Report on using autonomous measurements for monitoring and assessment in the sub-region

Prepared by MSI and SYKE

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Report on using autonomous measurements for monitoring and assessment in the sub-region

With contributions from GES-REG partners.

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1. Introduction

The purpose of this report is to chart the utilization of autonomous measurements for the purposes of monitoring and assessment compliant with the requirements of the Marine Strategy Framework Directive (MSFD) in the GES-REG project area, i.e. the Gulf of Finland, the northern Baltic Proper and the Gulf of Riga.

1.1 MSFD monitoring requirements

The main goal of the Marine Strategy Framework Directive (MSFD: 2008/56/EC) is to ensure the achievement of good environmental status by year 2020 in the marine areas under the jurisdiction of the Member States. Article 11 (1) requires that all Member States establish and implement monitoring programs based on the characteristics (Table 1) and pressures and impacts (Table 2) indicated in Annex III. The monitoring programs should also follow the specifications of Annex V. In addition, the monitoring programs should be compatible with the environmental targets and associated indicators established by the Member States under Article 10.

Furthermore, Article 11 (1;2) requires that the Member States sharing a region or a sub-region shall ensure consistency and comparability of the monitoring programs and methods used in order to facilitate comparability of results. Article 11 (2) further requires that transboundary impacts and features are also considered whilst establishing and implementing the monitoring programs.

Moreover, the monitoring programs shall build upon and be compatible with relevant provisions of European Union legislation, including Birds (BD: 2009/147/EC), Habitats (HD: 92/43/EMC), Water Framework (WFD: 2000/60/EC) and Environmental Quality Standards Directives (EQS: 2008/105/EC), Common Fisheries Policy (CFP: Council Regulation 199/2008 regarding data collection management and use on fishing sector) and international

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agreements, for example the Convention on the Protection of the Marine Environment of the Baltic Sea (1992).

1.2 Spatial and temporal coverage of monitoring

The MSFD applies to the marine waters under the jurisdiction and sovereignty of the Member States, potentially up to 200 nm (370.4 km) from the coast; however WFD and EQS only apply to 1 nm (1.8 km) from the coastline for the baseline monitoring and 12 nm (22.2 km) for surveying priority pollutants. The HD, BD and CFP apply to all marine areas where protected habitats and species occur and/or where fish populations under monitoring are found and fishery activities occur. Therefore, if not already done, it is necessary to extend the spatial coverage of the monitoring further out to sea, in order to cover all sea areas under jurisdiction of the Member States.

The MSFD itself does not define a suitable frequency for the monitoring activities. However, since the activities conducted within the framework of the MSFD should be reviewed and updated every six years, a minimum sampling frequency of once over that period might be suitable for some parameters. Zampuokas et al. (2012) recommend that the monitoring intervals should be indicator and parameter specific as some indicators require higher monitoring frequencies than others. In addition, other relevant EU legislation and international agreements, e.g. HELCOM, also provide recommendations regarding sampling intervals.

2. Existing autonomous measurement programs and systems

2.1 Baltic Operational Oceanographic System (BOOS)

The BOOS co-operation was formed in 1997 with the aim to promote and develop an operational oceanographic infrastructure including routine collection, interpretation and presentation of *in situ* and satellite data. This information is necessary in order to improve efficiency of marine operations, reduce risks for accidents, optimize monitoring of marine environment and climate, improve assessment of fish stocks and improve foundation of public marine management. At present BOOS has 19 members (institutes and agencies responsible for operational oceanographic services in all Baltic Sea countries) and 3 associated members. According to the Memorandum of Understanding signed by the BOOS members the goals and objectives of BOOS are to:

- Co-ordinate, harmonize and develop operational oceanographic observation, information and forecasting systems for the Baltic Sea;
- maintain real-time and near real-time exchange of observational data and forecasts among partners to increase the capability of the partners to do the best possible operational products serving societies;
- provide data and forecasts to protect the marine environment, conserve biodiversity and monitor climate change and variability;
- provide high quality data and long time-series required to advance the scientific understanding of the Baltic Sea;
- improve and further establish services to meet the requirements of environmental and maritime user groups;
- harmonize and increase the quality of user-oriented operational systems;
- optimize the production costs of public products and services by sharing the workload;
- co-operate with HELCOM and other relevant bodies with the aim to avoid duplication of work and to maximize mutual assistance.

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The BOOS comprises a network of active tide gauges, moored buoys, ferryboxes, fixed platforms and satellites for monitoring the physical and chemical properties of the sea water, (e.g. temperature, salinity, oxygen concentration, turbidity), concentrations of phytoplankton, waves, water level and sea ice. Information on different instruments and monitoring platforms operated by the members can be found at the BOOS website (www.boos.org). The data is available for all members in near real time via ftp boxes at member institutes and BOOS data portal (ftp.boos.org).

2.2 Ferryboxes

A detailed description of the ferrybox systems is given by Petersen et al. (2007). The ferrybox is an autonomous measurement, data logging and transmission system that operates continuously while the carrying ship is underway. Water is sampled from the surface layer (4–5 m depth) and it is circulated in the system with constant speed. There are sensors for measuring temperature, salinity, turbidity, phycocyanin and chlorophyll *a* (chl *a*) fluorescence. Samples for nutrient, chl *a*, and phytoplankton species composition analyses are collected using automatic refrigerated water samplers, which store the samples in cool and unlit conditions (e.g. Rantajärvi and Leppänen, 1994). In the Baltic Sea there are nine ship lines that are equipped with ferryboxes, eight of them (Fig. 1) under Alg@line consortium. One additional system was applied within the GES-REG project in 20013 along the Riga-Stockholm ferry line. Most of the flow-through data gathered via those systems is available to BOOS members and water sample data through the framework of Alg@line, which connects the institutions employing ferryboxes, to the members of this consortium.

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Figure 1. Ship lines equipped with ferrybox system within the Algaline framework (image by Seppo Kaitala)

2.3 Moored buoys and fixed stationary platforms

BOOS maintains a system of coastal stations and tide gauges. In many those stations also water temperature, salinity and/or other parameters are measured (see at ww.boos.org). Data is delivered in real time via ftp boxes of member institutions.

There are several moored buoys and fixed platforms in the Baltic Sea. Moored buoys and fixed platforms are used for measuring physical, chemical, meteorological and biological parameters (Karlson *et al*., 2009). Potential employment of navigational buoys as carriers of environmental sensors are also investigated and tested. In the present numerous navigational buoys are used for wave measurements. The possibilities for launching deep sea stations to measure physical and chemical parameters in the deep layers (either depth profiles or monitoring of the near-bottom waters) are looked and worked towards to.

Within the framework of BOOS it is planned to cover all the basins of the Baltic Sea with a network of fixed platforms and moored buoys (Lips *et al.*, 2010).

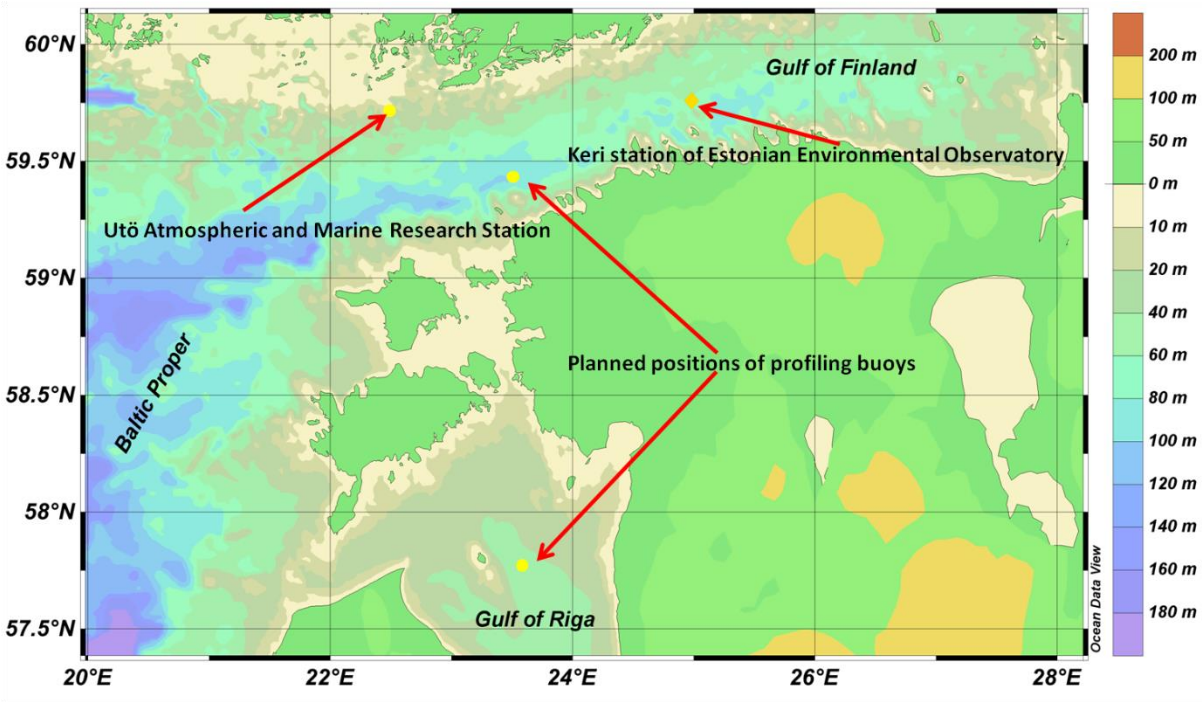

Figure 2. Location of existing and planned marine stations in the project area, which include devices for autonomous measurements from the entire water column and real time data delivery.

2.4 Floating profilers

Floating profilers drift at a predetermined specific "parking depth", where they are neutrally buoyant. It measures salinity and temperature at this specific depth, and surfaces every 10 days to send the data and location information via satellite. There is a global array of profilers belonging to the Argo network. (www.argo.ucsd.edu, 2012) Floating profilers are currently not very much employed in the Baltic Sea. The Finnish Meteorological Institute started testing ARGO floats in the Baltic Sea in 2011. In 2013 they have conducted successful almost 4 month lasting survey collecting vertical profiles of temperature, salinity and oxygen. SMHI had plans to employ floating profilers with chl *a* sensors (Karlson *et al.,* 2009).

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2.5 Gliders

Gliders glide through the water without a propeller due to byoancy control. They send data and fixes its position using GPS while at the surface. Gliders can be used for measuring salinity, temperature and chl *a*. (Karlson *et al.,* 2009) Tests to employ gliders have been carried out in the southern Baltic. There are planned testing of gliders in 2013 in the Bothnian Sea and Gulf of Finland by Finnish Meteorological Institute and in the Gulf of Finland in 2014 by Marine Systems Institute.

2.6 Remote sensing

The Swedish Meteorological and Hydrological Institute (SMHI) is using weather satellites equipped with AVHRR (Advanced Very High Resolution Radiometer) sensors to detect surface accumulation of cyanobacteria. The European Environmental satellite ENVISAT equipped with a MERIS (Medium Resolution Imaging Spectrometer) sensor was employed to measure sea surface temperature, chl *a* and turbidity (Karlson *et al*., 2009) until the end of its mission decleared on May 8 2012. MERIS sensor had a spatial coverage of 1150 km and a resolution of 300 m near nadir for the coastal areas (The World Data Center, 2013).

Most of the institutes in the region providing remote sensing products (e.g. SMHI, SYKE, EMI and MSI) have used MERIS sensor for sea surface temperature, chl *a*, turbidity and CDOM (coloured dissolved organic matter). At the moment MODIS is used by some institutes. The new Sentinel satellites including sensors for marine monitoring will be launched in 2014-2016.

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3. Pros and cons of autonomous systems

The selection of a suitable autonomous system or a combination of systems depends on the data and resolution required. Most of the systems can measure several parameters such as salinity, temperature, chl *a*, turbidity, etc., and transmit data in near real time. In addition, most of the systems have already been employed in the Baltic Sea which facilitates comparison with already existing datasets. All systems discussed above require a calibration of the sensors.

The advantages and disadvantages of different autonomous systems are summarized in Table 1. The ferrybox provides a good data coverage on a horizontal and temporal scale. The spatial coverage of the sensors are however limited to the ship route and do not allow vertical profiling of the water column. Contrarily, buoys and other stationary platforms are best suited for vertical profiling, whereas they lack horizontal coverage.

Gliders and floating profilers provide both good horizontal and vertical coverage and their movements are not restricted by the shipping route. However, they are dependent on the water mass movements and therefore cannot provide a long term data coverage of a pre-defined route or at a fixed point.

Remote sensing provides an excellent spatial and temporal coverage; however the measurements are restricted by the cloud and ice cover and can be distorted in the coastal areas due to land vegetation and water turbidity. Moreover, it can only measure parameters that are optically detectable, such as temperature, chl *a* and other pigments. In addition, the data needs verification by other methods.

All compared systems display advantages and disadvantages (Table 1), however, when combined, a comprehensive data coverage is achieved. This is also emphasized by Karlson and others (2009), who propose that employment of a combination of autonomous systems allows the acquisition of data with high spatial and temporal coverage, the verification of different monitoring systems against another, and increases the precision of models.

Table 1. Pros and cons of autonomous systems based on GES-REG expert opinion (partly from Karlson *et al.,* 2009)

System	Ferryboxes	Buoy profilers stationary platforms	Floating profilers	Gliders	Remote sensing
Pros					
High temporal resolution	+	++	++	++	+
High horizontal resolution	+			+	++
High vertical resolution		+	++	++	
Large spatial coverage	+			+	++
Cover entire water column		+	++	++	
Multi-parameter	++	++	++	++	+
Water sampling	++				
Real time data delivery	++	++	++	++	++
Validation of other systems	+	+	+	+	
No energy restriction	++	+			
Available experience	++	++	+		+
Low cost of investment	+	+			
Low cost of maintenance	++	+	+		
Cons					
Fixed position or route	–	– –	–		
No data from sub-surface	– –				– –
Depending on external availability of platform/data	–				–
Biofouling of sensors	–	–	–	–	
Requires additional sampling for calibration		–	– –	–	– –
Depending on weather			–	–	– –
Risks of loss or damage		–	– –	– –	

4. Case study: monitoring Estonian marine waters in terms of descriptor 5 (eutrophication) under the MSFD

The aim of this section is to demonstrate the possibilities of different systems exemplified by monitoring eutrophication (descriptor 5 under the MSFD) in one water body during a year, as well as to compare the expenses related with employing the various systems. In addition, this chapter hopefully demonstrates the potential for co-operation in terms of fulfilling the commitments under the MSFD and other international agreements as well as reducing the overall cost of monitoring.

Monitoring data for most of the indicators can be collected by employing a research vessel (Table 2). In addition to data for the indicators listed in Table 2, all monitoring methods provide background information (salinity, temperature) for interpreting the data, however only ferryboxes and an autonomous buoys provide continuous near real time datasets with high temporal and spatial (horizontal or vertical) resolution. Therefore, different monitoring methods complement each other by providing sufficient resolution and by allowing measurements of parameters for various indicators.

In Table 3 the yearly cost of monitoring by employing different systems is shown. The calculations are based on the costs of monitoring Estonian marine waters in terms of descriptor five (eutrophication) under the MSFD. Those three systems are compared as they are available for monitoring in Estonia. Currently, the research vessel is mainly used for activities required by the national marine monitoring programme. In addition, part of the data collected by ferryboxes on the routes Tallinn–Stockholm and Tallinn–Helsinki is used for open sea monitoring. Furthermore, the ferrybox data is uploaded to a database, where it is available to all the institutions, which have joined the Alg@aline network. Measurements taken by the operational buoy are currently not used for the purposes of the national monitoring program, however these data are planned to be included in the program in the coming years.

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Table 2. Local indicators for monitoring eutrophication (descriptor 5 under the MSFD) covered by the methods applicable when using autonomous systems and research vessels for monitoring.
± indicates that monitoring is in principle possible, but may be affected by ice cover (winter measurements with research vessel and buoy) or may lack temporal resolution (measurements of dissolved oxygen in the near bottom layer with the research vessel); – indicates that the parameters for the indicator are not measurable with the system

Indicators	Ferrybox	Buoy/stationary platform	Research vessel
Total nitrogen concentration during summer	✓	–	✓
Total phosphorus concentration during summer	✓	–	✓
Dissolved inorganic nitrogen concentration during winter	✓	–	±
Dissolved inorganic phosphorus concentration during winter	✓	–	±
Chl *a* concentration during summer	✓	✓	✓
Phytoplankton biomass during summer	✓	–	✓
Water transparency / turbidity during summer	✓	✓	✓
Dissolved oxygen in near bottom layer	–	✓	±
Macrozoobenthos	–	–	✓
Phytobenthos indicators	–	–	–
Background information (e.g. temperature, salinity, currents to account for water masses movements, upwelling events, mixing etc)	±	±	±

During 2012 the research vessel was commissioned to make six cruises in order to fulfill national monitoring requirements. Four of them were during the growth season, i.e. the time period from early spring to autumn, when temperature and light favor primary production. However, the proposed sampling frequency did not cover all months during the

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growth season, causing gaps in the data regarding e.g. phytoplankton blooms and community structure. Therefore, it was put forward that the number of cruises should be increased from six to eight. In addition, employment of autonomous systems to complement the existing sampling strategy has also been discussed.

Table 3. A comparison of the costs of monitoring Estonian marine waters in terms of descriptor five (eutrophication) under the MSFD, by research vessel, ferrybox system and buoy (or other stationary platform).

Expenses	R/V - 6 cruises	R/V - 8 cruises	Increase in monitoring costs	Ferrybox	Buoy/stationary platform
Ship cost per day (incl. VAT)	2 400	2 400			
Samplings per year	6	8		365 / 12	960 / 6
Ship/system cost per year	**72 000**	**96 000**	**24 000**	**12 000**	**20 400*** **
Number of open sea stations	20	20		4	1
Number of samples per year*	480	640		48	24
Cost of full sample analysis**	200	200		200	200
Analyses costs per year	**96 000**	**128 000**	**32 000**	**9 600**	**4 800**
Total expenses per year	**168 000**	**224 200**	**56 000**	**21 600**	**25 200**

* for R/V and buoy station, the number of samples is calculated as number of samplings multiplied by 4 discrete samples

** only analyses costs for nutrients, Chl *a* and phytoplankton are counted

*** the yearly costs include maintenance costs and expenses for 6 samplings (ship time costs)

Increase in monitoring costs from six to eight cruises is presented in Table 3. The expenses related to the employment of a ferrybox and autonomous buoy are also shown. The cost of the R/V and autonomous systems are not included to the yearly expenses in order to compare the systems only by the costs related to the monitoring of a water body. Moreover, as the systems can also be used for other purposes besides fulfilling national monitoring requirements the cost of purchasing the systems should be divided equally by all different activities.

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Based on the Table 3 the monitoring expenses increase with a total of 56 000 euros per year, when the number of cruises is raised from the current six to the suggested eight per year. The maintenance costs of a ferrybox system are about 12 000 euros per year and the additional analyses costs depend on the number of samples (4 samples 12 times per year are used in the estimate). For the profiling buoy the yearly maintenance costs are taken 12 000 euros and expenses of 6 R/V days is added taken that sampling for calibration is needed. If adding sample analyses costs (4 samples 6 times per year) for those maintenance and ship time costs then yearly running costs of a buoy station are 25 200 euros. Altogether adding 1 ferrybox and 1 buoy station increases the costs of monitoring by 46 800 euros. Thus, these costs are comparable to the increase in monitoring expenses if increasing the number of cruises from 6 to 8 cruises per year.

In this example, we have only considered one of the eleven MSFD descriptors, i.e. descriptor 5, eutrophication. Obviously, the ferrybox system and the buoy can be used for monitoring indicators under other descriptors of the MSFD. For example, autonomous buoys can be exploited for measuring underwater noise under descriptor 11. Pigment sensors in ferrybox systems can contribute to detecting distributional range and composition of photosynthetic species (descriptor 1) as well as trends in abundance of functionally important selected groups/species (descriptor 4). Additionally, both systems can measure physical and chemical properties of the sea water, which can be used as background information for several descriptors. Therefore, employment of autonomous systems instead of increasing the number of cruises will augment the monitoring data and allow monitoring of several indicators under different descriptors of the MSFD. However, it is clear that for many purposes the most appropriate monitoring method is and will be the measurements and sampling using research vessels.

This case study was conducted only on the basis of Estonian information on monitoring activities and costs related to open sea eutrophication monitoring. This approach was chosen since the costs in neighbouring countries could differ in large ranges. However, the conclusion would be similar for other countries as well. In order to increase the confidence of assessment results one should have data with good enough temporal resolution and spatial coverage. By using only research vessels it is not possible to increase resolution and coverage without very large increase in expenses. Thus, autonomous observations (by ferryboxes, buoys etc.) will increase the amount of data quite remarkably while the increase of costs are not high. The best approach would be if the autonomous systems will be used jointly by sharing the investment and maintenance costs.

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5. Co-operation options, conclusions and recommendations

Co-operation between the Baltic Sea countries is already supported and facilitated by the existing networks and policies such as BOOS, HELCOM, Alg@line and MSFD that support knowledge and data sharing, joint investments and consistent monitoring methods. In addition, collaboration between the states supports meeting the environmental protection commitments made under international agreements as well as compliance with monitoring requirements on both national and international levels.

Ideally, monitoring activities in the central and north-eastern sub-regions of the Baltic Sea, i.e. the Gulf of Finland, northern Baltic Proper, and Gulf of Riga, should be jointly organized to optimize the monitoring costs, exchange knowledge and establish compatible monitoring methods. Collaboration can be also facilitated through joint investments to new ferrybox routes, buoys and other stationary platforms and floating devices such as gliders. Jointly owned systems would allow efficient data collection with lower investment and maintenance costs. A prerequisite for this would be open data sharing in near real time between the institutes and monitoring agencies from different countries.

Ferryboxes are already in place collecting data from EEZ and territorial waters of neighbouring countries. Similar approach is natural when using drifting profilers and gliders. However, easy permit application procedures should be agreed between the countries.

Employment of new autonomous equipment, shared datasets, and uniform monitoring methods will increase the amount and precision of data as well as decrease the cost of monitoring. Higher spatial and temporal coverage provides more accurate information on the condition of the Baltic Sea, thereby contributing towards achieving the good environmental status.

Besides of autonomous *in situ* measurements close collaboration is needed also in the field of remote sensing. Similarly to co-operation in *in-situ* observations and modelling for operational oceanography products (e.g. as set in the Memorandum of Understanding of BOOS and HIROMB agreement) the co-operation in the field of remote sensing would be beneficial. In the recent past (until MERIS data was available) several institutes provided similar products. It would be advisable to divide responsibilities in development of new products after Sentinel satellites will be in operation. Production must be supported by algorithm development, ground truth measurements and operational commitments from different institutes.

Suggestions for a coordinated program

- collaboration and joint investments in the ferrybox systems (Riga–Stockholm, the St. Petersburg line);
- joint investments in the network of autonomous buoys (both unattended measurements and laboratory analyses of samples);
- sharing of experience in using gliders and floating profilers (if tests are carried out nationally, information could be made available to other stakeholders);
- coordination of monitoring cruises for calibration and maintenance of the autonomous systems (sampling, replacement of batteries etc.)

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