ICES SGPROD Report 2006

ICES Baltic Committee
ICES CM 2006/BCC:04

Report of the Study Group on Baltic Sea Productivity Issues in support of the BSRP (SGPROD)

6-7 April 2006

Tallinn, Estonia

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

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Recommended format for purposes of citation:

ICES. 2006. Report of the Study Group on Baltic Sea Productivity Issues in support of the BSRP (SGPROD), 6–7 April, 2006, Tallinn, Estonia. ICES CM 2006/BCC:04. 70 pp. https://doi.org/10.17895/ices.pub.9131

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Executive summary

Study Group on Baltic Sea Productivity Issues in support of the BSRP (SGPROD) met from 6–7 April 2006 in Tallinn, Estonia. The meeting was attended by 17 participants.

During the first phase of the BSRP a functioning network of lead laboratories and coordination centres was established. Technical and human capacity for productivity assessment was improved by the arrangements for a new SOOP line between Gdynia and Karlskrona, by training and intercalibration of phytobenthos monitoring specialists, improvement of coastal fish monitoring methods, and testing of productivity indicators based on zooplankton data and on trophic network modelling in coastal areas.

The BSRP also tested the feasibility of a combined fisheries–ecosystem survey, integrating a lower trophic level monitoring programme into the May 2006 hydroacoustic survey for sprat/herring in the Eastern Gotland Basin. Based on the survey results SGPROD suggests that fisheries monitoring should include zooplankton measurements as the key food source for fish larvae and adult planktivores. To further improve the knowledge on foodweb relations, stomach sampling should be included regularly into surveys. Fisheries surveys should also include routine collection of hydrographic information (CTD casts), including oxygen profiles.

Productivity indicator testing focused on the use of zooplankton data and on the results of trophic network modelling in coastal areas. Case studies, primarily in the Gulf of Riga, showed that zooplankton dynamics are only weakly linked to eutrophication, but are strongly connected to the dynamics of planktivorous fish stocks. Zooplankton is therefore a useful productivity indicator, but less suitable for eutrophication assessment.

Trophic network modelling produced a number of indicators that quantify carbon flows between ecosystem components, especially phytoplankton primary production, production of secondary producers at the base of pelagic and benthic foodwebs, and food consumption of higher trophic level components by source. Ecotrophic efficiency of the network components is a further suitable indicator for the degree of direct trophic control, while mixed trophic impact analysis is a tool for showing indirect relations between ecosystem components.

Responding to the activities of WKIAB, SGPROD should focus its activities on delivering productivity information on indicator time-series of hydrographic variables, nutrients, phytoplankton and zooplankton to be used by WKIAB.

SGPROD also outlined potential activities for the BSRP productivity module during the second phase of the project. Open sea work should continue the activities initiated during BSRP phase I (development of the SOOP network, analysis of monitoring network design, use of cost efficient technologies). BSRP phase II should also encourage the use of primary production measurements in Baltic Sea productivity assessment. In the coastal zone, interactions between BSRP lead laboratories and ongoing EU funded research projects should be strengthened and the use of productivity information for integrated coastal zone management should be demonstrated at a trial site.

1 Opening of the meeting

SGPROD met on 6–7 April 2006 at the Estonian Marine Institute in Tallinn, Estonia.

Georg Martin welcomed the participants of the meeting on behalf of the Estonian Marine Institute. The chair, Bärbel Müller-Karulis, apologized for shifting the meeting dates to avoid overlap with WKIAB and wished the participants a fruitful meeting.

2 Adoption of the agenda

The meeting served both to discuss the terms of references (Annex 5), as well as a planning meeting for future activities in the productivity module during the second phase of the Baltic Sea Regional Project (BSRP). To structure discussion, the agenda (Annex 2) was divided into open sea (day 1) and coastal issues (day 2), which was supported by the participants

3 Discussion of the Terms of Reference

3.1 Lead laboratory activities

ToR a) review the results of the work of the BSRP lead laboratories on Zooplankton and Phytobenthos, including monitoring and survey strategies developed within the BSRP;

3.1.1 LL Zooplankton

The Lead Laboratory on Zooplankton and Ichthyoplankton (LL Zooplankton) was established at the Sea Fisheries Institute in Gdynia (Poland) with the appointment of Piotr Margonski as head of laboratory in December 2005. The laboratory is supported by two part-time technical assistants. Main LL Zooplankton activities were:

- Establishment of a network of Eastern Baltic zooplankton scientists in cooperation with the ICES/HELCOM zooplankton expert networks
- Increase participation and contribution to the ICES and HELCOM activities (e.g. participation in ICES WGZE with compilations of zooplankton time series from Baltic subbasins)
- Propose zooplankton indicators for ecosystem based management of the Baltic Sea (see 3.4.1)
- Assessment of equipment needs in BSRP beneficiary country institutes and procurement of field and laboratory equipment (zooplankton nets, sample handling equipment, microscopes)
- Support for BSRP Ships of Opportunity activities (assistance in CPR procurement)
- Support for BSRP Open Sea Survey
- Organize zooplankton taxonomy trainings and intercalibrations of sampling and analytical methods

3.1.2 LL Phytobenthos

Monitoring of phytobenthos communities is activity required by number of international agreements and legal mechanisms. Among those are HELCOM COMBINE programme, EU Water Framework Directive, EU Habitats Directive. Despite this the regular phytobenthos monitoring activities are carried out only in a very few countries around the Baltic Sea. Especially countries from eastern coast of the Baltic have suffered difficulties in establishing phytobenthos monitoring programmes due to several reasons (lack of knowledge, expertise, funding). One of the aims of the BSRP was to establish phytobenthos monitoring activities in the BSRP recipient countries through assistance in relevant training and equipments supply.

According to BSRP Project Procurement and Implementation Plan (PIP) the activities of the lead laboratory on phytobenthos monitoring (LL PB MON) have been concentrated on following topics:

Development of Phytobenthos monitoring methods for the eastern part of the Baltic Sea area. This work has been mostly based on the existing “Guidelines for monitoring of phytobenthic plant and animal communities in the Baltic Sea, HELCOM, 1999” and national experiences gained so far. From BSRP recipient countries, operating phytobenthos monitoring programme has been established only in Estonia, but several phytobenthos monitoring or mapping studies are available from all participating countries. Due to differences in coastal environment characteristics and traditions the used methods differ in some extent between different laboratories. Unified methodology should provide opportunity to develop cooperation between laboratories and establish intercallibration schemes for assessment of QA procedures. The outcome of this activity is a proposal for amendment of HELCOM COMBINE manual with technical details concerning substrate classification and sampling procedures.

Development of new monitoring and mapping techniques as Under-Water Video techniques. This activity is carried out in the cooperation with Baltic Life project and concentrated on development of UW video sampling protocols and intercalibration of laboratory performance.

Development of relevant environmental indicators and reference conditions for eutrophication assessment. This work has been based on outcomes of different previous activities as EU CHARM project as well as national eutrophication assessment schemes. The relevant eutrophication assessment scheme has been developed for the Gulf of Riga coastal and open-sea areas. The results of the activity are two prepared scientific manuscripts.

Training and intercalibration of field sampling activities. Two field workshops have been organized to discuss and intercalibrate field sampling techniques. Besides that participation in relevant international activities has been supported (Participation in two German National Phytobenthos Monitoring training and intercalibration workshops in 2005).

Supply of equipment needed for phytobenthos monitoring activities. In the framework of the activities altogether seven laboratories from BSRP recipient countries will be supplied with relevant equipment ranging from basic diving equipment to aluminium boats and laboratory equipment.

Workshops organised by BSRP LL Phytobenthos Monitoring:

1) BSRP CC Prod/LL PB Mon WS on strategic design of phytobenthos, water quality and productivity monitoring in the coastal zone, September 2004, Tallinn, Estonia
2) LL PB Mon Phytobenthos monitoring training workshop, May 2005, Kõiguste field station, Saaremaa, Estonia
3) LL PB Mon WS on development of UW video techniques for habitat mapping and monitoring, 24-28 May 2006, Saaremaa, Estonia

Participating institutions:

Estonian Marine Institute EST
Institute of Aquatic Ecology LAT
Coastal Research and Planning Institute LIT
Marine Research Center LIT
Institute of Meteorology and Water Management POL

Maritime Institute in Gdansk POL
Komarov Botanical Institute RUS
Atlantic Research Institute ATLANTNIRO RUS

Main results of the activities of BSRP LL Phytobenthos monitoring

- Establishment of network of PB monitoring specialists in BSRP recipient countries
- Training on basic phytobenthos monitoring techniques
- Intercalibration of UW video monitoring techniques
- Development and testing of phytobenthos related environmental indicators
- Development of amendments for HELCOM COMBINE manual (sediment classification, video techniques)
- Equipment supply
- Two paper manuscripts

LL PB MON Future activities (recommendations for ToR for BSRP Phase II)

The need for regular intercalibration of PB monitoring techniques and laboratory procedures is obvious and was recommended also by ICES/OSPAR/HELCOM STGQAB (Steering Group on Quality Assurance of Biological Measurements). BSRP LL on Phytobenthos monitoring can be perfect body to coordinate these activities in the Baltic Sea region. During the BSRP Phase II the active intercalibration scheme should be developed for different aspects of Phytobenthos Monitoring.

Development of new monitoring methods and harmonising them with different reporting needs (HELCOM COMBINE, EU WFD, EU HD, EEA etc.) could be coordinated by LL PB MON. Rapid development of technology in underwater measurements can provide the monitoring schemes with very powerful and cost-effective tools (side scan sonars, RUV, remote sensing, aero-photography etc.). BSRP LL PB MON and associated network of PB monitoring experts is an excellent forum for testing and discussing the applicability of possible new methods and technologies in the Baltic Sea conditions.

Further development and application of PB eutrophication and productivity indicators. Set of indicators has been developed already in BSRP phase I but applicability of PB indicators for productivity monitoring should be developed further.

Methodological harmonisation of benthic mapping and monitoring schemes (WFD+HD) cooperation with other projects (Life, Balance, see Annex 7). Several international activities are going on in the Baltic Sea area dealing with mapping and modelling of coastal habitats. These activities are very closely linked to PB monitoring, especially on methodological level. Coordination and harmonisation of the methodological aspects of mapping and monitoring methods is need and BSRP LL PB Mon could be a good forum for the discussions in this field.

Development of benthic habitat classification is a crucial point in assessment and monitoring of Baltic Sea biodiversity and eutrophication effects. There is no common classification system existing for the Baltic Sea area at the moment and the development of EUNIS classification system for the Baltic Sea area has stopped. BSRP LL PB Mon in cooperation with wide range of relevant experts is relevant body to take the task for promoting further development of benthic habitat classification system.

3.1.3 Lead Laboratory on Ships of Opportunities

One of the main objectives of the BSRP Phase I was to establish a cost-effective, rapid way of reporting changing conditions in the Baltic Sea plankton communities, the food chain affecting fisheries yields, and the health of the Baltic Sea ecosystem. Usage of Ships-of-Opportunity (SOOP) for marine data collection is accepted worldwide as one of the most cost-effective methods, that combines low costs, high temporal resolution (SOOP observations are typically done from passenger or cargo vessels commuting on regular lines), and good geographical coverage. In the Baltic Sea, SOOP observations were initiated in the 1980s and they now include one longitudinal transect and few transects crossing the northern part of the sea (Figure 3.1.3-1). Experts agree that the most desired would be adding of a southern transect, crossing the Bornholm basin which is the northern most area for cod stock reproduction in the Baltic. BSRP committed itself to establish such a line and announced the call of expression of interest to find the operators for the southern SOOP line. After reviewing several Eastern Baltic laboratories interested to operate the new SOOP line, BSRP SOOP Lead Laboratory selected Polish Institute of Meteorology and Water Management (branch in Gdynia) as possessing necessary capacity and being able to demonstrate ability to sustain measurements in longer time.

Figure 3.1.3-1: SOOP transects in the Baltic Sea in 2006.

The ferry company "StenaLine" have been very supportive from the beginning of the negotiations to install the measuring equipment onboard one of their passenger ferries plying between Gdynia and Karlskrona. At the present water intake installations have been conducted and place for measuring equipment selected onboard "Stena Nordica" (Figure 3.1.3-2).

Figure 3.1.3-2: StenaLine's passenger ferry Stena Nordica.

New SOOP line in the Southern Baltic Sea will be operated in close cooperation with Swedish Meteorological and Hydrological Institute (SMHI). Beside the equipment installed inside the ferry for temperature, salinity and fluorescence measurements, and water sample collection, a CPR will be towed once per month to get additional zooplankton data.

SOOP workshop for new operators was organized in October 2004 with kind support of Finnish Institute of Marine Research (FIMR). All the presentations made during the workshop can be viewed and downloaded from webpage http://www.fimr.fi/en/itamerikanta/uutiset/604.html. During the workshop preliminary responsibilities, sampling strategies and data policies were discussed.

The long equipment procurement process is over for now and the companies are awarded: CPR is supplied by Chelsea Technology Group, UK and ferrybox system will be supplied by Elke Sensor, Estonia.

In the beginning of April SOOP technical meeting was held onboard "Stena Nordica" in Karlskrona, Sweden. During that meeting SOOP line operators, ferrybox and data transmission system suppliers and ferry company representatives met, ferrybox installation site was defined and all technical details important for the successful installation were discussed. Also the future perspectives about sensor additions to the system and use of undulating approach in the tow of CPR was discussed.

From the future perspectives it has also been discussed that the Southern Baltic Sea SOOP line will become a part of Alg@line consortium after the work is fully operational.

3.2 Lead Laboratory on Coastal Activities

Henn Ojaveer provided an overview of the lead laboratory activities to facilitate integration of work within the BSRP.

During the Phase I of the BSRP, the LL on Coastal Activities has been involved in the following activities:

1) Three HELCOM/BSRP coastal fish monitoring workshops (2004, 2005 and 2006) and starting to plan the fourth in 2007;

2) Initiation and creation of the coastal fish metadatabase for the following three categories: experimental surveys of warm-water fish, experimental surveys of cold-water fish and sampling from commercial catches. The database provides the following information (if applicable): country, ICES SD, sub-region/location/site, coordinates, depth range, period of years, fishing gear/method, sampling time, fish species analysed, purpose of the study,

parameters measured, stomach analysis performed, indices calculated and contact person;

3) Contribution to the HELCOM assessment of coastal fish in the Baltic Sea published in 2006;

4) Co-organising the Cold-water fish monitoring workshop in 2005;

5) Contributing to the ICES SGBFFI work (meetings in 2004, 2005 and 2006);

6) Contributing to the ICES SGEH work (meetings in 2003, 2004 and 2005)

7) Co-organising (together with the LL on Fish Age and Stomachs) two fish ageing workshops on pikeperch and flounder;

8) Involvement of the LL CA specialist network and knowledge to the EU FP6 projects and project applications: SAFMAMS, MARBEF, IMAGE).

The HELCOM/BSRP Third Coastal Fish Monitoring workshop decided that the following community and species level indicators should be tested using the national data available:

Community level indicators

- Total number of species and number of species by categories (marine and freshwater origin)
- Total biomass
- Species diversity based biomass (Shannon-Weaver index)
- Slope of size spectrum
- Average trophic level of catch based on biomass
- Number of alien species

Species level indicators

- Species abundance
- Species biomass
- Mortality
- Size and age structure of population (median size and age ±90 percentiles)
- Growth rate
- Slope of size spectrum

Several of these listed indicators should contribute to the productivity estimates of the upper trophic levels in the coastal areas. Some of the results are expected to be ready by end-2006.

Currently, the ongoing coastal fish monitoring activities are mainly concentrating on studying the coastal fish communities in the warmest season. Relatively less is known for the remaining time of the year, i.e., for the colder period. Therefore, reliable estimates for cold-water preferring fish (e.g., sculpins, lumpsucker *Cyclopterus lumpus*, seasnail *Liparis liparis*) which distribution is confined below the seasonal thermocline in summer but are present in coastal areas in colder time (spring and autumn) are practically absent. In addition, the currently suggested methodology doesn't allow to provide representative estimates on either the small-sized fish species (like gobies *Pomatoschistus* spp. and sticklebacks *Gasterosteus aculeatus* and *Pungitius pungitius*) or the smaller size-classes of commercially exploited species (e.g., various species of cyprinids and percids) in fish communities. Therefore, the LL on CA has started some activities in order to expand the scope of the coastal fish monitoring with an aim to reduce this gap of knowledge and obtain more comprehensive information on the Baltic fish communities especially in coastal areas.

3.3 Combined fishery – ecosystem survey

ToR b) analyse the technical functioning of the open-sea survey conducted during 2005, and develop a proposal for a combined ecosystem-fisheries survey

Monitoring of the lower trophic levels in the Baltic Sea ecosystem (hydrography, nutrients, and phytoplankton) and its upper trophic levels (fish, fisheries) is currently institutionally separated with little interaction between the relevant HELCOM and ICES working groups. Integrating lower trophic level sampling into a fisheries survey, or vice versa, adding fish monitoring to a HELCOM monitoring cruise, could potentially save shiptime and lead to a more integrated ecosystem data analysis. Therefore the BSRP tested the combined fishery – ecosystem survey during the Latvian/Polish May hydroacoustic survey for sprat and herring in the Eastern Gotland Basin (15–24 May).

Technical functioning

The survey was conducted with RV "Baltica" owned by the Sea Fisheries Institute and the Institute of Meteorology and Water Management in Gdynia. Baltica is a 620 BRT vessel, equipped with hydroacoustic station, biological, chemical, physics, and ichthyology laboratories, a side port with winch and CTD/rosette sampler, and seven on-deck stations for sampling and fishing. The vessel can host 11 scientists.

The survey followed the standard May hydroacoustic survey track (Figure 3.2.1). Stations for additional ecosystem sampling were integrated into the track and mostly sampling took place at trawl stations required for the hydroacoustic survey to minimize additional sampling time. Only the four HELCOM COMBINE monitoring stations in the survey area were sampled at their precise coordinates, off the hydroacoustic survey track. This was done at the end of the working day, when the ship was closest to the respective station.

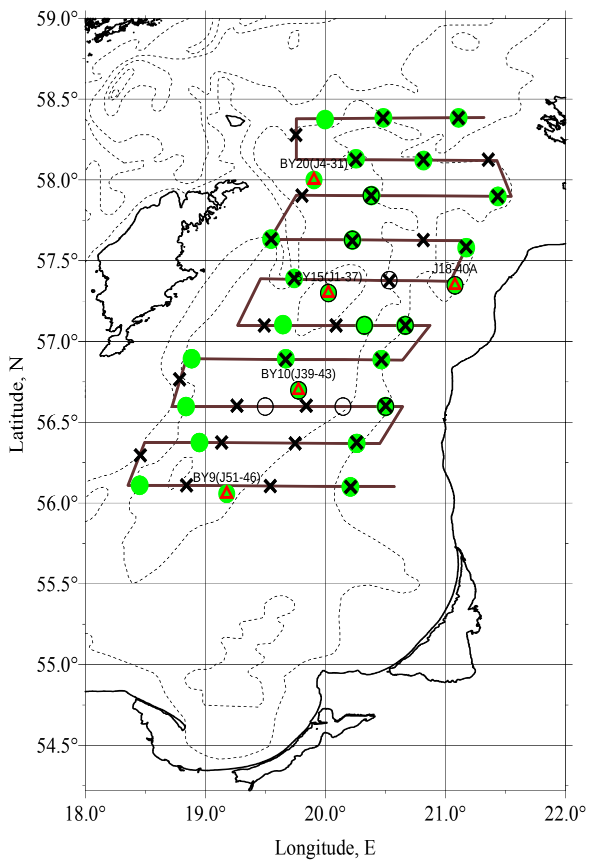

Figure 3.2.1: Combined fishery – ecosystem survey track, including trawl stations (crosses), nutrient/plankton stations (green circles), additional LFRA zooplankton stations (hollow black circles and HELCOM COMBINE monitoring stations (red triangles).

The following ecosystem parameters were added to the survey programme (Table 3.2.1):

Table 3.2.1: Ecosystem parameter added to combined survey.

PARAMETER	NUMBER OF STATIONS	COMMENTS
Hydrography (CTD profiles of salinity and temperature, water samples for O_2 and H_2S)	31	CTD profiles and oxygen samples were part of the fisheries survey programme and were taken from the same water samples as nutrient analysis with additional depth horizons
Nutrients (N_{tot}, NO_{23}, NH_4, P_{tot}, PO_4, SiO_4)	27	dense sampling at 1 – 60 m, deeper horizons at 4 HELCOM stations
Chlorophyll *a*	27	0–10 m, 10–20 m
Phytoplankton biomass and species composition	10	0–20 m
Mesozooplankton	31 (of which 6 stations were part of the fisheries monitoring programme)	0–50 m and 0–100 m (below halocline)
Ichthyoplankton	27	
Herring and sprat stomach sampling	aggregated into SD 26 and SD 28	

Additional sampling effort for ecosystem parameters was caused by the net hauls for zoo- and ichthyoplankton. The vessel was equipped with a CTD with rosette sampler (12 bottles), so that water sampling did not require additional station time. Phytoplankton samples were taken with a hose for integrated water sampling, a fast and simple sampling method. In total, ecosystem sampling required approximately 30–60 minutes additional station time at each trawl station.

While the additional station time for ecosystem sampling appeared to be low, manpower requirements for nutrient analysis proved to be the most serious limitation for a combined fishery – ecosystem survey. Nutrient analysis for marine water samples has to be done mostly immediately after sampling, requiring a chemical laboratory on board the ship and additional scientists responsible for the analysis. In this case, two scientists responsible for nutrient analysis and water sampling were added to the team, and due to the limitations of the research vessel, the fisheries survey team had to be reduced by one person.

The sampling effort was shared between the hydroacoustic survey team and the ecosystem survey personnel. The ecosystem survey personnel provided also the sampling and analysis for H_2S and O_2, while net samples were mostly taken by the fisheries survey team. Since the sampling program had to be slightly modified during the survey, it was very important that both teams cooperated and communicated well.

Synergies between fisheries and ecosystem sampling

CTD casts at each trawl station provided a very detailed image of the hydrographic situation, with implications not only for the spatial distribution of e.g. sprat, but also for the assessment of the water exchange and ventilation of the entire eastern Gotland Basin. Combination of salinity and oxygen data showed two distinct water masses, because a sill at 150 m depth separates the oxygen deficient southern part of the basin from the northern part, where oxygen deficiency was even more severe (Figure 3.2.2). Obviously the last major Baltic salt water inflow from 2003 has not reached the northern part of the basin yet. Interestingly, salinities are similar in both parts of the basin and the differing water masses are not visible in a south-north salinity transect through the basin (Figure 3.2.3).

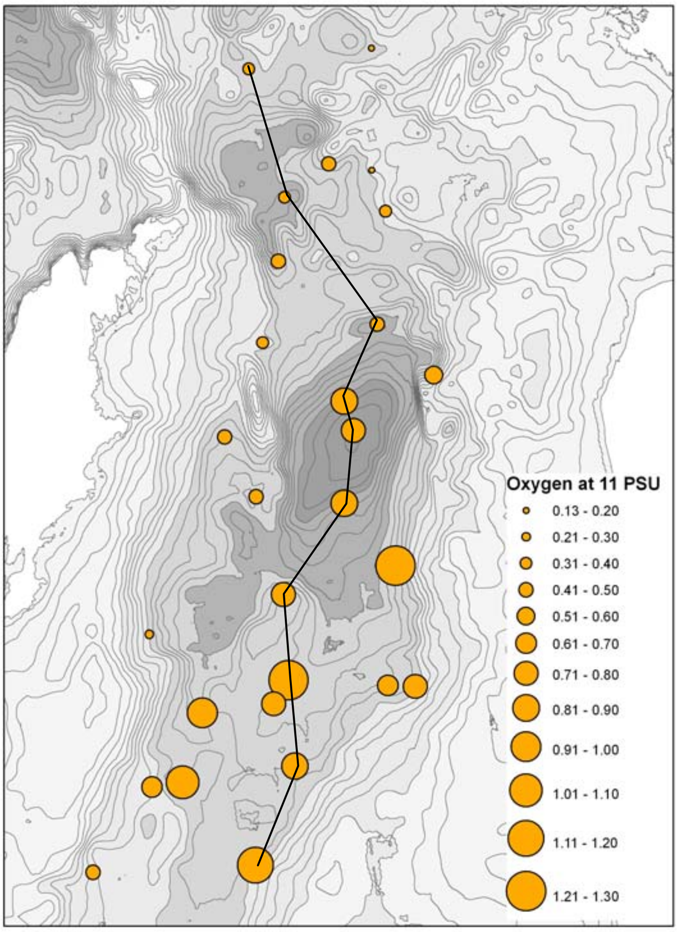

Figure 3.2.1: Dissolved oxygen content at 11 PSU isohaline in ml l^{-1}, with central transect marked in black.

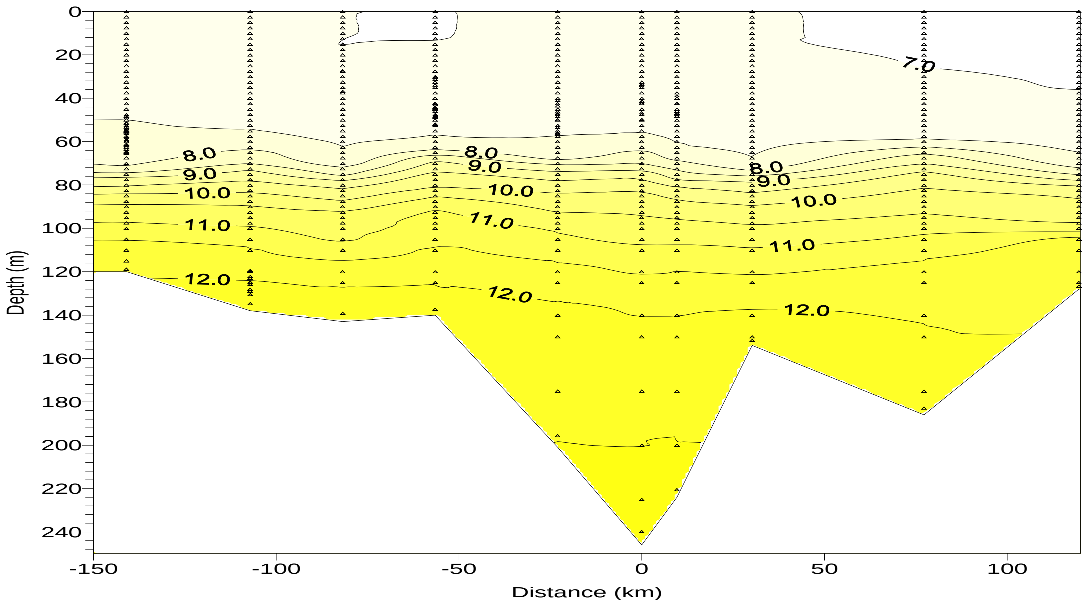

Figure 3.2.2: South – north salinity transect through the Gotland deep. The transect location correspondents to the transect line in Figure 3.2.1.

The nutrient and phytoplankton situation at the time of the cruise was typical for the end of the spring bloom, with DIN already depleted and a small DIP surplus above the thermocline. Chlorophyll *a* concentrations were low and the phytoplankton community was dominated by dinoflagellates. The timing of the survey did not allow direct observations of spring bloom intensity; instead, we estimated the magnitude of spring new production from the difference to winter DIP concentrations in the survey area. Assuming Redfield ratios, the new production during the spring bloom was 21 g C m^{-2} in the northern part and 28 g C m^{-2} in southern part of the basin.

The role of food-web relationships versus physical factors in determining the spatial distribution of fish (sprat) and zooplankton was tested using a general linear model with temperature, salinity, oxygen conditions, chlorophyll *a* concentrations, estimated new production, zooplankton biomass (sprat models) and sprat biomass (zooplankton models) as independent variables. Significant ($p<0.05$) relationships were found for the biomass of *Synchaeta spp.*, *Arcatia spp.*, and *Termora longicornis*, which depended on the temperature in the upper layer (0–50 m), while no significant models were found for the distribution of *Pseudocalanus acuspes*. Sprat density was weakly related to temperature and salinity at the depth of its main distribution (75 m).

Sprat and herring feeding during the survey was intense, with stomach fullness indexes of 28 and 39 ‰ for sprat and 23 and 31 ‰ for herring in SD 26 and 28, respectively, which is larger than the long-term median for the spring season published in Möllmann *et al*., 2004. In SD 26 both sprat and herring preyed preferentially on *Pseudocolanus acuspes* and supplemented their diet with *Acartia spp.* In SD 28, where the abundance of *Pseudocolanus acuspes* was slightly lower, *Mysis mixta* dominated the herring stomach content, while sprat fed on *Acartia spp.* (Figure 3.2.3). Unfortunately, the prey field of macrozooplankton was not sampled during the survey.

Lack of correlation between estimated new primary production or chlorophyll *a* concentrations with zooplankton biomass indicate low dependency of zooplankton on phytoplankton during the survey. Top-down control of zooplankton on phytoplankton is more likely during summer, when phytoplankton biomass is low, but zooplankton biomass is at its maximum.

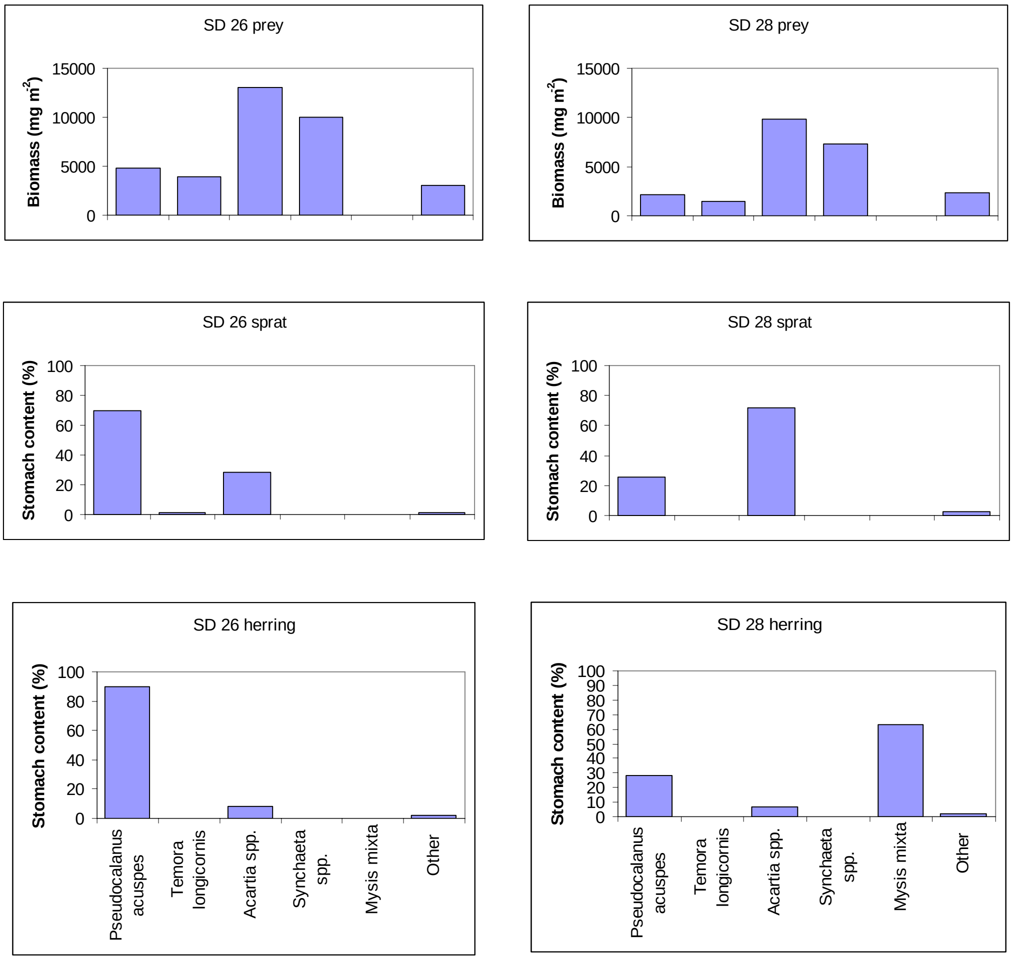

Figure 3.2.3: Mesozooplankton biomass and sprat and herring stomach content in SD 26 (left panel) and SD 28 (right panel).

Findings from this survey agree well with our knowledge about the seasonal state of the foodweb in the Baltic Proper. Especially in spring, zooplankton development is sensitive to water temperature, with exception of the salinity dependent *Pseudocalanus acuspes* (Möllmann *et al.*, 2003). Feeding of both herring and sprat reflects their preferences for *Pseudocalanus acuspes* and, in the case of herring, also *Mysis mixta* (Möllmann *et al.*, 2004). Stomach contents differed considerable from the composition of the zooplankton community, indicating that feeding activity was not limited by the availability of food during the survey.

Spatial sampling density

Fisheries surveys employ a denser station grid than the HELCOM COMBINE station network used in eutrophication monitoring. To test, how the spatial sampling density affects the precision of hydrographic, nutrient, and biological data, the spatial statistics of the sample fields were analyzed (for a detailed report, see Annex 6). Spatial correlation scales were of the order of 30–50 km. Random fluctuations, i.e. spatially uncorrelated noise, was low for hydrographic parameters (temperature) and nutrients (PO_4), larger for zooplankton and extremely large for chlorophyll *a*. Interestingly, chlorophyll *a* data from a satellite image taken during the mid May in the survey area showed high spatial correlation at low noise. We suggest two potential sources of additional error in the survey chlorophyll data: First, satellite derived chlorophyll *a* data represent average values over the satellite pixel size, compared to the point sample measurements. Averaging chlorophyll *a* values over a larger sample volume, e.g. via flow-through analysis along the survey track, should be tested to reduce the variability. Second, satellite data present a snapshot of the entire survey area, while the station data were collected in the course of 10 days. Temporal fluctuations therefore might have contributed to the high noise in the data.

The relative standard error in aerial parameter averages over the survey area was smallest for temperature (5 %), but large for chlorophyll *a* (19 %), PO_4 (27 %) and zooplankton biomass (40 – 82 %, depending on species). The zooplankton variability appears high, but in the PEX dataset, which was collected end of April 1986 from a number of vessels in the south of the survey area, spatial correlation was completely masked by the high noise in the data.

Reducing the number of stations increased the error of the spatial average, especially for parameters with low noise-to-signal ratio. Moreover, sampling along longitudinal or latitudinal transects through the basin produced high extrapolation errors, as large parts of the survey area were far away from the transect stations. Lower trophic level sampling would clearly benefit from a dense station network and care should be taken to estimate the standard error of chemical and biological data for e.g. trend analysis.

Survey timing

The timing of fisheries surveys (Table 3.2.1) does not cover all critical periods in the seasonal cycle of the Baltic Sea ecosystem. Zooplankton for example is most important as food source for the larvae of all fish species after spawning and for planktivorous fish during the most intensive feeding time (June – October). The spawning time of commercial fish species (Table 3.2.2) is best covered by the spring hydroacoustic survey (May), but the feeding time of planktivorous fish is not covered by fisheries surveys. To cover the summer period, sampling and analysis effort should be shared with HELCOM COMBINE summer cruises.

Table 3.2.1: Priority fisheries surveys in the Baltic Proper and Gulfs (herring surveys).

SURVEY	SURVEY TYPE	TARGET SPECIES	SEASON
BITS	Trawl survey	Cod and other demersal species	First and fourth quarters (usually March and November)
Herring acoustic survey	Acoustic with control trawls	Herring, sprat	Third and fourth quarters (usually May and October)
Sprat acoustic survey	Acoustic with control trawls	Sprat	Second quarter (usually October)

Table 3.2.2: Spawning time of commercial Baltic fish species.

SPECIES	SPAWNING TIME
Herring, Baltic Proper Herring, Gulfs	April – May May
Sprat	May – June
Eastern Baltic Cod	currently July – August, historically April – May
Western Baltic Cod	February
Flounder	April

Recommendations

- CTD casts, including oxygen profiles, provide a precise description of the hydrographic field at low cost They should be routinely included into fishery surveys as the hydrographic situation affects the spatial distribution of both zooplankton and fish as well as their long-term population trends.
- Chlorophyll *a* sensors should be integrated into CTD casts during the productive season, analysis of calibration data should be taken over by HELCOM COMBINE laboratories and data should be exchanged to increase the density of chlorophyll *a* observations in the Baltic Sea.
- Mesozooplankton data is needed both for fisheries management as well as for the assessment of eutrophication. Foodweb links between planktivorous fish and mesozooplankton appear stronger than the top-down control on phytoplankton. Fisheries management should therefore be the main driver of mesozooplankton monitoring in the Baltic Sea and data collection should be included into fisheries surveys covering fish spawning periods and periods of intensive feeding of planktivorous fish.
- Mysids can be the preferred food item of Baltic herring. Nectobenthos (mysid) monitoring should therefore be added to fisheries related surveys.
- Food consumption differs from the composition of the prey fields. Stomach analysis should be therefore included into ecosystem survey programs.
- Data exchange and harmonization of methods should be intensified between fisheries and HELCOM COMBINE monitoring.

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Möllmann, C., Kornilovs, G., Fetter, M., Köster, F.W. 2004. Feeding ecology of Central Baltic herring and sprat. Journal of Fish Biology 65: 1563–1581.

3.4 Productivity indicator testing

ToR c) test the performance of the developed system of indicators in characterizing the productivity state of different areas of the Baltic Sea based on existing long-term data, the results of the open-sea survey conducted during 2005 and the results of trophic network modelling;

SGPROD (ICES, 2005) defined the productivity as key species within a community that have a measurable impact on the next trophic level and/or respond to changes in the trophic level below. BSRP work in testing productivity indicators focused on zooplankton as a crucial link between phytoplankton to fish larvae and planktivorous fish, as well as on trophic network modelling in coastal areas.

References:

ICES. 2005. Report of the Study Group on Baltic Sea Productivity Issues in Support of the BSRP (SGPROD), 2–4 December 2004, Klaipeda, Lithuania. ICES CM 2005/H:02. 68 pp.

3.4.1 Zooplankton

The main activities for zooplankton indicator testing were carried out by the BSRP Lead Laboratory on Zooplankton and Ichthyoplankton, based on available long-term time series of monitoring data. A presentation by Michael Olesen (Annex 8) also pointed out the usefulness of in-situ measurements for investigating trophic coupling between zooplankton and phytoplankton.

Statistical analyses were carried out for the Gulf of Riga and the Gulf of Finland so far. The Vistula Lagoon case is still relatively undeveloped as Polish data were used only. Recently very promising dataset covering the open waters of the Baltic Main Proper became available. There are also plans to use Polish HELCOM Monitoring database for the open waters of the southern Baltic Sea (data needed for analyses are being completed). During the Zooplankton Indicator Workshop, just preceding SGPROD meeting, the idea to use data of the Kattegat and the Curonian Lagoon was discussed and agreed.

Where it was possible we were dividing independent factors into three groups: (1) hydrological, (2) those indicating changes in trophic status, and (3) a group of 'herring' factors (herring recruitment, abundance, and average weight).

Gulf of Riga example

Time series of data were coming from different sources. The Latvian Fish Resources Agency (LatFRA) database provided information on long-term time series of mesozooplankton and hydrography (period 1973 – 2004). The sampling of zooplankton was performed in May (spring) and August (summer) on 10–13 stations from two depth layers (0-20 m, 20 m-bottom) or from surface to the bottom. For each station the total abundance ($n*m^{-3}$) of each zooplankton taxa/stage was computed for the whole water column (0-bottom) and afterwards the average value was calculated for all the stations. Biomasses ($mg*m^{-3}$) were estimated from individual standard wet weights (Hernroth, 1985). Hydrographic data regarding observations of temperature, salinity, Secchi depth and chlorophyll a concentrations (time period 1973 – 2004) were provided by the Institute of Aquatic Ecology University of Latvia, LatFRA and Latvian Hydrometeorological Agency. Average values were calculated for the Gulf of Riga open water stations. Winter DIN and DIP (January – February, 1973 - 2004) were provided by the Institute of Aquatic Ecology University of Latvia.

Herring recruitment, abundance, and average weight data were obtained from an Extended Survivor Analysis (XSA) conducted by the International Council for the Exploration of the Sea (ICES) Baltic Fisheries Assessment Working Group for the period 1973 – 2004.

The long-term changes (1973–2004) in the biomass of main zooplankton taxonomic groups were analysed for two different seasons. In spring (Figure 3.3.1-1) an apparent shift in *Acartia* and *Eurytemora* biomass was observed since the late 1980s. *Limnocalanus* almost disappeared from May samples since mid 1980s. *Bosmina* biomass was significantly higher during the 1989–2000 period.

Significant decrease in salinity was observed (Figure 3.3.1-2). Summer Secchi depth in May and in August showed a significant decreasing tendency over the whole period. The opposite trend was observed in the case of chlorophyll *a* concentration in August. Both indicate the increasing eutrophication in the Gulf of Riga. A shift in herring recruitment and abundance has been recorded since the late 1980s, but the average herring weight was decreasing in the same time (Figure 3.3.1-3). There were no apparent trends in other factors in the whole available dataset.

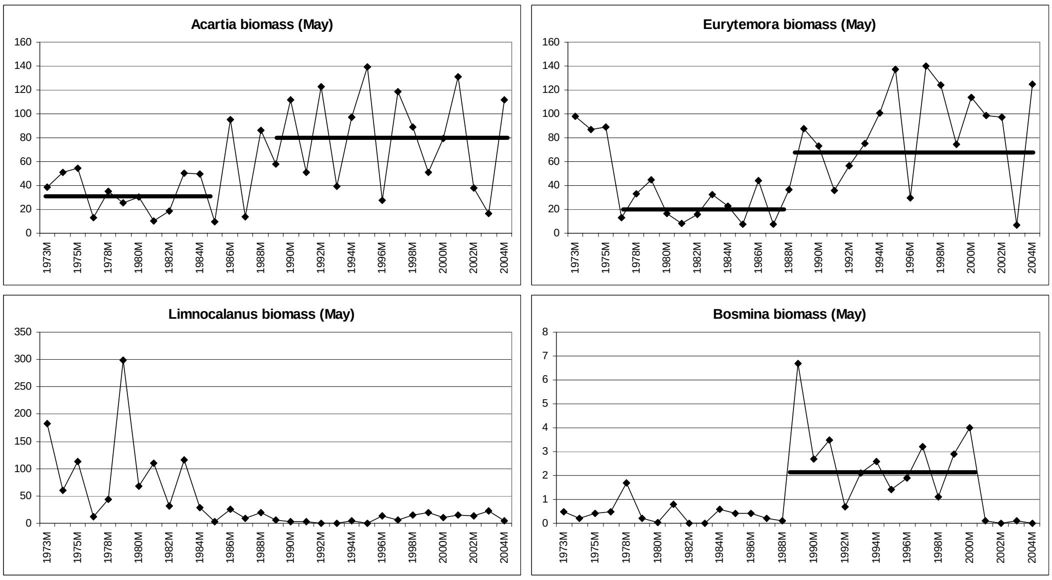

Figure 3.3.1-1: Long term-changes of biomass of selected zooplankton taxonomic groups (spring).

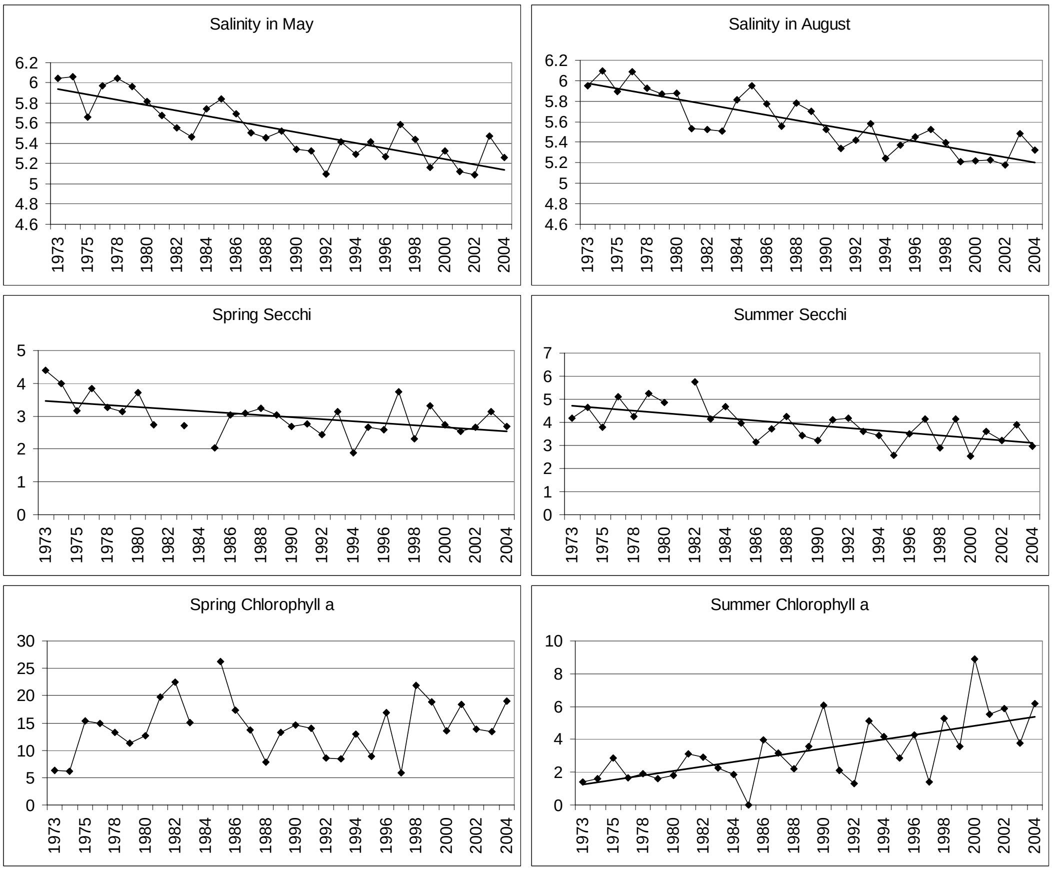

Figure 3.3.1-2: Long term-changes in selected 'environmental' factors.

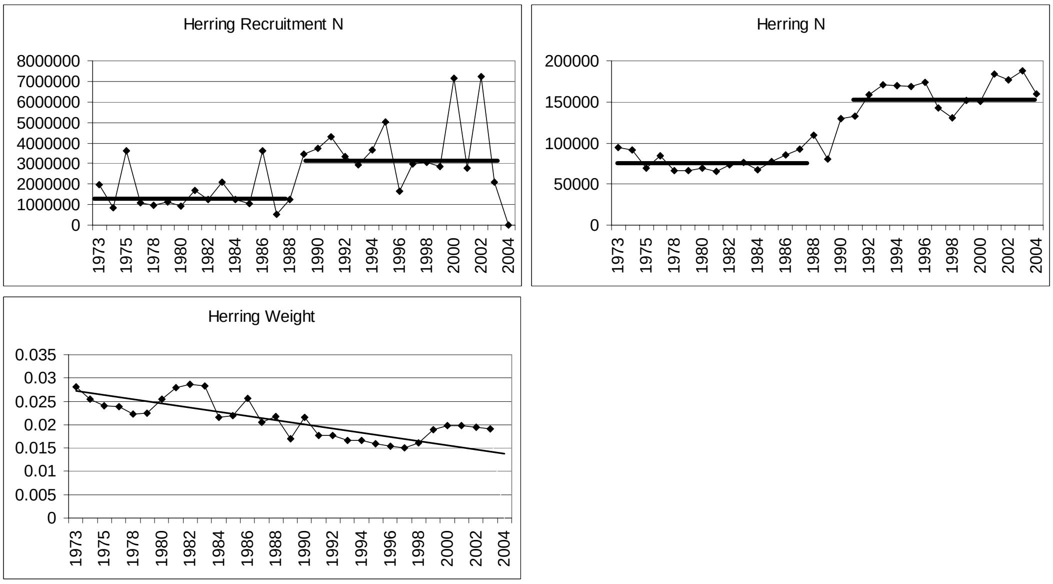

Figure 3.3.1-3: Long term change in 'herring factors'.

To identify the environmental variables best explaining the zooplankton community pattern the BIOENV analysis was selected (Spearman rank correlated method). Long-term changes in zooplankton community structure consisting of eight main groups were tested against all environmental factors: hydrological; those indicating changes in trophic status; and group of 'herring' factors (herring recruitment, abundance, and average weight). No significant correlation was found. Then only hydrological and trophic factors were selected. Again there was not significant correlation. Eventually, zooplankton community changes were tested against the 'herring factors' only:

In May: correlation 0.326 for all variables (herring recruitment, abundance, and average weight); significance level of sample statistics in RELATE test equalled 0.1%;

In August: correlation 0.354 for herring abundance, and

correlation 0.346 for all variables (herring recruitment, abundance, and average weight); significance level of sample statistics in RELATE test equalled 0.2%;

The Gulf of Riga zooplankton community changes are significantly correlated with changes in herring abundance, recruitment level and also with decrease of herring average weight.

To find if zooplankton biomass of particular groups is correlated with any of available independent factors multiple correlations were tested. Natural LOG transformation was used for zooplankton, herring, and Summer_Chlorophyll data. Analyses were divided into two groups: 1) abiotic including temperature, salinity, Secchi depth, DIN, DIP, and Chlorophyll a concentrations; and 2) 'herring' factors.

In all the cases, correlations with independent factors belonging to the first group, even sometimes statistically significant, were relatively weak ($0.05>p>0.01$). For 'herring' factors all identified relationships were much stronger ($0.01>p>0.001$ or even $p<0.001$).

In May, *Acartia* and *Eurytemora* were strongly and positively correlated with herring recruitment; and *Limnocalanus* (positively) and *Bosmina* (negatively) with average herring weight only. In August, negative correlation of *Bosmina* and herring abundance; and positive between *Synchaeta* and average herring weight were found. In the case of *Synchaeta*, more information is needed as this rotifer species definitely is not a positively selected food item for herring.

Concluding remark

The general conclusion, based on still incomplete picture, is that zooplankton indicators are not among the best to describe eutrophication as correlations with independent factors belonging to this group, even sometimes statistically significant, were relatively weak, but they are promising in terms of ecosystem productivity issue as analyses presented much stronger correlations with 'herring' factors.

References:

Hernroth, L. (ed.) 1985. Recommendations on methods for marine biological studies in the Baltic Sea. Mesozooplankton biomass assessment. Baltic Marine Biologists Publications, No 10.

3.4.2 Trophic network modelling

Trophic network models were constructed for 5 eastern Baltic coastal ecosystems, ranging from the hypertrophic Curonian Lagoon to protected coastal bays (Puck Bay, Pärnu Bay) to exposed coastal areas (Open Baltic coast, exposed Gulf of Riga), using a mass-balance approach implemented in the ECOPATH software (Christensen *et al.*, 2004, Christensen and Pauly, 1992). Model results were presented in detail in Tomczak *et al.*, 2005.

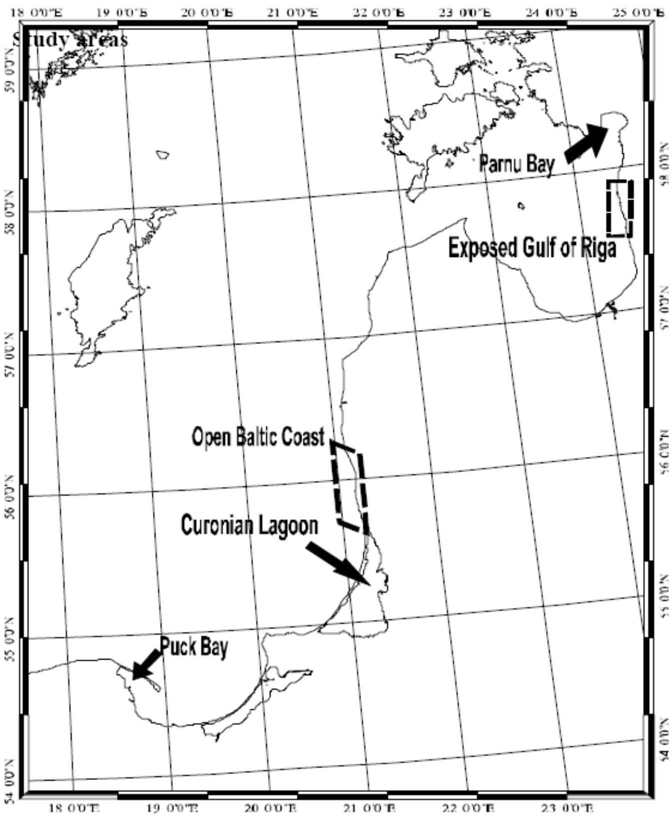

Figure 3.3.2-1: Trophic network models for Baltic Sea coastal areas.

The simple trophic networks facilitated analyzing carbon flows in pelagic and benthic foodwebs of the studied systems. Calculated carbon flows between ecosystem components provided direct indicators for sources and fate of carbon in the investigated ecosystems. Because phytobenthos production was mainly lost to detritus, phytoplankton primary production provided the basis of secondary production in the coastal foodwebs (Figure 3.3.2-

2). Further, mesozooplankton production describes the base of the pelagic foodweb, while secondary production of benthic deposit- and filter feeders limit the magnitude of the benthic foodweb (Figure 3.3.2-3 A, B). For higher trophic levels, the carbon flows making up their food source provide an indicator of the importance of each food item for secondary production. In turn, the ecotrophic efficiency – the fraction of carbon production channelled to higher trophic levels in the foodweb - of each primary or secondary producer describes the intensity of trophic coupling in the ecosystem.

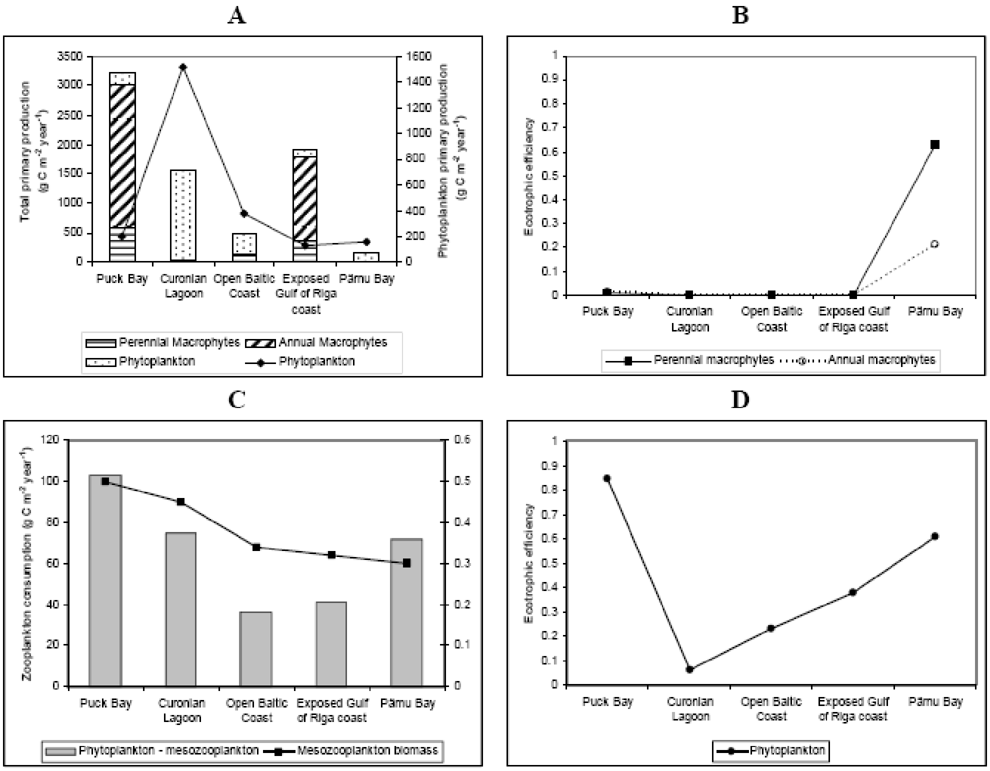

Figure 3.3.2-2: Estimated primary production (A) and fate of primary producers shown by the ecotrophic efficiency of macrophytes (B), mesozooplankton predation of phytoplankton (C) and ecotrophic efficiency of phytoplankton (D).

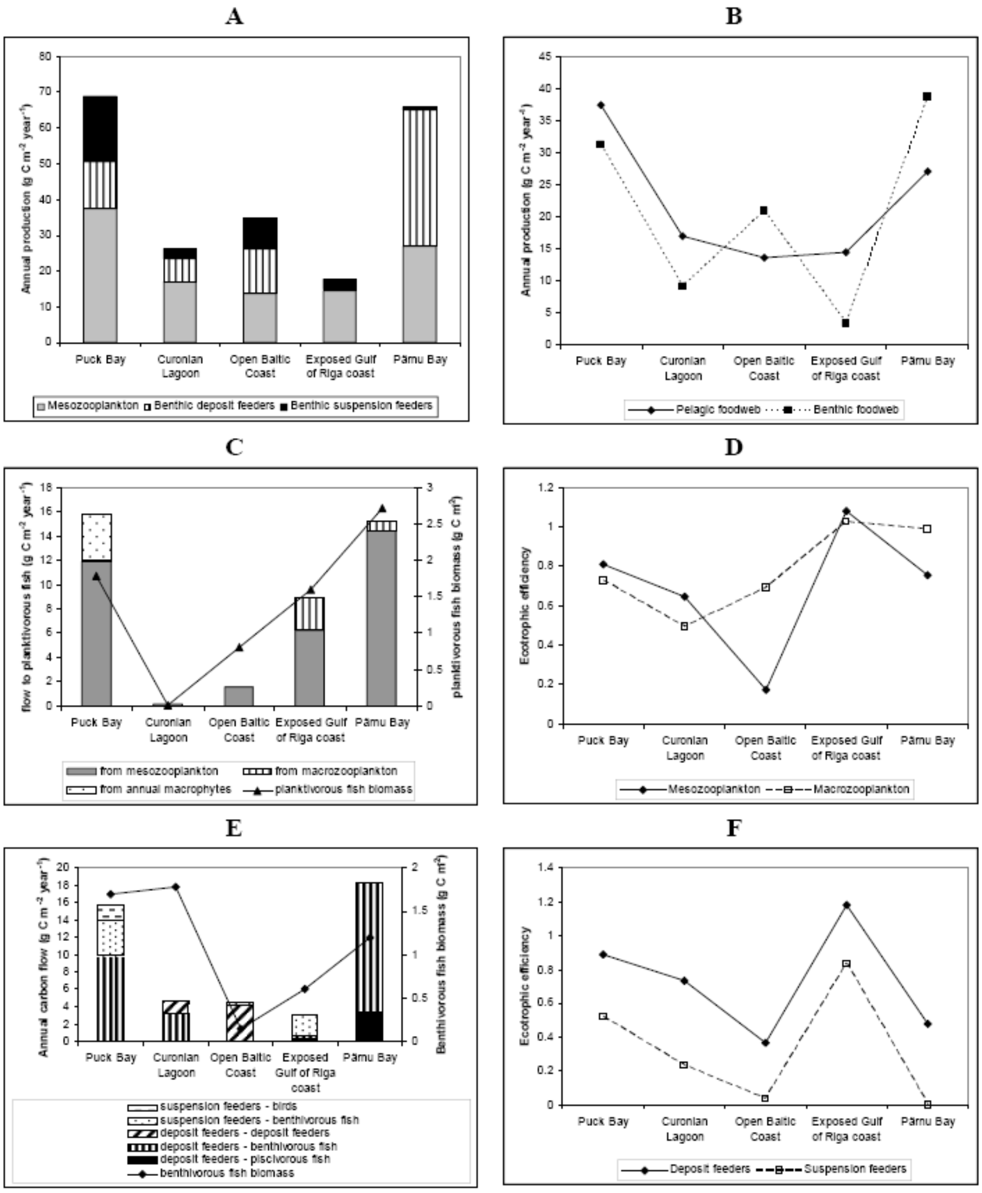

Figure 3.3.2-3: Annual production of primary consumers (A) and carbon flow channelled into benthic and pelagic foodwebs (B). Middle panels show food consumption of the main pelagic secondary consumer, planktivorous fish (C) and ecotrophic efficiency of its major prey items (D), while bottom panels show carbon flows in the benthic foodweb (E) and ecotrophic efficiency of benthic groups (F).

Mixed trophic impact analysis (Christensen *et al*., 2004) further helped to reveal interrelations in the investigated foodwebs. Mixed trophic impact analysis estimates, how other ecosystem components are affected by slight disturbances in other components and captures also indirect relationships. For example in the mixed trophic impact analysis of the exposed Gulf of Riga model (Figure 3.3.2-4) marine birds were highly affected by fishing intensity. This was not due to bycatch of birds, but rather because fishing targeted piscivorous fish, thereby increasing the competition from benthivorous fish for benthic filter feeders, the main waterfowl prey in this area.

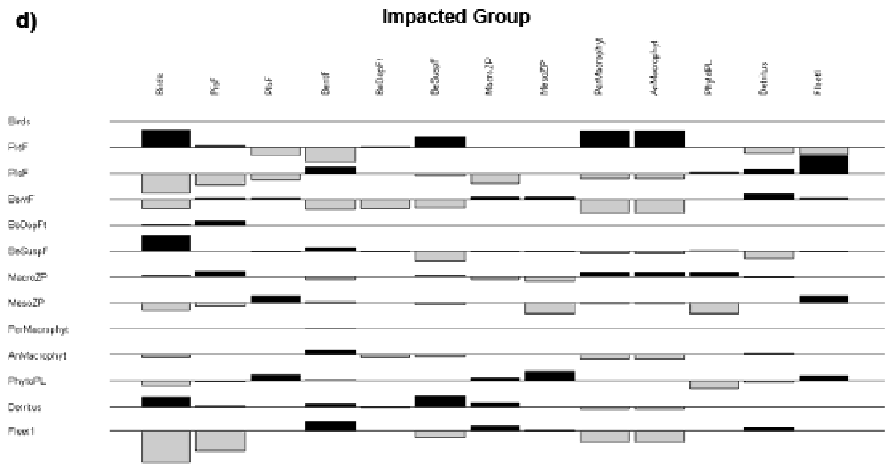

Figure 3.3.2-4: Mixed trophic impact analysis of the exposed Gulf of Riga coastal foodweb.

Since the foodweb structure underlying to ecosystem models was similar, higher aggregated indicators based on linearization of foodwebs provided no immediate advantage over the direct comparison of carbon flow patterns. Aggregated indicators, like total system throughput, sum of all consumption, etc. would be more important when models with highly different structure are compared.

The comparative analysis of the coastal foodwebs showed, that productivity indicators can be based on trophic network modelling. Most useful indicators were phytoplankton primary production, mesozooplankton production, production of benthic deposit and filter feeder, food consumption by source for secondary and higher trophic level producers, ecotrophic efficiency of model components, as well as the sensitivity patterns derived from mixed trophic impact analysis (Table 3.3.2-1).

Table 3.3.2-1: Productivity indicators based on trophic network modelling.

Indicator	**Comment**
Phytoplankton primary production	basis for secondary production
Mesozooplankton production	basis of pelagic foodweb
Production of benthic deposit- and filter feeders	basis of benthic foodweb
Food consumption by source of secondary and higher trophic level producers	importance of food items for secondary production
Ecotrophic efficiency of each producer	intensity of trophic coupling, degree of top-down control by the higher trophic level
Sensitivity patterns from mixed trophic impact analysis	indicates critical links in foodwebs and indirect effects between ecosystem components

References

Christensen, V., Walters, C.J., and Pauly, D. 2004. ECOPATH with ECOSIM: A user's guide. Fisheries Centre, University of British Columbia, Vancouver, Canada, 151 p.

Christensen, 1995. Ecosystem maturity – towards quantification. Ecol. Model. 77, pp. 3-32.

Tomczak, M.T., Järv, L., Kotta, J., Martin G., Minde A., Müller-Karulis, B., Põllumäe A., Razinkovas A., and Strake, S. 2005. Trophic networks and carbon flows in South Eastern Baltic costal ecosystems. ICES CM 2005/M:01.

3.5 Productivity information delivery

ToR d) characterise the productivity state of selected parts of the Baltic Sea ecosystem in 2005 based on the results of the open-sea surveys using identified suitable productivity indicators as a support for the work of fisheries-related groups (e.g. WGBFAS, SGBFFI, SGMAB);

ToR g) review and take necessary action on the outcome of the Workshop on Developing a Framework for Integrated Assessment for the Baltic Sea (WKIAB);

WKIAB suggested a framework for restructuring the Baltic Sea related ICES working and study groups. In the proposed framework SGPROD focus on lower trophic level dynamics related to the physical and chemical environment, and linking these to fish population dynamics. SGPROD should interact with and deliver information to the proposed Working Group on Integrated Assessment of the Baltic Sea (WGIAB). WGIAB will produce annually updated ecosystem status reports, which at the same time will provide information to the fisheries related working groups.

For the first trial integrated assessment of the Baltic conducted by WKIAB, information on nutrient state and hydrography was assembled by SGPROD members from various data sources (Baltic Environment Database at Stockholm University, ICES datacenter, national monitoring data), but the collection of long-term phytoplankton indicators (chlorophyll a, phytoplankton biomass/species composition for spring and summer seasons) proved to be difficult. Raw data is only partially available through the ICES datacenter. Especially with respect to phytoplankton biomass data, raw data need to be aggregated by species groups and seasons, which should be done by experts to ensure quality control of the aggregated time series. SGPROD has started to discuss opportunities for a closer cooperation with the HELCOM project "Quality Assurance of Phytoplankton Monitoring in the Baltic Sea in 2005-2007" to improve accessibility of phytoplankton information and the improvement of indicator time series for Baltic Sea sub-basins.

Zooplankton information for the WKIAB trial assessment was readily available, as the trial areas were covered by the zooplankton monitoring of the Latvian Fish Resource Agency (LatFRA). To expand the area covered by integrated assessment data sources for zooplankton information have to be identified. Relevant time series should be updated in cooperation with the HELCOM/ICES zooplankton expert network and the BSRP zooplankton lead laboratory.

Macrozoobenthos is the basis of benthic foodwebs in the Baltic Sea. So far macrozoobenthos has not been discussed as a productivity indicator by SGPROD due to lack of expertise within the group. However, macrozoobenthos is a regularly monitored under HELCOM COMBINE and recently long-term data has been aggregated into an HELCOM indicator report on the state of macrozoobenthos communities in the Baltic Proper, Gulf of Finland, and Bothnian Sea and Bothnian Bay (http://www.helcom.fi/environment2/ifs/ifs2005/benthos_folder/en_GB/benthos/). Cooperation with the relevant HELCOM groups and projects should be intensified to include zoobenthos information in describing Baltic Sea productivity.

3.6 BSRP Phase II planning

ToR e) develop a strategy for ecosystem monitoring in BSRP Phase II, based on analysis of available technologies, sampling design, and cost-benefit considerations;

3.6.1 Open sea activities

Cost-efficient monitoring methods

Experience from the BSRP joint open sea survey showed, that nutrient sampling and analysis is time-consuming with respect to both shiptime and laboratory and therefore is relatively costly and difficult to integrate into survey programmes. Currently, technology to integrate nutrient autoanalyzers based on the flow injection principle into undulating oceanographic samplers is becoming available. SGPROD discussed the possibilities of using an undulating oceanographic sampler within the project and suggested to organize a manufacturer trial to demonstrate the usability of the autoanalyzer under Baltic Sea conditions. Mark Berman reported on the use of the Mariner Shuttle within the US National Marine Fisheries Service an agreed to help organize a Baltic trial.

The value of the Mariner Shuttle, an undulating oceanographic sampler, for assessing the productivity of an LME is being demonstrated in the United States by the National Marine Fisheries Service's Narragansett Bay Monitoring Program. The prototype Mariner Shuttle in use in that program is equipped with CTD-Fluorometer, dissolved oxygen sensor, PAR sensor, Fast Repetition Rate Fluorometer (to measure primary production rates), Continuous Plankton Recorder, Optical Plankton Counter, and a nutrient sensor measuring concentrations of nitrate/nitrite, ammonium, silicate, and phosphate. The WG discussed the value of such a device as part of the Baltic LME Productivity Module. A Mariner Shuttle, modified for the Baltic, could play a key role in measuring productivity indices. Specific Mariner Shuttle sensors, e.g. the FRRF and the nutrient analyzer, could also be added to the ferry-box sensor suite, for routine assessments. Mark Berman agreed to look into the possibility of a demonstration of the key technologies in the Baltic, perhaps as soon as the summer of 2006.

SOOP

The already defined main objectives of the 2nd Phase of the BSRP are to enhance the Large Marine Ecosystem approach in the whole Baltic Sea area through better understanding of linkages of inputs and effects between land, coastal and open sea areas and to provide better thematic and integrated assessments of the ecosystem status that will guide future management of human activities affecting the Baltic Sea. SOOP measurements are very valuable tools to fulfil these objectives as these measurements reach from coast to coast and hence provide valuable information about the status and dynamics of both coastal and open sea environments. The collected data can be used in thematic indicator report compilations, in developing different indexes to describe the status and fluctuations of the Baltic Sea environment. Additionally SOOP data can be operationally displayed in several web pages and made available to the large oceanographic community to be used in several conceptual and integrated environmental models for assessment and prediction purposes.

For the future perspectives during the second phase of the project it could also be considered the addition of one more SOOP line from Riga to Stockholm to cover also the Gulf of Riga and to cross the northern part of the open Baltic Proper (Figure 3.6.1-1).

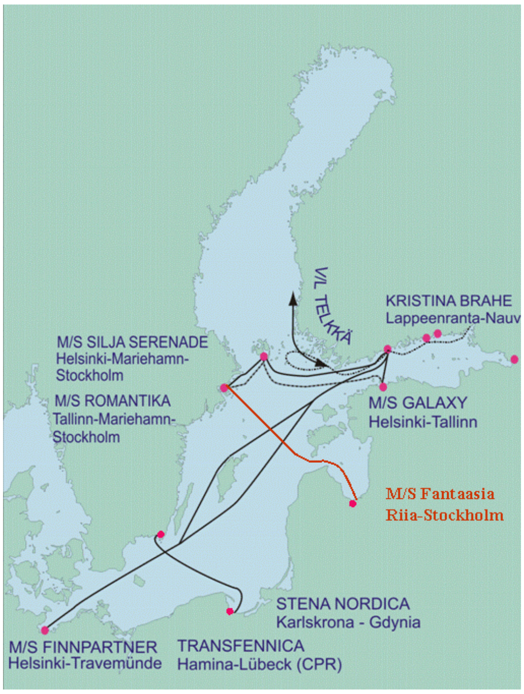

Figure 3.6.1-1: Existing and potential SOOP lines in the future in the Baltic Sea.

Statistical analysis of monitoring networks

Trial statistical analysis of the joint open sea station network demonstrated the dependency of precision in aerial averaged parameter values on the density of the station network. The trial analysis was, to our knowledge, the first statistical analysis of monitoring networks for biological parameters in the Baltic Sea. The BSRP should continue its support for monitoring network design, especially in cooperation with the HELCOM EUTRO-PRO and MON-PRO projects, to maximize the cost-efficiency of mapping surveys proposed by MON-PRO for the reformed HELCOM monitoring programme. Mapping surveys are suggested to cover key ecosystem processes (winter nutrient concentrations, late summer oxygen minimum, spring and summer phytoplankton communities) together with annual (summer) surveys of phytobenthos and macrozoobenthos.

The trial statistical analysis also showed that data collected on close spatial intervals is a prerequisite for estimating noise-to-signal ratio and spatial correlation. High spatial density is best achieved by the current Baltic Sea SOOP monitoring activities. SGPROD therefore suggested cooperation with Alg@line for further statistical analysis of monitoring data.

Satellite monitoring

The BSRP has supported networking and training for the use of remote sensing in productivity monitoring during its first phase, especially by co-operating in the JRC/IOCCG Ocean colour course (http://ecomar.jrc.cec.eu.int/index.php?module=announce&ANN_user_op=view&ANN_id=4). Despite the difficulties in deriving chlorophyll a information from remote sensing in case 2 waters like the Baltic Sea, support for the use of remote sensing for productivity monitoring should be continued, especially to improve algorithms to estimate atmospheric corrections and link remote sensing data to pigment concentrations.

Primary production

As pointed out during the SGRPOD meeting, primary production has been removed from most Baltic Sea routine monitoring programmes, despite of its significance for describing ecosystem productivity. To encourage use of primary production information in Baltic Sea assessment, SGPROD suggested the BSRP to support a selected Eastern Baltic laboratory with training and equipment support to serve as a trial laboratory for primary production monitoring.

3.6.2 Coastal activities

Both LL Phytobenthos monitoring and LL Coastal activities have proposed activities to improve the quality of indicators and to strengthen expert network in their respective fields (see 3.1.2., 3.1.4.). The BSRP Productivity Coordination Center should improve the networking between lead laboratories and ongoing coastal zone research projects (Annex 7). Because data collection in coastal areas will be mostly driven by coastal fish monitoring and the habitat mapping efforts in the BALANCE project, whereas management plans are established within the LIFE project, a case study area involved in all programmes should be identified to test, how productivity information can be used in integrated coastal zone management. Potential tools could be trophic network modelling targeted on species or habitats to be protected in the study sites. For coastal fish monitoring specifically, it would be very important to start systematic fish stomach analysis in order to track energy flow in upper trophic links in coastal areas. Perhaps, it would be important to consider starting these investigations for the most abundant fish species in a given area.

4 2007 Activity planning

ToR f) plan a meeting in 2007, as a joint or overlapping meeting with at least one other Baltic EG (e.g., WGGIB, SGEH), in order to promote the development of integrated ecosystem knowledge and the integration of work across expert groups;

As planned right now, SGPROD should provide input on productivity indicators for WKIAB, which plans to meet 10–14 March 2007. This implies that SGPROD should meet no later than early February 2007, which limits the opportunities for back to back meetings with other Baltic groups. Therefore we propose a separate meeting for SGPROD in 2007 and the possibilities for joint meetings in 2008 should be discussed during the Baltic Committee meeting at the 2006 ASC.

2006 will be a transition period between BSRP Phases I and II, with a reduced budget for field work and data analysis. This implies that some activities proposed during the SGPROD meeting can only be prepared during 2006 and will have to be started in 2007.

SGPROD activities to prepare its 2007 meeting should focus on:

- Refine Baltic Sea productivity indicators;
- Update lower trophic level (hydrography, nutrient, phyto- and zooplankton) indicator time series for WKIAB and fisheries assessment groups;
- Identify a trial area from current coastal zone research projects to test the integration of productivity information into integrated coastal zone management;
- Identify a suitable institute in the BSRP beneficiary countries to serve as a centre for primary productivity monitoring;
- Prepare a trial demonstration of an undulating nutrient sensor in the Baltic Sea;
- Identify priority parameters for analysing the statistical design of the Baltic lower trophic level monitoring network.

Annex 1: List of participants

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Annex 2: SGPROD 2006 Meeting Agenda

Thursday, April 6

9:00	Welcome, technical announcements, adoption of agenda (B. Müller-Karulis, G. Martin)
	BSRP Productivity module open sea activities – Plenary
9:15	Open sea zooplankton indicators (P. Margonski)
9:40	BSRP joint productivity – fisheries open sea survey (B. Müller-Karulis)
10:05	Cost efficient monitoring – statistical analysis for survey design (A. Toompuu)
10:30	Ships of Opportunity (I. Lips)
10:50	**Coffee break**
11:20	Cost efficient monitoring – satellites, SOOP, primary production measurements (S. Kaitala)
11:45	Summer primary production in the Baltic Proper: role of respiration (M. Olesen)
12:10	Open sea assessment framework – WKIAB, HELCOM activities, fisheries (B. Müller-Karulis, M. Plikshs)
12:35	BSRP project overview (A. Andrushaitis)
13:00	**Lunch**
14:00 – 17:00	**Discussion**
	joint productivity survey success, strategies for information exchange productivity/fishery indicator performance indicators needed to characterize current year productivity integrated assessment for open sea areas plans for BSRP phase II

Friday, April 7

	BSRP Productivity module coastal activities – Plenary
9:00	Phytobenthos lead laboratory activities and indicators (G. Martin)
9:25	Coastal zooplankton indicators (P. Margonski)
9:50	ECOPATH modelling experience summary (B. Müller-Karulis)
10:15	Coastal activities lead laboratory activities, productivity and coastal fish indicators (H. Ojaveer)
10:40	Ongoing coastal area projects - LIFE, Balance (J. Kotta, G. Martin)
11:05	**Coffee break**
11:30	Coastal assessment framework (B. Müller-Karulis)
11:45	**Discussion**
	indicator performance, indicators for coastal assessment inclusion of coastal areas into integrated assessment plans for BSRP phase II
13:00	**Lunch**
14:00 – 15:30	**Discussion continued**
15:30	**Closing plenary**

Annex 3: SGPROD Draft Resolutions 2006

The **Study Group on Baltic Sea Productivity** [SGPROD] (Chair: B. Müller-Karulis) will meet in Gdynia, Poland from 23–26 January 2007 to:

a) Refine Baltic Sea productivity indicators, especially with respect to zooplankton, review available phytoplankton productivity indicators and their data sources and initiate analysis of macrozoobenthos as a potential productivity indicator;

b) Update lower trophic level (hydrography, nutrient, phyto- and zooplankton) indicator time series for the use of WKIAB and fisheries assessment groups;

c) Initiate a BSRP case study to integrate productivity information into integrated coastal zone management;

d) Prepare a training and technical capacity building programme to establish a suitable institute in the BSRP beneficiary countries as a local centre for primary productivity monitoring;

e) Prepare a BSRP trial demonstration of an undulating nutrient sensor in the Baltic Sea;

f) Identify priority parameters for analysing the statistical design of the Baltic lower trophic level monitoring network in cooperation with HELCOM MON-PRO.

SGPROD will report by DATE to the attention of the XXXXX Committee.

Supporting Information

PRIORITY:	SGPROD was founded as Study Group on Baltic Sea Productivity Issues in Support of the BSRP. Within the new Baltic related study and working group structure proposed by WKIAB it should continue its work, strengthening productivity indicator development and supplying lower trophic level information for both fishery management and integrated assessment purposes. Work of the group should therefore be given high priority.
	a) – 1.12, 2.2 b) – 1.12, 2.2 c) – 3.3, 4.14 d) – 1.2, 1.10 e) 1.10 f) 1.10 a) Data on lower trophic level components in the Baltic Sea are collected within fisheries monitoring (zooplankton, nectobenthos) and environmental monitoring programs (phytoplankton, macrozoobenthos). For use in integrated assessment and ecosystem based management, indicators must be developed that characterize the productivity of these components. SGPROD has so far successfully summarized the theoretical background for a system of lower trophic level indicators, as well as suggested and tested zooplankton indicators. Future work should refine the developed zooplankton indicators and initiate work on using phytoplankton and macrozoobenthos as productivity indicators. b) Trial integrated assessments for the Central Baltic and Gulf of Riga at WKIAB showed, that raw data time series have to be integrated into basin and process specific indicators by scientific experts. SGPROD will prepare and describe the hydrographic, nutrient, phytoplankton and zooplankton indicator time series required by the Baltic integrated assessment processes and make the relevant indicator time series available to fisheries related groups, as an important step to organize the information flow for Baltic Sea integrated assessments.

SCIENTIFIC JUSTIFICATION AND RELATION TO ACTION PLAN:	c) Monitoring and assessment of the state of coastal waters in the Baltic Sea is currently driven by the requirements of the EU Water Framework Directive, and to a lesser degree by the EU Habitats Directive and the HELCOM network of Baltic Marine Protected Areas, as well as coastal fish monitoring. The BSRP/SGPROD has previously studied ecosystem functioning for five case study areas by foodweb modeling. In order to strengthen the functional aspects of coastal habitats the BSRP and SGPROD will cooperate to develop strategies to incorporate productivity information into integrated coastal zone management in a case study area. d) Though describing the basis of pelagic foodwebs, primary productivity measurements have been removed from most Baltic Sea monitoring programs, especially in the Eastern Baltic countries. The BSRP aims, with advice from SGPROD and through cooperation with its US partner organization, to provide training opportunities in primary productivity measurement methods and at the same time to improve the data coverage for the Eastern Baltic Sea. e) The use of modern technology – undulating sensors that provide fast 3D profiling of marine survey areas – is currently hampered by the lack of suitable nutrient sensors. Recently, flow injection analyzers have become available for use on towed bodies. To test this technology for the Baltic Sea, a trial will be arranged within the BSRP project. f) Efficient monitoring strategies have to select a minimum number of stations to achieve desired confidence and power for the target parameters. Statistical analysis of a Baltic Sea monitoring network has – with respect to the spatial properties of biological parameters – for the first time been done within the planning and data analysis for the BSRP joint open sea survey. Results were discussed during the 2006 SGPROD meeting. It became clear, that successful statistical analysis of the spatial properties has to rely on densely sampled data sources, e.g. SOOP data. Further work to improve the statistical design of the Baltic lower trophic level monitoring network has to be cooperated with the HELCOM MON-PRO project, which currently reorganizes the HELCOM monitoring strategy. SGPROD should identify priority parameters, for which the statistical properties of the monitoring network should be improved, to initiate further analysis within the second phase of the BSRP.
RESOURCE REQUIREMENTS:	None
PARTICIPANTS:	The group was attended by 17 participants from 7 countries in 2006.
SECRETARIAT FACILITIES:	None
FINANCIAL:	BSRP covers participation costs of two members/eastern Baltic country.
LINKAGES TO ADVISORY COMMITTEES:	ACE, ACME. In the consideration of indicator issues, the Group will closely follow the guidelines prepared by ACE.
LINKAGES TO OTHER COMMITTEES OR GROUPS:	There are close working relationships to the other groups established in support of the BSRP (SGBFF/follow-up group, SGEH), to Baltic Integrated Assessment activities (WKIAB and follow-up goup), to the HELCOM/ICES zooplankton expert network as well as to ongoing HELCOM assessment activities (HELCOM EUTRO-PRO).Contacts are also established to the HELCOM phytoplankton expert network.
LINKAGES TO OTHER ORGANIZATIONS:	HELCOM
SECRETARIAT MARGINAL COST SHARE:	BSRP 100%

Annex 4: Recommendations

RECOMMENDATION	ACTION
1. integrate SGPROD as Study Group on Baltic Sea Productivity into the Baltic Committee study and working group structure suggested by WKIAB	ICES Baltic Committee
2. improve biological data submission to the ICES datacentre and data aggregating capacities in the data centre	develop internet access to data centre, develop data viewing capabilities and automated data querriing
3. discuss approaches to include lower trophic level data into fisheries assessment, refine data needs	SGMAB, or under reformed Baltic Committee structure, Working Group on Fish Ecology

Annex 5: 2005 Terms of References

2005/2/BCC04 The **Study Group on Baltic Sea Productivity Issues in Support of the BSRP** [SGPROD] (Chair: Bärbel Müller-Karulis, Latvia) will meet in Tallinn, Estonia, from 4–6 March 2006 to:

a) review the results of the work of the BSRP lead laboratories on Zooplankton and Phytobenthos, including monitoring and survey strategies developed within the BSRP;

b) analyse the technical functioning of the open-sea survey conducted during 2005, and develop a proposal for a combined ecosystem-fisheries survey;

c) test the performance of the developed system of indicators in characterizing the productivity state of different areas of the Baltic Sea based on existing long-term data, the results of the open-sea survey conducted during 2005 and the results of trophic network modelling;

d) characterise the productivity state of selected parts of the Baltic Sea ecosystem in 2005 based on the results of the open-sea surveys using identified suitable productivity indicators as a support for the work of fisheries-related groups (e.g. WGBFAS, SGBFFI, SGMAB);

e) develop a strategy for ecosystem monitoring in BSRP Phase II, based on analysis of available technologies, sampling design, and cost-benefit considerations;

f) plan a meeting in 2007, as a joint or overlapping meeting with at least one other Baltic EG (e.g., WGGIB, SGEH), in order to promote the development of integrated ecosystem knowledge and the integration of work across expert groups;

g) review and take necessary action on the outcome of the Workshop on Developing a Framework for Integrated Assessment for the Baltic Sea (WKIAB).

SGPROD will report by 10 April 2006 for the attention of the Baltic Committee.

Supporting Information

Priority:	ICES manages Component 1 of the BSRP, Baltic Sea Large Marine Ecosystem Activities and SGPROD provides scientific advice to the productivity module of BSRP Component 1. The current activities of the Group address important parts of the BSRP project implementation plan (productivity indicator development, open sea and coastal surveys) and will serve to review the results of BSRP phase I. Supporting the BSRP, the work of the group also contributes to implementing the ecosystem approach to the management of marine resources and should therefore have a high priority.
Scientific Justification and relation to Action Plan:	a) – 1.10, 2.2 b) – 1.7, 4.11.1 c) – 2.2 d) – 4.11.1, 4.11.2, 4.11.4, 2.2 e) 1.7, 1.10 f) 1.7 a) Work of the BSRP lead laboratories on Zooplankton and Phytobenthos aims to provide better tools for assessing biological properties, including productivity, of the zooplankton and phytobenthos components of marine ecosystems. SGPROD will review the monitoring and survey strategies applied within BSRP Phase I, to strengthen the scientific basis for zooplankton and phytobenthos monitoring in the Baltic Sea. Both lead laboratories will also contribute substantially to the development of productivity indicators. The performance of the developed indicators will be reviewed under ToR c. b) The BSRP open sea survey is based on integrating productivity monitoring with an ICES fisheries survey, providing both productivity (nutrients, phytoplankton, zooplankton) and fisheries data collected within a coherent framework. Technically, integration of both surveys could lead to cost reductions for productivity monitoring. More important, cooperation between the scientists involved encourages holistic ecosystem assessment, addressing interactions between lower and upper trophic levels which are so far widely analyzed separately in the Baltic Sea. SGPROD will review the results of the pilot open sea survey and will develop a proposal for future combined

	ecosystem-fisheries surveys. c) SGPROD has summarized the theoretical background for a system of indicators addressing lower trophic level productivity in the Baltic Sea, developed criteria for productivity indicator performance, and proposed a set of potential indicators. Within the work of the BSRP Productivity Coordination Center and its associated lead laboratories the developed indicator system will now be tested against field data and the performance of individual indicators will be evaluated. d) SGPROD will evaluate the productivity of the lower trophic levels (nutrients -> zooplankton) in selected parts of the Baltic Sea, that were covered by previous work in the framework of ECOPATH models or that were included into coastal and open sea surveys. The information will be made available to fisheries working groups to encourage the use of environmental information in fisheries assessments. e) A sampling strategy for productivity monitoring in BSRP Phase II will be drafted, considering the statistical properties of observed variable fields in sampling network design, as well as cost-benefit considerations, especially with respect to the implementation of modern monitoring technologies (e.g. towed undulators, satellite information). Close cooperation with Baltic Sea monitoring bodies (HELCOM, BOOS) will establish the basis for efficient strategies to improve productivity monitoring in the Baltic Sea. f) Productivity assessment is currently not explicitly addressed in existing Baltic Sea monitoring programmes, though parameters characterizing the lower part of the food web are an integral part of e.g. HELCOM monitoring programmes. During BSRP Phase II productivity assessment has to be anchored within the existing environmental and fisheries assessment programmes and its added value has to be demonstrated. Scientific input from SGPROD to the workplan of BSRP Phase II will be essential to reach this goal. g) WKIAB is going to produce a framework and work plan for an integrated assessment for the Baltic Sea and will revise the TORs of all relevant EGs accordingly. As a result, the TORs for SGPROD are expected to be changed in close cooperation with SGPROD as soon as WKIAB has developed the work plan.
Resource Requirements:	None
Participants:	The Group was attended by 26 participants in 2005. It is planned to increase cooperation with other groups concerned with the lower trophic levels, e.g., WGZE, WGPE.
Secretariat Facilities:	None
Financial:	BSRP covers participation costs of two members/eastern Baltic country.
Linkages To Advisory Committees:	ACE, ACME. In the consideration of indicator issues, the Group will closely follow the guidelines prepared by ACE.
Linkages To other Committees or Groups:	There are close working relationships to the other groups established in support of the BSRP (SGBFF, SGEH, SGBEM). Contacts have been also established to WGPE.
Linkages to other Organisations:	HELCOM
Secretariat Marginal Cost Share:	BSRP 100%

Annex 6: Statistical analysis of joint survey data

Statistical spatial analysis of data collected in the East Gotland Basin in May 2005

Technical Report

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1. Objective

The objective of the work was to perform statistical spatial analysis of data on variables measured within a 10 day survey cruise in the East Gotland Basin in May 2005. The analysis was aimed to estimate the second-order statistics (variances and correlation functions) of the fields under consideration and, based on the estimated statistics, to reconstruct (interpolate) the field realizations. The field realizations are coupled with the estimated spatial distribution of standard deviations of the respective reconstructions. The analysis performed allows to draw conclusions on the effectiveness of the applied sampling strategy during the survey cruise as well as to estimate the uncertainty of variables averaged over the sampling area.

2. Data

The variables and data values together with sampling coordinates and station names are presented in Appendix, Tables A1 to A4. There are 31 data values (Table A1) on each of the 9 zooplankton biomass variables (8 species and total biomass), 27 data values (Table A2) on PO_4 concentration measured at 7 depths (1, 5, 10, 15, 20, 40 and 60 m), 27 data values (Table A3) on temperature at 7 depths (1, 5, 10, 15, 20, 40 and 60 m) and 27 data values (Table A4) on chlorophyll-a for 3 depth intervals 0-10m, 10-20m, 0-20m. In total 26 variable fields were analyzed. In addition to the in situ measured data from the survey in May 2005, a satellite image data set on chlorophyll-a from the coinciding Baltic Sea area from 20 May 1999 was utilized for the chlorophyll surface concentration correlation estimate. The survey and reconstruction area with coordinates 18°20' to 22°00' E times 55°50' to 58°40' N transformed into the Cartesian coordinates 20 to 230 km to the east times 210 to 520 km to the north with an arbitrary coordinate origin is shown in Figure 1a together with the location of sampling stations. Another available set of zooplankton biomass data from 83 locations in the south-west corner of the survey area (Figure 1b) measured beyond the framework of the conducted survey and treated as a support data set.

3. Method and model

The method applied to the data analysis and interpolation is the optimum analysis of a random field based on the second-order field statistics. The essence of the approach is concisely presented in Appendix 2 (Gandin, 1965; Bretherton *et al*., 1976; Toompuu and Wulff, 1996). The statistical model applied presumed the variable fields statistically isotropic and second-order homogeneous. Each measured set of data on a variable at a specific depth (or depth interval) was considered as a sample out of a 10-day (the duration of measurements) realization of the respective random variable field.

4. Correlation estimates

Application of the optimum analysis method presumes estimation of the field second-order statistics (spatial correlation function). The Pearson estimator of correlation

$$\mu = \frac{\sum_{i.j} z_i z_j}{\sqrt{\sum_i z_i^2 \sum_j z_j^2}},$$

where the distances between the measured data with values z_i and z_j belong to the same specified distance lag bin, was used for correlation estimates for 5 distance lag bins, 0 – 20, 20 -40, 40 -60, 60 – 80 and 80 - 100 km (Figures 2, 7 – 9). From the satellite chlorophyll data the correlation was estimated for 15 distance lag bins in the interval 0 – 150 km (Figure 10). The indicated in Figures 2–10 limits of 95% confidence are calculated from the Fisher transform $\rho = 0.5\log((1+\mu)/(1-\mu))$. The transformed correlation ρ is normally distributed with variance 1/(n - 3). The estimated correlations are approximated by the Gaussian function (Figure 2, 7–10)

$$\mu(x) = \alpha \exp\left(-\frac{x^2}{\beta^2}\right),$$

where x is the distance lag, α and β are the coefficients determining the noise-to-signal ratio (Appendix 2) of the data and the field correlation scale respectively. The number of data pairs available for the correlation estimates was 3-4 for the first 0-20m bin of the in situ measured data and varied between 49–62 for the rest four distance lag bins. For the correlation estimated from less than 4 data pairs (the bin 0-20 km in Figure 7–9) the confidence limits are not available.

Zooplankton biomass concentration

The correlation function parameters for zooplankton species biomass were estimated to be $\alpha =$ 0.8 and $\beta = 50$ km for all 9 zooplankton variables (Figure 2). The correlation was estimated also for the zooplankton support data set measured in the south-west corner of the selected reconstruction area (Figure1b). According to the spatial correlation estimates for the zooplankton area content field (Figures 3 and 4) as well as for the zooplankton concentration field (Figures 5 and 6) these data represent either spatially highly variable field realizations with correlation scales smaller than 10 km or have relatively large noise-to-signal ratio so that the correlation function parameters remain undetermined.

PO_4 concentration

The PO_4 concentration correlation estimates behave in a similar way at the upper 6 depth levels (Figure 7), only the estimate of the PO_4 concentration at the lowest level of 60 m depth is much smaller than at other depths in the first bin. Nevertheless, the uncertainty of estimates in the first bin is the largest; therefore the correlation scale of the PO_4 concentration is estimated to be $\beta = 30$ km and $\alpha =$ 0.9 for all 7 depths.

Temperature

There was only 3 temperature data pairs available for the bin 0-20 km therefore the correlation estimate confidence limits are not available for this distance bin. The temperature correlation parameters are estimated to be $\alpha = 0.9$ and the scale $\beta = 90$ km for 1 – 15 m depths and $\beta = 40$ km for 20 -60 m depths (Figure 8).

Chlorophyll-a concentration

Due to the low and uncertain correlation values (Figure 9) the correlation approximation was problematic and another correlation function was estimated from a satellite image data from 20 May 1999. The approximated Gaussian function parameters were $\alpha = 0.9$ and $\beta = 40$ km for the image data (Figure 10). It was assumed that the correlation scales β of the satellite-recorded and the in situ measured Chl fields are close and for the field realization reconstruction the Gaussian function with $\alpha = 0.4$, $\beta = 40$ km was selected for all three analyzed fields.

5. Reconstructions and their standard deviations

The reconstruction area is selected in the limits 18°20' to 22°00' E times 55°50' to 58°40' N or as transformed into the Cartesian coordinates 20 to 230 km to the east times 210 to 520 km to the north with an arbitrary coordinate origin (Figure 1a).

Zooplankton species biomass area content.

The reconstructed realization of Acartia field together with the corresponding spatial distributions of the reconstruction standard deviation are depicted as an example in Figure 11 as isoline curves. The average (integrated) over the reconstruction area field values as well as the average standard deviations of reconstructions for all 9 zooplankton variables are shown in Table A5.

In order to illustrate how a reduced number of measurements influence the field realization reconstruction and the reconstruction uncertainty, the fields of Arcatia, Fritillaria, Psedocalanus, Synchaeta, Temora, and Total were reconstructed on the basis of data from seven stations, 27_P34, J51, P38, 14_P18, 13, 12 and 11, retaining the correlation function parameters $\alpha = 0.8$ and $\beta = 50$ km. The reconstruction of Acartia is shown as an example in Figure 12. The average (integrated) over the reconstruction area field values as well as the average standard deviations of reconstructions are shown in Table A5.

The 95% confidence limits of the correlation estimates of the zooplankton species biomass appeared rather wide (especially in the first 0-20 km bin with 4 data pairs) for all 9 variable fields (Figure2), therefore the Gaussian approximation was utilized as common for correlation of all 9 variables. Nevertheless, the correlation function applied does not contradict the correlation estimates and the presented reconstructed field realizations can be considered as highly plausible. The standard deviation spatial distribution depending strongly on the noise-to-signal ratio (value of parameter α in the correlation function approximation) is probably less certain. The reduction of number of stations involved into the reconstruction causes an increase of the reconstructed realizations uncertainty.

PO_4 concentration

PO_4 –field realizations were reconstructed for the depths 1, 5, 10, 15, 20, 40 and 60 m and the corresponding spatial distributions of the reconstruction standard deviation were calculated. As an example the distributions for the depth 1 m are depicted in Figure 13 as isoline curves. The average (integrated) over the reconstruction area field values as well as the average standard deviations of reconstructions are shown in Table A6.

The space correlation of the PO_4 –fields is rather similar for all indicated depths. The Gaussian function approximating the correlation was selected visually. The approximation applied does not contradict the available correlation estimates and the reconstructed field realizations can be considered as highly plausible. The confidence limits are not available for the correlation estimates in the first, 0 – 20 km, lag bin (Figure7), nevertheless the proximity of the correlation estimates at the six upper sea depth levels allows to hypothesize with relatively large certainty the α parameter value of the selected Gaussian correlation function.

Temperature

The Temperature field realizations were reconstructed for depths 1, 5, 10, 15, 20, 40 and 60 m together with the corresponding spatial distributions of the reconstruction standard deviations. The Temperature reconstructed at 1 m depth together with the standard deviation distribution is depicted as an example in Figure 14 as isoline curves. The average (integrated) over the reconstruction area field values as well as the average standard deviations of reconstructions are shown in Table A7.

In order to illustrate how a reduced number of measurements influence the field realization reconstruction and the reconstruction uncertainty, the Temperature field at 1 m depth was reconstructed on the basis of data from 8 stations 4_P2, J4, 10_P13, J1, 16_P20, 19_P23, J39, J51 (Figure 15) and 4 stations J4, J1, J39, J51 (Figure 16), retaining the estimated correlation function parameter values $\alpha = 0.9$ and $\beta = 90\ \mathrm{km}$. The average (integrated) over the reconstruction area field values at 1m depth as well as the average standard deviations of reconstructions for reduced number of stations (8 and 4) are shown in Table A7.

The space correlation of the Temperature fields behaves rather similar way for the upper 4 depths (1, 5, 10 and 15 m). The correlation for the lower 3 depths (20, 40 and 60 m) is more scattered. The Gaussian function approximating the correlation was selected visually for both cases. The approximations applied do not contradict the available correlation estimates and the presented reconstructed field realizations can be considered as highly plausible. The confidence limits are not available for the correlation estimates in the first, 0 – 20 km, lag bin (Figure 8), nevertheless the proximity of the correlation estimates at the 6 upper sea depth levels allows to hypothesize with relatively large certainty the α parameter value of the selected Gaussian correlation function. The least certain is the value of α for the lowest depth level (60 m). The mean standard deviation of reconstruction increases substantially with the decrease of the number of measurements involved into the procedure (Table A7).

Chlorophyll-a concentration

The three Chl-a field realizations were reconstructed together with the corresponding spatial distributions of the reconstruction standard deviation and the distribution of Chl 0 – 20 m is depicted in Figure 17 as isoline curves. The average (integrated) over the reconstruction area field values as well as the average standard deviations of reconstructions are shown in Table A8.

In order to illustrate how a reduced number of measurements influence the field realization reconstruction and the reconstruction uncertainty, the field of Chl 0 – 20 m was reconstructed on the basis of data from 8 stations J1, J39, J51, 10, 4, 16, 19, 3 (Figure 18) and 4 stations J1, J51, 4, 19 (Figure 19) retaining the estimated correlation function parameter values $\alpha = 0.4$ and $\beta = 40\ \mathrm{km}$. The average (integrated) over the reconstruction area field values as well as the average standard deviations of reconstructions are shown in Table A7.

The 95% confidence limits of the chlorophyll variables correlation estimates appeared rather wide (not available for the first 0-20 km bin with only 3 data pairs) for all 3 variable fields (Figure 9), therefore a Gaussian approximation was utilized as common for correlation of all 3 variables. Nevertheless, the scale of the correlation function $\beta = 40\ \mathrm{km}$ estimated from the satellite image data does not contradict the correlation estimates of the in situ data and the presented reconstructed field realizations can be considered as highly plausible. The standard deviation spatial distribution depending strongly on the noise-to-signal ratio (value of parameter α in the correlation function approximation) is less certain. The reduction of number of stations involved into the reconstruction causes a substantial increase of the reconstructed realizations uncertainty.

6. Conclusion

1) The station configuration selected for the survey is in general reasonably good, all stations lay at the distances comparable with correlation scales of the measured variables.

2) Different variables have different correlation scales and therefore need measurements with different spatial resolution, e.g. for temperature in the upper 4 layers the measurement sites could be located much more sparsely than for Chl *a* in order to achieve the same interpolation quality.

3) The determination of the noise-to-signal ratio was rather uncertain for all variables due to a small number of closely located measurement sites, therefore it would be desirable to have around 5 – 10 measurements of each variable with distances less than 20 km spread over the survey area.

4) The noise-to-signal ratio of Chl *a* data appears much too high to obtain reasonable spatial interpolation results, the measures should be taken to reduce the noise, e.g. to take several samples at each station.

5) If the area of the variable reconstruction was selected smaller, not extending beyond the region covered by the sampling locations the average reconstruction error would have been smaller, because the reconstruction error increases relatively fast moving off the cluster of the sampling locations region reaching the highest possible field variance value.

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Gandin, L.S. 1965. Objective analysis of meteorological fields, Jerusalem, 242 pp.

Toompuu, A. and F. Wulff, 1996. Optimum spatial analysis of monitoring data on temperature, salinity and nutrient concentrations in the Baltic Proper, *Environmental Monitoring and Assessment*, 43, 283–308.

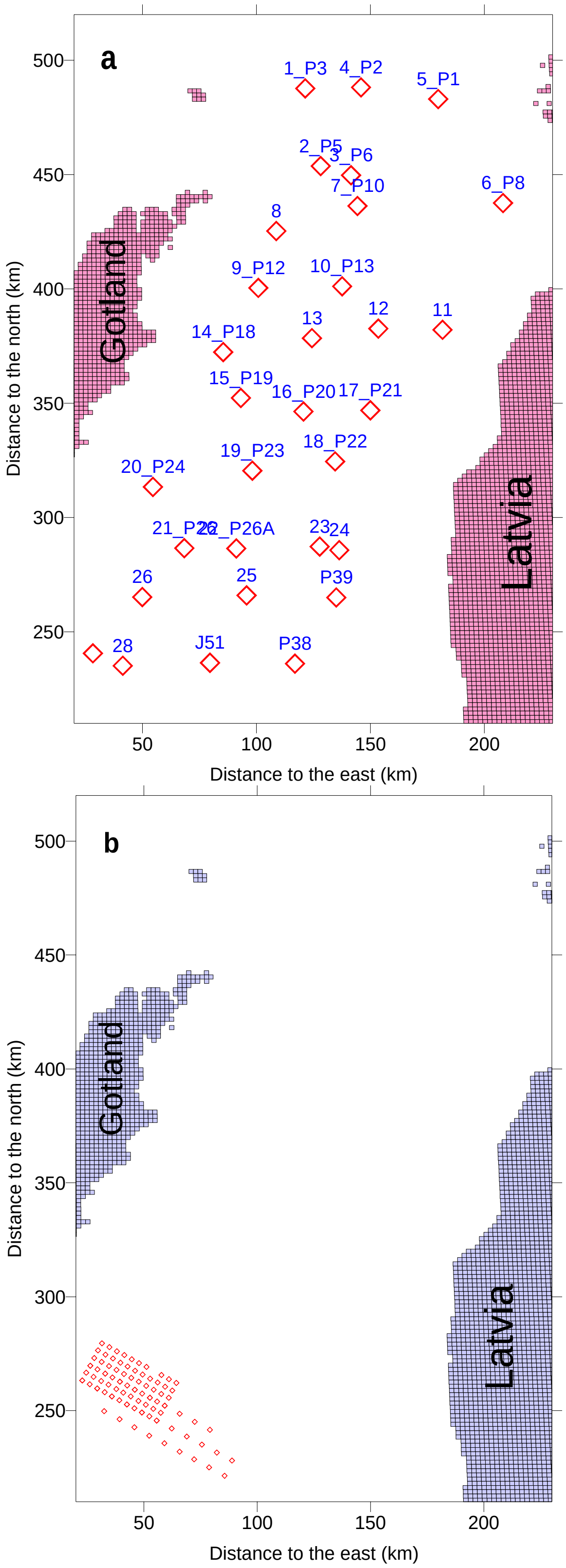

Figure 1: The survey and reconstruction area together with the location of sampling stations (a) and the location of measurements of a zooplankton biomass support data set (b).

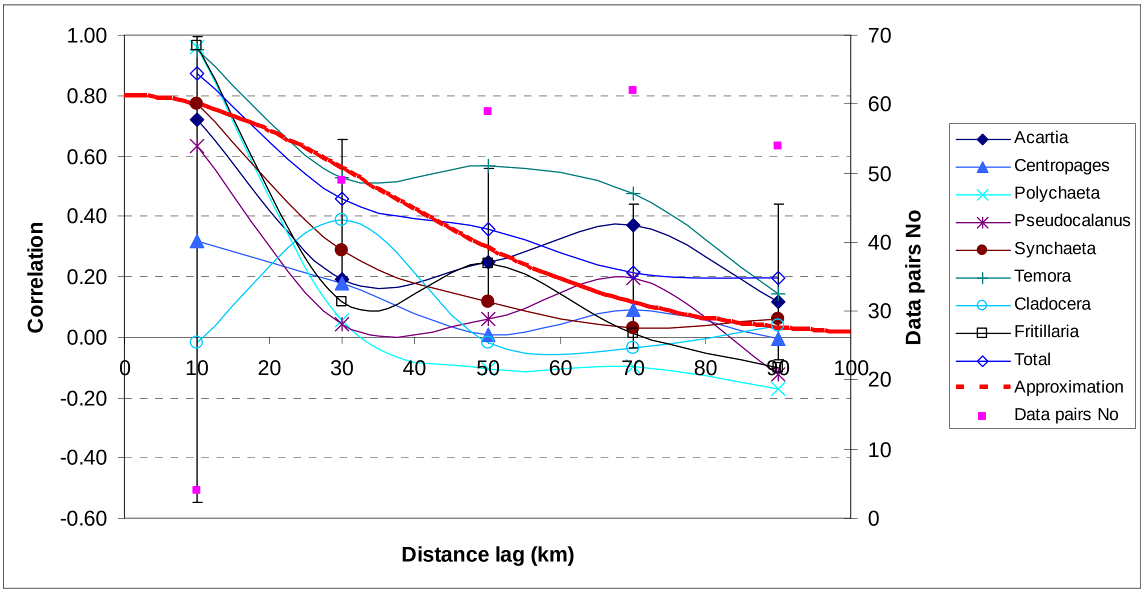

Figure 2: The estimated spatial correlation (curves with markers) of zooplankton biomass area content fields with 95% confidence presented for correlation estimates of Total, the approximated correlation function used in the reconstruction procedure (dashed curve) and the number of data pairs (markers) used for correlation estimates.

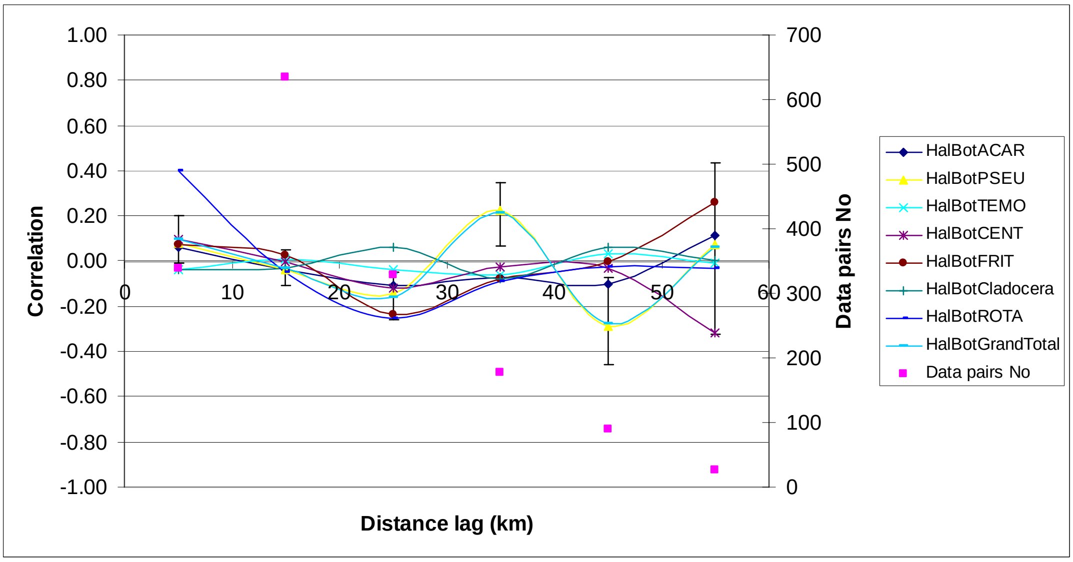

Figure 3: The estimated spatial correlation (curves with markers) of zooplankton (halocline to bottom haul) biomass area content fields with 95% confidence presented for correlation estimates of HalBotGrandTotal and the number of data pairs (markers) used for correlation estimates.

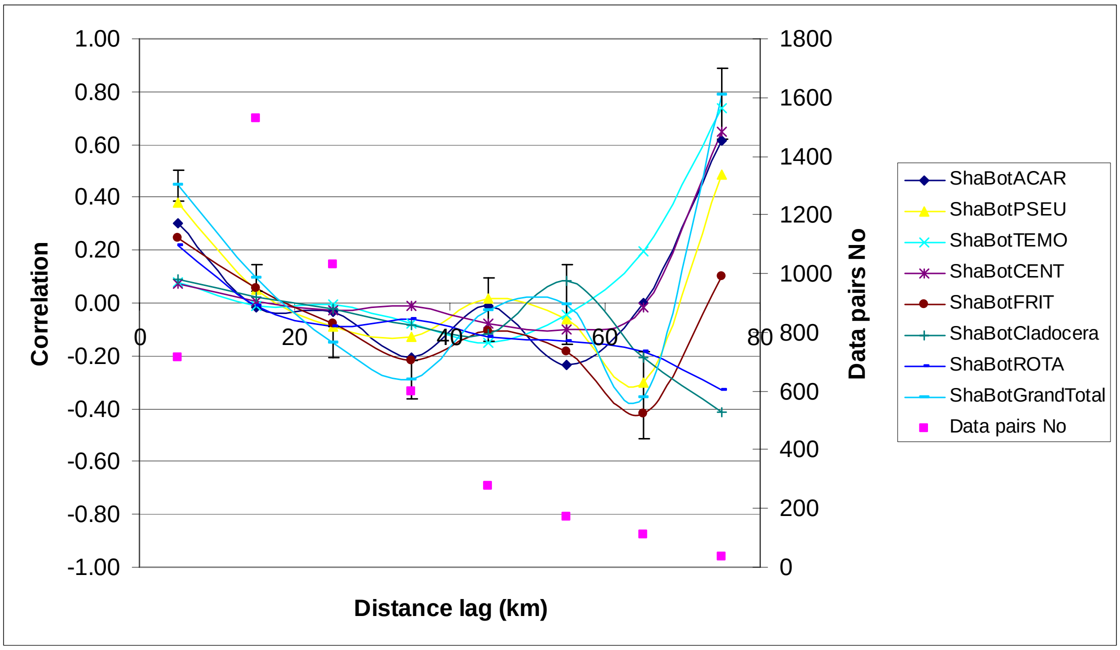

Figure 4: The estimated spatial correlation (curves with markers) of zooplankton (shallow bottom haul) biomass area content fields with 95% confidence presented for correlation estimates of ShaBotGrandTotal and the number of data pairs (markers) used for correlation estimates.

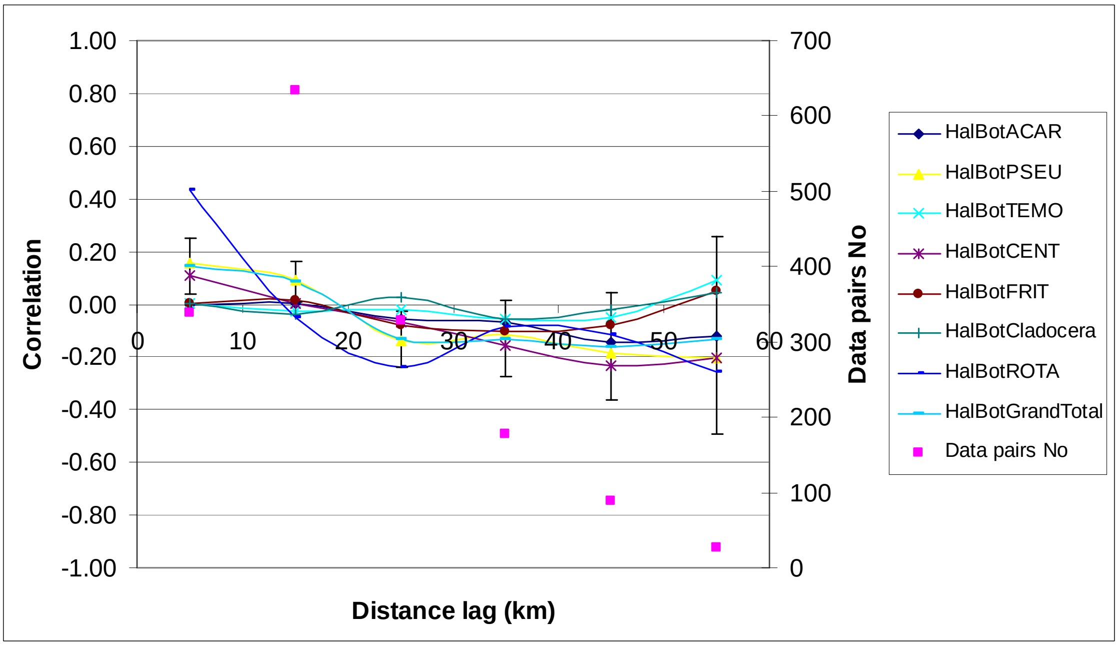

Figure 5: The estimated spatial correlation (curves with markers) of zooplankton (halocline to bottom haul) biomass concentration fields with 95% confidence presented for correlation estimates of HalBotGrandTotal and the number of data pairs (markers) used for correlation estimates.

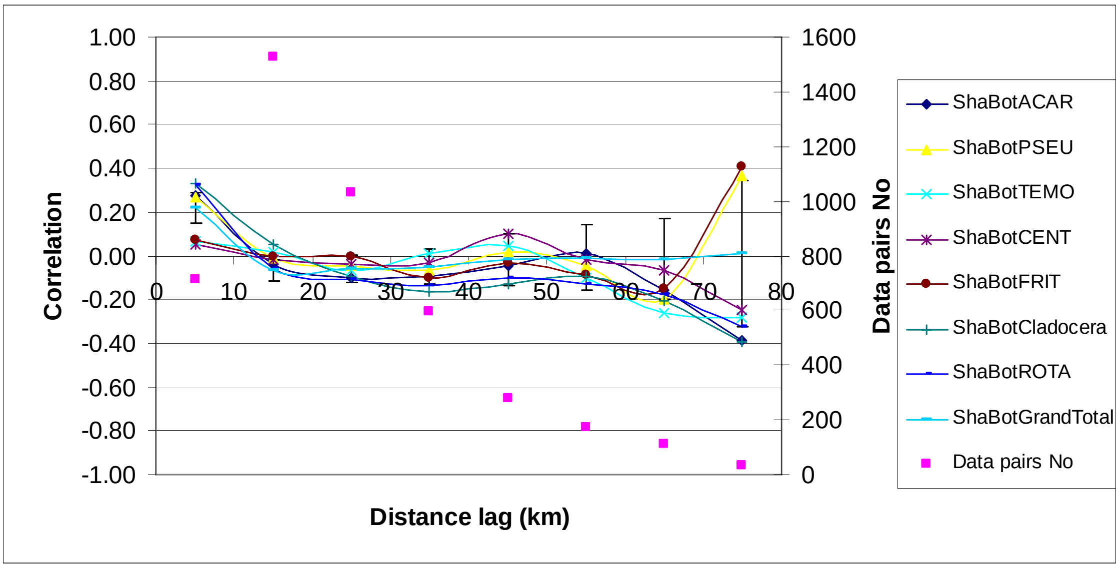

Figure 6: The estimated spatial correlation (curves with markers) of zooplankton (shallow bottom haul) biomass concentration fields with 95% confidence presented for correlation estimates of HalBotGrandTotal and the number of data pairs (markers) used for correlation estimates.

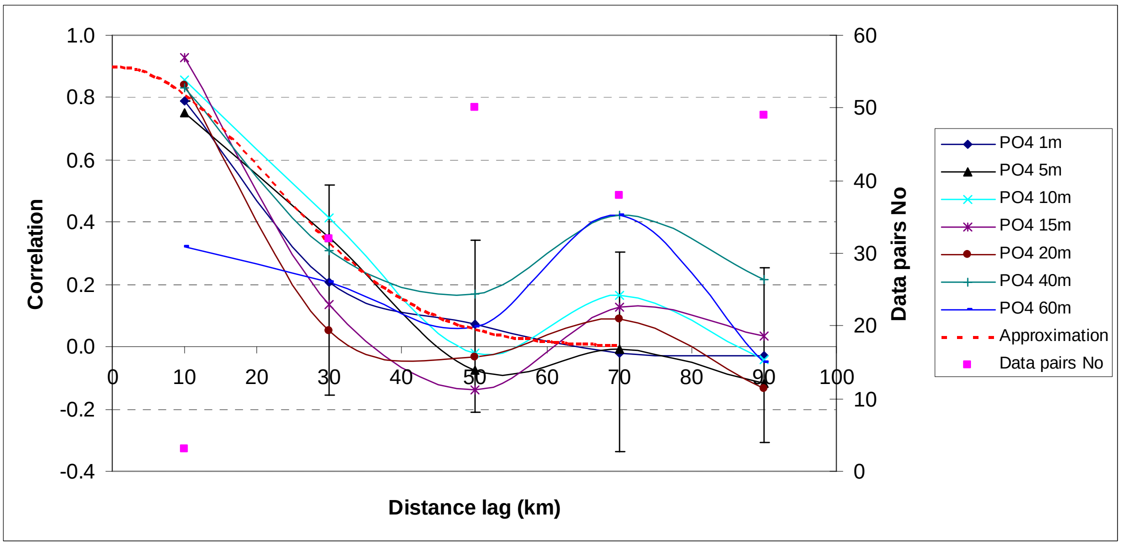

Figure 7: The estimated PO_4 –field correlation (curves with markers) with 95% confidence limits presented for PO_4 at 1 m depth, the approximated correlation function used in the reconstruction procedure (dashed curve) and the data pairs number (markers) used for correlation estimates.

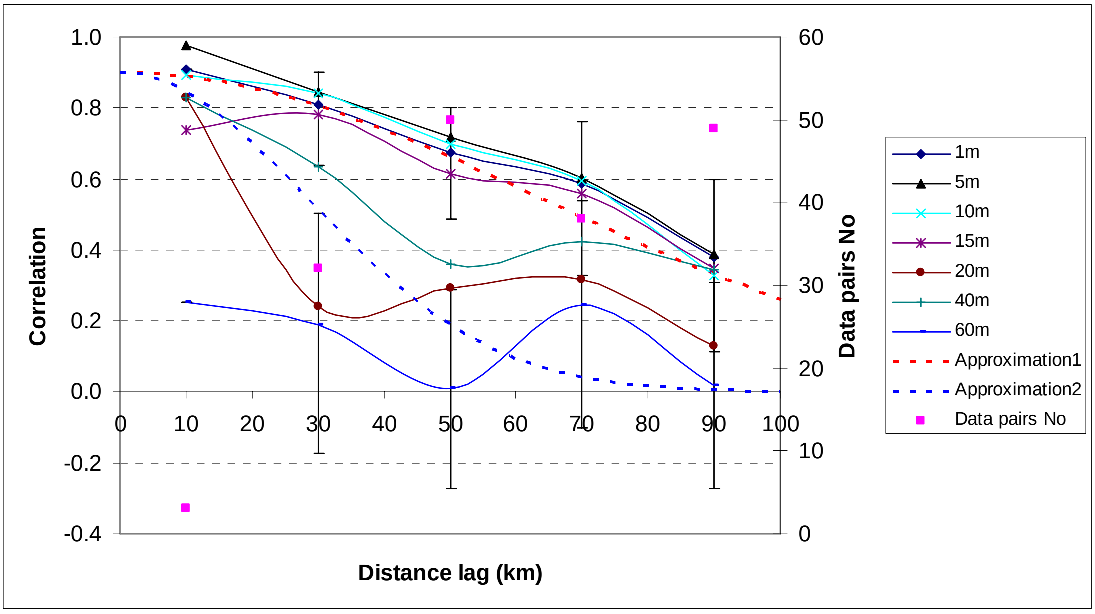

Figure 8: The estimated Temperature field correlation (curves with markers)with 95% confidence limits (presented for correlation estimates at 1 m and 60 m depths), the approximated correlation functions used in the reconstruction procedure (dashed red and blue curves) and the data pairs number (markers) used for correlation estimates.

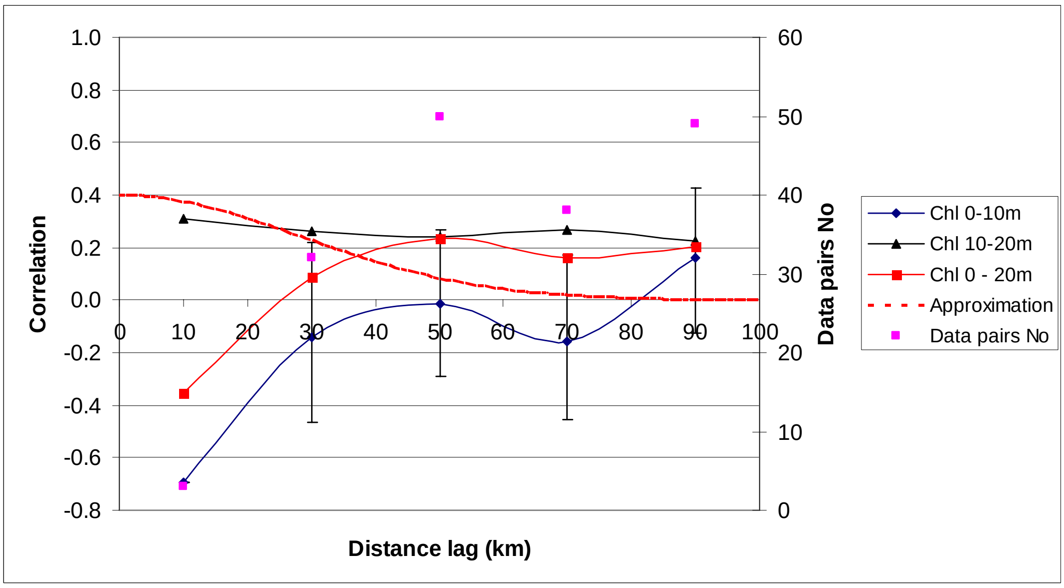

Figure 9: The estimated Chl fields correlation (curves with markers) with 95% confidence limits presented for correlation estimates of Chl 0 – 10m, the approximated correlation function used in the reconstruction procedure (continuous curve) and the data pairs number (markers) used for correlation estimates.

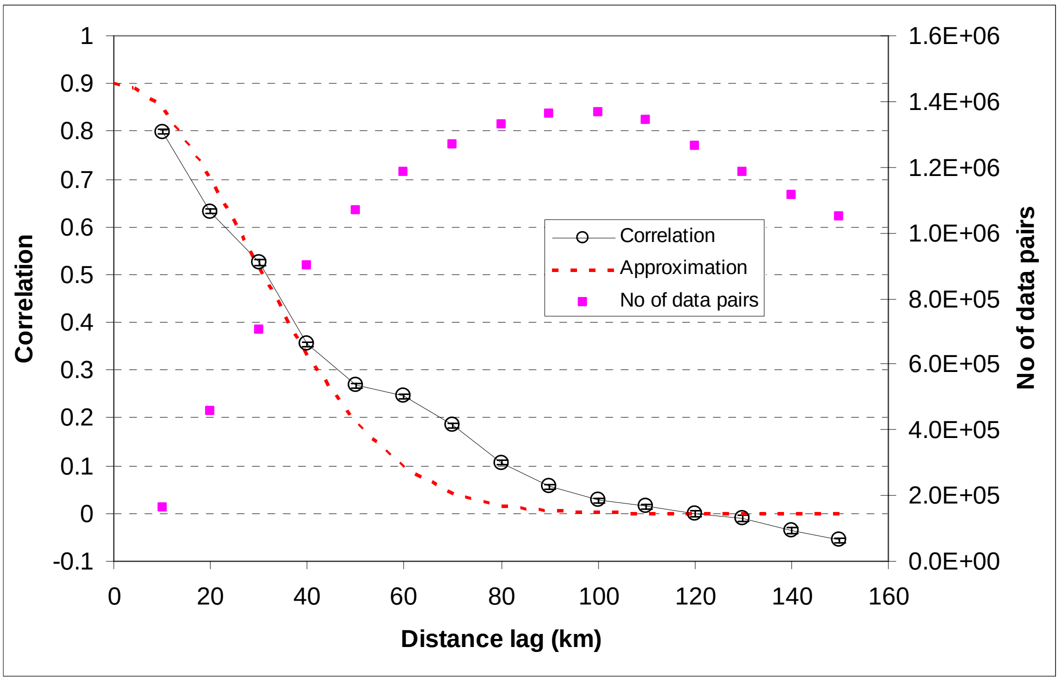

Figure 10: The Chl field correlation (curve with markers) estimated from satellite data with 95% confidence limits and the approximated correlation function (dashed curve) and the data pairs number (markers) used for correlation estimates.

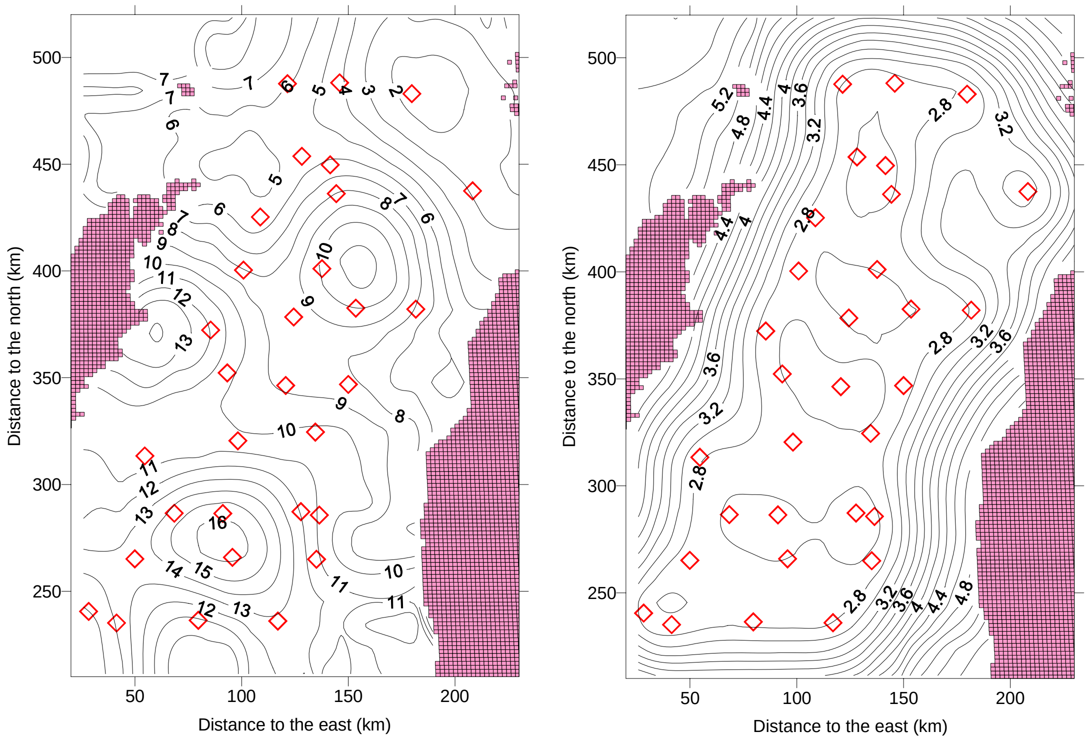

Figure 11. Reconstructed Acartia field realization (left panel) and the corresponding spatial distribution of the standard deviation of the reconstruction (right panel).

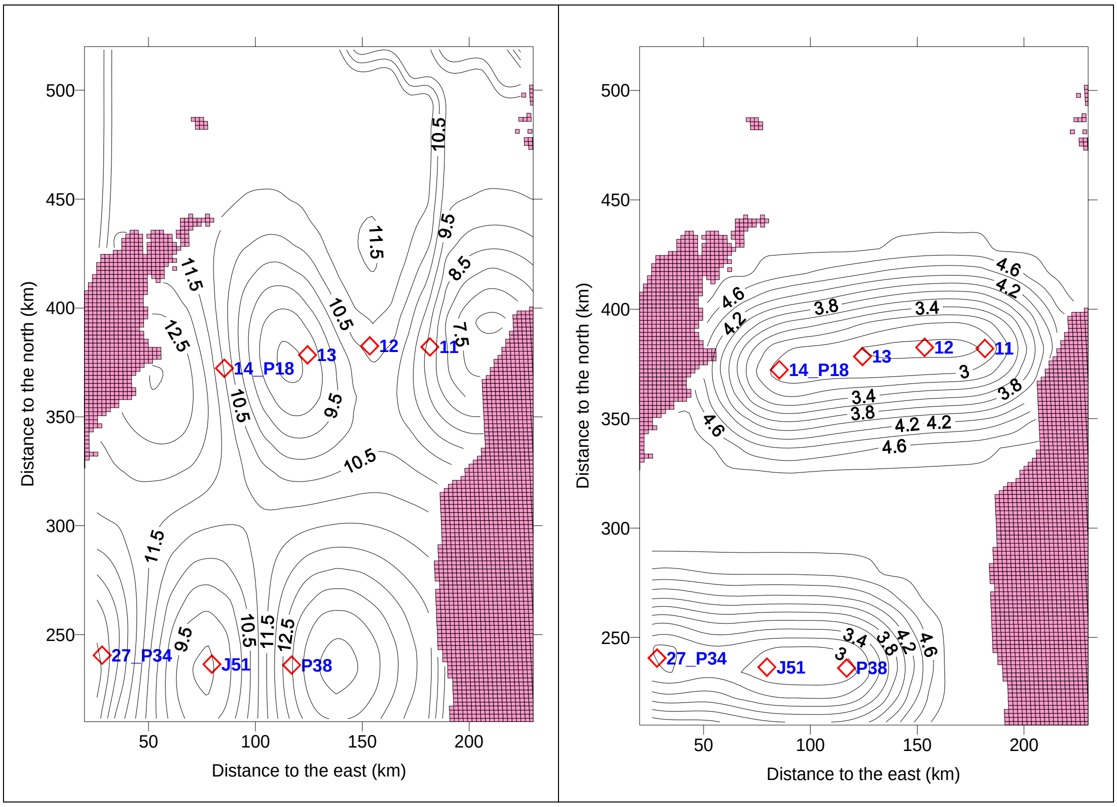

Figure 12: Acartia field realization reconstructed from seven stations (left panel) and the corresponding spatial distribution of the standard deviation of the reconstruction (right panel).

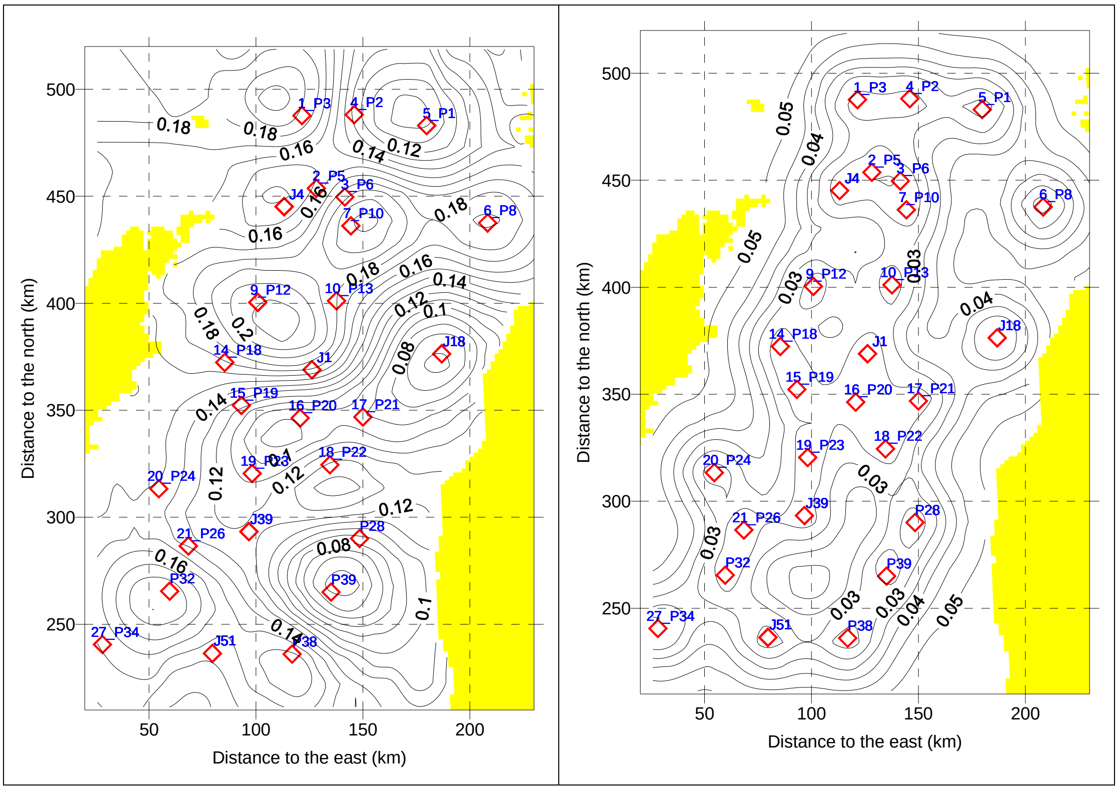

Figure 13: Reconstructed PO_4 –field realization at 1 m depth (left panel) and the corresponding spatial distribution of the standard deviation of the reconstruction (right panel).

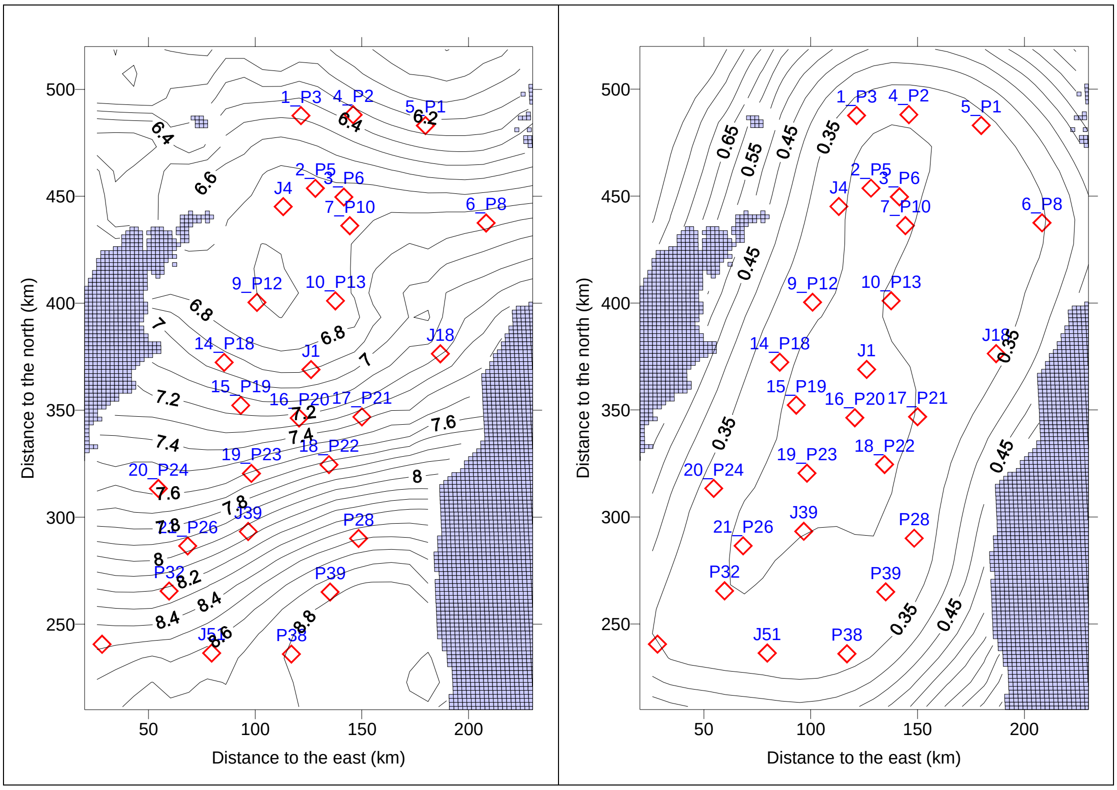

Figure 14: Reconstructed Temperature field realization at 1 m depth (left panel) and the corresponding spatial distribution of the standard deviation of the reconstruction (right panel).

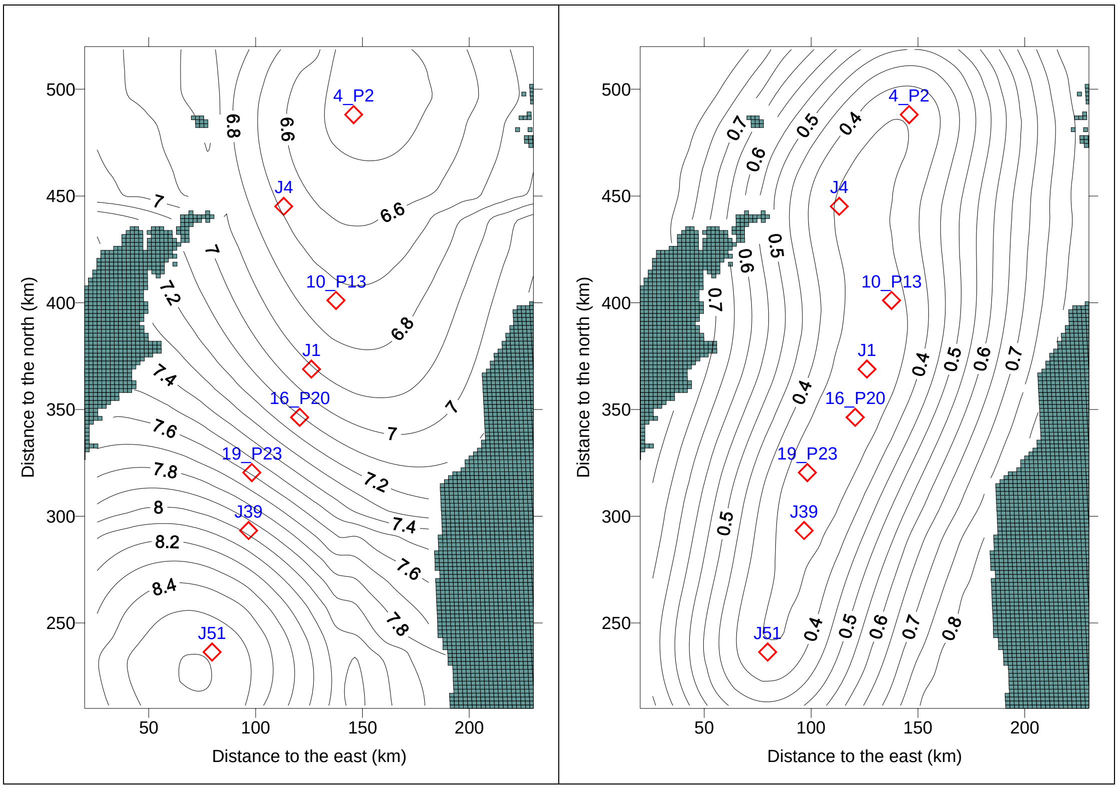

Figure 15: Reconstructed Temperature field realization at 1 m depth (left panel) for 8 stations and the corresponding spatial distribution of the standard deviation of the reconstruction (right panel).

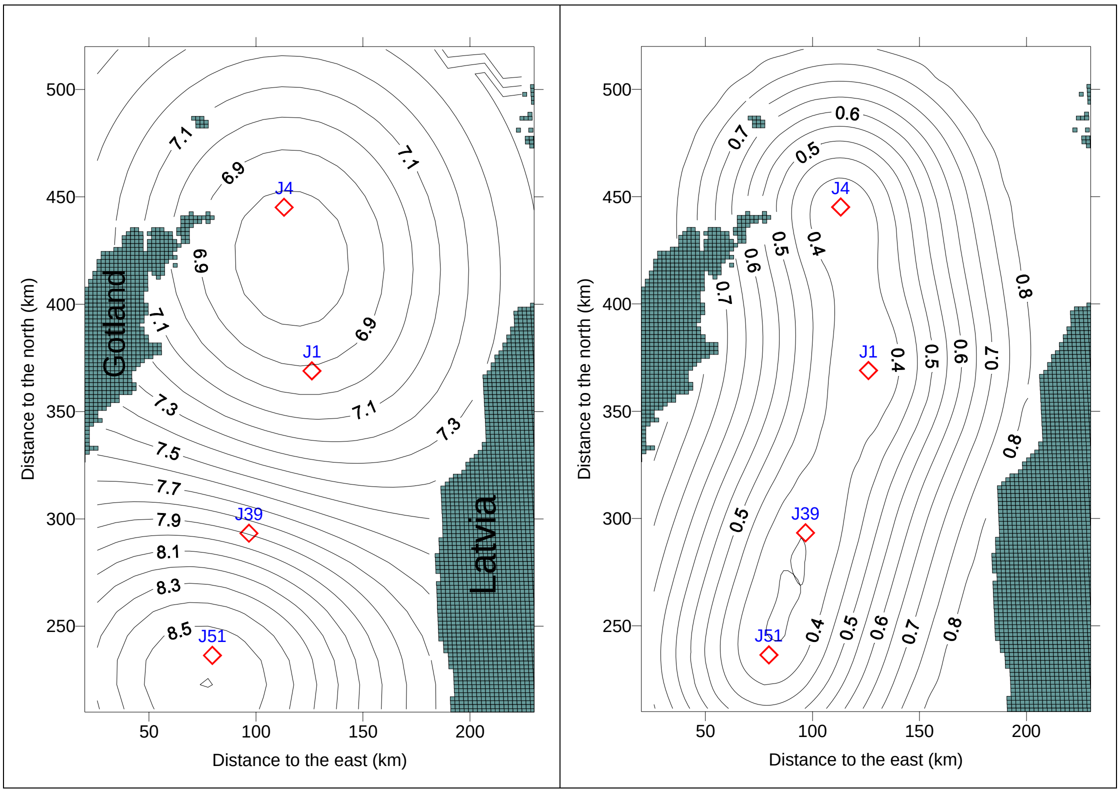

Figure 16: Reconstructed Temperature field realization at 1 m depth (left panel) for 4 stations and the corresponding spatial distribution of the standard deviation of the reconstruction (right panel).

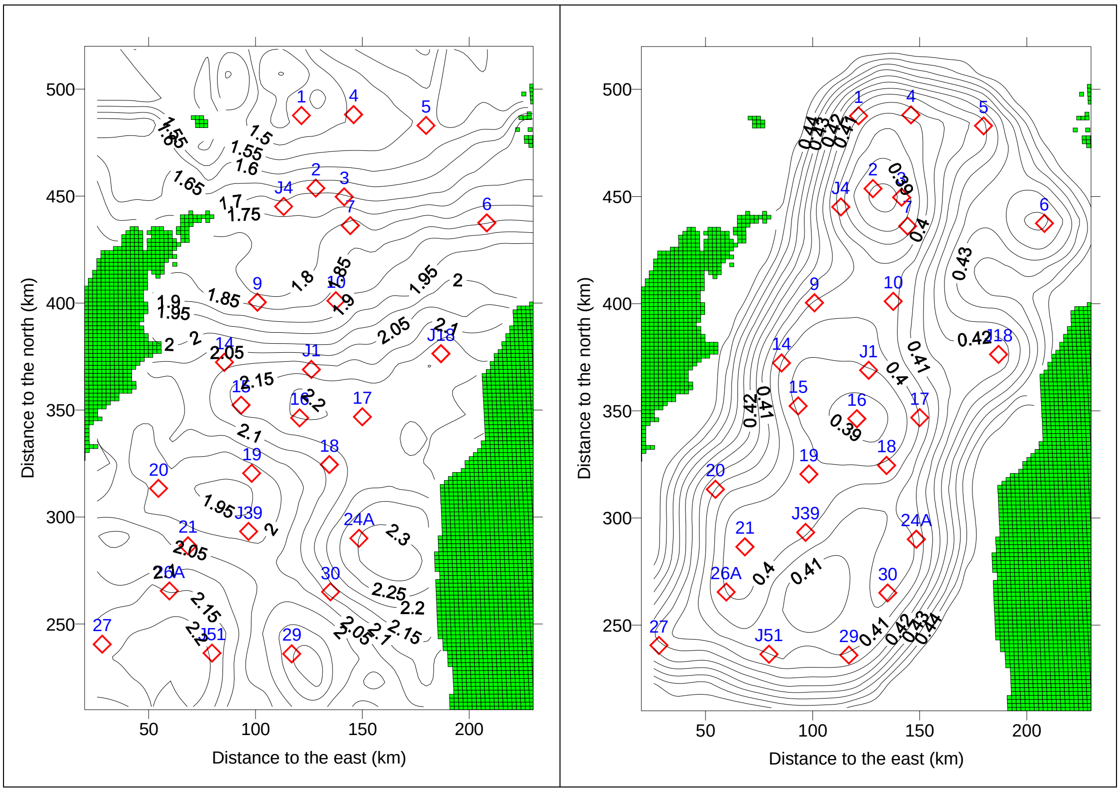

Figure 17: Reconstructed Chl 0 – 20m field realization (left panel) and the corresponding spatial distribution of the standard deviation of the reconstruction (right panel).

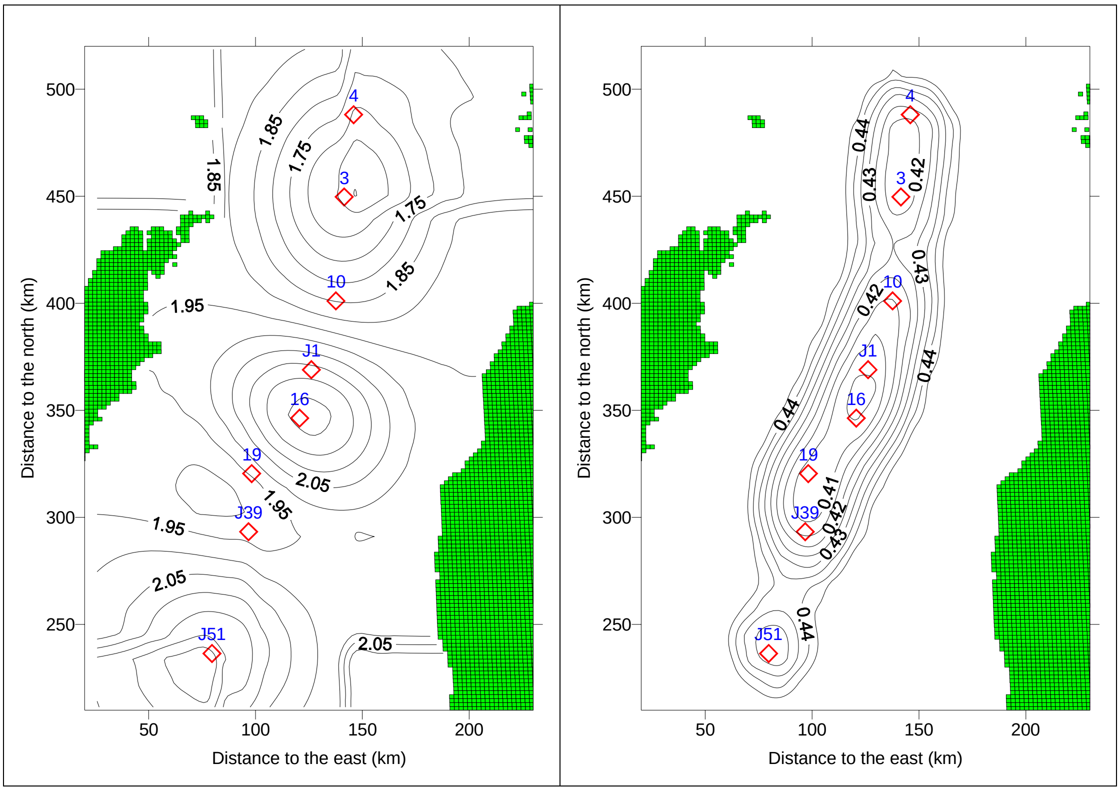

Figure 18: Chl 0 – 20 m field realization reconstructed from 8 stations (left panel) and the corresponding spatial distribution of the standard deviation of the reconstruction (right panel).

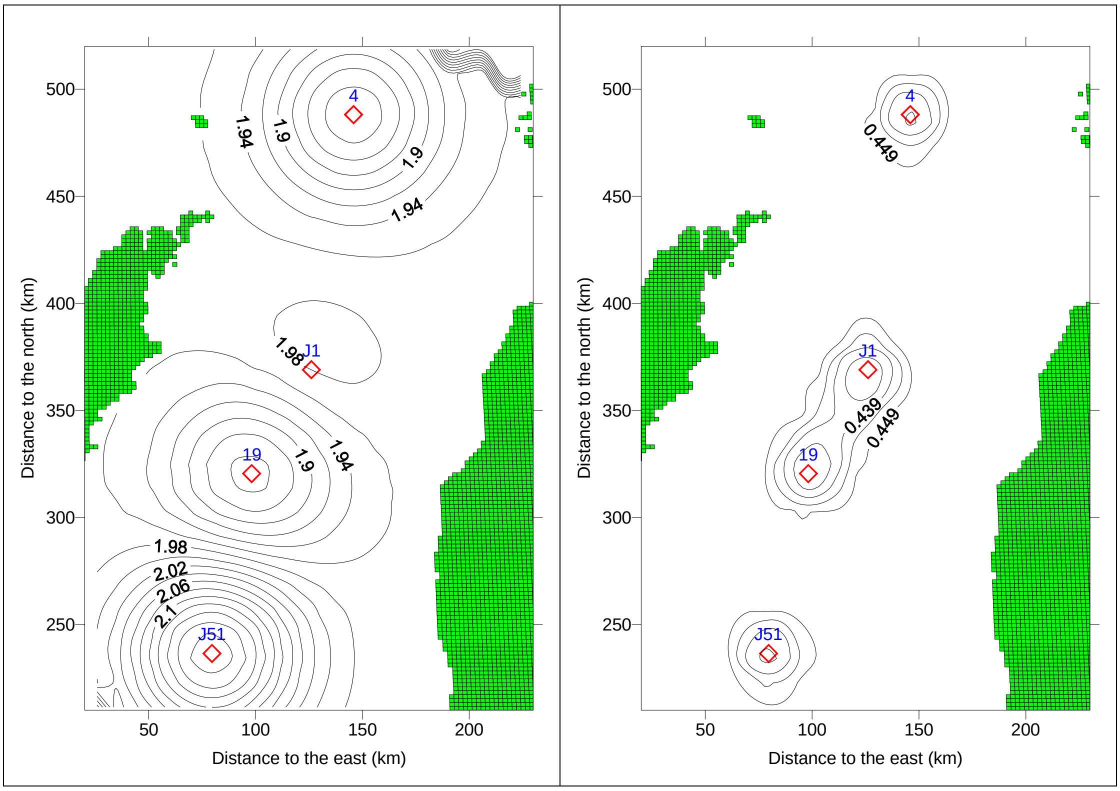

Figure 19: Chl 0 – 20 m field realization reconstructed from 4 stations (left panel) and the corresponding spatial distribution of the standard deviation of the reconstruction (right panel).

Appendix 1. The analyzed data and the integrated reconstruction results

Table A1. Original data on zooplankton biomass area content in g/m^2 (wet weight).

Station	Lon (km)	Lat (km)	Acartia	Centropages	Fritillaria	Polychaeta	Pseudocalanus	Synchaeta	Temora	Cladocera	Total
8	108.76	425.26	3.412	0.071	0.78	0.18	3.618	2.364	0.804	0.142	11.4761
1_P3	121.46	487.65	7.0275	0.1325	0.325	0.225	0.865	6.9375	0.212	0.024	16.0985
10_P13	137.64	401.08	10.076	0.34	0.46	0.33	1.9158	2.448	0.7385	0.2415	16.54986
11	181.66	382.09	6.09	0	0.42	0.945	0.294	3.105	0.617	0.735	12.2602
12	153.50	382.59	14.855	0	0.6	7.725	0.051	13.2	0.282	1.13	37.969
13	124.38	378.44	5.06	0.308	1.05	1.35	2.935	8.625	1.34	0.795	21.463
14_P18	85.46	372.33	12.245	0.345	1.175	0.5625	2.2	13.8	1.78	1.503	33.6235
15_P19	93.23	352.28	12.94	0.1595	0.1875	0.105	2.2025	5.175	0.494	0.5875	21.857
16_P20	120.63	346.35	8.36	0.0354	0.325	0.3825	1.4075	5.475	2.19	0.1275	18.3229
17_P21	150.01	346.85	5.1725	0.058	0.675	0.4875	1.164	7.8	0.8965	0.38	16.6335
18_P22	134.56	324.53	14.93	0.214	0.1875	0.255	2.1625	4.4625	0.9	0.1249	23.2504
19_P23	98.23	320.46	5.852	0.1025	1.94	0.12	2.6635	5.76	1.271	0.2425	17.979
2_P5	128.21	453.70	4.9	0.192	0.5375	0.3375	0.985	1.275	0.293	0.071	8.6135
20_P24	54.60	313.38	9.998	0.128	0.62	0.21	2.852	5.34	1.2985	0.2575	20.728
21_P26	68.39	286.55	14.22	0.152	0.94	0.78	1.921	4.56	1.378	0.1625	24.201
22_P26A	91.16	286.44	19.296	0.2345	1.66	0.1125	1.8305	14.04	4.333	0.795	42.3015
23	127.77	287.27	9.29	0.419	0.875	0.525	9.92	14.7	2.645	0.885	39.259
24	136.40	285.69	11.25	0.233	0.825	0.225	2.98	7.875	3.005	0.3235	26.7165
25	95.69	265.91	18.855	0.282	2.55	0.825	5.28	13.95	3.055	0.84875	45.72075
26	49.92	265.19	12.405	0.1415	1.125	0.225	0.684	12.825	2.375	0.8875	30.668
27_P34	28.25	240.57	15.035	0.5475	0.8	0.5625	6.31	8.7	3.16	0.1775	35.2925
28	41.34	235.17	15.735	0.266	0.925	0.3375	5.8075	9.6	4.535	1.44375	38.64975
3_P6	141.52	449.66	4.9025	0.1075	0.3375	0.3	1.46	1.8375	0.3875	0.0615	9.409
4_P2	145.92	488.09	3.879	0.092	0.33	0.18	0.9355	0.9675	0.292	0.051	6.853
5_P1	179.79	483.01	0.7255	0.00265	0.0025	0.0225	0.227	0.0345	0.066	0	1.09321
6_P8	208.24	437.51	2.562	0	0.14	1.395	0.2959	0.63	0.6655	0.165	5.8919
7_P10	144.36	436.20	10.78	0.32	0.16	0.135	1.785	0.735	0.438	0.143	14.54212
9_P12	100.86	400.40	9.315	0.1345	1.15	0.225	1.025	17.7	0.7675	0.165	30.61
J51	79.64	236.42	7.09	0.5	0.45	0.165	6.256	7.125	2.675	0.64875	24.90975
P38	116.94	236.05	14.43	0.395	0.8	2.55	0.845	14.4	5.32	1.23625	40.19425
P39	135.09	265.0178	9.9675	0.098	0.325	1.725	0.2355	7.125	2.1875	1.5375	23.27475

Table A2. Original data on PO_4 concentration (mmol m^{-3}).

STATION.	LON (DEG)	LAT (DEG)	LON (KM)	LAT (KM)	DEPTH						
					1 m	5 m	10 m	15 m	20 m	40 m	60 m
1_P3	20.09	58.38	121.46	487.65	0.20	0.14	0.15	0.18	0.22	0.56	0.95
2_P5	20.18	58.08	128.21	453.70	0.14	0.14	0.20	0.29	0.41	1.06	1.12
3_P6	20.41	58.04	141.52	449.66	0.20	0.20	0.22	0.24	0.38	0.88	2.41
4_P2	20.51	58.39	145.92	488.09	0.12	0.11	0.13	0.19	0.30	0.77	1.66
5_P1	21.08	58.34	179.79	483.01	0.09	0.08	0.08	0.08	0.10	0.56	1.49
6_P8	21.53	57.93	208.24	437.51	0.20	0.20	0.22	0.22	0.25	0.81	
J4	19.92	58.00	113.17	445.16	0.14	0.15	0.15	0.20	0.47	0.71	1.23
7_P10	20.45	57.92	144.36	436.20	0.22	0.20	0.19	0.18	0.24	0.57	1.61
9_P12	19.69	57.60	100.86	400.40	0.22	0.20	0.21	0.16	0.21	0.59	1.36
10_P13	20.31	57.61	137.64	401.08	0.18	0.19	0.20	0.29	0.42	0.52	0.83
J18	21.12	57.38	186.80	376.36	0.05	0.06	0.04	0.05	0.07	0.56	1.66
J1	20.10	57.32	126.16	368.96	0.18	0.17	0.17	0.15	0.17	0.61	1.17
14_P18	19.43	57.35	85.46	372.33	0.17	0.16	0.16	0.19	0.33	0.49	0.75
15_P19	19.55	57.17	93.23	352.28	0.12	0.12	0.14	0.14	0.23	0.45	1.16
16_P20	20.00	57.11	120.63	346.35	0.08	0.07	0.08	0.08	0.10	0.42	0.83
17_P21	20.49	57.12	150.01	346.85	0.08	0.08	0.10	0.09	0.11	0.57	0.79
18_P22	20.22	56.92	134.56	324.53	0.14	0.13	0.14	0.24	0.38	0.51	0.85
19_P23	19.62	56.88	98.23	320.46	0.10	0.12	0.11	0.17	0.24	0.63	1.46
20_P24	18.90	56.82	54.60	313.38	0.15	0.14	0.14	0.15	0.21	0.46	0.76
21_P26	19.12	56.57	68.39	286.55	0.13	0.14	0.12	0.13	0.16	0.51	0.85
J39	19.58	56.64	96.74	293.31	0.12	0.13	0.13	0.18	0.25	0.41	0.74
P28	20.43	56.61	148.40	290.08	0.08	0.09	0.09	0.12	0.16	0.49	1.04
P32	18.97	56.38	59.66	265.46	0.20	0.21	0.15	0.17	0.24	0.54	0.93
27_P34	18.46	56.16	28.25	240.57	0.15	0.13	0.11	0.16	0.28	0.58	0.92
P38	19.89	56.12	116.94	236.05	0.17	0.12	0.11	0.11	0.13	0.55	0.96
J51	19.29	56.12	79.64	236.42	0.14	0.14	0.14	0.17	0.28	0.48	0.96
P39	20.20	56.38	135.09	265.02	0.04	0.05	0.05	0.05	0.16	0.47	1.35

Table A3. Original data on Temperature (°C).

STATION	LON (DEG)	LAT (DEG)	LON (KM)	LAT (KM)	DEPTH						
					1 m	5 m	10 m	15 m	20 m	40 m	60 m
1_P3	20.09	58.38	121.46	487.65	6.28	6.23	6.23	6.18	5.11	3.30	2.18
2_P5	20.18	58.08	128.21	453.70	7.15	6.96	6.42	5.63	4.55	2.43	2.56
3_P6	20.41	58.04	141.52	449.66	7.15	6.60	5.94	5.18	4.97	2.05	4.25
4_P2	20.51	58.39	145.92	488.09	6.37	6.36	6.32	5.41	4.49	2.07	2.93
5_P1	21.08	58.34	179.79	483.01	6.01	5.99	5.97	5.91	5.81	2.47	3.61
6_P8	21.53	57.93	208.24	437.51	7.01	6.99	6.96	6.18	5.51	2.23	
J4	19.92	58.00	113.17	445.16	6.70	6.70	6.69	6.52	2.52	2.05	2.96
7_P10	20.45	57.92	144.36	436.20	6.45	6.46	6.43	6.37	5.48	2.64	3.43
9_P12	19.69	57.60	100.86	400.40	6.47	6.47	6.46	6.21	6.11	3.06	3.19
10_P13	20.31	57.61	137.64	401.08	6.75	6.76	6.57	6.30	3.78	3.09	2.32
J18	21.12	57.38	186.80	376.36	7.22	7.23	7.24	7.16	6.75	2.67	3.76
J1	20.10	57.32	126.16	368.96	6.88	6.89	6.89	6.60	6.56	2.79	2.66
14_P18	19.43	57.35	85.46	372.33	7.09	7.03	7.02	7.02	4.49	3.09	2.48
15_P19	19.55	57.17	93.23	352.28	7.26	7.25	7.23	7.19	6.63	3.14	2.69
16_P20	20.00	57.11	120.63	346.35	6.98	6.98	6.97	6.94	6.92	3.16	2.42
17_P21	20.49	57.12	150.01	346.85	7.39	7.36	7.13	6.99	6.96	3.00	2.39
18_P22	20.22	56.92	134.56	324.53	7.77	7.76	7.16	7.11	3.95	3.22	2.47
19_P23	19.62	56.88	98.23	320.46	7.77	7.78	7.48	7.11	6.69	3.18	2.79
20_P24	18.90	56.82	54.60	313.38	7.46	7.43	7.37	7.32	7.03	3.31	2.80
21_P26	19.12	56.57	68.39	286.55	7.99	7.97	7.91	7.42	6.70	3.66	2.44
J39	19.58	56.64	96.74	293.31	7.86	7.86	7.86	6.97	6.29	4.38	2.45
P28	20.43	56.61	148.40	290.08	8.46	8.46	8.39	7.23	6.91	3.48	2.54
P32	18.97	56.38	59.66	265.46	8.16	8.17	8.04	7.20	7.12	3.79	2.36
27_P34	18.46	56.16	28.25	240.57	8.53	8.37	7.95	7.88	7.64	3.38	2.41
P38	19.89	56.12	116.94	236.05	8.69	8.69	8.65	7.88	6.97	3.42	2.70
J51	19.29	56.12	79.64	236.42	8.72	8.32	7.70	7.20	6.48	3.36	2.37
P39	20.20	56.38	135.09	265.02	9.05	9.03	8.89	8.16	7.13	2.97	2.89

Table A4. Original data on Chl in mg/m^3

Station	Lat (deg)	Long (deg)	Lon (km)	Lat (km)	Chl 0-10m	Chl 10-20m	Chl 0 - 20m
J1	57.31603	20.10243	126.15703	368.95725	1.988	2.069	2.029
J18	57.38263	21.11875	186.80248	376.35785	2.369	2.349	2.359
J39	56.63528	19.58292	96.73586	293.31231	1.908	1.968	1.938
J4	58.00183	19.92195	113.16753	445.16335	1.747	1.687	1.717
J51	56.12333	19.28582	79.64250	236.42443	2.369	2.711	2.540
5	58.34238	21.08283	179.79208	483.00527	1.627	1.060	1.343
7	57.92120	20.44612	144.35576	436.20374	1.898	2.128	2.013
9	57.59900	19.69395	100.86238	400.40088	1.325	1.833	1.579
10	57.60513	20.31198	137.63835	401.08205	1.807	1.687	1.747
14	57.34638	19.42535	85.45799	372.32975	2.199	2.331	2.265
15	57.16593	19.54733	93.22686	352.27814	2.238	2.048	2.143
4	58.38815	20.50527	145.91917	488.09123	1.837	1.386	1.611
16	57.11262	19.99927	120.62994	346.35433	2.747	2.922	2.834
17	57.11712	20.48655	150.01273	346.85437	2.197	2.500	2.349
18	56.91622	20.21838	134.55916	324.53037	1.486	1.898	1.692
19	56.87957	19.61793	98.23430	320.45782	2.169	1.175	1.672
20	56.81583	18.89777	54.60195	313.37503	1.325	2.349	1.837
21	56.57438	19.11732	68.39216	286.54511	2.075	2.169	2.122
24A	56.60623	20.42652	148.40434	290.08428	2.490	3.052	2.771
1	58.38420	20.08518	121.46468	487.65230	1.533	0.201	0.867
30	56.38065	20.19568	135.08729	265.01783	1.928	2.169	2.048
26A	56.38467	18.96983	59.66164	265.46453	1.807	2.309	2.058
27	56.16063	18.45657	28.25210	240.56921	2.610	2.169	2.390
29	56.11992	19.88778	116.93771	236.04551	1.355	1.518	1.437
2	58.07862	20.18212	128.21104	453.69625	2.380	1.596	1.988
3	58.04232	20.40620	141.52067	449.66260	1.687	0.864	1.276
6	57.93292	21.52985	208.24320	437.50607	1.988	1.886	1.937

Table A5. Results of zooplankton species biomass fields' reconstruction and integration (wet weight).

	ACAR-TIA	CENTRO PAGES	FRITILL ARIA	POLY CHAETA	PSEUD-OCALANUS	SYN CHAETA	TEM-ORA	CLADO CERA	TOTAL
Mean of the inter-polated field (g/m^2), 31 stations	9.70	0.19	0.67	0.79	2.16	7.30	1.62	0.55	23.06
Mean standard deviation (g/m^2), 31 stations	3.86	0.11	0.44	1.12	1.78	4.02	1.11	0.37	9.47
Mean of the inter-polated field (g/m^2), 7 stations	12.35		0.88		2.94	11.25	2.68		33.37
Mean standard deviation (g/m^2), 7 stations	4.92		0.57		2.28	5.12	1.42		12.09

Table A6. Results of PO_4 concentration field reconstruction and integration.

	DEPTH						
	1 m	**5 m**	**10 m**	**15 m**	**20 m**	**40 m**	**60 m**
Integrated PO_4 concentration (10^3 mol m^{-1})	8471	8014	7845	8961	12703	25857	42620
Area of interpolation (km^2)	51844	51206	49833	48116	45026	36982	27810
Mean of the interpolated field (mmol m^{-3})	0.163	0.157	0.157	0.186	0.282	0.699	1.533
Integrated PO_4 standard deviation (10^3 mol m^{-1})	2297	2048	2152	3056	4304	5013	8293
Area of interpolation (km^2)	51844	51206	49833	48116	45026	36982	27810
Mean standard deviation (mmol m^{-3})	0.044	0.040	0.043	0.064	0.096	0.136	0.298

Table A7. Results of the Temperature field reconstruction and integration.

	Depth						
27 stations	1 m	5 m	10 m	15 m	20 m	40 m	60 m
Integrated Temperature	429816	424577	410761	379751	310395	133424	99059
Area of interpolation (km^2)	51844	51206	49833	48116	45026	37431	27810
Mean of the interpolated field	8.291	8.292	8.243	7.892	6.894	3.565	3.562
Integrated Temperature standard deviation	23375	22795	21689	19517	44063	15118	10878
Area of interpolation (km^2)	51844	51206	49833	48116	45026	37431	27810
Mean standard deviation	0.451	0.445	0.435	0.406	0.979	0.404	0.391
8 stations	1 m	5 m	10 m	15 m	20 m	40 m	60 m
Integrated Temperature	422503						
Area of interpolation (km^2)	51844						
Mean of the interpolated field	8.150						
Integrated Temperature standard deviation	32895						
Area of interpolation (km^2)	51844						
Mean standard deviation	0.634						
4 stations	1 m	5 m	10 m	15 m	20 m	40 m	60 m
Integrated Temperature	431582						
Area of interpolation (km^2)	51844						
Mean of the interpolated field	8.325						
Integrated Temperature standard deviation	36384						
Area of interpolation (km^2)	51844						
Mean standard deviation	0.702						

Table A8. Results of the chlorophyll *a* fields reconstruction and integration.

	Chl 0_10	Chl 10_20	Chl 0_20
Mean of the interpolated field (mg/m^3), 31 stations	2.169	2.111	2.140
Mean standard deviation (mg/m^3), 31 stations	0.416	0.672	0.477
Mean of the interpolated field (mg/m^3), 8 stations			2.172
Mean standard deviation (mg/m^3), 8 stations			0.498
Mean of the interpolated field (mg/m^3), 4 stations			2.198
Mean standard deviation (mg/m^3), 4 stations			0.503

Appendix 2. Optimum analysis

1. Basis

Notations and assumptions

Consider a realization of a random scalar field $C(\boldsymbol{r})$ at an arbitrary point with point-vector $\boldsymbol{r} \in \boldsymbol{R}^3$ in the 3D space $\boldsymbol{R}^3$. Let the ensemble of the field be given then the realization can be represented as a sum of the mean and fluctuation,

$$C(\boldsymbol{r}) = \langle C(\boldsymbol{r}) \rangle + \psi(\boldsymbol{r}) \, , \tag{1}$$

where angular brackets $\langle \ \rangle$ denote statistical averaging. The measured value of the field $C^o(\boldsymbol{r})$ do not necessarily coincide with its true value $C(\boldsymbol{r})$. Let the deviation (noise) $\psi'(\boldsymbol{r})$ be random:

$$C^o(\boldsymbol{r}) = C(\boldsymbol{r}) + \psi'(\boldsymbol{r}) = \langle C(\boldsymbol{r}) \rangle + \psi(\boldsymbol{r}) + \psi'(\boldsymbol{r}) \, . \tag{2}$$

Correlation of random field and noise-to signal ratio of the data

Let the true fluctuation field and noise field be homogenous with zero averages, $\langle \psi(\boldsymbol{r}) \rangle \equiv 0$, $\langle \psi'(\boldsymbol{r}) \rangle \equiv 0$, and with constant variances denoted as $\langle \psi(\boldsymbol{r})^2 \rangle = \sigma^2$, $\langle \psi'(\boldsymbol{r})^2 \rangle = \varepsilon^2$. It is assumed that the noise is not correlated, $\langle \psi'(\boldsymbol{r}_a)\ \psi'(\boldsymbol{r}_b) \rangle = 0$, where $\boldsymbol{r}_a \neq \boldsymbol{r}_b$, so is not the noise with the true fluctuation field, $\langle \psi'(\boldsymbol{r}_a)\ \psi(\boldsymbol{r}_b) \rangle \equiv 0$. Denote the measured fluctuation through the sum of the true fluctuation and the noise, $\psi^o(\boldsymbol{r}) = \psi(\boldsymbol{r}) + \psi'(\boldsymbol{r})$, and assume that the correlation of the true fluctuation field exists,

$$\tau(\boldsymbol{r}_a, \boldsymbol{r}_b) = \frac{\langle \psi(\boldsymbol{r}_a)\ \psi(\boldsymbol{r}_b) \rangle}{\sigma^2} \, . \tag{3}$$

Proceeding from the introduced notions notations and assumptions the correlation of the measured fluctuation field is the following:

$$\mu(\boldsymbol{r}_a, \boldsymbol{r}_b) = \frac{\frac{1}{\sigma^2}\langle \psi(\boldsymbol{r}_a)\psi(\boldsymbol{r}_b) \rangle + \frac{1}{\sigma^2}\langle \psi'(\boldsymbol{r}_a)\psi'(\boldsymbol{r}_b) \rangle}{1 + \frac{\varepsilon^2}{\sigma^2}} = \frac{\tau(\boldsymbol{r}_a, \boldsymbol{r}_b) + \eta^2 \delta(\boldsymbol{r}_a, \boldsymbol{r}_b)}{1 + \eta^2} \, , \tag{4}$$

where $\eta = \dfrac{\varepsilon}{\sigma}$ is the noise-to-signal ratio and the Kronecker symbol $\delta(\boldsymbol{r}_a, \boldsymbol{r}_b) = \begin{cases} 1 & \\ 0 & \end{cases}$, for $\begin{matrix} \boldsymbol{r}_a = \boldsymbol{r}_b \\ \boldsymbol{r}_a \neq \boldsymbol{r}_b \end{matrix}$. Assuming the true correlation τ continuous function, the measured correlation function μ has, according to (4), the first order discontinuity at the point $\boldsymbol{r}_a = \boldsymbol{r}_b$.

2. Reconstruction (interpolation) of the random field

Let there be n observations $C^o(\boldsymbol{r}_i) \equiv C_i^o$ measured at locations with point-vectors $\boldsymbol{r}_i\ , i = 1,2,\ldots,n$. The task is to estimate the fluctuation field value $\tilde{\psi}_k$ at an arbitrary point $\boldsymbol{r}_k$ as a linear combination of observed values,

$$\tilde{\psi}_k = \sum_{j=1}^{n} p_{k\,j}\ \psi_j^o\ , \tag{5}$$

where coefficients $p_{k\,j}$ are determined from n extreme conditions for the error variance of estimate $\tilde{\psi}_k$:

$$\frac{\partial \left\langle \left(\psi_k - \tilde{\psi}_k\right)^2 \right\rangle}{\partial\, p_{k\,j}} = 0 \quad , \quad j = 1,2,\ldots,n\ . \tag{6}$$

Therefore extreme conditions (6) are equivalent to the derived from them set of n linear equations for coefficients $p_{k\,j}$,

$$\sum_{j=1}^{n} p_{k\,j}\ M_{ji} = \frac{T_{k\,i}}{1+\eta^2} \quad , \quad i = 1,2,\ldots,n\ , \tag{7}$$

where $T_{k\,i} = \tau(\boldsymbol{r}_k, \boldsymbol{r}_i)$ is the matrix of coefficients of the true fluctuation field correlation between values at points $\boldsymbol{r}_k$ and $\boldsymbol{r}_i$ and $M_{ji} = \mu(\boldsymbol{r}_j, \boldsymbol{r}_i) = \left(T_{ji} + \eta^2 I_{ji}\right) / \left(1+\eta^2\right)$, where I_{ji} is unit matrix, is the matrix of coefficients of the measured fluctuation field correlation between all measurements.

If coefficients $p_{k\,j}$ are determined by (7), the linear estimator (5) becomes optimal in the sense of the least squares,

$$\tilde{\psi}_k = \frac{1}{1+\eta^2} \sum_{i=1}^{n} T_{k\,i} \sum_{j=1}^{n} M_{i\,j}^{-1}\ \psi_j^o\ , \tag{8}$$

where $\boldsymbol{M}^{-1}$ is the inverse of $\boldsymbol{M}$.

3. Reconstruction error

The most powerful tool of the approach, the relative error variance of the linear estimate (8) is

$$\left\langle \left(\psi_k - \tilde{\psi}_k\right)^2 \right\rangle = \sigma^2 + \sigma^2 \sum_{j,i} p_{kj} p_{ki} \left(T_{ji} + \eta^2 I_{ji}\right) - 2\,\sigma^2 \sum_j p_{kj} T_{jk} \ .$$

Accounting for $\sum_{j=1} p_{kj} \left(T_{ji} + \eta^2 I_{ji}\right) = T_{ki}$, we get

$$\left\langle \left(\psi_k - \tilde{\psi}_k\right)^2 \right\rangle = \sigma^2 + \sigma^2 \sum_i p_{ki} T_{ik} - 2\,\sigma^2 \sum_j p_{kj} T_{jk}$$

and further, replacing p_{ki} from (7),

$$\left\langle \left(\psi_k - \tilde{\psi}_k\right)^2 \right\rangle = \sigma^2 + \sigma^2 \frac{1}{1+\eta^2} \sum_{ij} T_{kj} M_{ji}^{-1} T_{ik} - 2\,\sigma^2 \frac{1}{1+\eta^2} \sum_{ji} T_{ki} M_{ij}^{-1} T_{jk}$$

.

Therefore, the variance of the relative reconstruction error,

$$E_k^2 = \frac{\left\langle \left(\psi_k - \tilde{\psi}_k\right)^2 \right\rangle}{\sigma^2} = 1 \ - \ \frac{1}{1+\eta^2} \ \sum_{i,j=1}^{n} T_{kj} \ M_{ji}^{-1} \ T_{ik} \ , \qquad (9)$$

depends only on the data noise-to-signal ratio and on the correlation function of the fluctuation field. It does not depend on the measured values. The maximum possible value of E_k^2 is 1. The second term on the right of (9) expresses additional information provided by measurements and reduces the reconstruction error of the fluctuation field.

Annex 7: Current Eastern Baltic coastal ecosystem projects

INTERREG IIB Project BALANCE

BALANCE is one of the larger-scale joint projects funded by the EU, involving eight countries and over 20 different partners. The overall aim is to establish a basis for sustainable marine spatial planning, making use of available information about this unique environment.

The Baltic Sea area, which as well as the Baltic proper includes the Skagerrak, Kattegat, Gulf of Bothnia and Gulf of Finland, constitutes a unique and sensitive ecosystem, affected by and of concern to a wide range of stakeholders. To achieve sustainable development and safeguard the special marine natural assets of the region, cooperation needs to take place across both national and sectoral boundaries.

Cooperation to ensure sustainable use of the Baltic

Under the EU-funded BALANCE project ('Baltic Sea Management – Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning'), the aim is to develop tools that will ensure long-term sustainable use and management of the Baltic Sea, Kattegat and Skagerrak.

Among other things, this involves collecting, making available and harmonizing existing data on the marine environment, but also using these data to develop methods to identify marine areas requiring protection. As part of the project, the concept of 'blue corridors' is also to be developed, the marine equivalent of green corridors on land, i.e. areas linking protected sites.

BALANCE was launched in the autumn of 2005, and one of its agreed milestones is to have a portal for marine data available on the project web site by the beginning of 2006. The project as a whole is expected to be completed in December 2007.

Five work packages

The BALANCE project as a whole is coordinated by the Danish Forest and Nature Agency. It comprises five component parts, or work packages:

Work package 1 is concerned with creating a platform for the data on which subsequent work will be based, and with harmonizing the data available, i.e. ensuring that different types of data from different sources and countries can be used together. Examples of relevant data include information on biology, benthic characteristics and currents. The aim is to set up a portal for marine data relating to the Baltic Sea on the BALANCE project web site.

SGU is the lead partner for this work package.

Work package 2 is focused on mapping marine landscapes and habitats. The aim is to assemble documentation for use in marine spatial planning and nature conservation. This documentation may for example include uniform maps of key spawning and nursery areas for fish, data on habitats for threatened species of vascular plants and algae, and more general maps showing distribution patterns of specific groups or communities of both animals and plants.

This work is headed by the Geological Survey of Denmark and Greenland (GEUS).

Work package 3 aims to develop the concept of 'blue corridors', i.e. the marine equivalent of green corridors, and to evaluate the existing network of marine protected areas. Another goal is to develop a method to identify a representative network of areas requiring protection in the Baltic Sea.

The responsible partner for this work is WWF Sweden.

Work package 4 is primarily concerned with developing strategies and tools to achieve sustainable and coordinated marine spatial planning in the region. These strategies and tools are intended to be of use to all stakeholders, including not only regional and local authorities, but also companies and organizations, in planning, protection and management of the marine environment.

The lead partner for this package is Metsähallitus Natural Heritage Services, Finland.

Work package 5, finally, has the aim of enhancing public awareness of the unique marine environment and natural resources of the Baltic, Kattegat and Skagerrak. This is to be done by disseminating and communicating the results emerging from BALANCE.

Here, Denmark's National Forest and Nature Agency is the lead partner.

Pilot areas

BALANCE is concerned to a large extent with coordinating and using existing information. In four pilot areas representing different habitats in the Baltic Sea area, for which good descriptions are already available, the information collated will be supplemented with field studies. The aim is to obtain a more detailed picture of the different habitats. The four areas are the Skagerrak and Kattegat, the Bornholm Basin, the area between Stockholm, the Åland Islands and Finland, and the Gulf of Riga.

EU LIFE project: Marine Protected Areas in the Eastern Baltic Sea

The project aims mainly at supporting the designation of marine protected areas according to Natura 2000 criteria in Estonia, Latvia and Lithuania. For this purpose we will investigate the proposed sites and research their biological diversity. Later management plans and maps shall be elaborated and recommendations for protections rules made.

The BALTIC MPAs project contributes to the overall objective of protection and sustainable use of marine biodiversity in the Eastern Baltic Sea (costal and offshore waters of Estonia, Latvia and Lithuania). In this context implementing the EU's Natura 2000 network in marine areas is a key instrument. The project aims at:

1) Completing the establishment of Natura 2000 in the marine territories of Estonia, Latvia and Lithuania (site selection, designation, protection rules and management plans)

2) Assessing and reducing the impact of fishery by-catch on target bird and mammal species.

3) Assessing and addressing other threats to marine Natura 2000 sites (e.g. caused by constructions /developments, disturbance of species by economic or recreational activities, pollution)

4) Increasing public and stakeholder awareness on Natura 2000, marine protected areas and biodiversity in general in Estonia, Latvia, Lithuania and Russia.

5) Promoting transboundary networking and capacity building on marine protected areas between the Baltic States, other EU Member States and Russia.

Project activities

- Inventories of marine species and habitats according to the Habitats and Birds Directives (birds, mammals, fish, and benthos habitats); completion of Natura 2000 data sheets; where necessary: delineation or adjustment of borders of marine SPAs or pSCIs, designation of new sites.
- Assessment of the impact of fishery by-catch, construction and dumping activities, disturbance and pollution on target species and habitats.
- Preparation of management plans for selected sites and general recommendations for protection and management of marine Natura 2000 sites.

- Pilot management activity: testing and promotion of alternative fishing methods and gear in order to reduce by-catch of birds and mammals of Community interest; facilitation of a network of fishermen and nature conservationists.
- Activities to raise the capacity of stakeholders to implement Natura 2000 and to increase stakeholders' and public awareness (workshops, media work, public events);

Annex 8: System production and respiration

Primary production in the Baltic proper during summer: The mutual dependence between system production and respiration

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Abstract

Primary production expressed as the maximum chlorophyll *a*-normalized rate of photosynthesis ($P^B{}_m$) was measured during two fortnight summer cruises in the Gotland Basin. The nutrients required for the photosynthesis was during both summer periods primarily based on local remineralisation (regenerated production) but differs none the less in their trophical nature. $P^B{}_m$ was relative high and constant during the sunny and calm summer of the first year (about 6 g C g chl^{-1} h^{-1}) indicating primary production to be close its physiological limitation. The second year summer was cold and windy with $P^B{}_m$ varying from < 1 to > 5 g C g chl^{-1} h^{-1} indicating production to be mainly nutrient limited. Community respiration relative to gross production was twice as high during the warm summer compared to the cold summer. The relative higher heterotrophic activity the first year on one hand stimulates the primary productivity (higher $P^B{}_m$) on the other hand lowered the phytoplankton biomass. This was likely also the reason for the higher inorganic N and P concentration in the mixed layer in that year. A chlorophyll *a*-normalized rate of community respiration (CR^B) is suggested as overall indices of whether regenerated systems are nutrient limited or not. Apparently a CR^B above 2 g C g chl^{-1} h^{-1} indicated that heterotrophic remineralisation satisfies the nutrient requirements of the autotrophs.