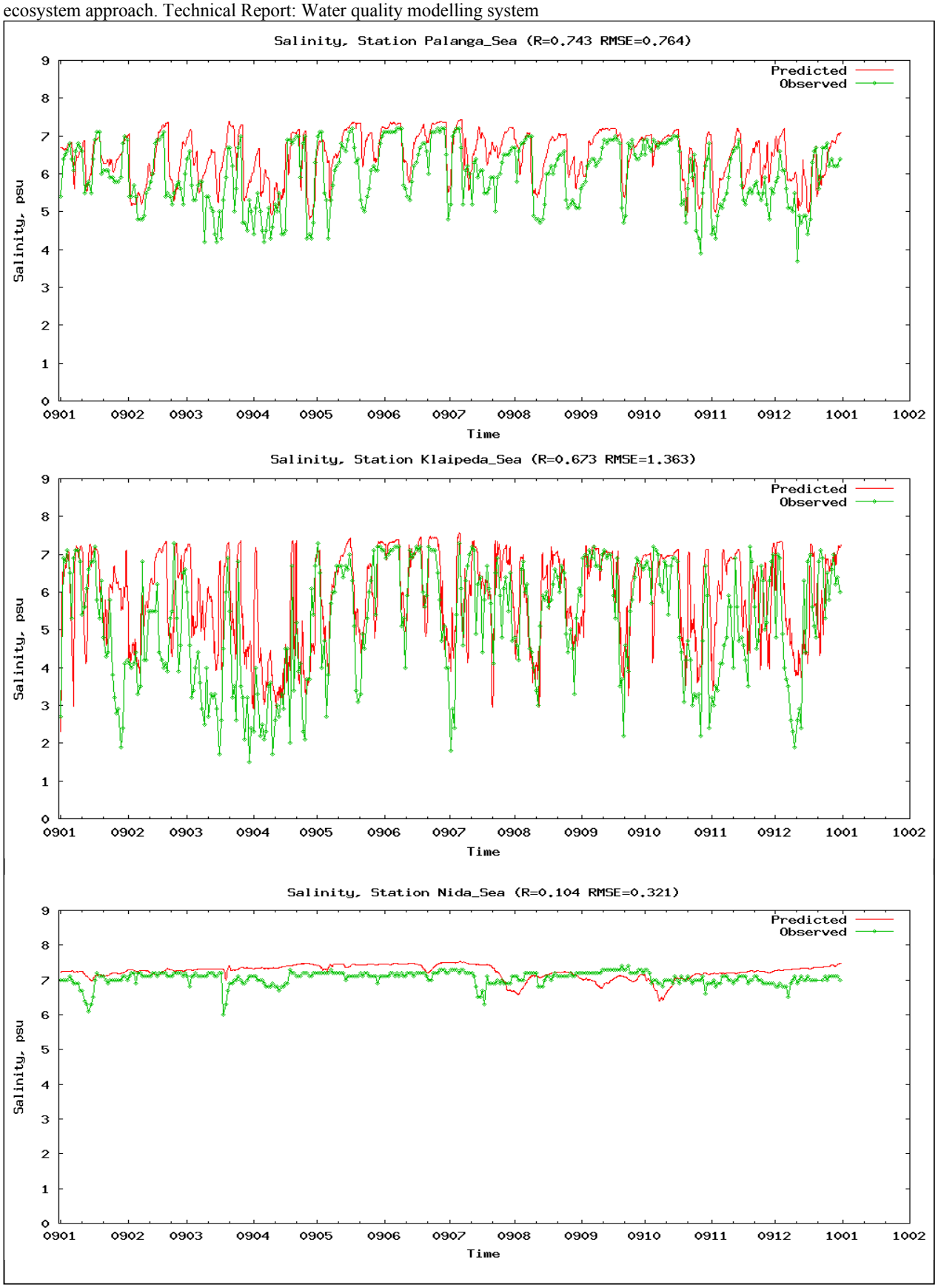


Fig. 2.6. Hydrodynamic model performance on surface water salinity in the Baltic Sea coastal stations Palanga, Klaipeda and Nida for 2009.

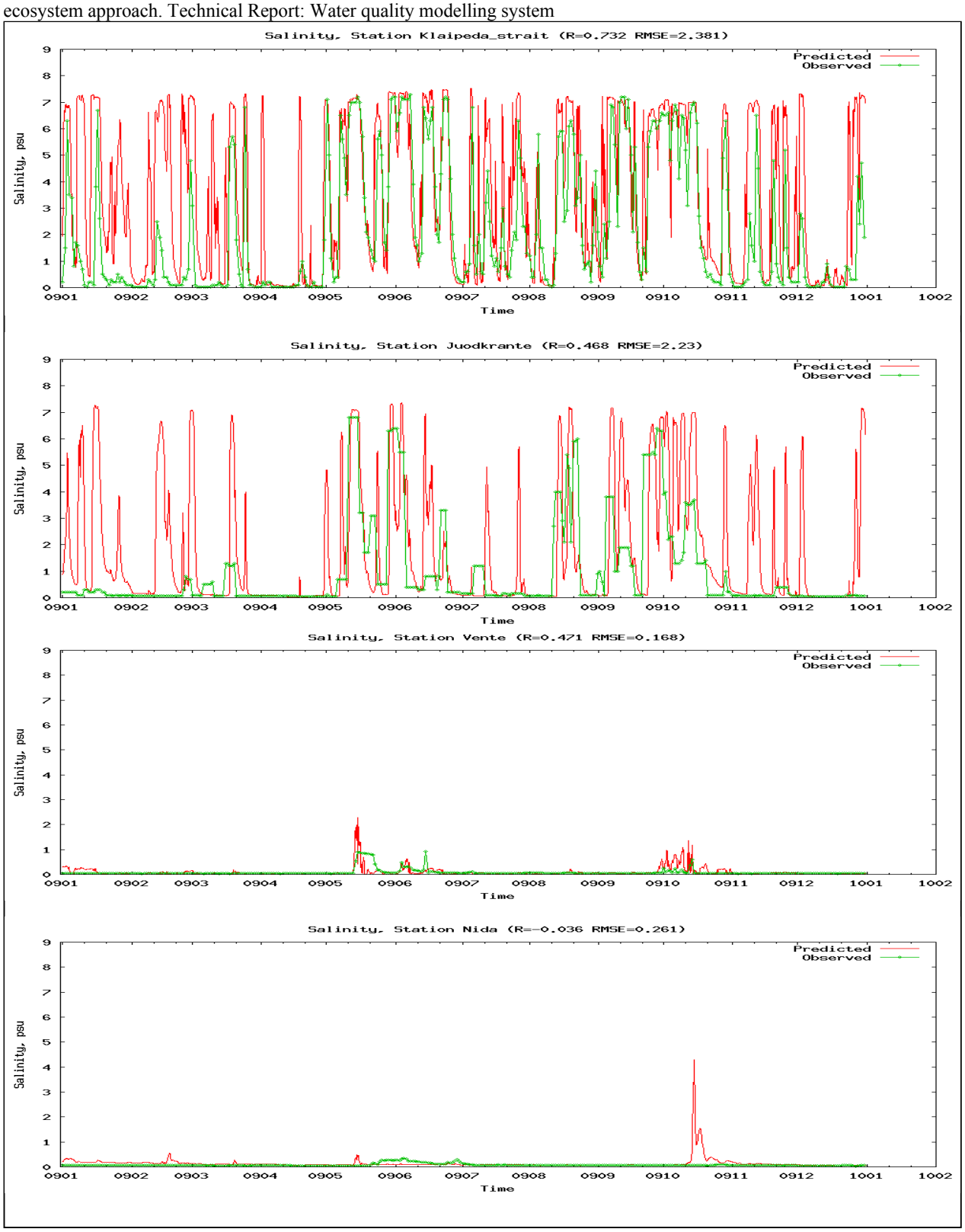


Fig. 2.7. Hydrodynamic model performance on surface water salinity in the Klaipeda strait and coastal stations of the Curonian lagoon Juodkrante, Vente and Nida for 2009.

Model validadion using buoy data

Hydrodynamic model was validated using buoy data for the period. 31 October – 18 November 2010. Validation results for water salinity and temperature in different depths are presented on fig. 2.8 – 2.9. Though model overestimates salinity in comparison with buoy data the discrepancy is just around 0.5 psu (fig. 2.8) and results may be treated as satisfactory. The tendency of slight underestimation of water temperature is seen on fig 2.9. The temperature error is in the range of just 1 degree what also proofs satisfactory model performance.

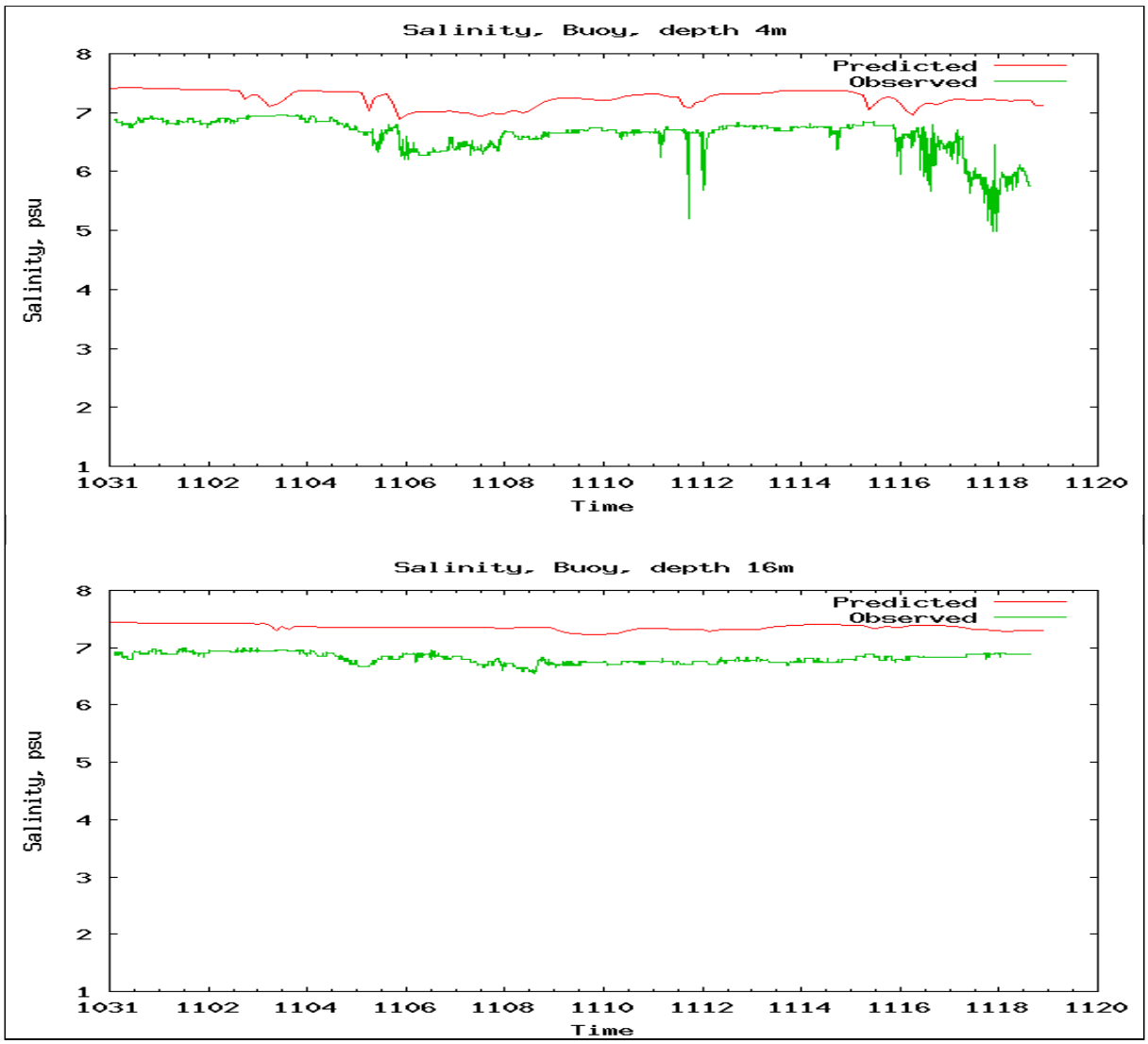


Fig. 2.8. Hydrodynamic model validation results for salinity in different depths using data from buoy for the period. 31 October – 18 November 2010.

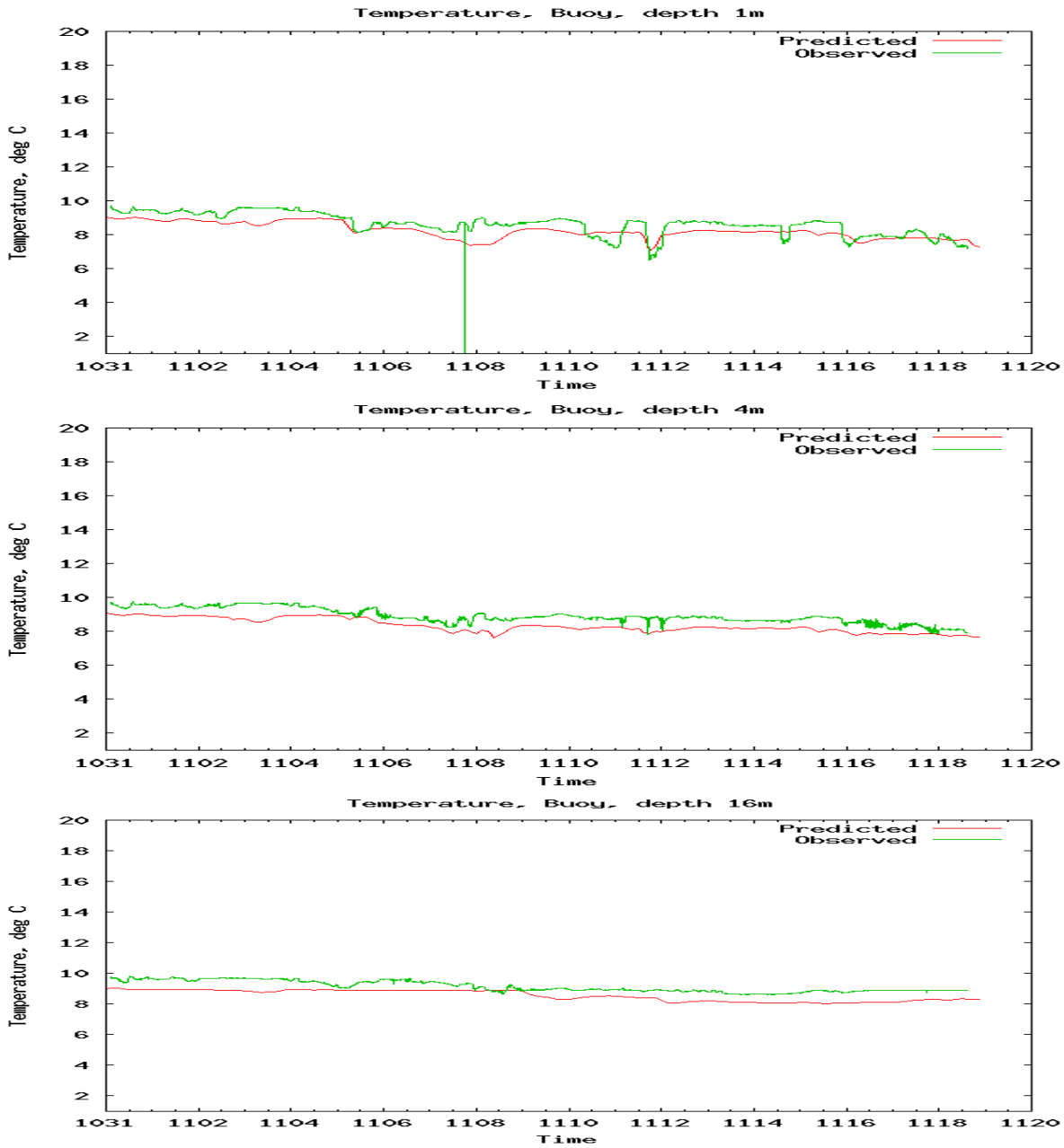


Fig. 2.9. Hydrodynamic model validation results for water temperature in different depths using data from buoy for the period. 31 October – 18 November 2010.

3. WATER QUALITY MODEL

General description

The aim of the water quality modelling in this project was to develop model which can be used to simulate the nutrient and detritus dynamics as well as phytoplankton based primary production in the Curonian Lagoon and coastal area of the Baltic Sea. The developed model AQUABC (AQUAtic Biogeochemical Cycling) is based on kinetic part of the box model ESTAS (Erturk et al., 2008). It was coupled on computer program source level with hydrodynamic model SHYFEM (2D version). Water quality model has 22 state variables. The kinetic part is called every hydrodynamic time step. The values for state variables are calculated and advection-diffusion equation is solved for each state variable using the same routines as in hydrodynamic model. Meteorological forcing as well as water temperature and salinity are obtained from hydrodynamic model. Sensitivity analysis to parameters and calibration

initially was done on the grid covering only the Curonian lagoon for the period 1999-2000. This saved much computing time because model runs much faster with this grid. Final testing of the model was done with the grid No 2 (fig. 2.1) covering the Curonian lagoon and Baltic Sea coastal waters.

Table 3.1. The list of water quality state variables

Number of variable	**Name of variable**
1	AMMONIUM NITROGEN
2.	NITRATE NITROGEN
3.	ORTHOPHOSPHATE PHOSPHORUS
4.	PHYTOPLANKTON CARBON FOR GREENS
5.	EXTERNAL LABILE DISSOLVED DETRITUS CARBON
6.	DISSOLVED OXYGEN
7.	EXTERNAL LABILE PARTICULATE DETRITUS CARBON
8.	EXT. REFRACTORY DISS. DETRITUS CARBON
9.	ZOOPLANKTON CARBON
10.	NONBIOGENIC SILICA
11.	EXTERNAL REFRACTORY PARTICULATE DETRITUS CARBON
12.	PHYTOPLANKTON CARBON FOR DIATOMS
13.	PHYTOPLANKTON CARBON FOR CYANOBACTERIA
14.	INORGANIC CARBON
15.	GREENS DISSOLVED DETRITUS CARBON
16.	GREENS PARTICULATE DETRITUS CARBON
17.	DIATOM DISSOLVED DETRITUS CARBON
18.	DIATOM PARTICULATE DETRITUS CARBON
19.	CYANOBACTERIA DISSOLVED DETRITUS CARBON
20.	CYANOBACTERIA PARTICULATE DETRITUS CARBON
21.	ZOOPLANKTON DISSOLVED DETRITUS CARBON
22.	ZOOPLANKTON PARTICULATE DETRITUS CARBON

Structurally model consist of 4 interacting subsystems that are: 1)nutrients, 2)detritus (dissolved and particulate), 3) phytoplankton, and 4) herbivorous zooplankton. The full list of state variables is given table 3.1

Sensitivity analysis to model parameters

Parameter sensitivity analysis was calculated dividing state variable variation coefficient by parameter variation coefficient. Variation coefficients were calculated as a result of splitting whole parameter variation range to 15 equal parts and calculation of variable values in the splitting points. The final value of sensitivity was obtained by averaging values for the vegetation season. While sensitivity is very time consuming task it was calculated only for most important variables and parameters. Results of sensitivity analysis are presented in tables 3.2, 3.3.

Table 3.2. Sensitivity to parameters analysis results. Grey highlighted the highest values of sensitivity.Variable numbers are the same as in table 3.1.

	k1c	k1c_2	k1c_3	k1d	k1d_2	k1d_3	k1rc	k1rc_2	k1rc_3	kcdenit	kcnit	kdenit	kn	kn_2
1	0.056	0.276	0.241	0.019	0.134	0.095	0.0254	0.153	0.159	0.012	0.611	0.1002	0.0958	0.2961
2	0.100	0.678	0.749	0.022	0.283	0.160	0.0148	0.262	0.244	0.054	0.447	0.4150	0.1007	0.2161
3	0.189	1.262	1.276	0.060	0.618	0.372	0.0492	0.653	0.617	0.048	0.009	0.3398	0.2105	0.5309
4	0.991	0.592	0.309	1.429	0.219	0.102	1.3115	0.324	0.143	0.011	0.002	0.0692	0.9807	0.1647
6	0.005	0.023	0.017	0.001	0.015	0.010	0.0025	0.019	0.008	0.001	0.010	0.0076	0.0070	0.0093
9	1.158	0.778	0.302	0.755	0.295	0.147	1.0936	0.446	0.156	0.011	0.003	0.0665	0.8319	0.2080
10	0.052	0.135	0.060	0.012	0.087	0.015	0.0085	0.084	0.010	0.003	0.001	0.0173	0.0057	0.0199
12	0.323	1.026	0.756	0.077	1.951	0.251	0.0478	2.0452	0.229	0.038	0.008	0.2350	0.1178	1.2448
13	0.108	0.783		0.029	0.306	1.518	0.0133	0.391	1.326	0.024	0.005	0.1642	0.0578	0.1537
14	0.043	0.189						0.133	0.130	0.009	0.002	0.0656	0.0126	0.0426

Table 3.3. The list of parameters investigated by the sensitivity analysis.

Parametro vardas	**Parametro paaiškinimas**
k1c	Maximal relative growth rate for greens
k1c_2	Maximal relative growth rate for diatoms
k1c_3	Maximal relative growth rate for cyanobacteria
kcnit	Relative rate for nitrifications
knit	Oxygen half saturation coefficient for nitrification
kcdenit	Relative rate for denitrification
kdenit	Oxygen half saturation coefficient for denitrification
kn	Nitrogen half saturation coefficient for growth of greens.
kn_2	Nitrogen half saturation coefficient for growth of for diatoms.
kn_3	Nitrogen half saturation coefficient for growth of greens for cyanobacteria.
kp	Phosphorus half saturation coefficient for growth of greens
kp_2	Phosphorus half saturation coefficient for growth of for diatoms
kp_3	Phosphorus half saturation coefficient for growth of greens for cyanobacteria
k1rc	Relative respiration rate for greens
k1rc_2	Relative respiration rate for diatoms
k1rc_3	Relative respiration rate for cyanobacteria
k1d	Relative mortality rate for greens
k1d_2	Relative mortality rate for diatoms
k1d_3	Relative mortality rate for cyanobacteria

Model calibration

State monitoring stations (fig. 1.3) water quality data for 1999-2000 were used for calibration of the model. Only data of stations (10, 12, 14) where sea water intrusion is minimal were used because reliable data were missing for the water quality variables boundary condition from the sea side. The comparison of predicted and measured data after calibration of some variables for station 14 is presented in fig. 3.1 – 3.2

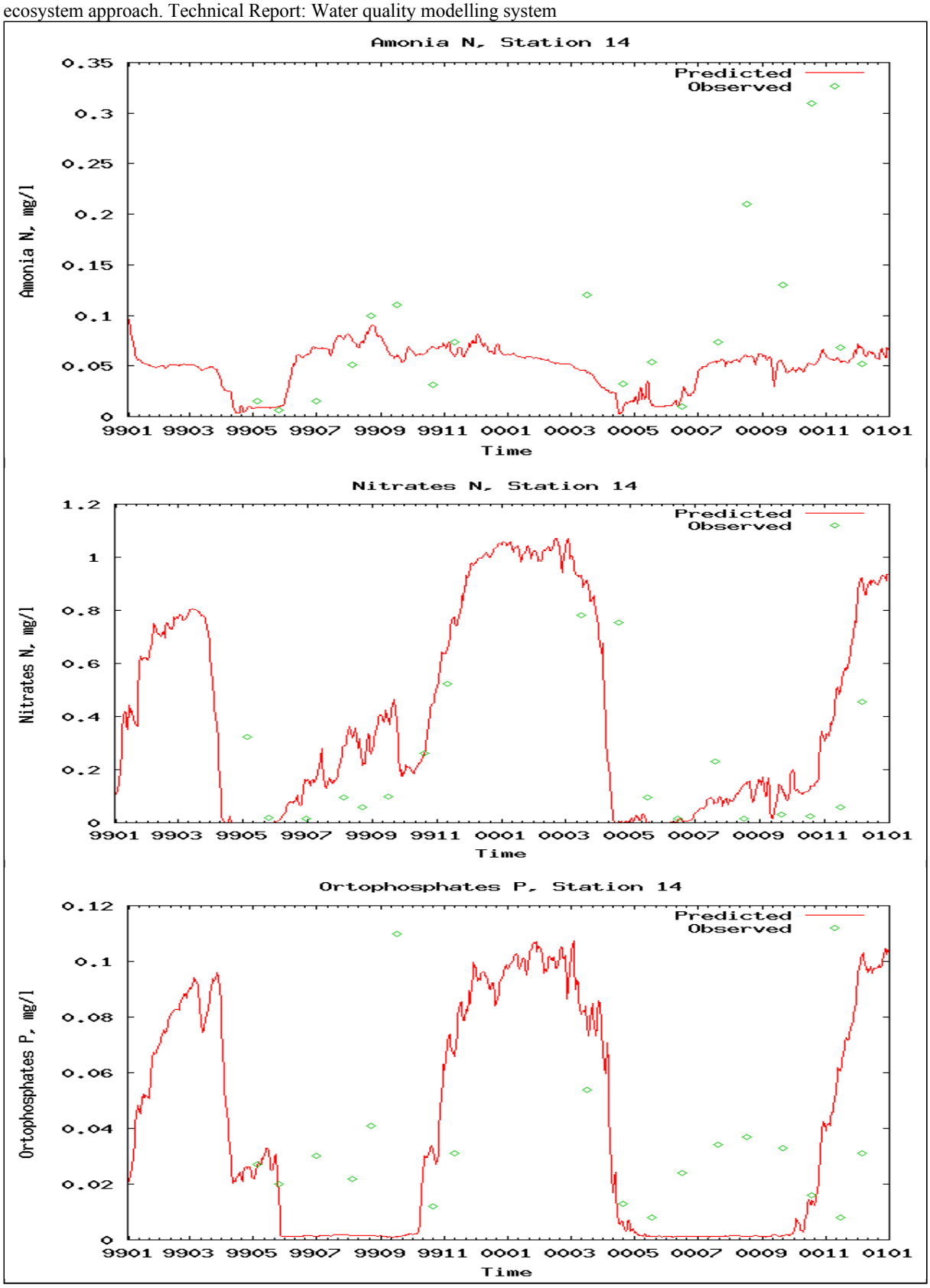


Fig 3.1. Comparison of predicted and observed values for ammonia, nitrates and orthophosphates after calibration.

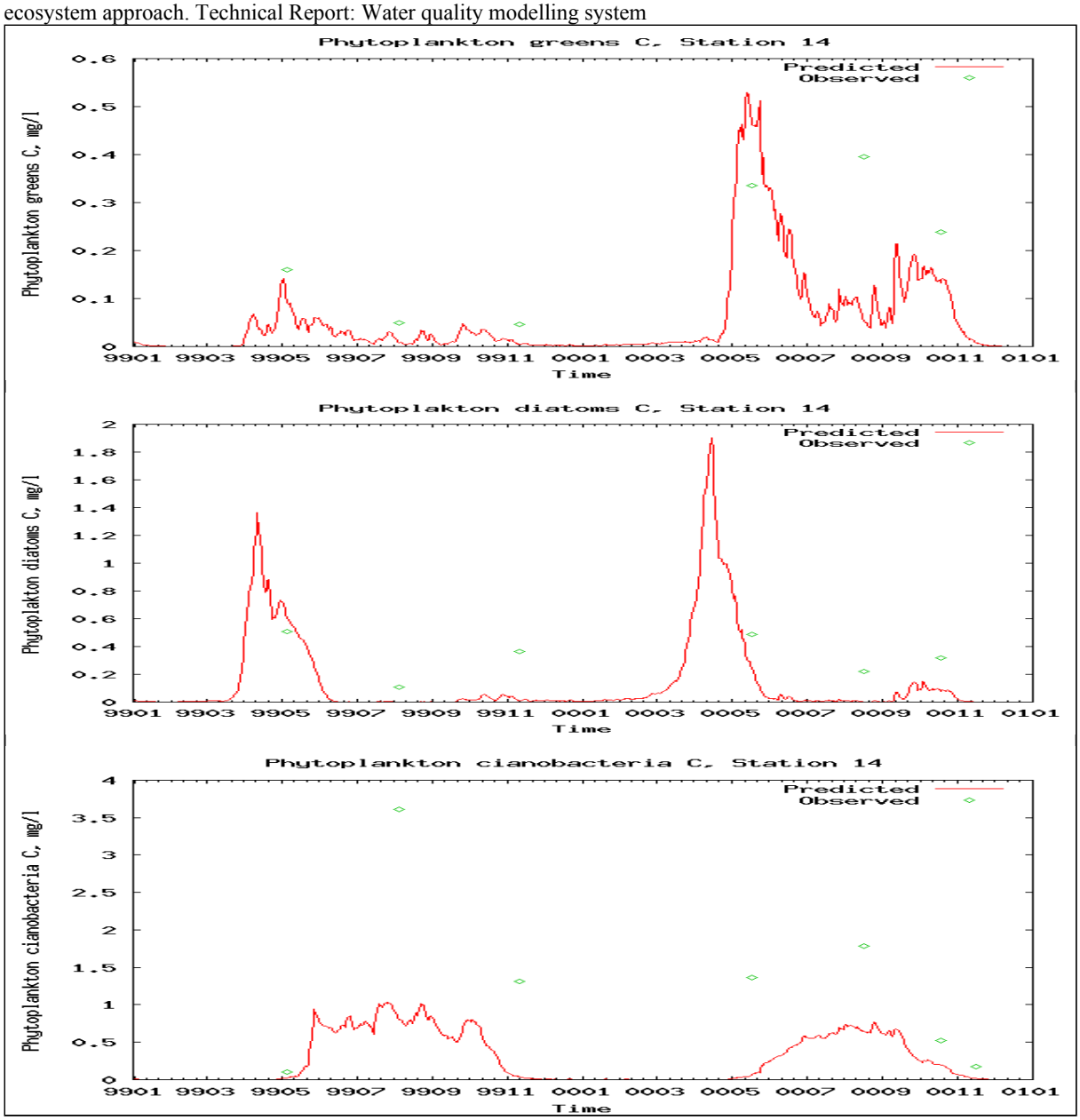


Fig 3.2. Comparison of predicted and observed values for greens, diatoms and cyanobacteria after calibration.

Model validation

Water quality model was validated using data from sampling campaign of 2009. The location of sampling stations is presented in fig.1.1. Three stations were located in the Curonian Lagoon and three in the Baltic Sea. Model grid No 2 (fig. 2.1) was used in 2D model simulations. Boundary conditions for water quality variables in the Baltic Sea were derived from the stations of state monitoring taking spatial and temporal averages. Model validation results are presented in fig. 3.3 - 3.20. In general model demonstrates satisfactory performance for all model variables, but there are some points that could be improved in future developments. These are discussed in chapter 5.

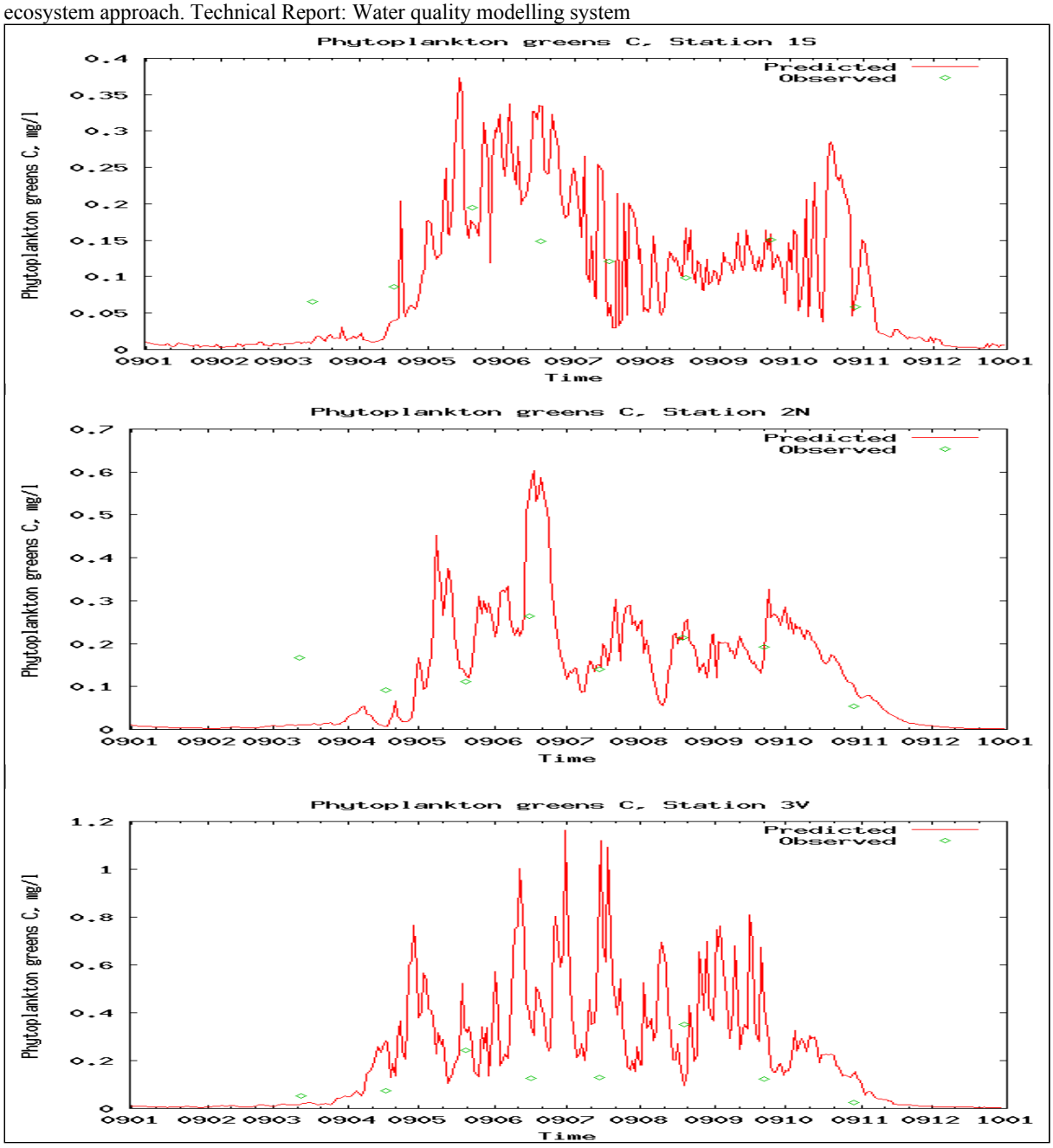


Fig. 3.3. Comparison of model predictions and observations of greens for stations located inside of the Curonian lagoon.

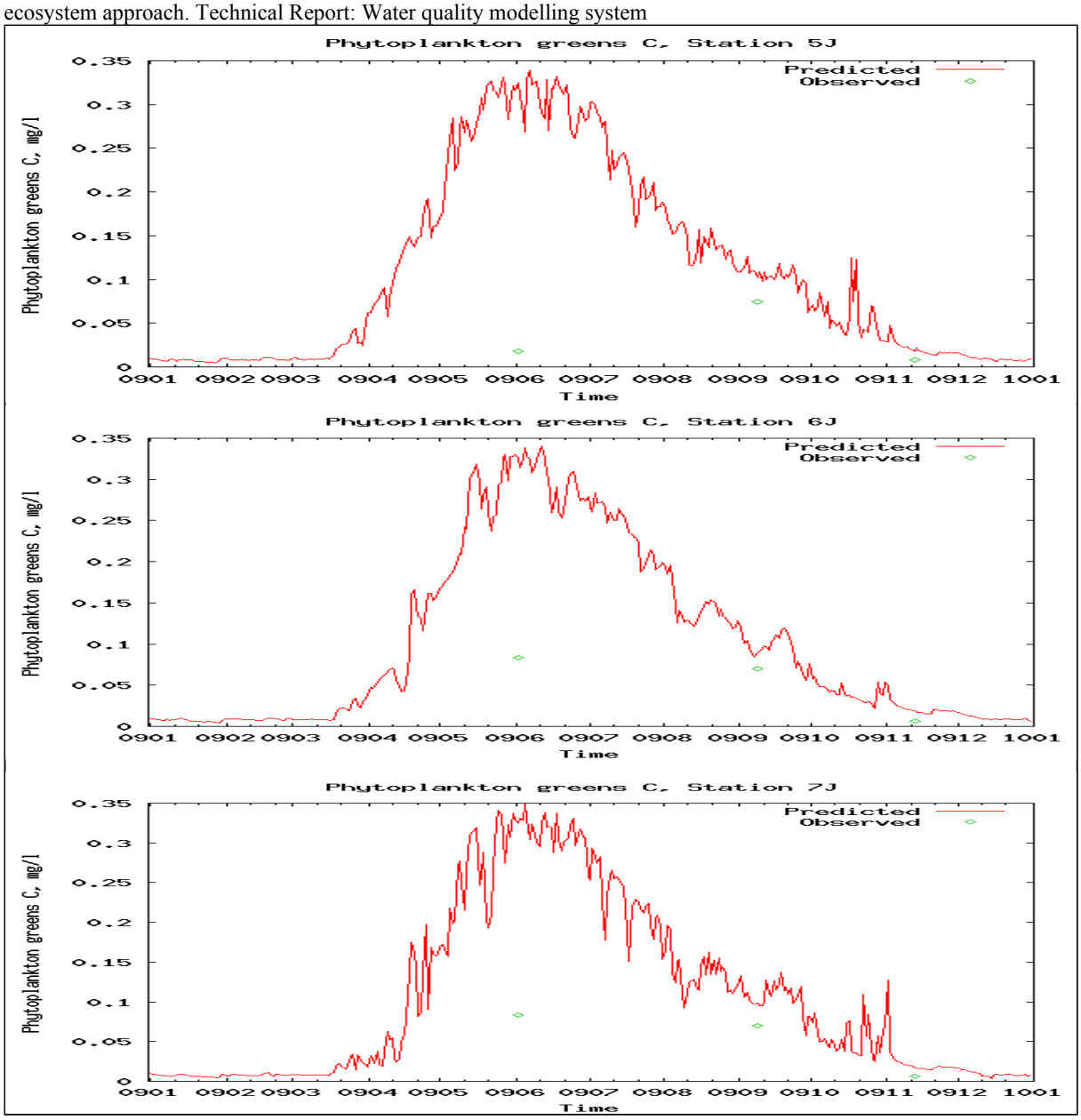


Fig. 3.4. Comparison of model predictions and observations of greens for stations located in coastal waters of the Baltic Sea.

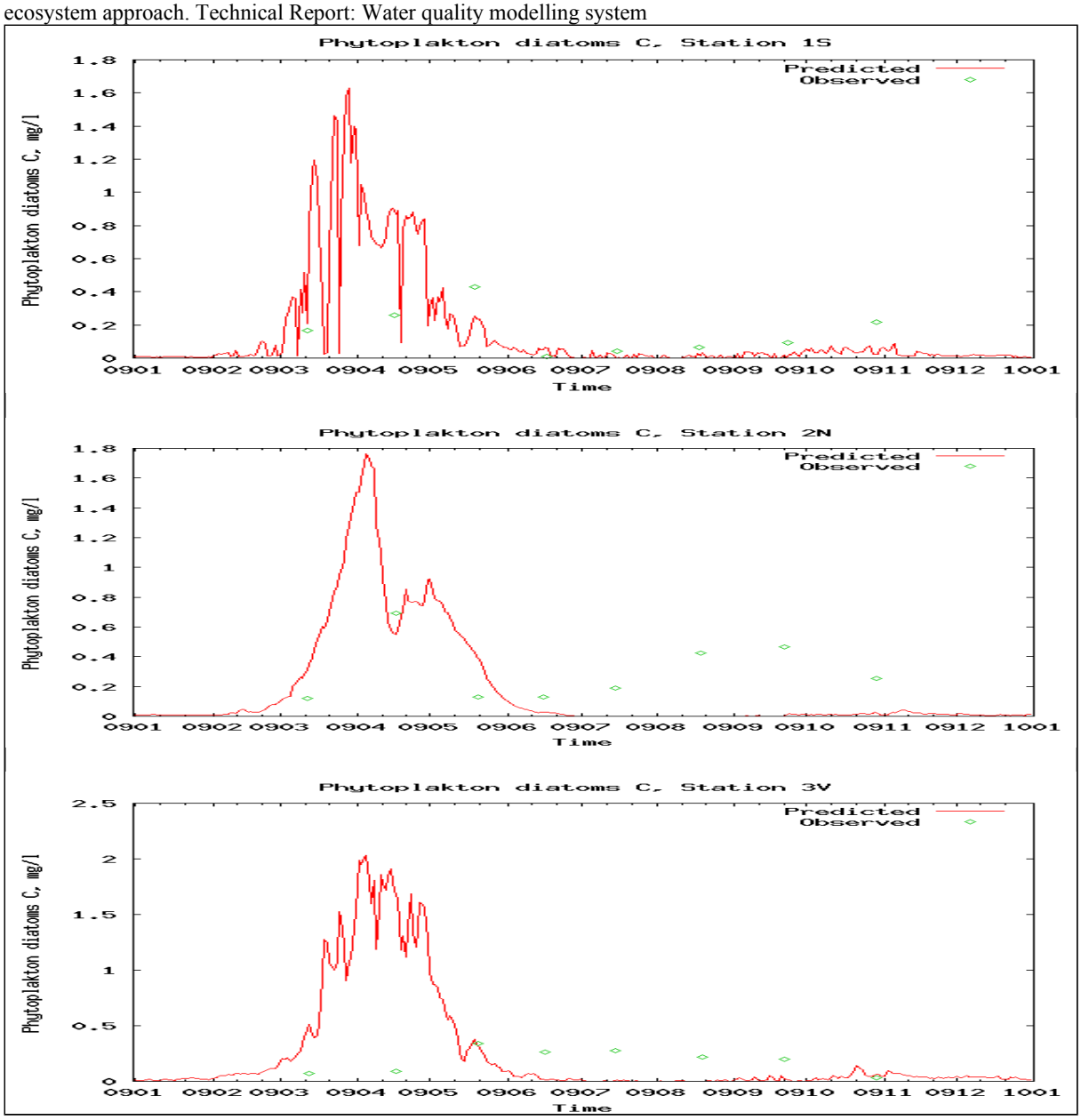


Fig. 3.5. Comparison model predictions and observations of diatoms for stations located inside of the Curonian lagoon.

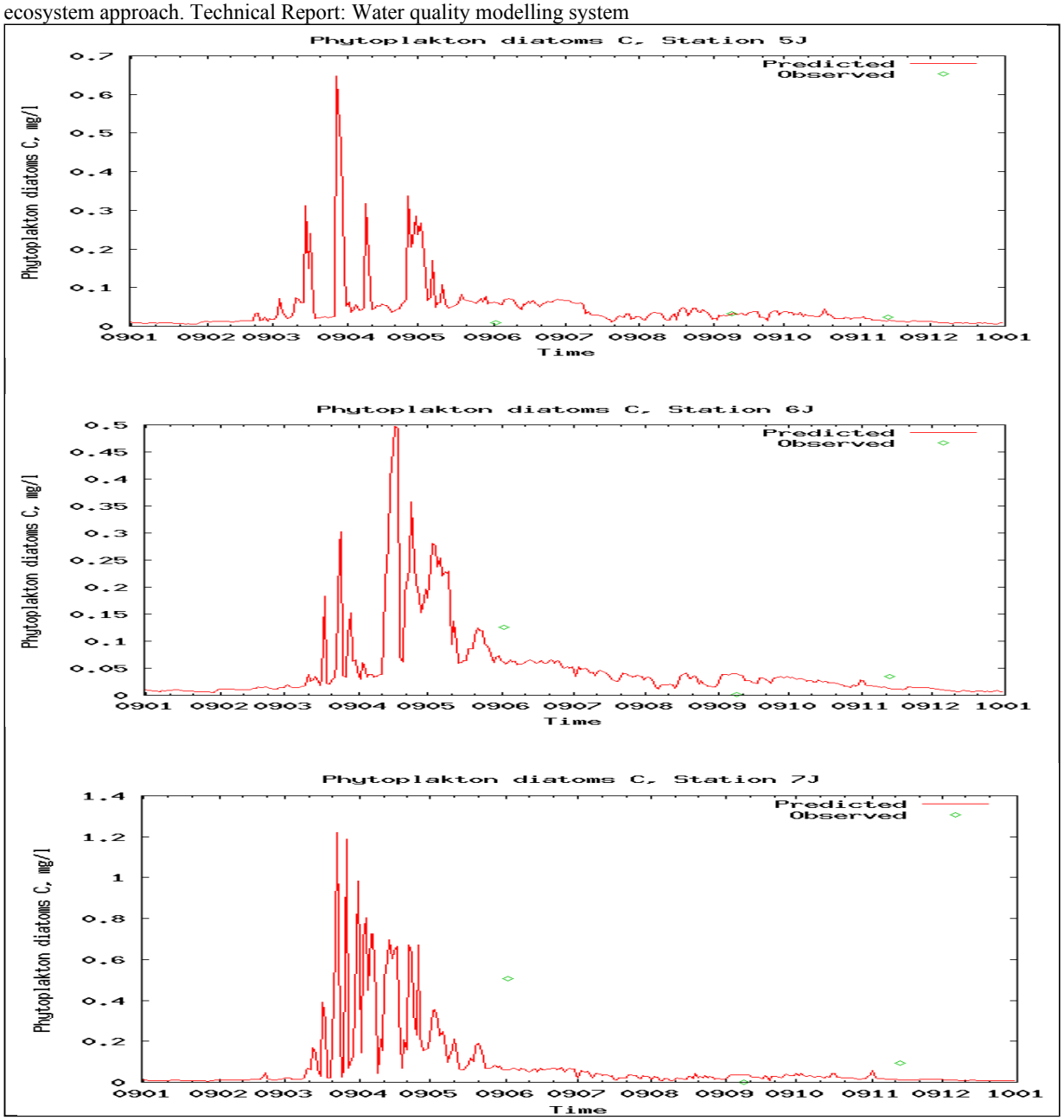


Fig. 3.6. Comparison of model predictions and observations of diatoms for stations located in coastal waters of the Baltic Sea.

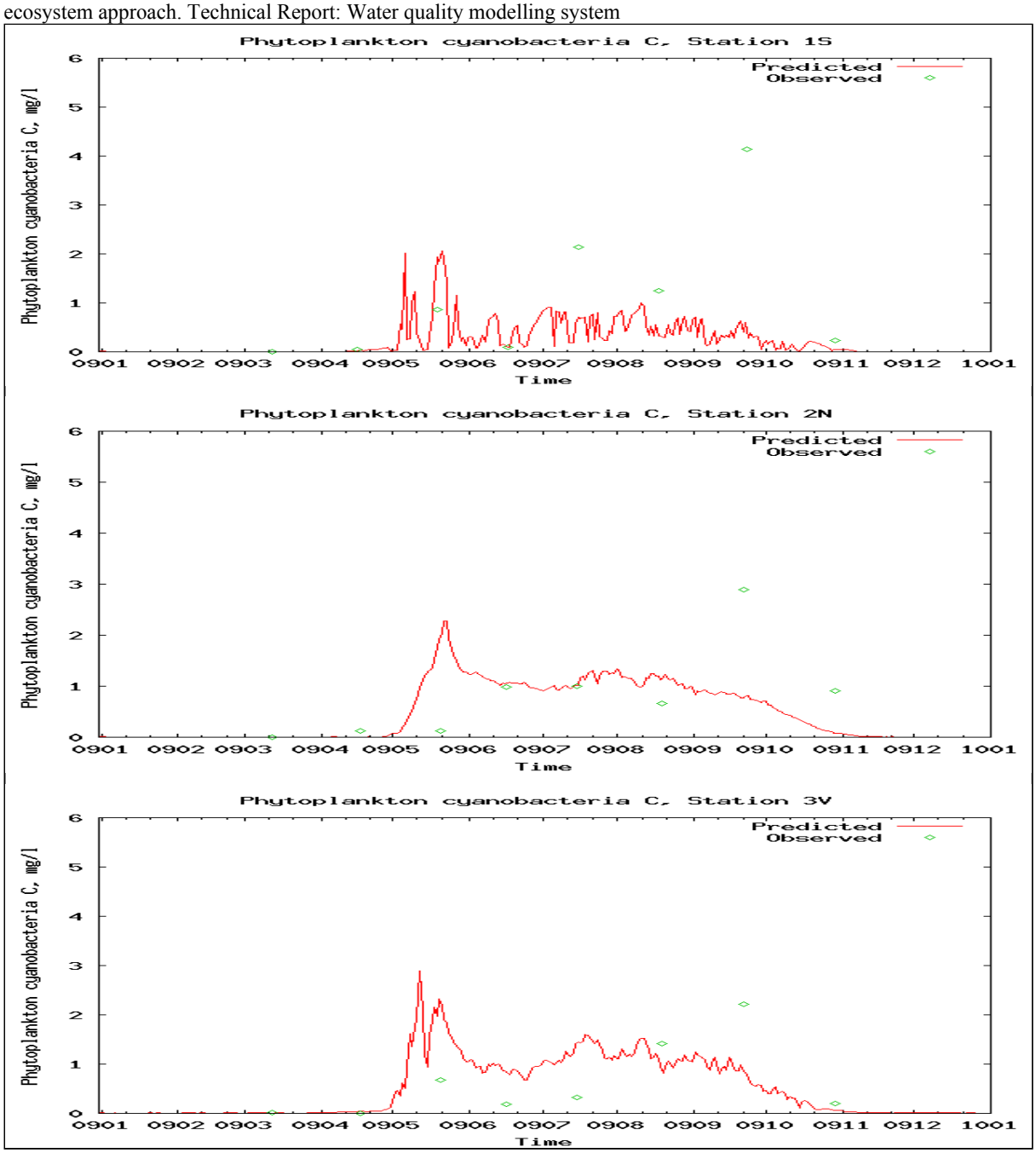


Fig. 3.7. Comparison model predictions and observations of cyanobacteria for stations located inside of the Curonian lagoon.

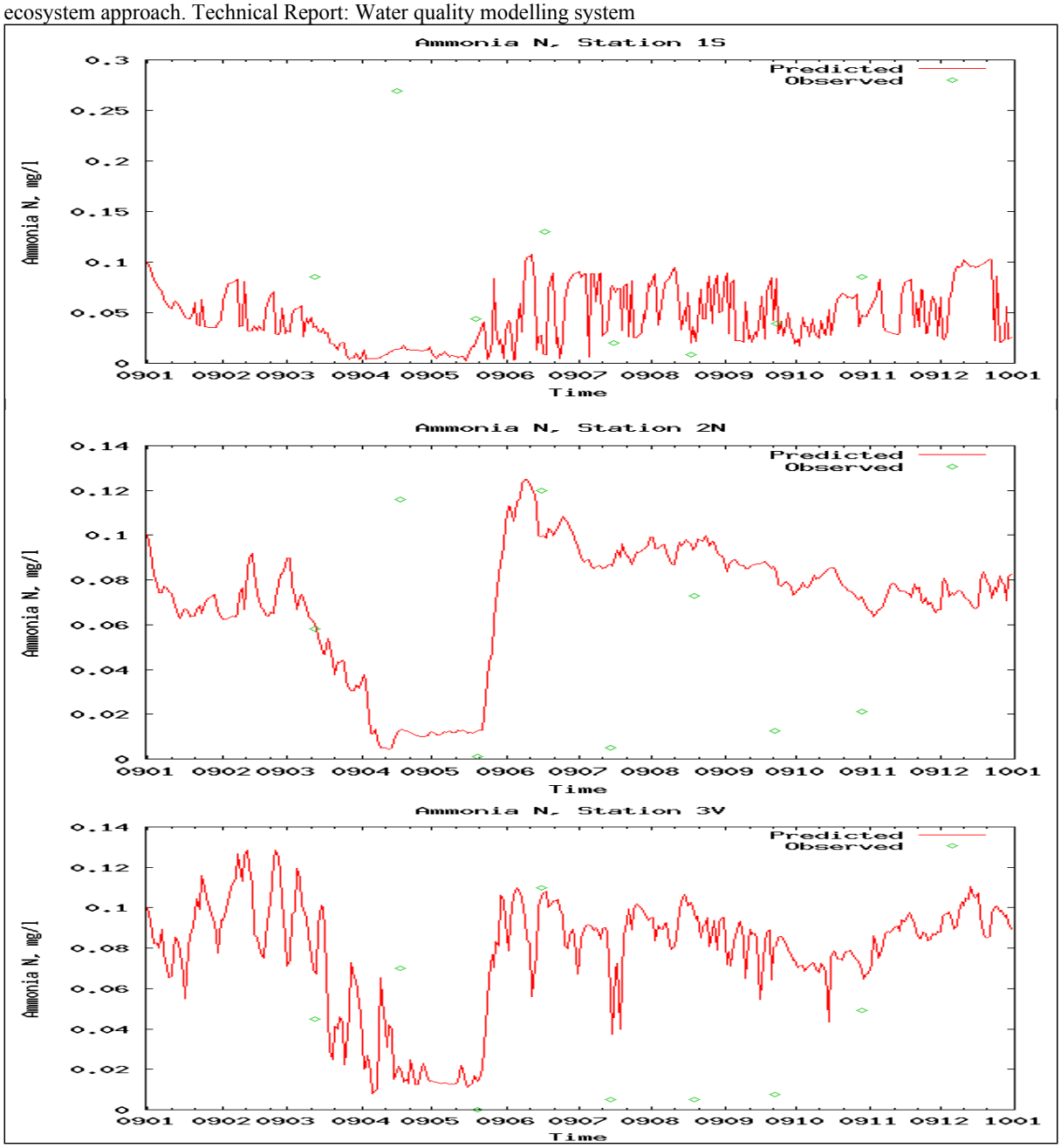


Fig. 3.8. Comparison model predictions and observations of ammonia for stations located inside of the Curonian lagoon.

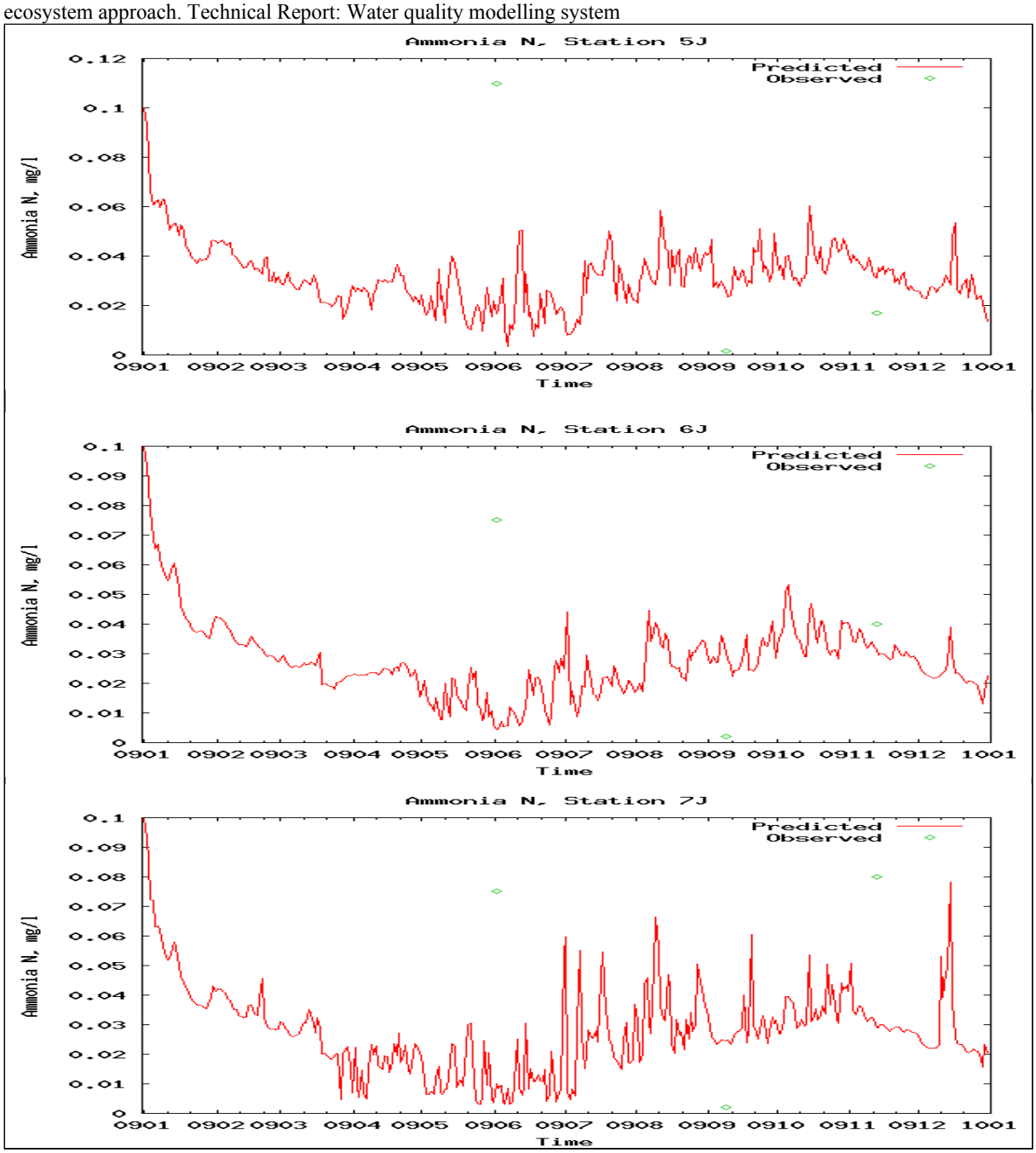


Fig. 3.9. Comparison model predictions and observations of ammonia for stations located in the coastal waters of the Baltic Sea.

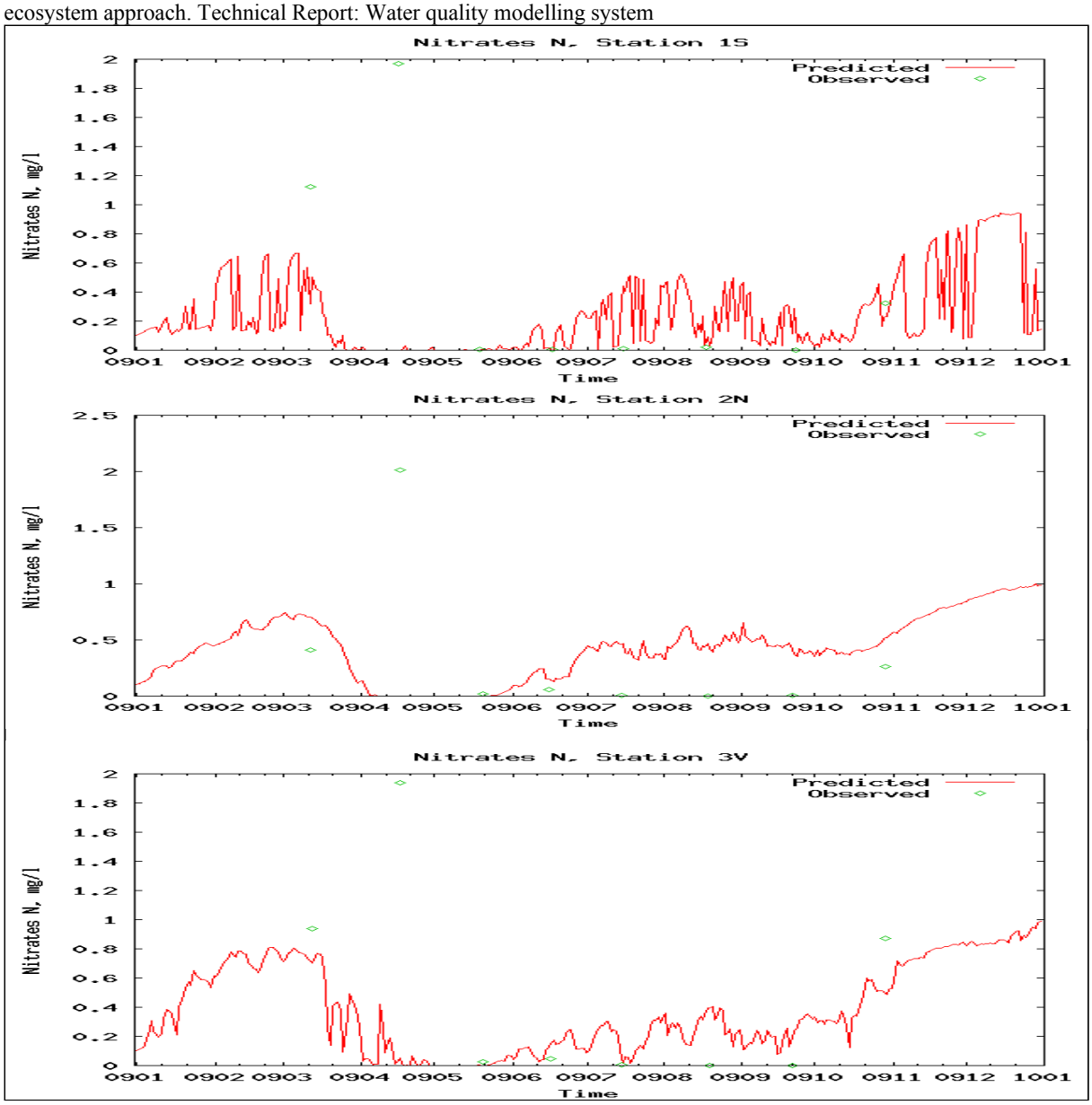


Fig. 3.10. Comparison model predictions and observations of nitrates for stations located inside of the Curonian lagoon.

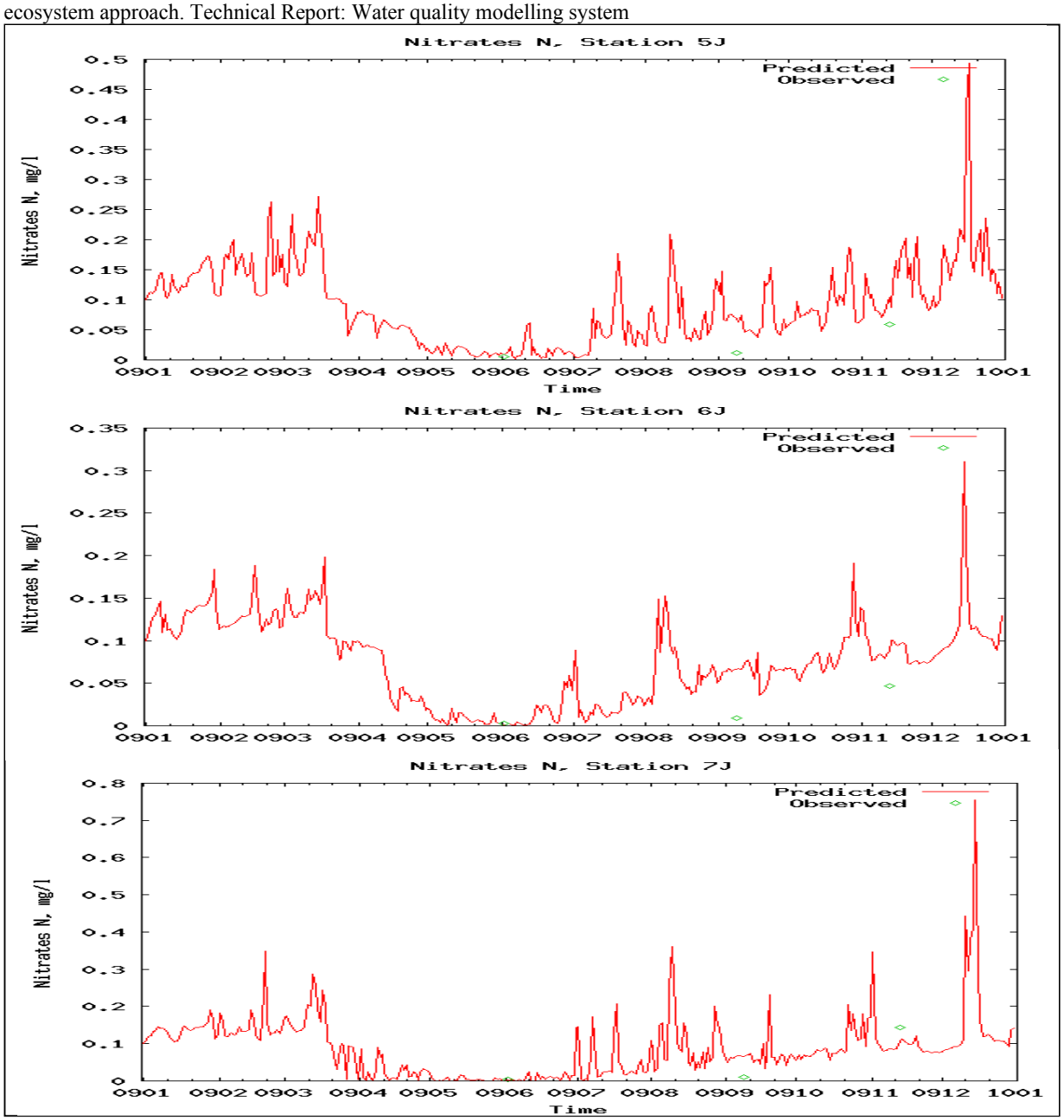


Fig. 3.11. Comparison model predictions and observations of nitrates for stations located in coastal waters of the Baltic Sea.

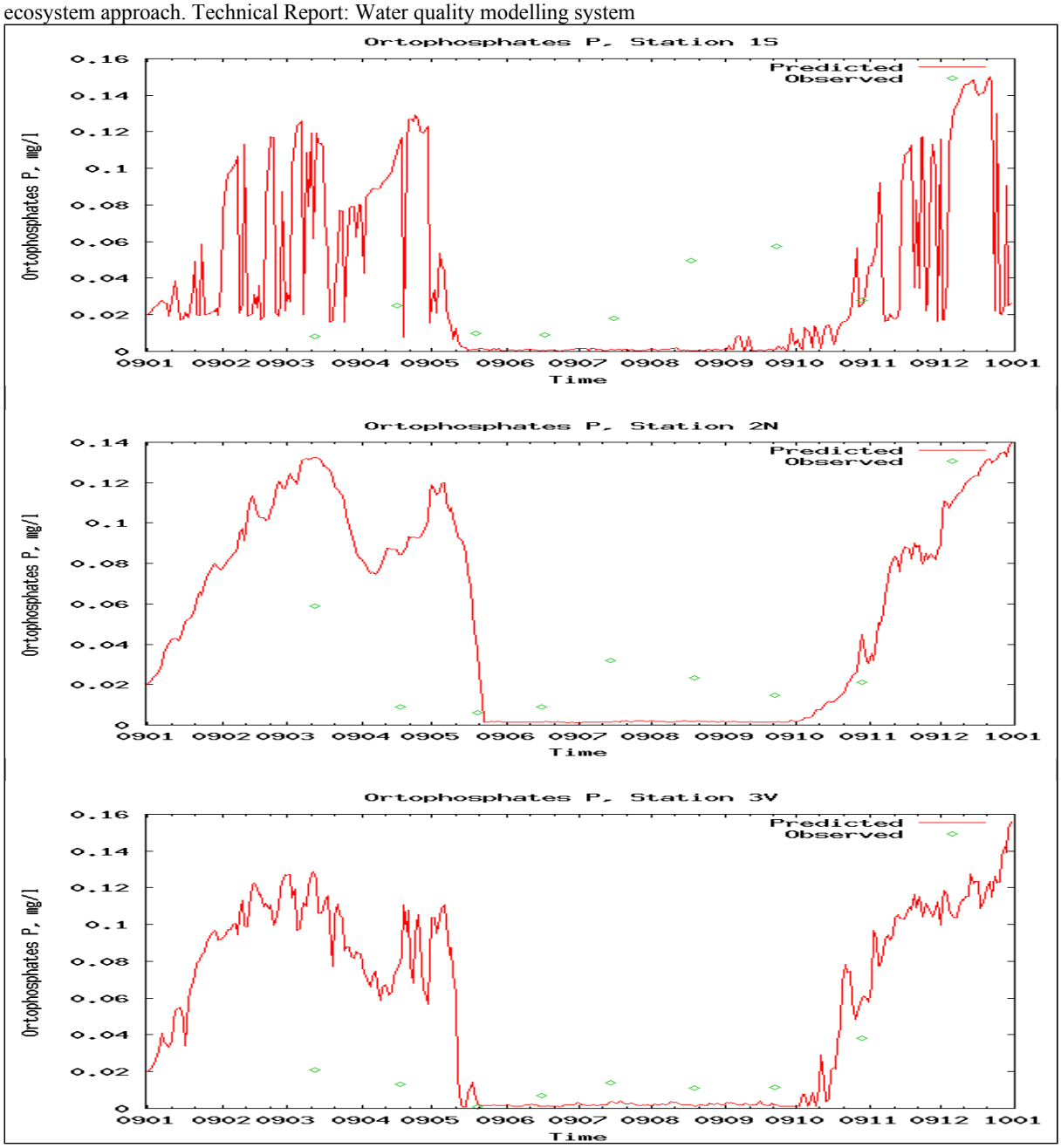


Fig. 3.12. Comparison model predictions and observations of orthophosphates for stations located inside of the Curonian Lagoon.

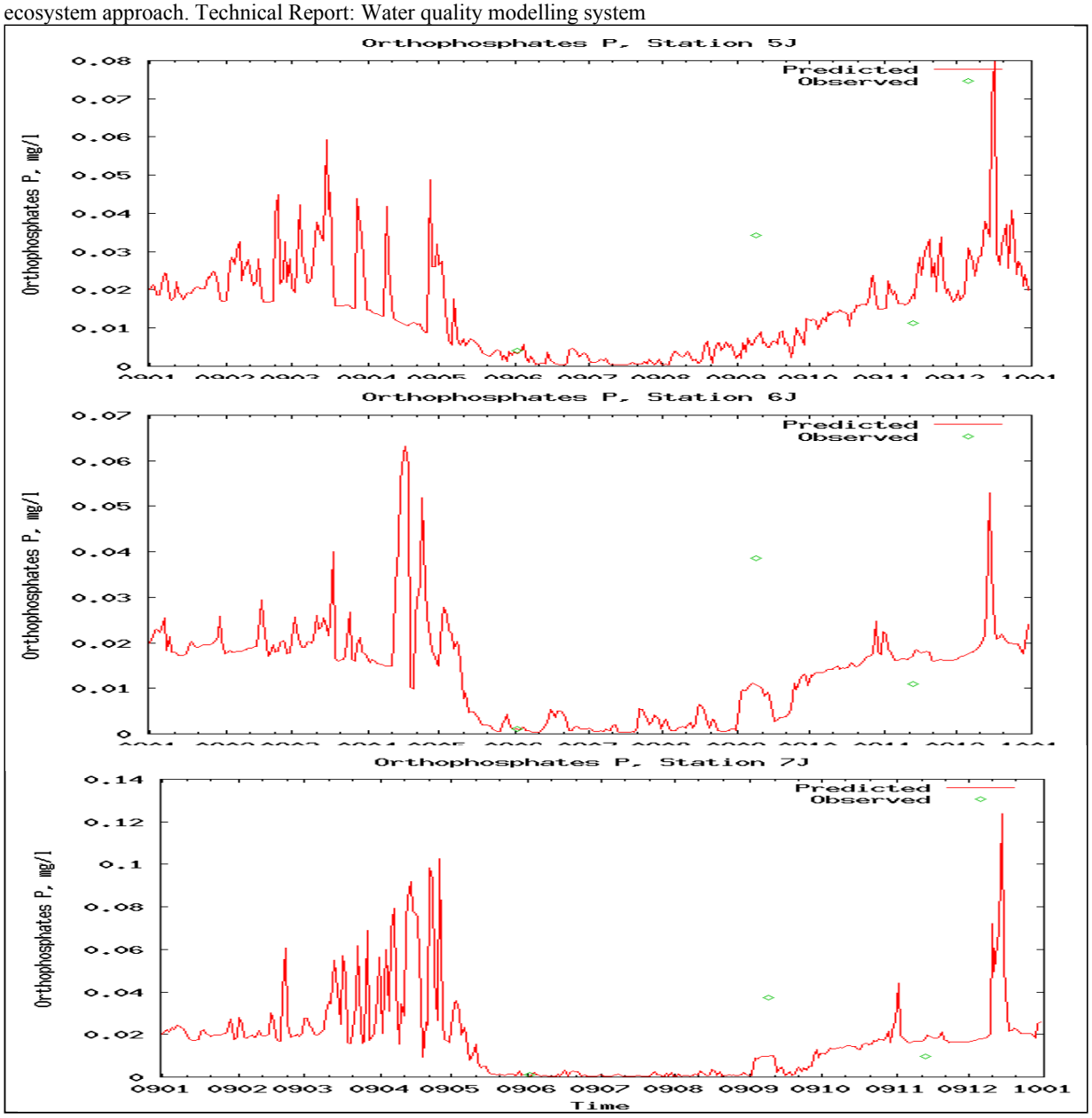


Fig. 3.13. Comparison model predictions and observations of orthophosphates for stations located incoastal waters of the Baltic Sea.

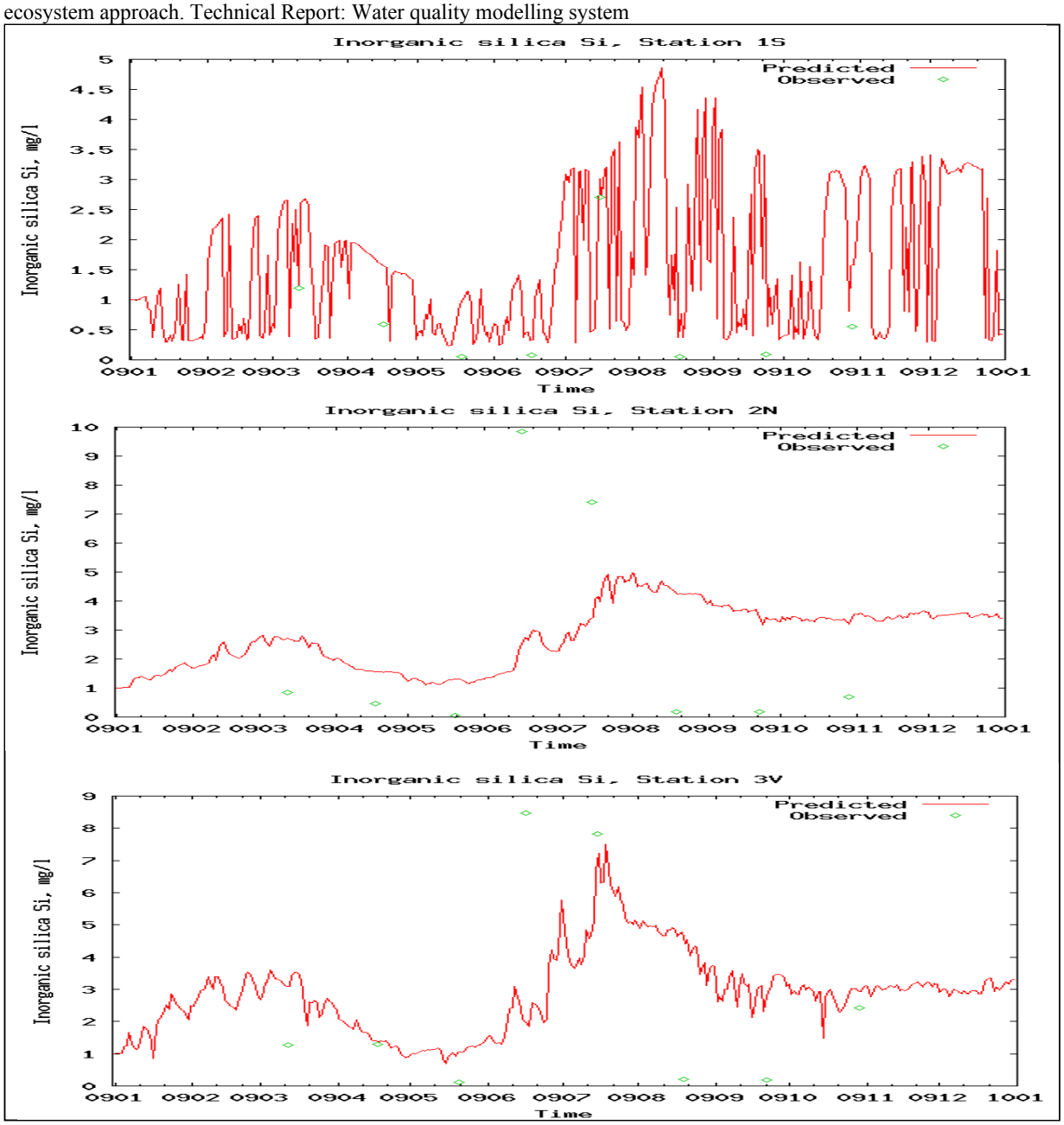


Fig. 3.14. Comparison model predictions and observations of inorganic silica for stations located inside of the Curonian Lagoon.

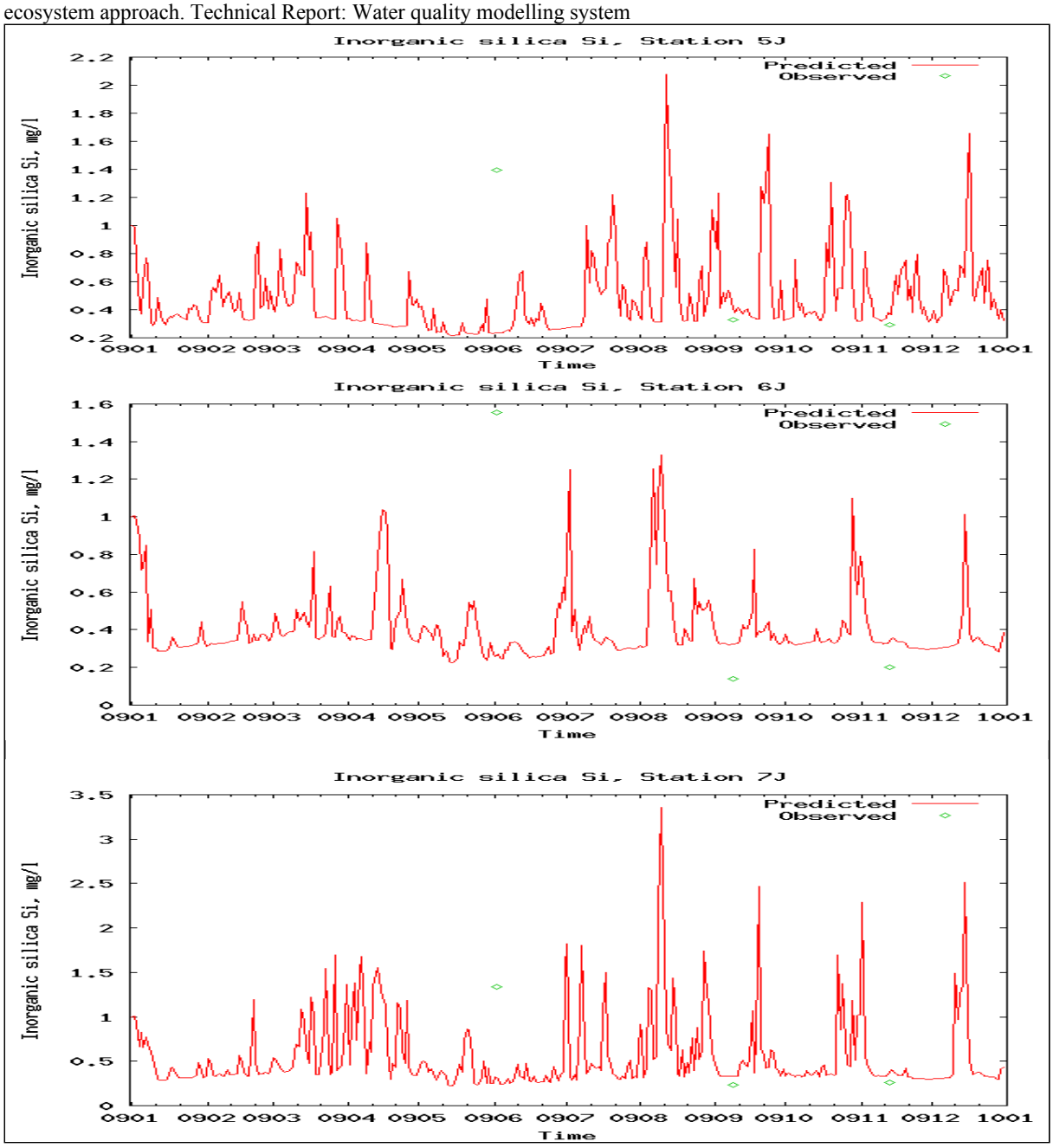


Fig. 3.15. Comparison model predictions and observations of inorganic silica for stations located in the coastal waters of the Baltic Sea.

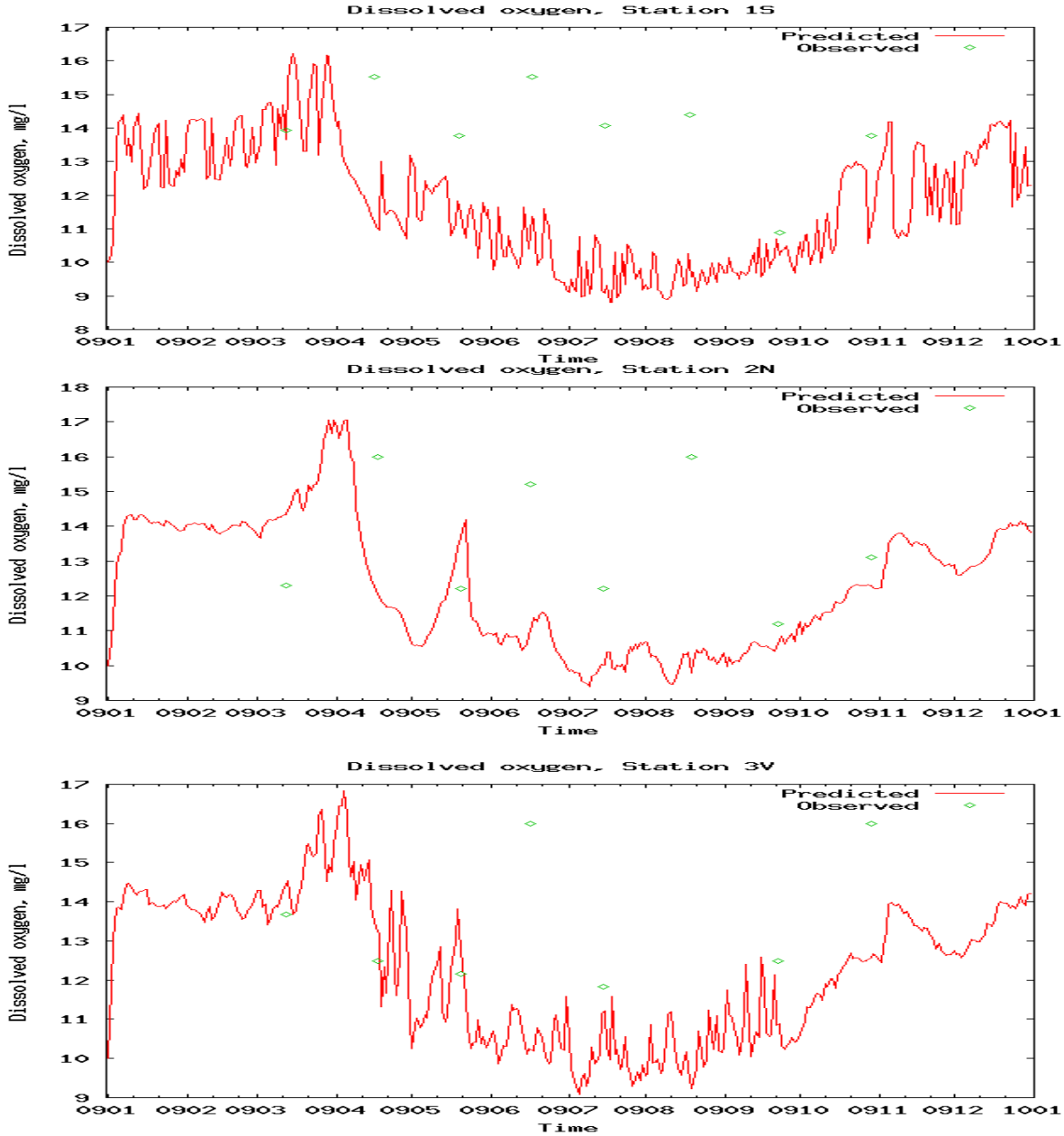


Fig. 3.16. Comparison model predictions and observations of dissolved oxygen for stations located inside of the Curonian lagoon.

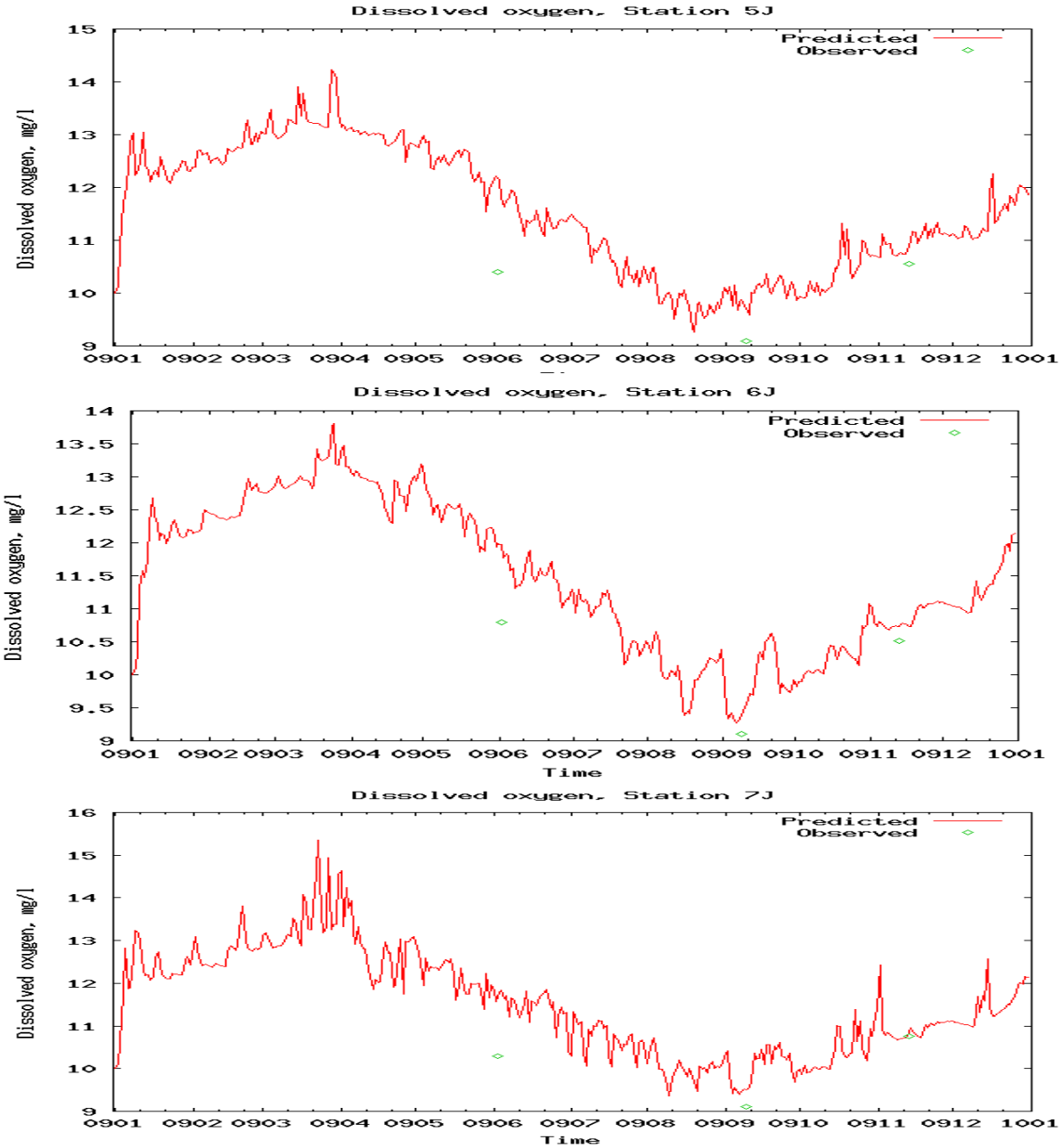


Fig. 3.17. Comparison model predictions and observations of dissolved oxygen for stations located in the coastal waters of the Baltic Sea.

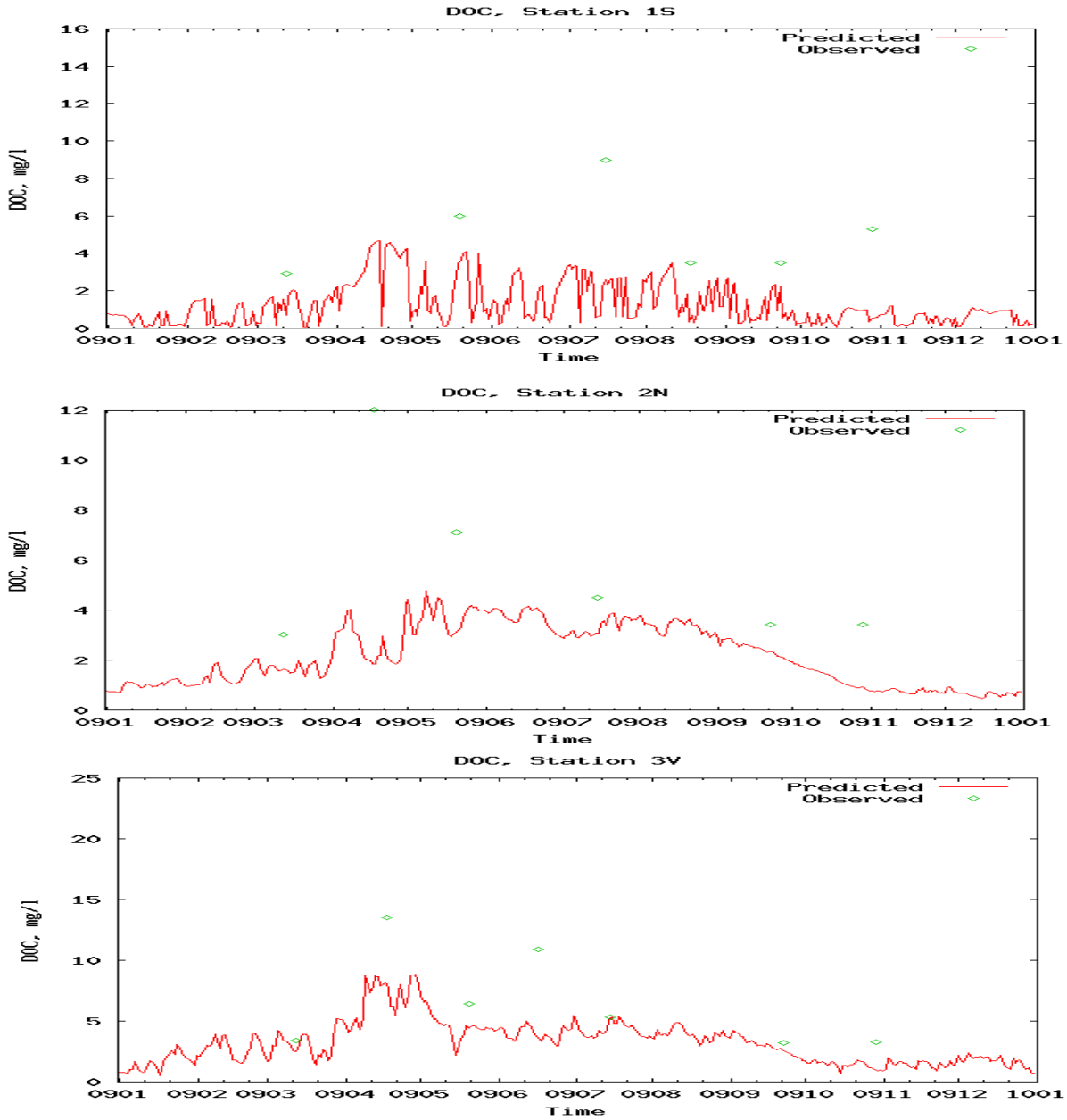


Fig. 3.18. Comparison model predictions and observations of dissolved organic carbon for stations located inside of the Curonian lagoon.

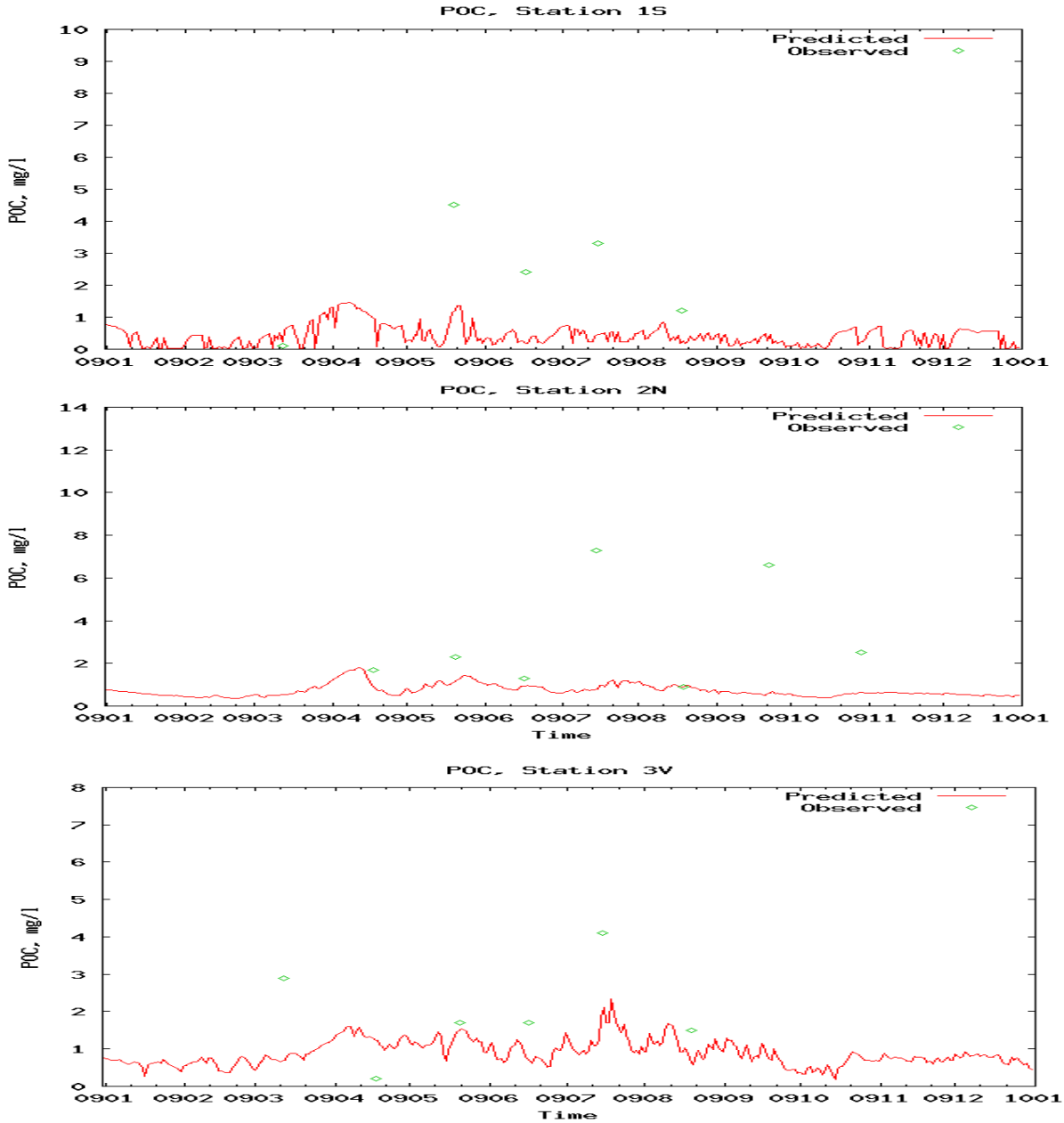


Fig. 3.19. Comparison model predictions and observations of particulate organic carbon for stations located inside of the Curonian lagoon.

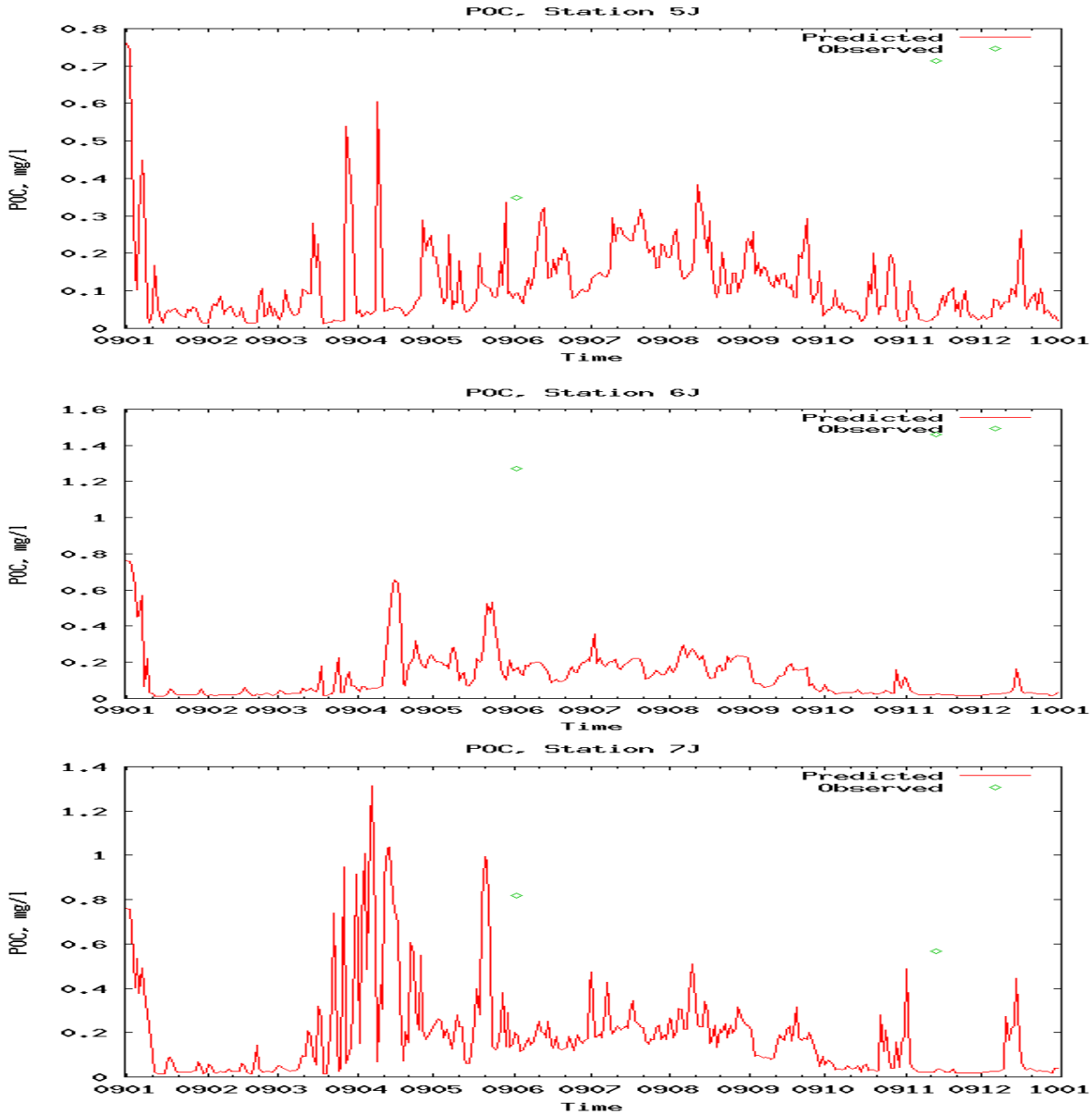


Fig. 3.20. Comparison model predictions and observations of particulate organic carbon for stations located in the coastal waters of the Baltic Sea.

4. APPLICATIONS

The developed model is a tool that can be used to answer important questions related to water exchange between the Curonian lagoon and the Baltic Sea and anthropogenic impact. From numerous possible applications only two are presented below in order to demonstrate model capabilities.

Vertical salinity distribution

Vertical salinity distribution in the modelled area and especially in the Klaipeda strait (area between harbour gates and island Kiaules nugara (fig. 4.2)) is important independent scientific problem that was not investigated until now. It is also important for the water quality because many chemical reactions the water column and bottom sediments depend on water salinity. The vertical section given in fig. 4.1 was investigated using simulation results of salinity for 2009.

Fig. 4.1. The location of the model grid nodes that belongs to vertical section. The most northern section end is located in the distance of 850m seawards from Klaipeda harbour gates and reaches Juodkrante by its south end.

Four types of salinity vertical distribution were found during analysis of simulation results (fig. 4.2 – 4.5): 1) whole depths of the Klaipeda strait is filled with fresh water (fig. 4.2); 2) fresh water in the surface layer and saline water in the bottom layer (fig. 4.3); 3) (fig. 4.4); 3) disappearance or formation of stratification; 4) no stratification, saline sea water in the whole vertical profile. The forth type takes place during the intrusion of saline sea water to the Curonian lagoon.

Analysis revealed that least frequent type of salinity vertical distribution is the first one. The total duration of this type during 2009 was only 20 days.

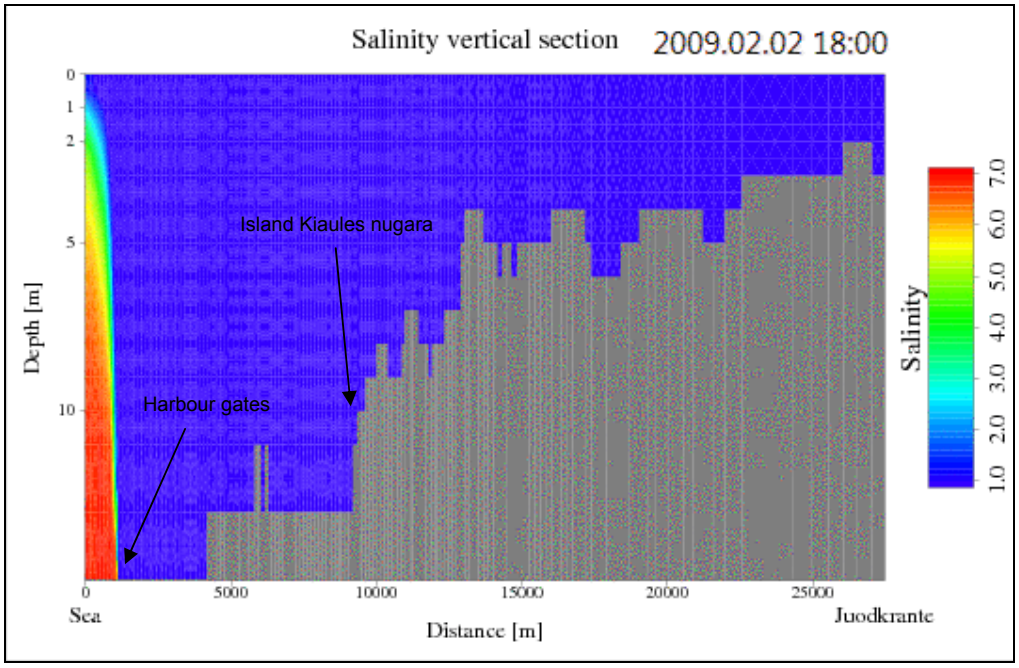


Fig. 4.2. First type of salinity vertical distribution: only fresh water in the Klaipeda strait

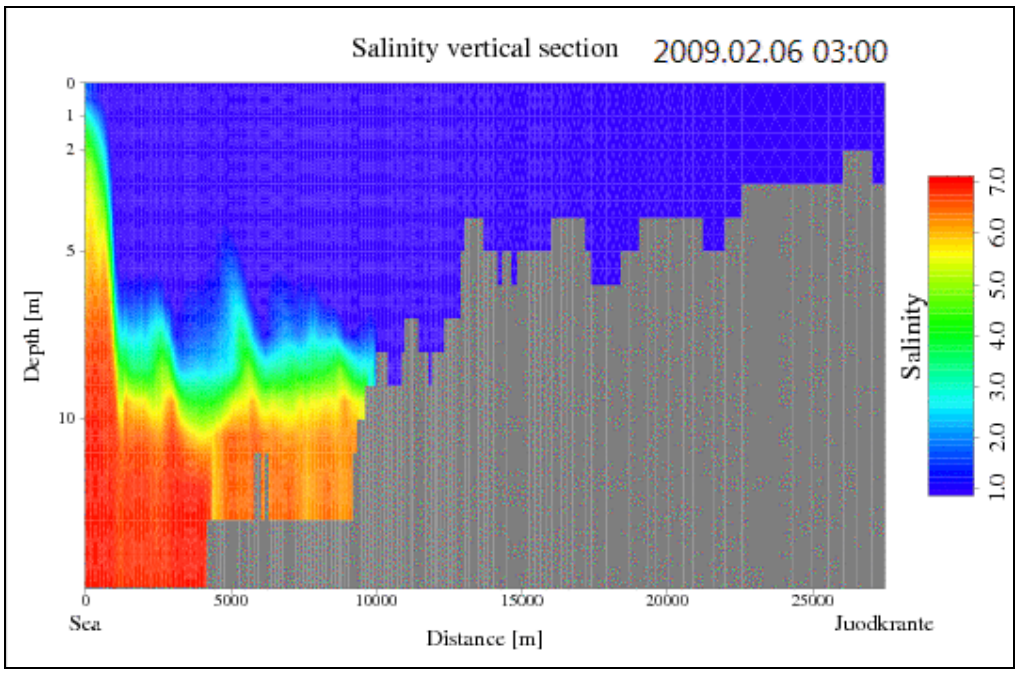


Fig. 4.3. The second type of salinity vertical distribution: stratification in the Klaipeda strait.

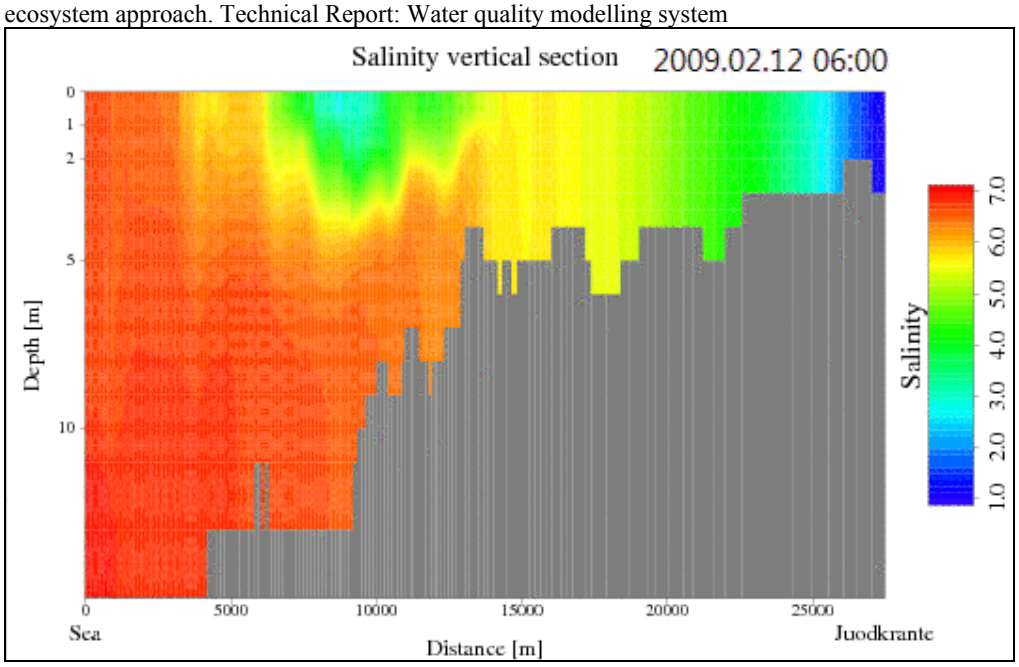


Fig. 4.4. Third type of salinity vertical distribution: stratification destruction (intrusion of saline water to the Curonian lagoon) or start (push of saline water from the Curonian lagoon).

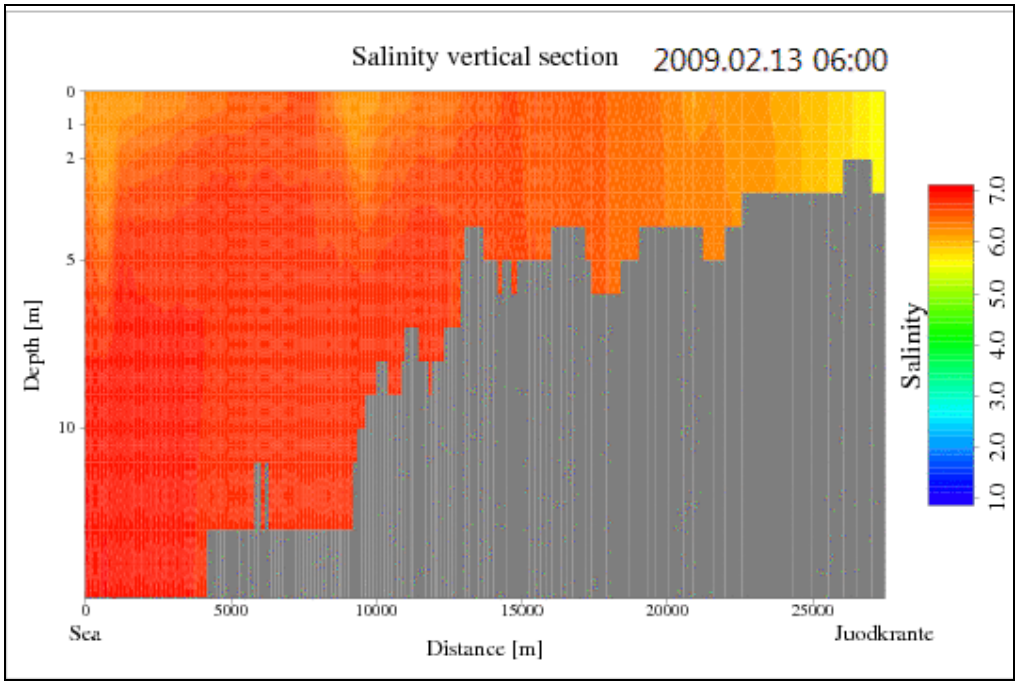


Fig. 4.5. Fourth type of salinity vertical distribution: deep intrusion of saline water into the Curonian lagoon, no stratification.

Impact of harbour deepening to the exchange of water between the sea and lagoon.

Here a demonstration is presented how model can be used for investigation of the impact to the water salinity of harbour reconstruction related in this case to the Klaipeda strait deepening and the

change of harbour gates configuration. Two scenarios were considered: 1) the depth and harbour gates configuration before the reconstructions works of 2005 (bathymetry of 2001); 2) the depth and harbour gates configuration after the reconstructions works of 2005 (fig. 4.6). The 3D hydrodynamic model was run for the both cases with meteorological forcing of the year 2009.

Salinity vertical averages were calculated for each node and raster maps for yearly salinity maximum, minimum, average and standard deviation were created for both scenarios. In order to the salinity changes would more visible corresponding raster map of the first scenario was subtracted from the second scenario. The results are presented in fig. 4.7 – 4.10. The general conclusion is that changes are small and do not exceed 1psu in majority of cases.

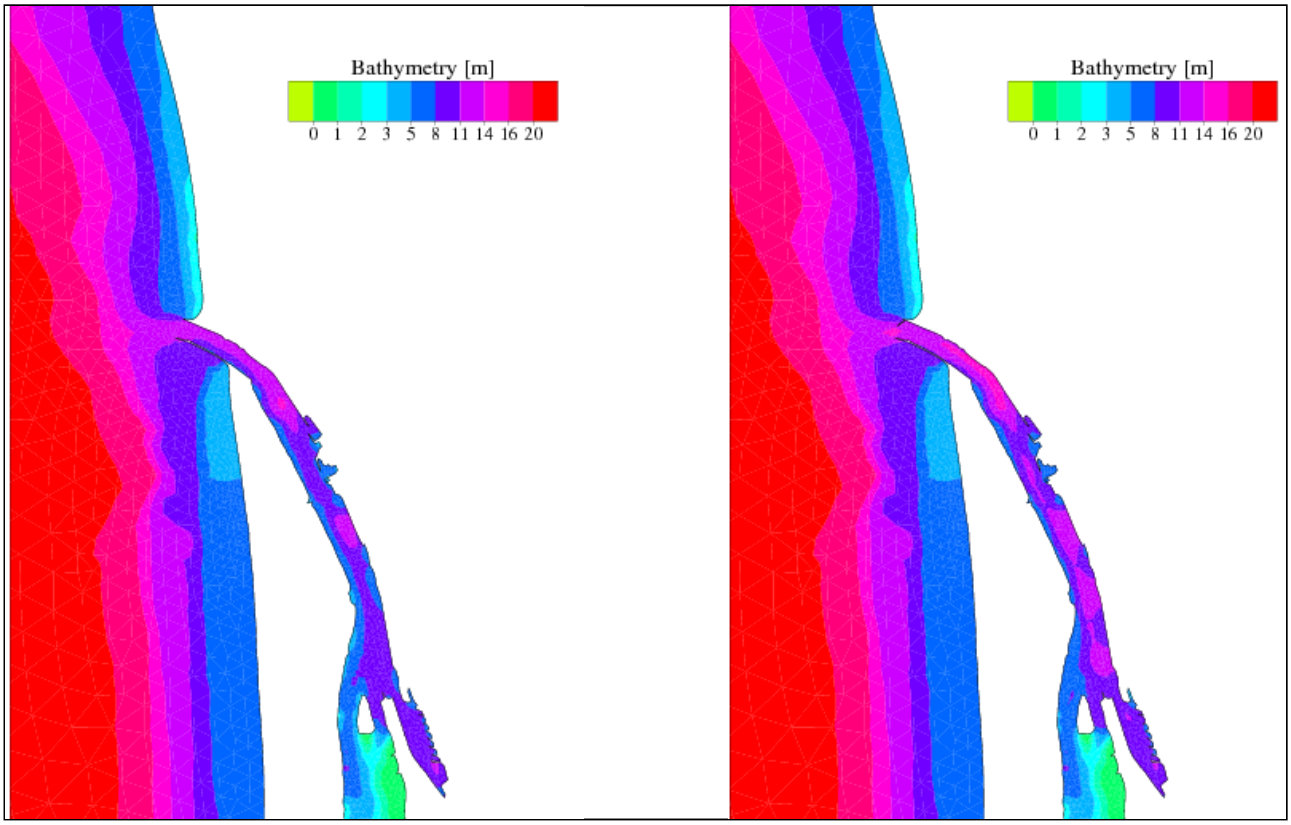


Fig. 4.6. Bathymetry and harbour gates configuration for scenario No 1 (on the left) and scenario No 2 (on the right).

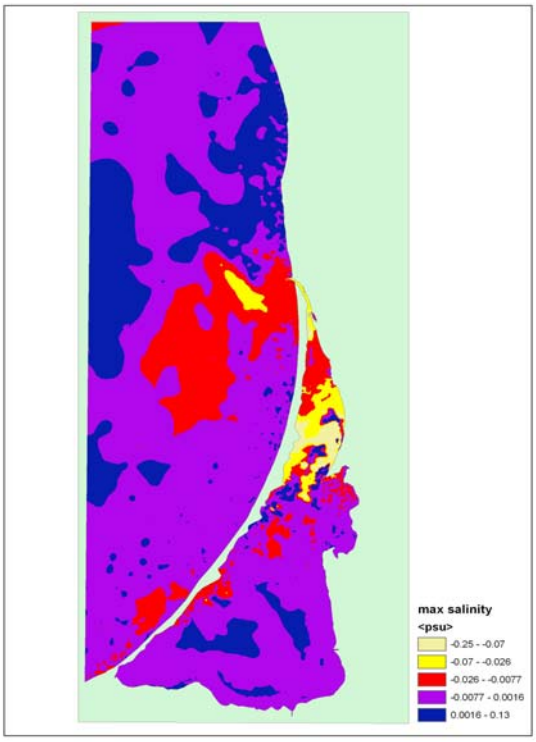


Fig. 4.7. The map of changes in yearly maximum salinity. Negative values means increase, positive the decrease of salinity maximum.

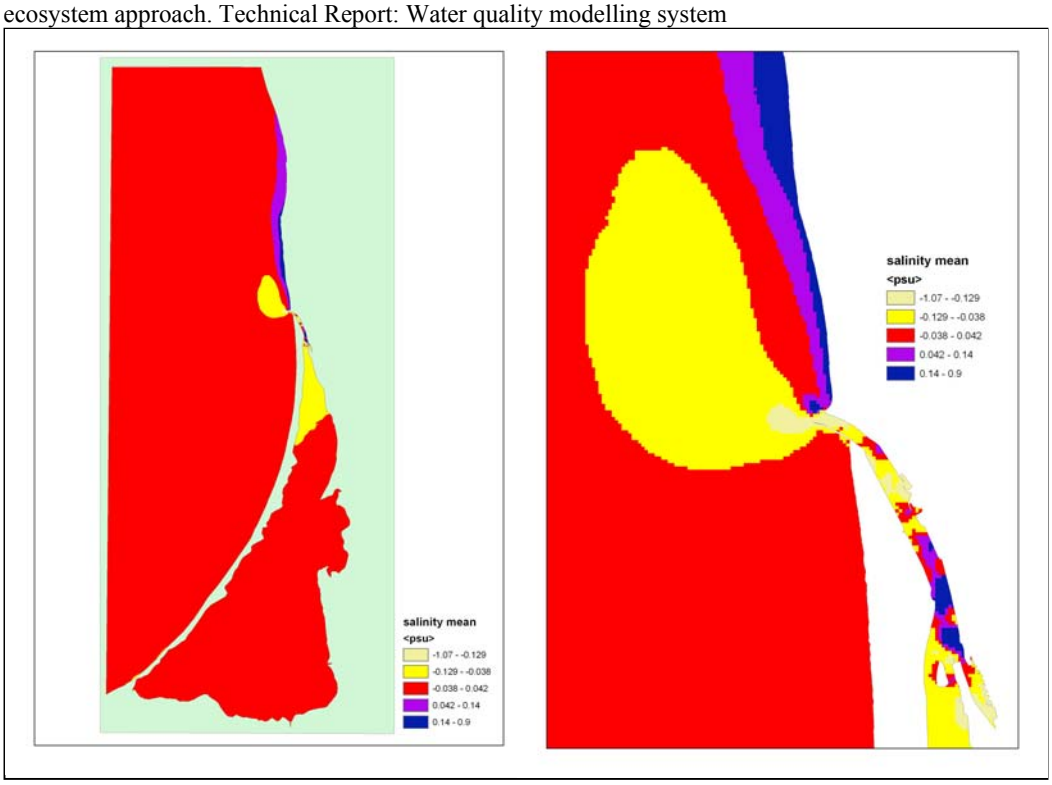


Fig. 4.8. The maps of changes in yearly average salinity. Negative values means increase, positive the decrease of salinity mean.

Fig. 4.9. The map changes in yearly minimum salinity. Negative values means increase, positive the decrease of salinity minimum.

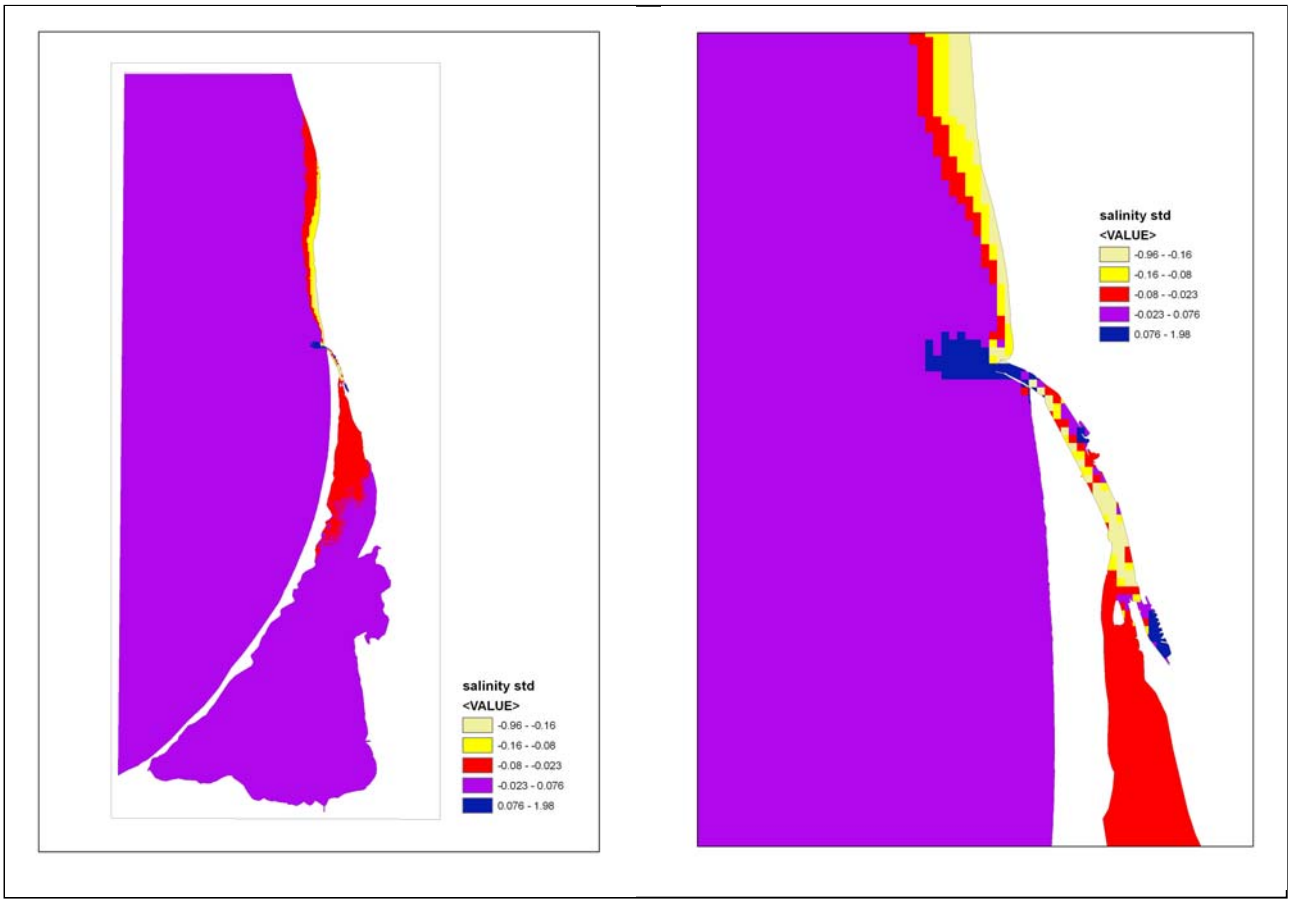


Fig. 4.10. The maps of changes in yearly salinity standard deviation. Negative values means increase, positive decrease of salinity standard deviation.

5. FUTURE DEVELOPMENTS

Creation of the water quality model is endless processes. In general model demonstrates satisfactory performance for all model variables and can be used for the decision support and research, but there are some points that could be improved in future developments. First of all resources of the project did not let to have high enough frequency of measurements for the Baltic Sea that would reflect full seasonal dynamics of variables and to draw more reliable conclusions about model capabilities to reproduce peaks and other peculiarities of the dynamics. More intensive field measurements in the Baltic Sea would help much for further model development.

Boundary conditions were derived from state monitoring stations data that were scarce and did not have some measurements like particulate and dissolved organic mater measurements. Better boundary conditions would improve performance of the model for all variables. One of the ways to solve this problem would be to obtain boundary conditions from coarser resolution water quality models that cover the whole Baltic Sea. International collaboration with the institutions in countries around the Baltic Sea that run such models would be very useful not only for the model development but also for the model applications.

Point source discharges information was not available during the project execution. Point sources discharges can influence nutrient and organic mater balance and their incorporation into the model can change the model performance. As one can see from fig. 3.5, 3.7 diatoms and cyanobacteria growth is underestimated in the late summer and autumn. The reason of this in the model is limitation by orthophosphates that are depleted (fig. 3.12). Putting orthophosphates into the system could improve reproduction by the model of the dynamics for these phytoplankton groups as well as for nutrients. Also introduction of adsorption desorption processes of phosphorus into the model could help to give better description of phosphorus cycle and could be treated as one of most important future revisions of the water quality model.

Hydrodynamic model SHYFEM does not model ice cover. The development of ice module would help better to describe water temperature, light and oxygen conditions during the winter period and would let forecast ice thickness and movement in the Curonian lagoon.

LITERATURE

Erturk A, Razinkovas A, Zemlys, P, Pilkaityte, R., Gasiunaite, Z. (2008) Linking NPZD and foodweb models of an estuarine lagoon ecosystem. Proceedings of the US/EU Baltic 2008 Symposium. IEEE Catalog Number:CFP08AME-CDR, ISBN: 978-1-4244-2268-5, Library of Congress: 2008902075

Jirka A.M., Carter M., May D., Fuller F., 1976, Ultramicro semi-automated method for the simultaneous determination of total Kjeldahl nitrogen in wastewaters, Environ. Sci. Technol., 10 (10), 1038–1044.

Kuznecov S. I., Dubinina G.A., 1980, Methods of investigation of aquatic microorganisms, Nauka, Moscow, 288 pp., (in Russian).

Merkienė R., Čeponytė V., 1994, Unified sewage and surface waters quality assessment methods, 1, Aplinkos apsaugos ministerija, Vilnius, 65 pp., (in Lithuanian).

Potapova L., 1980, Determination of carbon in organic matter of the bottom sediments, Nauka, Moscow, 394–396, (in Russian).