KLAIPĖDA UNIVERSITY

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APPLICATION OF UNDERWATER REMOTE IMAGERY AND ACOUSTIC DATA FOR QUANTITATIVE BENTHIC BIOTOPES IDENTIFICATION, PREDICTIVE MAPPING AND BUILDING OF EXPLANATORY MODELS

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The dissertation is available at the Library of the Klaipėda University.

Table of Content

1. Introduction

1.1 Relevance of the thesis

Remote sensing methods in recent decades play an increasingly important role in sea bed researches. In hard bottom environment and depths not reachable by SCUBA divers the remote sensing is the only practical method to obtain quantitative benthic biological data (Christie, 1983). Underwater imagery became a standard tool in benthic ecology (Solan et al., 2003), while acoustical surveys data is intensively used for sea bed mapping (McRea et al., 1999; Kostylev et al., 2001; Lurton, 2002; Brown et al., 2002, 2004a, 2004b; Pickrill & Todd, 2003; Allen et al., 2005; Riegl & Purkis, 2005; Roberts et al., 2005; Mayer, 2006; Brown, 2007; Collier & Humber., 2007; Orlowski, 2007; Freitas et al., 2008; Lindenbaum et al., 2008; Walker et al., 2008; van Overmeeren et al., 2009; Greenstreet et al., 2010; Quintino et al., 2010). Advanced remote sensing methods made possible large-scale coastal zone mapping programs aimed at full high resolution coverage mapping of exclusive economic zones of some maritime nations in Europe (Norway MAREANO; Irish National Seabed Survey, INFOMAR), including the Baltic Sea (The Finnish Inventory Programme for the Underwater Marine Environment, VELMU), North America (The California Coastal Mapping Program), and many more in other marine regions of the World. Similar works are being performed in the Lithuanian Exclusive Economic Zone, mostly by the Lithuanian Maritime Safety Administration (LMSA) and Marine Science and Technology Center of Klaipėda University (MARSTEC), although these activities are not yet combined in a framework of a program coordinated at the national scale.

Mapping programs generate huge amount of high resolution imagery and acoustical data. However the biological information that usually is extracted from underwater imagery is much less than actually exists in the collected data (Cuvelier et al., 2012). Similarly, acoustical data which collection is very expensive and requires significant efforts often is not used to its full potential (e.g. Brown et al., 2011). Importance of the more though use of the already collected data became more widely understood on various levels of the society, what resulted, for example, in a House Bill called “Map It Once, Use It Many Times” submitted into USA congress in April 17, 2013 by Congressman Doug Lamborn (https://www.govtrack.us/congress/bills/113/hr1604), calling for an overhaul of federal geospatial data collection and management, in light of the wasteful duplication of mapping efforts across US federal agencies.

Consequently, the demand for new, more efficient ways to deal with the remote sensing data is growing, especially in the light of increasing human pressure on marine environment (Halpern et al., 2008; Katsanevakis et al, 2011; Foley et al., 2010). The remote sensing data can be and should be innovatively used for none traditional applications, such as fast and accurate detection of changes in benthic communities, evaluation of natural stock conditions, habitat diversity assessment, etc., that are essential for proper coastal zones management (e.g. Levin et al., 2009; Francis et al., 2011). Combining underwater imagery as source of biological information with acoustical surveys, that providing full coverage data on physical properties of the environment, allows getting deeper understanding of the processes in the benthic environment, deriving complicated and non-evident interactions between biotic and abiotic parts of the ecosystems (Brown et al., 2011).

In this study underwater remote sensing data was used for quantitative identification of benthic biotopes, for building explanatory models in order to formulate potential wind park impact hypotheses on key benthic species in the Norwegian Sea rocky bottom environment and for predictive mapping of the Baltic Sea herring spawning grounds. A new semi-automatic method for benthic cover estimation has been developed and tested to address some gaps existing in manual underwater imagery analysis methods in use today.

1.2 Objectives and main tasks of the study

The aim of this study is to develop and explore procedures of using underwater remote imagery and acoustic data for quantitative identification of benthic biotopes, predictive mapping and building of explanatory models.

The following tasks were raised for this work:

1. Assess performance of different manual underwater imagery analysis methods with different benthic features types and operators experience.
2. To compare newly developed semi-automatic underwater imagery analysis method with point-based manual method in terms of accuracy, reliability and cost effectiveness.
3. To perform and assess a quantitative identification of benthic biotopes in coastal and offshore areas of the Lithuanian part of the Baltic Sea from the underwater video using developed formalized procedure.
4. To build explanatory models deriving preferences of key benthic species at the exposed cost of the Norwegian Sea with geomorphology in order to identify their significance and to formulate grounded impact hypotheses.
5. To derive factors driving distribution patterns of the Baltic herring spawning grounds in the Lithuanian coastal area, using geomorphological analysis of bottom profiles and probability map based on acoustical survey data built with Maxent model.

1.3 Novelty of the study

This study explores new approaches in the use of remote sensing data. A new semi-automatic color-based benthic cover estimation method using video mosaics have been developed and compared with the traditional point-based manual method. The proposed method is more objective and accurate than the traditional one because it uses much larger proportion of collected imagery (potentially, up to 100%

of the imagery can be used). For the first time the impact hypotheses of a planned wind farm on extremely exposed rocky shore were formulated based on explanatory models build on underwater remote sensing data. A high resolution (20x20 meters) predictive map of the Baltic herring spawning grounds was built for a Lithuanian coastal area based on SCUBA diving field surveys in combination with remote sensing data in order to provide new insights on the spawning grounds distribution. A new workflow for the quantitative benthic biotopes identification based on underwater video analysis had been proposed and tested in the Lithuanian part of the Baltic Sea.

1.4 Scientific and applied significance of the results

The results of this study broaden the applicability of underwater remote sensing methods in benthic ecology. The proposed semi-automatic colour-based benthic cover estimation from video mosaics method can be used for scientific and environmental monitoring programs. The results of the comparative analysis of different underwater imagery processing methods could assist in choosing a proper video analysis method for practical applications. The analysis of remote sensing data from the extremely exposed Norwegian Sea rocky shore expanded our knowledge about preferences of several key-species in terms of local bottom geomorphology. The analysis of bottom profiles in a spawning area of the Baltic herring and high resolution (20x20) predictive map helps to clarify why the spawning grounds are repeatedly being found in the same coastal locations, the fact which was documented (but not explained) in many previous studies.

1.5 Defensible statements

1. A newly developed semi-automatic benthic cover estimation method based on video mosaics has better accuracy, consistency and reliability than manual treatment method compared.

2. Benthic biotopes in the coastal and offshore areas can be quantitatively identified from the underwater video using proposed formalized approach.

3. The integration of environmental data derived from multibeam bathymetry and underwater imagery in the Generalized Additive Models can be used for formulation of grounded hypotheses on environmental impact from construction and exploitation of the wind park on the key-benthic species at the extremely exposed rocky coast.

4. Geomorphological analysis of bottom profiles and probability map built with Maxent model based on acoustical and SCUBA divers survey data provided the insight into driving factors behind the distribution of the Baltic herring spawning grounds: local elevations are playing a major role.

1.6 Scientific approval

Results of this study were presented in 9 international and 4 Baltic Sea regional conferences and seminars:

3rd scientific-practical conference „Marine and coastal researches – 2009“, Nida, Lithuania, April 2009;

8th international symposium “GeoHab 2009”, Trondheim, Norway, May 2009;

4rd scientific-practical conference “Marine and coastal researches – 2010”, Palanga, Lithuania, April 2010;

5th International Student Conference: Biodiversity and Functioning of Aquatic Ecosystems in the Baltic Sea Region, Palanga, Lithuania, October, 2010;

10th International symposium “Geohab 2011”, Finland, Helsinki, May, 2011;

World Conference on Marine Biodiversity, Aberdeen, UK, September, 2011;

Seminar at Faculty of Natural Sciences and Mathematics, Klaipėda University, Klaipėda, Lithuania, October, 2011;

IEEE/OES Baltic 2012 International Symposium, Klaipėda, Lithuania, May, 2012;

6th international student conference „Aquatic environmental research“, Palanga, Lithuania, October, 2012;

MAREANO: International workshop on seabed mapping methods and technology, Trondheim, Norway, October, 2012;

7th scientific-practical conference „Marine and coastal researches – 2013“, Klaipėda, Lithuania, April, 2013;

International conference WinMon.BE 2013: Environmental impact of offshore wind farms. Brussels, Belgium, November, 2013;

International Conference on Wind power and Environmental impacts, Stockholm, Sweden, February 2013.

The material of this study was presented in 5 original publications, published in peer-reviewed scientific journals and books:

Schläppy M-L., **Šaškov A.**, Dahlgren T. G. ***2014***. Impact hypothesis for offshore wind farms: explanatory models for species distribution at extremely exposed rocky areas. Coastal Shelf Research. Vol. 83 pp. 14-23.

Šaškov A., Šiaulys A., Bučas M., Daunys D. ***2014***. Spawning grounds of the Baltic herring, *Clupea harengus membras* L. at the Lithuanian coast: current status and shaping factors. Oceanologia. Vol. 56 (4) pp. 789-804.

Šaškov A., Dahlgren T. G., Rzhanov Y., Schläppy M-L. ***Accepted, in press***. Comparison of manual and semi-automatic underwater imagery analyses for monitoring of benthic hard bottom organisms at offshore renewable energy installations. Hydrobiologia.

Dahlgren T. G., Schläppy M-L., **Šaškov A.**, Andersson M., Rzhanov Y., Fer I. ***2014***. Assessing impact from wind farms at subtidal, exposed marine areas. In Marine Renewable Energy and Society. Ed. by M. A. Shields. Springer, Dordrecht. pp. 39-48.

Šaškov A., Olenin S. ***2012***. Use of remote underwater video survey for quantitative analysis of benthic biotope features and their identification Integrated study of the bottom landscapes in the White Sea using remote methods. In: Proceedings of the Pertsov White Sea Biological Station. V.11. Editors: V.O. Mokievsky, V.A.Spiridonov,

A.B.Tzetlin, E.D.Krasnova. Moscow, KMK Publish House, pp. 46-55 (in Russian).

1.7 Thesis structure

The dissertation includes eight chapters: introduction, literature review, material and methods, results, discussion, conclusions, references and technical annex. The material is presented in 140 pages, 43 figures and 19 tables. The dissertation refers to 201 literature sources. Dissertation is written in English with an extended summary in Lithuanian language.

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1.9 Abbreviations

Abbreviation	**Explanation**
AUC	Area Under Curve (statistical term)
BPI	Benthic Position Index (geomorphic descriptor variable)
CTD	Conductivity, Temperature, Depth (hydrographical probe type)
EDRA	Encrusting Dark Red Algae (benthic feature)
ERBL	Erect Red and Brown aLgae (benthic feature)
GAM	Generalized Additive Model (statistical model type)
GPS	Global Positioning System (positioning system)
MaxEnt	Maximum Entropy (statistical model type)
ROC	Receiver Operating Characteristic (statistical term)
ROV	Remote Operated Vehicle (underwater equipment type)
RTK	Real-Time Kinematic (GPS operational mode)
SSS	Side Scan Sonar (sonar type)
SVP	Sound Velocity Profiler (hydrographical probe type)
USBL	Ultra Short Base Line (underwater navigation system type)

2 Literature analysis

2.1 Benthic biotopes

2.1.1 Concept of benthic biotopes in benthic ecology and marine management

In recent decades, an ecosystem based management of marine areas gaining increasing recognition over traditional space based management (Halpern et al., 2008; Foley et al., 2010; Katsanevakis et al., 2011). Despite some difficulties reported implementing this approach (Arkema et al., 2006; Tallis et al., 2010), theoretical and practical concepts are continue to develop (Levin et al., 2009; Francis et al., 2011), and conception of benthic biotopes is an important tool for the ecosystem based management of marine ecosystems (Olenin & Ducrotoy, 2006; Brown et al., 2011).

Number of biotope classification systems appeared in the last few decades: marine biotope classification for Joint Nature Conservation Committee (JNCC) in Great Britain (Connor et al, 2004); Zones Nationales d'Interet Scientifique, Faunistique et Floristique (ZNIRFF) classification in France (Dauvin et al., 1996); Europe Nature Information System (EUNIS) (EUNIS, 2010); regional international classification of the benthic biotopes and their complexes in the Baltic Sea region (HELCOM, 1998, 2013), etc. Similar works had been taking place in Lithuania (Olenin et al., 1996; Olenin, 1997; Olenin & Daunys, 2004). Despite successful examples of practical use of the conception, some theoretical questions regarding it still remain unanswered and raise discussions. For example, how to distinguish an elementary biotope (a mapping unit) and how to define biotope borders. Two different hypotheses about biotopes borders are currently dominating: one state that biotope is usually well-defined spatially, containing a biotope core and a narrow strip on the border with other biotopes, which is called ecotone (Smith & Smith, 1975; Martin et al., 2011). Species richness in ecotone is higher than in neighbour biotopes. Another hypothesis state that biotopes, do not have well defined borders, and there is a single continuum where one biotope gradually pass into another (Naumov, 1991).

2.1.2 Methods used to distinguish biotopes

According to the task and work scale different methods can be used for biotopes identification. To quickly distinguish biotopes only few characterized features could be used. Those might be biological features (set of specific species, their density, etc) and/or physical (Babkov & Golikov, 1984; HELCOM, 1998; 2013; Connor et al., 2004). For practical purposes, when abiotic and biotic features of biotopes are already known, biotopes matrices can be created (Olenin et al., 1996).

When biotope classification system contains large quantity of different biotopes, they could be combined into larger groups forming a hierarchical classification system (Connor et al., 2004; EUNIS, 2010; HELCOM, 2013). Biotopes groups can be formed based on different principles: bottom substrate, key-species or geographical boundaries. Other approaches also could be used: for example, biogeographic division due to the differences in the water masses (Babkov & Golikov, 1984), based on Helland-Hansen temperature (T) and salinity (S) curves analysis (Helland-Hansen & Nansen, 1927 cit. from Babkov & Golikov, 1984).

In the last several decades multivariate statistical methods become common for the benthic biotopes identification. The first biotopes classification system developed using multivariate statistical methods was BioMar (Hiscock & Connor, 1991). For data analysis TWINSPAN and DECORANA software were used (Mills, 1994). Later those methods were adapted in PRIMER software (Clarke & Warwick, 1994). Very similar approach was used creating Marine Habitat Classification for Britain and Ireland (Connor et al., 2004). This is a large scale system, and to deal with a great amount of data during multivariate statistical analysis, field samples were *a priori* divided into smaller groups using substrate as a dividing factor. At the first stage of the analysis, those groups were processed separately, distinguishing groups of similar samples within them. To avoid artificial division, on the second stage of the analysis distinguished similar sample groups are compared, to see if they really different. After that identified biotopes properties are described using groups biotic and abiotic properties (Connor et. al., 2004).

Slightly different approaches are being used by geographers and biogeographers in underwater landscapes studies. Their understanding of "biotope" term is closer to classical Dahl interpretation (Dahl, 1908): biotope is only a physical environment which is inhabited by a biocenosis (Arzamaztcev & Preobrazhenskij, 1990). Therefore in their studies almost all attention goes to the physical features, biological features are used only for verification and as indicators of impact (natural or anthropogenic) on the biotope (Arzamaztcev & Preobrazhenskij, 1990).

In Klaipeda University the marine benthic biotopes were studied since 1993 (Olenin & Labanauskas, 1994; Olenin et al., 1996; Olenin, 1998), and presently a marine benthic habitats research conception had been developed. From first descriptive works is moved to the quantitative benthic biotopes research (Olenin & Ducrotoy, 2006) with wide use of modern underwater survey methods (e.g. Bučas et al., 2007).

2.2 Underwater remote sensing methods: imagery and acoustic

2.2.1 Underwater imagery in benthic ecology

The first photo camera for underwater use was created by French zoologist Louis Boutan in 1892, and from the forties of 20 century underwater photography was routinely used for scientific purposes (Heezen & Holister, 1971). With the development of video techniques, amount of information that can be received from underwater imagery had been greatly increased. The first documented usage of television equipment underwater was during "Operation Crossroads", the first USA nuclear bomb testing after Hiroshima and Nagasaki bombardments. Testing was conducted on Bikini Atoll in 1946 ("Baker" Shot). First scientific paper based on underwater television was published in 1952 (Barnes, 1952). Further developments in this field were promoted by studies of the optical properties of the sea (Duntley, 1963), resulting into better understanding of underwater video limitations, leading to better quality of underwater video materials and/or better methods for colours correction (Gasparini & Schettini, 2004). Nowadays underwater imagery consists of large variety of still images and video records.

With technological advances video equipment become more reliable and widely available, and nowadays underwater photo and video are common tools used by benthologists all over the world (Solan et al., 2003). Various types of imaging equipment have been developed: hand-held diver operated video and photo cameras, remote video such as drop-down and sledged systems, video or/and photo equipped ROV (Davies et al., 2001) and AUV devices (Griffiths, 2002). Regardless of system construction, underwater video allow to cover significant bottom areas: tenths, hundreds or even thousands of square meters. This allows seeing a larger scale patterns, overcoming a long known shortcoming of traditional benthic sampling methods, recognized even by the first benthic grab developer (Peterson, 1913).

In many cases underwater imagery is used just for groundtruthing. For example, underwater video was used to verify data about certain animals or plants distribution distinguished from aero photo (Roob et al., 1998; McMath et al., 2000) or to verify SCUBA divers bottom descriptions (Lindenbaum et al., 2002; Roberts et al., 2004). But also there are examples when underwater imagery is used as a primary research method, such as the long term Great Barrier Rife survey (Cristie et al., 1996).

2.2.2 Qualitative and quantitative approaches to the imagery analysis

Quantitative parameters estimation from the video could be quite challenging (White et al., 2007), therefore often visual information analysis is based solely on the expert judgment. By the end of 20 century several methods for more objective quantitative video analysis were proposed (Magorrian & Service, 1998). One of them was named RVC, or Rapid Visual Count (Kimmel, 1985; Michalopoulos et al., 1992). It has been a subject to unknown amount of systematic errors, because “weight” points used in it are depending on many casual factors (DeMartini & Roberts, 1982). To increase accuracy another method, called VFC or “Visual Fast Count” was proposed (Kimmel, 1985). Comparing VFC and RVC methods with SCUBA divers surveys was determined that VFC results are closer to SCUBA divers survey descriptions comparing with RVC (Michalopoulos et. al., 1992). Both VFC and RVC methods share common shortage, video profiles are divided by time, not by distance. Because of that, filming process need to be strictly standardized, or segments might be not comparable, especially when data coming from different places. Due to the technical difficulties strict filming standardization is not always possible, and now RVC and VFC methods are not used often. When they do, additional means are used to ensure that not only duration of video profiles are the same, but their length also. In number of studies a distance was used as a dividing factor, instead of time (Shucksmith et. al., 2006; Rooper & Zimmerman, 2007).

There are no universal and widely accepted methods for quantitative benthic cover estimations from underwater imagery. Most common methods existing today involve quadrant (which can be replaced with single frames from the video) sampling (Greig-Smith, 1983; Sutherland, 2006), with benthic cover estimation using manual point-based analysis (Carleton & Done, 1995; Foster, 1991; Leonard & Clark, 1993; Meese & Tomich, 1992), grid projections (Benedetti-Cecchi et al., 1996; Fraschetti et al., 2001; Bussotti et al., 2006; Virgilio et al., 2006) or region based percentage estimation (Garrabou et al., 1998; Garrabou et al., 2002; Teixidó et al., 2002; Pech et al., 2004). Various software tools exist to aid some or several of those approaches (Kohler & Gill, 2006; Teixidó et al., 2011; Trygonis & Sini, 2012; etc.).

To make analysis of large datasets easier and more objective, there were attempts to automate benthic features estimation using computer techniques. Unfortunately those methods still have limited capabilities and can be applied only to estimate very specific features (Vincent et. al., 2003; Zhanga et al., 2005; Ferrini et. al., 2006; Correia et. al., 2007; Jerosch et. al., 2007; Guinan et al., 2009; Lüdtke et al., 2012).

2.2.3 Acoustical data in benthic ecology and associated difficulties

In the last decades, as modern acoustical equipment became more widely available, number of acoustical surveys was increasing rapidly, providing researches with wide scale surveying data (Hughes Clarke et al., 1996; Lurton, 2002; Mayer, 2006; ICES, 2007; Anderson et al., 2008). Various echosounders (single beam, multibeam and Side Scan Sonars (SSS)) are being used for seafloor characterization for different tasks, including mapping and discrimination of benthic biotopes (Kenny et al., 2003; Brown et al., 2011). Number of studies had shown that there is a strong connection between physical seabed characteristics, which could be derived from acoustical data, and biological features (Collins et al., 1996; Hamilton et al., 1999; Preston et al., 1999; Preston, 2001; Anderson et al., 2002; Ellingsen et al., 2002; von Szalay & McConnaughey, 2002).

Type of acoustical data, generally used for benthic features mapping, is a backscatter data derived either from singlebeam sonars (Lurton, 2002; Riegl & Purkis, 2005; Brown, 2007; Orlowski, 2007; Freitas et al., 2008; Lindenbaum et al., 2008; Walker et al., 2008; Greenstreet et al., 2010; Quintino et al., 2010), side scan sonars (Blondel & Murton, 1997; McRea et al., 1999; Huvenne et al., 2002; Brown et al., 2002, 2004a, 2004b; Allen et al., 2005; Collier & Humber, 2007; van Overmeeren et al., 2009;) or, more increasingly, multibeam sonars snippets (Kostylev et al., 2001, 2003; Pickrill & Todd, 2003; Roberts et al., 2005; Mayer, 2006).

Various acoustical data analysis methods are used for seabed classification (Greenstreet et al., 1997; Hamilton et al., 1999; Kloser et al., 2001; Anderson et al., 2002). One of the oldest, is manual interpretation by an expert, when boundaries between different sediment types or other kind of benthic zones are derived “by eye” (Brown et al., 2002; Nitsche et al., 2004, 2007; Conway et al., 2007; Greene et al., 2007; Cook et al., 2008). Lately, automatic classification methods have been emerged (Ehrhold et al., 2006; Brown & Collier, 2008; Lucieer, 2008; van Overmeeren et al., 2009). Automatic backscatter data analysis methods could be broadly divided into two large groups: image based (Cochrane & Lafferty, 2002; Ojeda et al., 2004; Hühnerbach et al., 2007; Lucieer, 2007; Ierodiaconou et al., 2007; Yeung & McConnaughey, 2008; Marsh & Brown, 2009; Simons & Snellen, 2009; Blondel & Gomez Sichi, 2009; Rattray et al., 2009) and signal based (van Walree et al., 2005; Fonseca & Mayer, 2007; Brown & Blondel, 2009; Fonseca et al., 2009; Lamarche et al., 2011). Signal based classification methods have greater potential comparing with image-based, because some particularities of the seabed acoustic response that are defined by roughness, grainsize, compaction and slope (Lurton, 2002), are not available when using image-based methods. Unfortunately, this also means that signal-based classifications cannot be used effectively with widely available SSS data (where slope and beam angle are unknown), only with singlebeam and multibeam sonars data (Preston, 2001; Brown et al., 2011).

Side Scan Sonar systems are relatively simple, comparing with multibeam systems, but their performance depend on the sonar head altitude over the bottom (which makes mounting type (hull mounted or towed body) an important factor) and hydrological conditions. Side Scan Sonar data resolution consist of two physical resolutions: transversal (perpendicular to track) and axial (along the track) (Lurton, 2002). Because of the angular nature of the SSS acoustical signal, they both are range dependent: the greater the range the lower the resolution. For towed body scanning range depend on the sonar fish altitude. In the relatively big study areas, with significant depth gradients, maintaining constant altitude of a passively towed device during the whole survey is extremely difficult. Therefore, an actual physical resolution of the collected data is varying in the unknown way.

3 Materials and methods

3.1 Underwater imagery

3.1.1 Filming procedures and data collected

3.1.1.1 Baltic Sea, coastal area

Drop-down type remote underwater video system (for more details, *see Technical annex*) was used for video data collection. The filming was arranged into video transects, during which the underwater unit was descended vertically on the rope and hovered over the bottom. The altitude above the bottom was constantly monitored from the video stream and regulated manually, to ensure video quality and equipment safety, usually within 0.5 – 1 meter above the bottom. During the procedure a boat drifted freely. Because the underwater unit was descended vertically and hovered freely, it position did not differ from the position of the control unit with GPS antenna for more than GPS accuracy error (according to the used GPS module specifications, 5-15 meters). Video transect duration was ca. 3 minutes and the distance covered, calculated from GPS coordinates, varied between 14 and 121 meters (average 41 meter). Transects were assembled into profiles, majority of them at the same traverse to the shore. In total, 202 video transects connected into in 37 video profiles were made during 2006-2007 in the Lithuanian coastal area of the Baltic Sea covering depth range from 2 to 20 meters (Fig. 1).

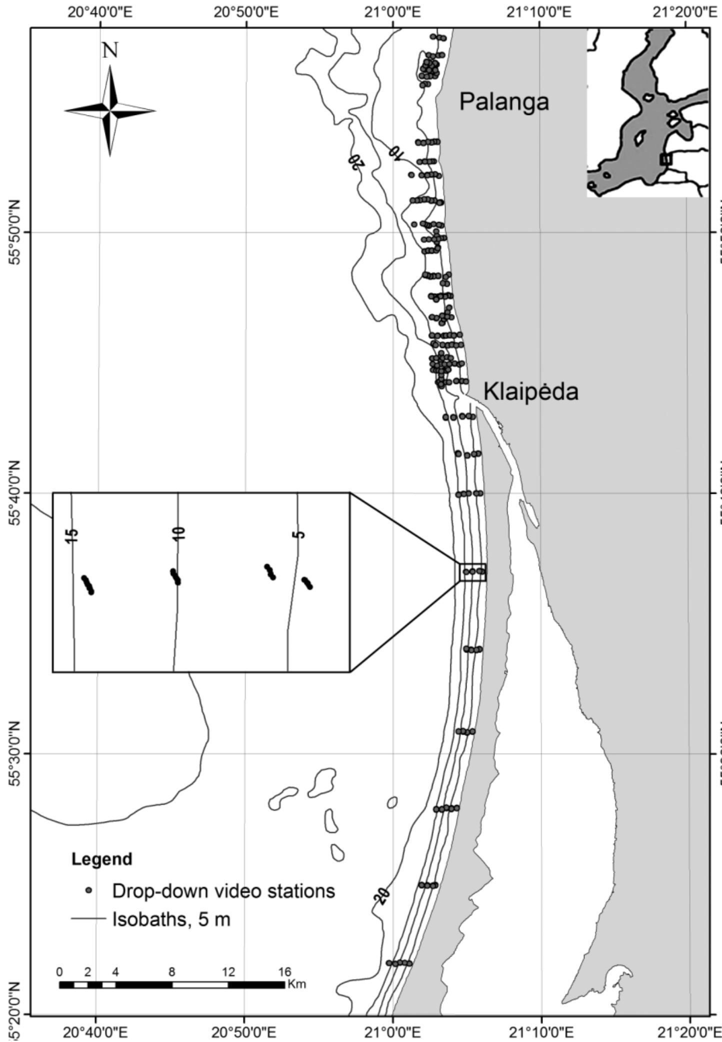

Figure 1. *Location of video transects and according video profiles filmed in the Lithuanian coastal area of the Baltic Sea using drop-down video system. Black square in top right shows location of the study area. Black box in the centre are video transects along the profile zoomed in.*

3.1.1.2 Baltic Sea, offshore area

Mariscope ROV (for more details, *see Technical annex*) was used for filming. Same as before, the filming was arranged into video transects. The transect direction was chosen randomly according to the direction which the remotely operated vehicle (ROV) happen to be facing after descent and was maintained using the internal compass readings. ROV altitude above the bottom (in range of 0.5-1 meters) had been chosen by scientific camera image to ensure maximum imagery quality and maintained using acoustical altimeter readings. The ROV speed during the filming was 1-2 knots, and did not depend on the external factors. The scientific camera shutter speed was manually fixed at 1/250, therefore no frames blurring appeared at this speed. The scientific camera had been set into progressive scan mode to avoid interlace artefacts (Keith, 1996) and fullHD resolution video was recorded into camera internal storage. The video signal from the navigation camera in real time was transferred to the surface and was recorded as 720x576 DV video. Additionally, screen content of the control computer was logged into video files providing with synchronized data from navigation camera, altimeter, ROV USBL navigation, ship navigation, ROV depth sensor and internal compass. Duration of video transect was ca. 5 minutes covering approx. 150 meters.

The system was used in 2013 for the offshore operations in the Baltic Sea, where 30 video transects were filmed in three study areas (North, South and West) at the depth range from 30 to 60 meters (Fig. 2).

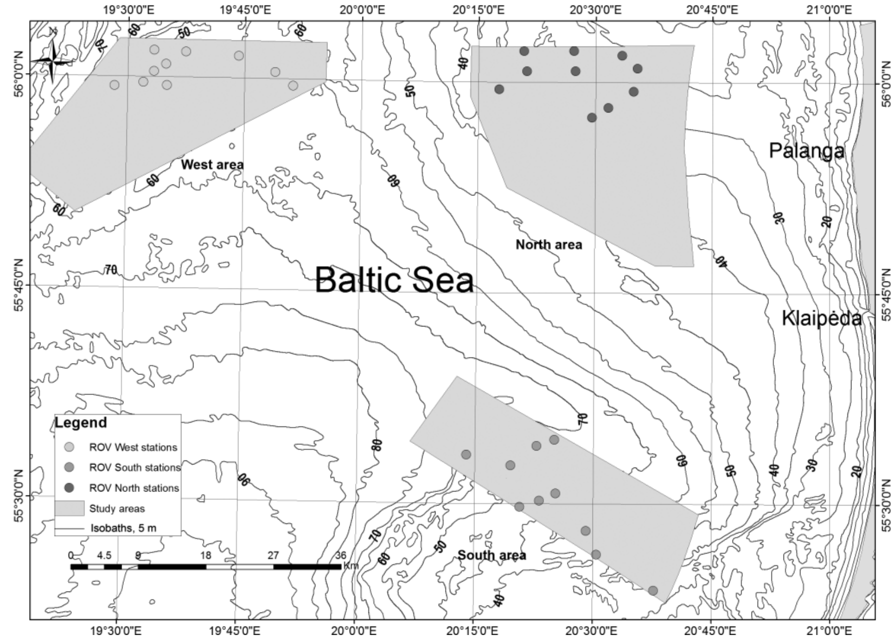

Figure 2. *Offshore study areas in the Baltic Sea. Video transects positions filmed with Mariscope ROV are shown with dots.*

3.1.1.3 Norwegian Sea

Medium class Argus ROV (for more details, *see Technical annex*) was used for data collection. The filming was arranged into 200 meters long video transects (Fig. 3). The design used for video collection was stratified haphazard, meaning that transects were all carried out along a depth range (min. 21 m – max. 37 m) but the start of each transect was placed haphazardly (i.e. not truly randomly) on the rocky substratum (for more details see: Shlappy et al. 2014). Real time video streams were observed on the monitors on board of the vessel and the HD video was recorded. The speed of the ROV was maintained between 1-2 knots. The study area is characterized by strong currents, even on calm days, and some variability in the ROV's speed and altitude were unavoidable.

Data was collected during 2010 and 2011 season in the Norwegian Sea, at the location of planned wind farm called Havsul, near town of Alesund. Video was collected in two areas: Control (C) and Impact (I) (Fig. 3). For the 2011 season the USBL navigation data from 2010 was used as guide, therefore video was collected from the same locations. Collected video was used in two separate studies. In the first study, semi-automatic benthic coverage estimation, four video transect (two from the (I) area and 2 from (C) area) filmed in 2010 and repeated in 2011 were used (8 in total). For the second study, building of explanatory models, twelve video transects filmed in 2010 in the (I) area were used (Fig. 3). In total, 18 video transects from Havsul video data set were used.

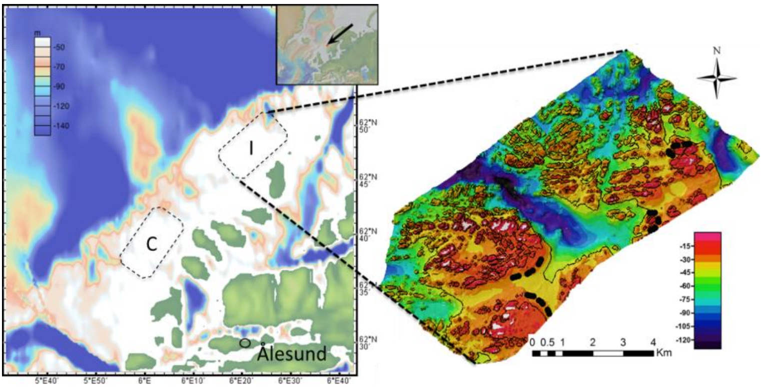

Figure 3. *Study area in the Norwegian Sea. Bold black lines are Argus ROV video transects. Narrow black lines are 20 and 40 meters isobaths.*

3.1.1.4 Benthic macrofauna samples for ground truthing

In the Baltic Sea coastal area, in addition to video profiling, the benthic makrofauna samples were collected from the number of locations with the same GPS coordinates as of the video transects (Fig. 1). On soft bottoms samples were collected with a 0.1 m^2 Van-

Veen grab, on hard bottoms samples were taken by SCUBA divers using a 20*20 cm frame (Kautsky, 1993).

All samples were fixed in 4% formalin solution, soft bottom samples were sieved through 0.5 mm mesh. The samples were treated under a binocular microscope (magnification up to 80x); animals were identified to species or higher taxonomic level where practicable; for example, such groups as oligochaets and chironomides were identified to class or family. Biomass was determined as formalin wet weight (g/m^2).

From hard bottom 102 benthic makrofauna samples from 32 locations were collected by SCUBA divers (on average, 3-4 samples from one location) and from soft bottoms 29 Van-Veen grab samples were collected from 29 locations. All samples were treated in the benthic laboratory of MARSTEC, Klaipėda University, by Andrius Šiaulys and Martynas Bučas, who kindly shared those results with the author.

In the benthic makrofauna samples from hard bottom 25 animal species and higher taxons were identified. In samples from soft bottom 16 animal species and higher taxons were identified. Some identified animals were found in both sample sets, but some were unique for only hard or soft bottoms (Tab. 1).

Table 1. Macrofaunal species and higher taxons identified from the benthic makrofauna samples in the Lithuanian coastal area of the Baltic Sea.

Phylum, class	Hard bottom, SCUBA divers samples	Occurrence, %	Soft bottom, Van-Veen grab samples	Occurrence, %
Plathelmintes	*Planaria sp.*	37,5 %		
Nemertini	*Nemertini. sp*	18,8 %		
Nemathelmintes, Priapula			*Halicryptus spinulosus*	6,9 %
Anellida, Polyhaeta	*Fabricia sabella*	87,5 %		
	Harmothoe sarsi	18,8 %	*Harmothoe sarsi*	3,4 %
	Hediste diversicolor	78,1 %	*Hediste diversicolor*	31,0 %
	Marenzelleria	59,4 %	*Marenzelleria*	93,1 %

	viridis *Pygospio elegans*	28,1 %	*viridis* *Pygospio elegans*	86,2 %
			Streblospio	24,1 %
Anellida, Hirudinea	*Pisciola geometra*	3,2 %		
Oligochaeta	*Oligochaeta*	31,3 %	*Oligochaeta*	34,5 %
Arthropoda, Crustacea	*Balanus improvisus*	100 %	*Balanus improvisus*	3,4 %
	Bathyporeia pilosa	15,6 %	*Bathyporeia pilosa*	37,9 %
	Corophium sp	93,6 %	*Corophium sp*	27,6 %
	Crangon crangon	3,1 %		
	Gammarus sp	96,9 %		
	Idothea balthica	43,8 %		
	Jaera albifrons	56,3 %		
	Mysis sp	6,3 %		
	Praunus inermis	6,3 %		
			Ostracoda	3,4 %
Arthropoda, Insecta	*Chironomidae*	34,4 %	*Chironomidae*	3,4 %
	Diptera sp. larva	3,1 %		
Mollusca	*Hydrobia sp.*	71,9 %	*Hydrobia sp.*	27,6 %
	Macoma balthica	15,6 %	*Macoma balthica*	31,0 %
	Mya arenaria	71,9 %	*Mya arenaria*	37,9 %
	Mytilus trossulus	100 %	*Mytilus trossulus*	3,4 %
	Theodoxus fluviatilis	71,9 %		

3.1.2 Analysis of underwater imagery

3.1.2.1 Tools and software

For the raw video handling commercially available non-linear video editing software Sony Vegas (http://www.sonycreativesoftware.com/) was used. This software allows browsing the video stream forward and backwards, in fast and slow motion, frame by frame, splitting, measuring of video segment duration with accuracy 1/25 of the second, extracting and saving individual frames, etc. Some tasks related with video editing (video format conversion, video resizing, video cropping, etc.) were performed using freely available VirtualDub (http://www.virtualdub.org/) software. Individual frames and video mosaics processing was done using commercially available image editing package Adobe Photoshop (http://www.adobe.com).

3.1.2.2 Video samples

To make video data sets more manageable for the analysis and to ensure accuracy of benthic features estimations the raw video transects were divided into video samples. In this study, a video sample was defined as a short video segment, derived using time or distance: for drop-down videos, where vessel was drifting freely distance was used, for ROV videos, where filming platform had moved uniformly, time was used as dividing factors. The length or duration of video samples was chosen empirically to be long enough for represent essential properties of a biotope and, on another hand, to be convenient for manual treatment of the samples. Typically it was 20 meters when chosen by distance and 15-30 seconds when chosen by time. Such time laps are well below the upper limit of human focused attention abilities, and this insures accuracy of estimations, especially when only few features needed to be estimated in one pass (Deutsch & Deutsch, 1963). For drop-down videos, where video samples were derived by distance, sometimes their duration was more than 30 seconds, and hence accuracy of the manual treatment could be compromised. In order to compensate for this, drop-down video samples were additionally divided into three sub-samples. In such cases, sample properties was calculated as either mean value of the sub-samples (for quantitative features) or as cumulative value (for qualitative features).

3.1.2.3 Video mosaicing of underwater imagery

Video mosaicing is a process of converting video sample into a single still image containing overlapping video frames (Fig 4).

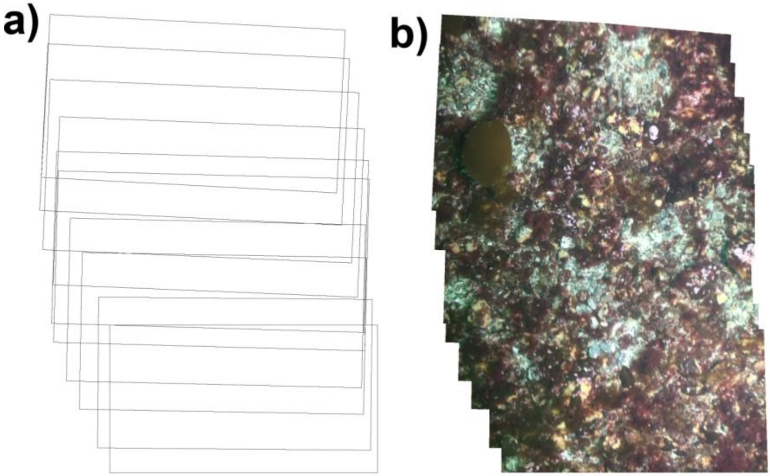

Figure 4. *Example of overlapping frames outline (a) and resulted video mosaic (b).*

Advantages of video mosaics include that practically all video data is used in the still image (frames that are dropped out do not contain additional information, that is not present in overlapping frames). In addition, each feature appears on the mosaic only once, in contrast to raw video, where each object appears several times, on different overlapping frames. In this study, a video mosaicing method developed by the Centre for Coastal and Ocean Mapping, National Oceanic and Atmospheric Administration was used (Rzhanov et al., 2004). The process of video mosaicing contained several steps:

1. Raw video was divided into 30 sec segments (video samples). During this process frame rate and frame size were reduced

to eliminate interlace artifacts (Keith, 1996) and to shorten computing time.

2. Filming platform roll and pith were compensated.

3. Each frame was enhanced using specific video enhancing algorithms, provided by mosaicing software developer (Rzhanov et al., 2004).

4. Frame to frame pair-wise registration was performed for enhanced video

5. Video mosaics were built from non-enhanced video using pair-wise registration data from previous step.

Frame to frame pair-wise registration success is directly dependent on the imagery quality: if details on image are poorly recognizable (due to blur, insufficient lights or other factors), registration is more likely to fail. In this case neighbouring frames could be registered manually. This gave some kind of proxy evaluating imagery quality. If the number of pairs that failed to register were more than 10, the video segment was considered of too poor quality and mosaic was not built. This number had been chosen empirically: single mosaic contain 150 frames, therefore ten pairs (20 frames) makes more than 10% of the imagery, which is considered by us as a significant amount.

3.1.2.4 Criteria for identification of visual features

Based on the reviewed literature (Kimmel, 1985; Michalopoulos et. al., 1992; Marrigan & Servise, 1998; Samoilys & Carlos, 2000; Solan et. al., 2003; McDonald et. al., 2006; White et. al., 2007; etc) and our experience in using UW video for benthic researches (Olenin et al., 1996; Olenin, 1997; Olenin & Daunys, 2004; Bučas et al., 2007; Bučas et al, 2009) the following criteria were formulated for the selection of features suitable for description of bottom biotopes properties from underwater imagery (Tab. 2).

Table 2. Criteria for selection and scaling of visual features.

Principle	Explanation
Visibility	A feature should be visible and confidently identifiable from the imagery
Consistency	A quantitative feature should be confidently identifiable from all the data. Features that are not constant in all video materials should not be used as quantitative. However, in some cases they can be used as qualitative features
Reliability	Scaling of quantitative features should ensure their reliable estimation. It is better to reduce the scale than make incorrect assumptions
Representativity	A feature should represent certain environmental properties of biotope and should not be casual or random
Variability	Feature should vary within video data set. Features that are not changing (for example, if substrate type remaining the same in all imagery) should not be included in analysis

3.1.2.5 Absolute counts

Big benthic organisms, that could be distinguished visually, were counted to individuals, following widely used practices (Aronson et al., 1994; Vogt et al., 1997; Sweatman et al., 2001; Lejac & Ordmon, 2007; Dumas et al., 2009; Schläppy., et al. 2014). Counting was performed from the raw video samples or from video mosaics. When organisms are easily distinguished from the background (Fig. 5), this approach could be very accurate. However for more cryptic organisms their identification could be more challenging (Fig. 6), and subject to errors.

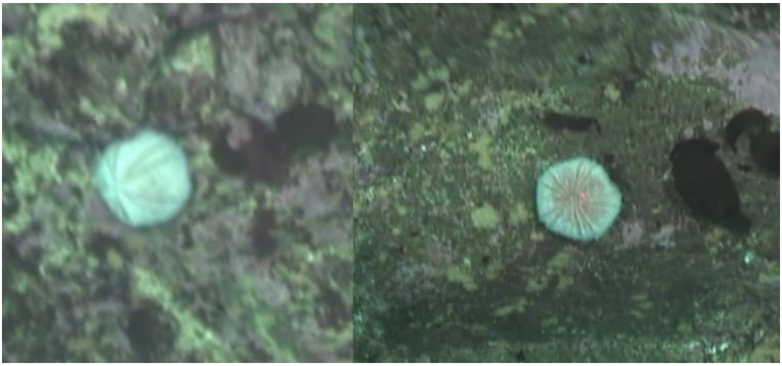

Figure 5. *Sea urchins (probably Strongylocentrotus sp.) from the Norwegian Sea underwater video.*

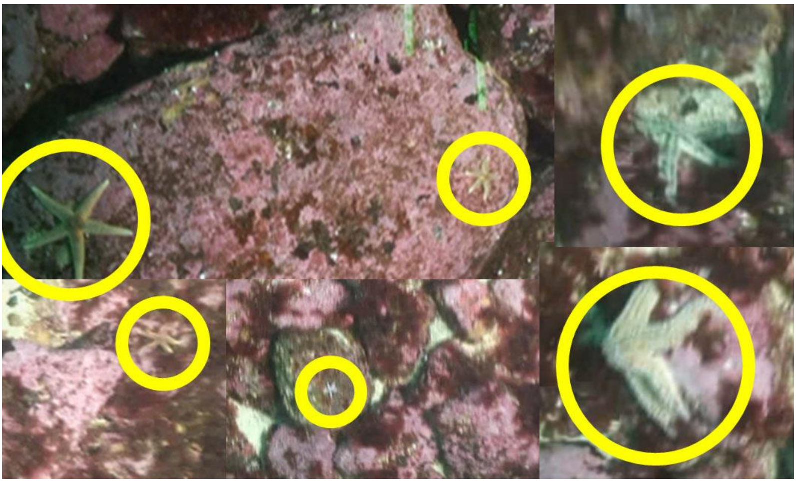

Figure 6. *Various seastars (marked with circles) from the Norwegian Sea underwater video.*

3.1.2.6 Benthic cover estimation approaches

Simple visual census method

For drop-down video system, where field of view of the camera is constantly changing due to the wave actions, simple visual census was deemed by us to be the most appropriate way to treat the data. Small colonial animals and algae were estimated visually from a raw video as cover with 10% accuracy for each of the sub-samples (for the sample properties average was calculated). Qualitative features were accounted as presence/absence in the sample (from 0 to 1) or for each sub-sample. For sample properties cumulative value (from 0 to 3) was used (for more detail see *section 3.1.2.2*). In some cases not animals themselves, but tracks of their activity (crawling tracks, burrowing, etc.) were used as a visual feature.

Manual point based video analysis approach

For the Norwegian Sea study case percentage estimates of benthic cover were assessed using the point-based method modified from Miller & Müller (1999). The 200 meters video transects were divided in 50 equal segments, making the average distance between the frames approximately 4 m. The video was stopped at each start of a segment and the screen that represents the segment start was used for cover estimation. Five fixed sampling points were placed on the screen and each sample screen was analyzed using those 5 points. Percentage cover was estimated by identifying which benthic cover was directly underneath the 5 sampling points on each sample-screen of the paused film (see Ohlhorst et al., 1988). We chose to use 5 points because this value was realistic in terms of manpower needed for the analysis and because this value was used by Miller & Müller (1999) and found appropriate to estimate benthic cover on a coral reef, an environment much more diverse than used in this work.

Full manual point-based analysis procedure was:

1. Select 5 points on the screen where you apply 5 empty squares which will serve to guide where to look for a benthic category. The squares are empty so that there is less confusion as to what

category of benthos is under them. The squares stayed on the screen in the same spot for all visual analyses.

2. Open the video.
3. Scroll to the desired video position, go frame-by-frame in order to select the frame that is of sufficient quality for the analysis (not blurred and with satisfactory colours, etc.).
4. Record the value under each point.
5. Repeat from step 2 once the video is finished (the same square on the screen are used for the next one).

Benthic covers that were possible to distinguish visually by an expert from the example imagery included:

1. *Lithothamniom* sp. encrusting algae
2. Red algae
3. Encrusting dark red algae (EDRA)
4. Sponge/bryozoans
5. Kelp
6. Sand
7. Stones
8. Bedrock

Semi-automatic method

Relatively high quality of the ROV underwater imagery from the Norwegian Sea allowed testing a new semi-automatic approach for benthic cover estimation. Raw video samples were converted into video mosaics and a computer aided semi-automatic colour-based approach (*sensu* Beuchel et al., 2010) was used to estimate benthic cover. Pixels of similar colours that belong to a certain benthic cover were extracted from the imagery (Fig. 7) that yielded the proportion of the extracted pixels to the total pixels in the image as a quantitative estimation of benthic cover.

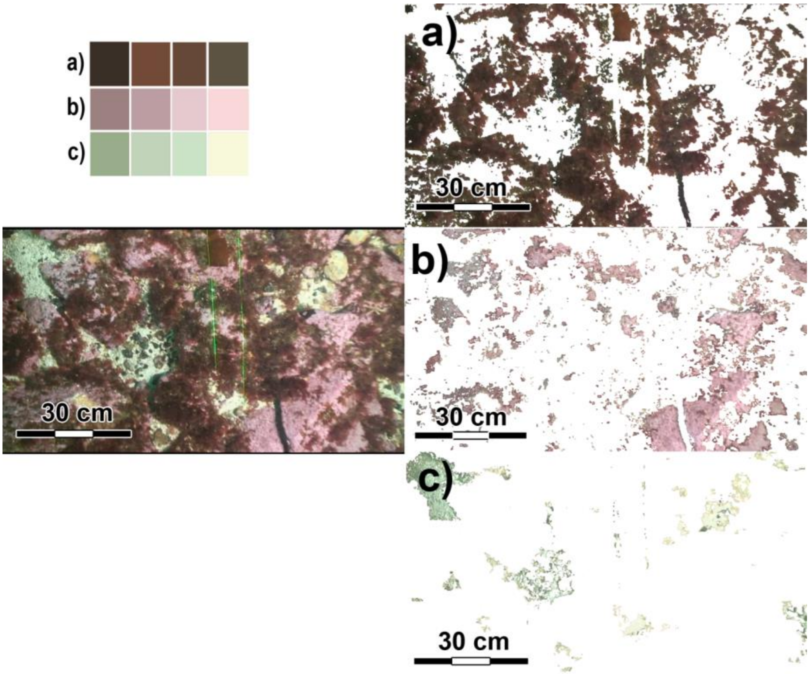

Figure 7. *Benthic covers extracted by pixel colours. Raw frame to the middle left; a) extracted erect red algae layer; b) extracted Lithothamnion sp. encrusting algae layer; c) extracted sand layer. In top left, simulated colour palettes used to extract according benthic cover layers.*

Because of the nature of the benthic cover features and imagery inconsistencies, a set of colours (e.g., a benthic cover colour palette, Fig. 7) was needed for consistent extraction by colour. The number of colours in different colour palettes that were used varied from 5 to 12, and was hand-picked until the selection results on test mosaics were satisfactory. Having all colour palettes in the same image-editing software workspace allowed to ensure that the colour palettes did not overlap; i.e., an individual palette colour could not be picked together with any other of palette colours.

Benthic covers were independently extracted, one at the time, rather than classifying every pixel in the image. A variety of graphic editing packages can be used to select and extract visual features by colour and to provide the count of extracted pixels. We used the Adobe Photoshop (http://www.adobe.com) “magic wand” tool in non-contiguous mode for benthic covers selection and Reindeer Graphics (http://reindeergraphics.com/) “Wide histogram” Photoshop plug-in for counting pixels. To ensure consistency and repeatability, the “magic wand” settings was fixed (tolerance set to 10) and the same benthic cover colour palettes were used throughout the analysis. Additionally, the order that colours were picked was fixed, always from the darkest to the brightest. This procedure ensured repeatability of results and made the analysis completely operator independent. Using Adobe Photoshop and WideHistogram plug-in, the full analysis procedure is:

1. Open the mosaic in Adobe Photoshop.
2. Select the background colour, inverse the colours, open WideHistogram and record the mosaic pixel count.
3. Paste benthic cover colour palettes into the open image, apply the colour palettes in appropriate order for the first feature.
4. Open WideHistogram, check the number of selected pixels, and record the values.
5. Repeat step 4 for all remaining benthic covers.
6. Close the mosaic, repeat the procedure by starting with step 1.

The human eye is a very powerful instrument in visual analyses and its performance exceeds by far the capacity of the semi-automatic approach used in this study. Therefore, the number of benthic cover types that could be reliably distinguished with a semi-automatic approach was less than those distinguishable with the human eye. Even with very careful and precise tuning of the colour selection tool and benthic cover colour palettes, erect red algae, EDRA and kelp produced colour overlaps. With slightly larger tolerances (that are necessary for the method to be applicable to a wide variety of video mosaics that contain colour inconsistencies), stones and bedrock selections included a significant proportion of erect red algae. The same problem was encountered with sand and sponge/bryozoanians. Considering this, benthic cover types suitable for semi-automatic estimations were chosen as:

1. Erect red and brown algae (ERBL). Cumulative value that contains the covers of red algae, EDRA and sometimes portions of kelp.
2. *Lithothamnion* sp. encrusting algae cover.
3. Sand cover. Cumulative value that contains sand and a significant proportion of the sponge/bryozoans cover.
4. Unidentified pixels. The difference between the sum of identified pixels and the total pixel count in the mosaic. The unidentified pixels count was used to evaluate the quality of the mosaic and of the analysis. Positive pixel count indicates that some pixels were not classified by any of the benthic cover colour palettes. The high positive pixel count usually indicates a high degree of inconsistency in the mosaic (part of image was poorly classified). To compensate for this inconsistency, all further cover calculations were made with the total classified pixels count used as 100%. Sometimes the unidentified pixel count was negative, which means that some of the pixels were counted more than once, e. g. an obvious indication that some of the features were overestimated. Mosaics with more than 8% negative unidentified pixel counts were considered unreliable and removed from the analysis.

Because selection results can be seen on a screen, it makes human supervision instantaneous and easy; i.e., the operator can immediately see if the segmentation is acceptable or not.

Inconsistency in data

Although all efforts were made to make the video images as uniform as possible during filming, some variations were unavoidable because even small changes in the altitude of the ROV resulted into noticeable changes in the colours of visual features. Such inconsistencies could significantly affect the performance of a colour-based approach. Moreover, different ROV pilots had different habits of flying the ROV, which resulted in systematic differences in the imagery between transects. To compensate for these differences, the video mosaics were visually divided into three different colours classes: colours class I, colours class II and colour class III (Fig. 8).

The differences between colour classes are represented by mean colour channels distribution in the sample segments. Colour class I with mean colour channels values 154 for Red, 118 for Green and 117 for Blue representing more or less natural colours in the artificial lights that were used. Colour class II with mean colour channels 68 for Red, 89 for Green and 81 for Blue representing images filmed from greater ROV altitude, resulted into reduction of the all colour channels, but especially Red (with have greatest absorption rate in the water). Colour class III with mean colour channels values 110 for Red, 112 for Green and 70 Blue most probably represent images that were filmed with ROV xenon bulbs not fully "warmed up", and therefore having different colour temperature, with reduced Blue channel.

Separate sets of benthic cover colour palettes were created for each class.

Figure 8*. Examples of the mosaic fragments that belong to different colour classes (from left to right: colour class I, II and III).*

Different benthic cover colour palettes, derived from different mosaic colour classes, were checked for overlap: a unique colour was not allowed to correspond to different benthic cover; e.g., a shade of red colour could be used as the proxy for ERBL on different classes of mosaics, but could not be the proxy for *Lithothamnion* sp. in any of them. Although it was a time consuming and subjective process, in the end we were able to select appropriate colour palettes for all benthic covers and mosaics colour classes.

3.1.2.7 Data for comparison of video analysis methods

Choosing the colour palettes for semi-automatic benthic cover estimation

Although the sensitivity settings of the colour picking tool and the order of the palette colours used to extract benthic cover could be easily standardized to completely eliminate operator bias, the benthic cover colour palettes themselves were chosen manually; therefore some degree of bias during this process was unavoidable. To test an error induced by manually chosen colour palettes, four randomly chosen video mosaics (Mosaic 1 to 4, see in *Results, 4.1.1*) were analyzed using sets of independently prepared 28 colour palettes for the ERBL and 28 colour palettes for *Lithothamnion* sp. Benthic covers were calculated using each palette only once, hence, the mosaics were analyzed 7 times each, providing with enough statistics.

Manual and semi-automatic benthic cover estimation

Any new proposed approach should correspond with traditional manual point-based methods, because it had already proven it capability to reflect the reality (Foster, 1991; Meese & Tomich, 1992; Leonard & Clark, 1993; Carleton & Done, 1995; Miller & Müller, 1999). To test our colour-based semi-automatic benthic cover estimation method against manual point-based method Norwegian Sea video data was used: four 200 m video transects filmed in 2010 season and repeated in 2011 season (*see Section 3.1.1.3*). For manual point-based analysis 50 frames and 5 points were used for each transect, for semi-automatic colour-based computer assisted analysis 10 video mosaics from each transects were used. The total number of mosaics was 80, what makes about 1/3 of the total imagery.

After an evaluation of the preliminary results, mosaics that belonged to colour class III were excluded from the analysis because of an inconsistency with other colour classes. The reason for the inconsistency was colours degradation within this colour class (the blue channel was significantly reduced), which made the discrimination of *Lithothamnion* sp. from sand and erect red algae, in some cases, impossible.

For the final analysis, five mosaics (four from 2010 and one from 2011) were excluded because they were of the colour class III and seven more (four from 2010 and three from 2011) were eliminated because of high negative unidentified pixels counts. Eventually, 31 mosaics from the 2010 season and 37 mosaics from the 2011 season remained. The number of mosaics per transect that remained in the analysis varied between 6 and 10 (Tab. 3).

Table 3. Number of mosaics used for semi-automatic analysis after imagery rejection process (maximum possible count is 10, and indicates that no mosaics were rejected).

	Transect			
Season	***5D***	***6E***	***8D***	***9D***
2010	6	8	10	7
2011	10	10	8	9

Regarding mosaic colour classes, all mosaics that remained from 2010 season after the rejection process belonged to colour class II. Only transect 9D (nine mosaics) from 2011 belonged to colour class II whereas the remaining 28 mosaics from transects 5D, 6E and 8D belonged to colour class I.

Estimation of visual benthic features from raw video and video mosaics

In this study it was assumed that counting individual organisms and estimating benthic cover from still images (for example, from video mosaics) should be easier and hence more accurate than from the raw video. To test this hypothesis, two video samples from Norwegian Sea were analyzed by several groups of people (Ecology and Biology BSc and MSc students, Klaipėda University; and MSc students of ERASMUS EMBC program during their study the same university) with no previous experience in video analysis. Each sample duration was 90 seconds, samples were divided into three 30 sec sub-samples. Three counting features were tested:

1. counts of well camouflaged seastars (Fig. 6),
2. counts of easily distinguishable sea urchins (Fig. 5)
3. presence/absence of small kelp

Also three benthic cover features were tested:

1. Erect red algae cover
2. Encrusting red algae *Lithothamnion* sp. cover
3. Sand cover

In total 51 people evaluated selected visual features from the raw video (each 30 sec. sub-sample was reviewed three times) and 21 from them additionally evaluated features from the video mosaics produced from the raw video (total time given was 20 min., about 3 min. per mosaic). Additionally the same samples were carefully examined by an expert with no time limit, to determine the actual counts of the benthic organisms, and benthic covers were evaluated using semi-automatic method.

Influence of operator training on visual coverage estimation

As with any activity that requires certain level of training and experience, we can expect improved simple visual census video analysis results with growing operator experience. To test this, three video transects from Norwegian Sea (durations 16:30 min, 8.45 min and 8.00 min; total 33:15 min) had been analyzed by a ERASMUS EMBC MSc student. Visual features assessed included biological and abiotic, categorical and quantitative:

1. Sand cover, %
2. Erect red algae cover, %

3. *Lithothamnion* sp. cover, %
4. Dark coralline algae cover, %.
5. Pebbles (1-25 cm) cover, %
6. Boulder (>25 cm) cover, %
7. Bedrock cover, %
8. Bryosoan, presence/absence (1/0)
9. *Didellium* sp., presence/absence (1/0)
10. Kelp, categories (0-4)
11. Encrusting spongies, categories (0-2)
12. Branching spongies, presence/absence (1/0)
13. Unidentified red algae, presence/absence (1/0)
14. Sea urchin, presence/absence (1/0)
15. Seastars, presence/absence (1/0)

Because of the higher number of features to be assessed, video samples duration had been chosen to be 15 seconds. To test how results are changing with growing operator experience, quality control procedure was implemented. After analyzing 5 video samples bunch, operator had to re-process first sample in the bunch (quality control (QC) sample), the difference between original estimation and quality control analyses indicated how consistent operator has became.

3.2 Acoustical methods

3.2.1 Acoustical data collected

Norwegian Sea

In the Norwegian Sea multibeam sonar bathymetry data was collected (for more details, *see Technical annex*) within Work Package 5 of the Norwegian Centre for Offshore Wind Energy (NORCOWE). A wind farm development on offshore rocky reef is currently being planned on the West coast of Norway. Named Havsul, it will be the first full-scale offshore wind farm project in Norway, and is unprecedented because its location is a rocky reef characterized by a complex topography where shallow rocky reefs (0-30 m), which are situated only meters away from deep (120 m) sedimented troughs. The entire area of Havsul (11.5x5.5 km) was surveyed using Kongsberg EM3002D multibeam ecosounder and this data opportunistically become available (Fig. 3).

Baltic Sea

In the Baltic Sea coastal area for Baltic herring spawning grounds study full coverage SSS data was obtained (for more details, *see Technical annex*) for the area of 21.6 km^2 and multibeam bathymetry data (for more details, *see Technical annex*) for the area of 10.7 km^2 opportunistically become available (Fig. 9).

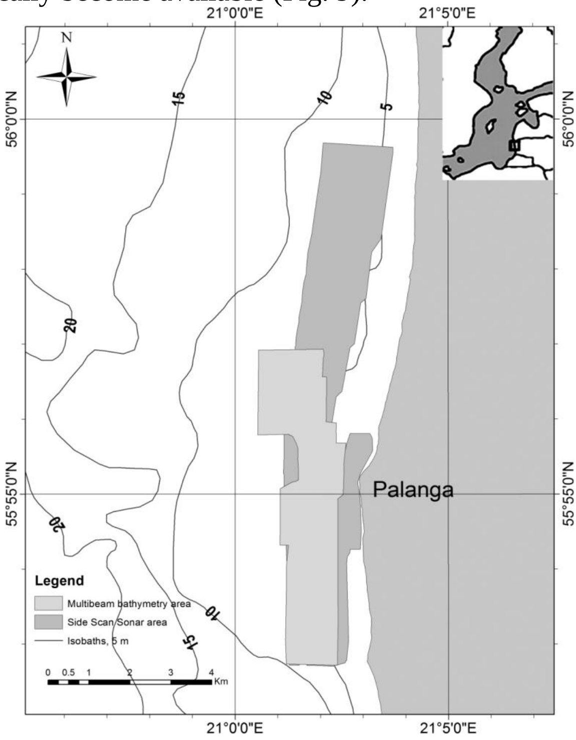

Figure 9. *Multibeam and Side Scan Sonar data collected in the Baltic Sea coastal area.*

3.2.2 Analysis of acoustical data

Multibeam sonar data processing

During the Norwegian Sea multibeam survey the OLEX hydrographical software (www.olex.no) was used for the collection and processing of the multibeam data. The data was filtered in real-time during the survey to avoid obvious errors and, later, data had been manually inspected and edited using 3Dview. The OLEX software allows area-based post-processing editing, but has no tools to edit an individual soundings, which limits its editing capabilities. A system used in the Baltic Sea was controlled by HYPACK 2012 hydrographical software. This software package, in additional to real-time filtering during the survey, allows manual editing of individual soundings during the post-processing. In both cases, after data cleaning and processing, raw bathymetry grids were created.

For further data processing IVS Fledermaus 7, ERSI ArcGIS with 3D analyst extension toolbox and Benthic Terrain Modeler (Wright & Heyman, 2008) were used. Using those tools, from high resolution multibeam data additional to depth number of benthic geomorphic descriptor variables could be extracted (Pickrill & Todd, 2003), which have a potential helping to explain the distribution of benthic organisms (Wilson et al., 2007). Several types of geomorphic descriptor variables, produced from multibeam bathymetry were used in this study (for more details, *see Technical annex*).

Geomorphic descriptor variables used in this study are shown in the Tab 4.

Table 4: Geomorphic descriptor variables derived from the multibeam bathymetry and used this study.

Geomorphic descriptor variable	Description
Aspect	Indicates the direction of the slope in degrees, can be used as a proxy for shelter (if the slope is open from one direction, it should be closed from the opposite direction). Aspect was calculated using the ERSI ArcGIS 3D analyst extension toolbox.
Slope	Indicates the steepness of the slope (*i.e*. degree of slope angle). It indicates the average angle of the cell. The slope was calculated using ERSI ArcGIS 3D analyst extension toolbox.
Rugosity	Refers to the complexity of local relief. Shows how different the slope and aspect are of the current cell comparing to that of the neighbouring cells. Rugosity was calculated using IVS Fledermaus7 and ArcGIS extension or a Benthic Terrain Modeller as the ratio of surface area to planar area (*see Wright & Heyman, 2008*).
Benthic position index (BPI)	Indicates the position of the current cell in relation to that of its neighbours: it shows local elevation or depression. BPI was calculated at two scales: fine, and broad. The fine scale had an inner cell diameter of 3 m and outer neighbours at 25 m. The broad scale had an inner cell diameter of 25 m and outer neighbours at 250 m. For more detail see Benthic Terrain Modeller description (*see Wright & Heyman, 2008*).

After assessing available data, the spatial models resolution scale used in this study was chosen to be 20 x 20 meters. Accordingly, geomorphic descriptor variables layers were produced on models resolution (e. g. 20 meters per pixel). Geomorphic descriptor variables required neighbouring cells for calculation settings (e. g. 3 x 3 cell neighbourhood around the processing or center cell) were calculated using a 4 x 4 meters grid and subsequently downscaled to models resolution. Predictor downscaling also minimized the influence of small imperfections present in the multibeam data (Fig. 10) on the models performance.

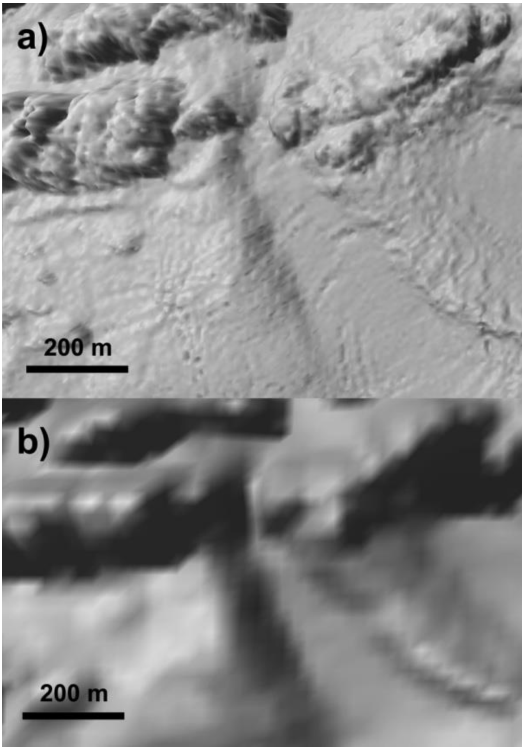

Figure 10. *Raw multibeam bathymetry (a) and downscaled to models resolution (b). Note small imperfections present in raw data and not present in downscaled.*

Side Scan Sonar data processing

For data visualization (SSS mosaic creation) IVS Fledermaus7 and HYPACK 2012 were used. SSS mosaic interpretation had been done manually in the ArcGIS. Technical 2D resolution of the SSS mosaic was 20 cm per pixel, but because physical transversal and axial resolutions of SSS data vary, and because for objects and/or patterns to be recognizable they need to be consisted of several pixels, practical resolution was significantly lower (approximately 0.5-1 m) (for more details, *see Technical annex*).

Sandy bottoms were distinguished by the acoustical backscatter strength: softer sediments appear darker than harder. Rocky areas were qualitatively distinguished by significant amount of boulders visible in the acoustical image. Areas with strong acoustical backscatter but with no acoustical shadows from the boulders were classified as gravel (areas where big ripples were visible on the bottom) or mixed bottom (areas with strong backscatter but with no clearly distinguishable bottom features).

Bottom sediments were manually classified into following classes:

1. Soft sand, appear darker on the SSS images.
2. Gravel, light areas on the SSS image, with distinguishable big ripples.
3. Rocky bottom. Distinguished by significant amount of boulders (at least one visible in majority (>50%) of 10x10 meters segments).
4. Mixed bottom. Complex mix of bottom sediments that could not be reliably classified as any of the classes above.

3.3 Herring spawning grounds data collection

Mapping of the Baltic herring spawning grounds was performed in 2009-2010 during it spawning period: March-May. Generally Baltic herring do not spawn on soft substrates (Rajasilta et. al., 1989; Kääriä et. al., 1997), and no spawning events along the Curonian spit were previously registered. Therefore only northern part of the Lithuanian coast was investigated during this study.

During 2009 season sampling points were evenly distributed (average distance between them was approximately 800 meters) over *F. lumbricalis* biotopes (Fig. 18), reported to be the most important for the Baltic herring spawning in the Lithuania coastal waters (BaltNIIRH, 1989; Olenin & Labanauskas, 1994; Maksimov et al., 1996; Fedotova, 2010). In 2010 season sampling efforts were concentrated in the central part of the study area, where high resolution (1.9x1.9 meters per pixel) multibeam bathymetry (KU MARSTEC, unpublished data) opportunistically became available (Fig. 9 & 11).

Baltic herring eggs are relatively small (<2 mm) and semitransparent, therefore hardly detectable by remote methods (e.g. underwater video), especially in low visibility conditions. Field data was collected by SCUBA divers. On each sampling point the diver recorded presence/absence of the Baltic herring eggs and spawning substrate. Additionally benthic sample was collected from the substrate using a 20x20 cm frame (Kautsky, 1993). Benthic samples were analyzed using Nikon Eclipse E200 microscope to confirm eggs presence/absence and development stages (from *a* to *q*) were distinguished according to Veersalu & Saat (2003).

In total 93 points were sampled by SCUBA divers (Fig. 11). Opportunistic data on five occasional findings of the Baltic herring eggs in 2006-2008 (KU MARSTEC unpublished data) was added (Tab. 5, Fig. 11).

Table 5. SCUBA divers sampling data during 2006-2010.

	Start date	End date	Number of locations	Min depth (m)	Max depth (m)
2006-2008	April	May	5	6	11
2009 season	7 April	29 April	52	4	14
2010 season	19 April	7 May	41	3	10

Weather conditions were very calm during 2009 season, allowing us to perform additional detailed survey of a single spawning bed: 5 transects, which length ranged from 46 to 149 m (Fig. 12). Baltic herring eggs presence/absence was recorded by divers who used a floating buoy to signal their findings and position to the crew on the boat. During the same season sampling window was relatively wide (22 days) with more or less evenly distributed sampling dates, which allowed us monitoring eggs development.

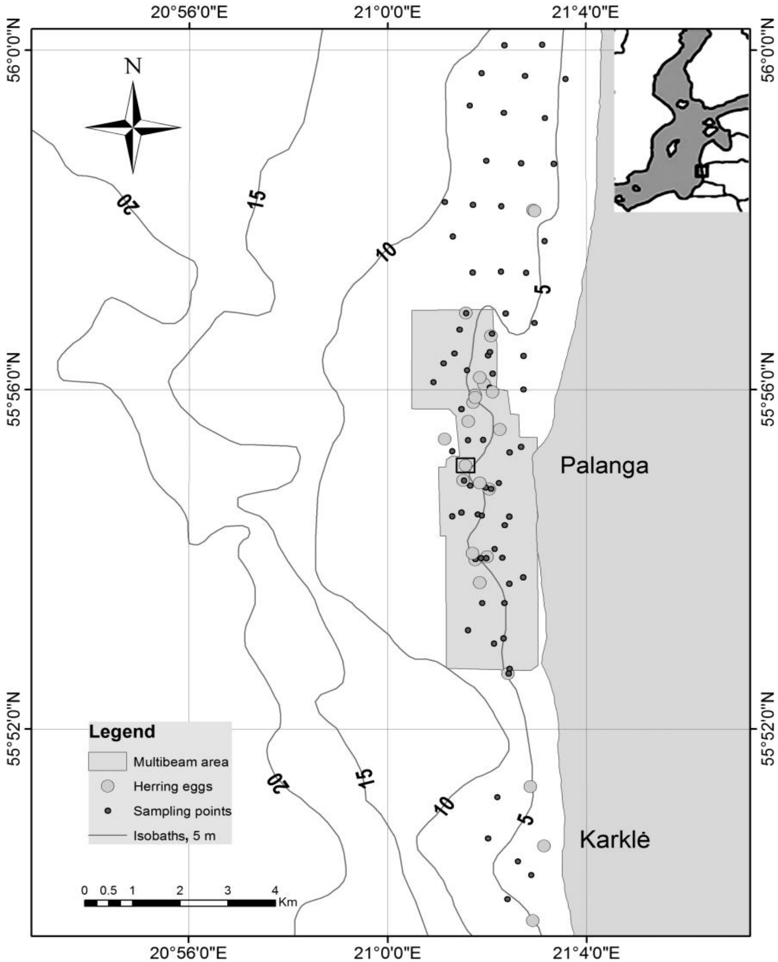

Figure 11. *Sampling points and detected spawning beds. Black square in top right shows location of the study area. Black square in the middle indicates the spawning bed where detailed inspection was performed in 2009 (see Fig. 12).*

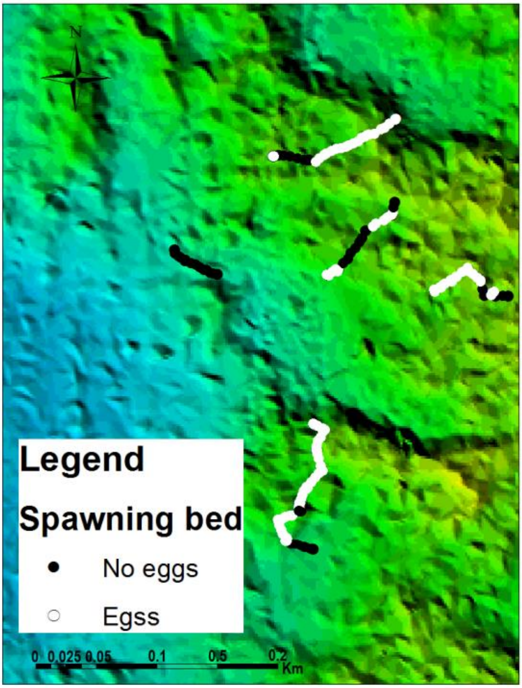

Figure 12. *Spawning bed inspected in details in 2009. Five transects were made, multibeam bathymetry is shown. White transects segments indicate parts with herring eggs presence and black segments are without eggs.*

3.4 Statistical methods

3.4.1 Procedure of quantitative benthic biotope identification

The developed procedure of quantitative benthic biotope identification based on the general approach outlined by Olenin & Daunys (2004), is shown at Fig. 13. After splitting of raw video transects into video samples (*see Section 3.1.2.2*) and the inventory of biological and geological features (*see Section 3.1.2.4*), biological and geological properties of the samples were estimated. In cases, when new features appear during the analysis the inventory of features was updated.

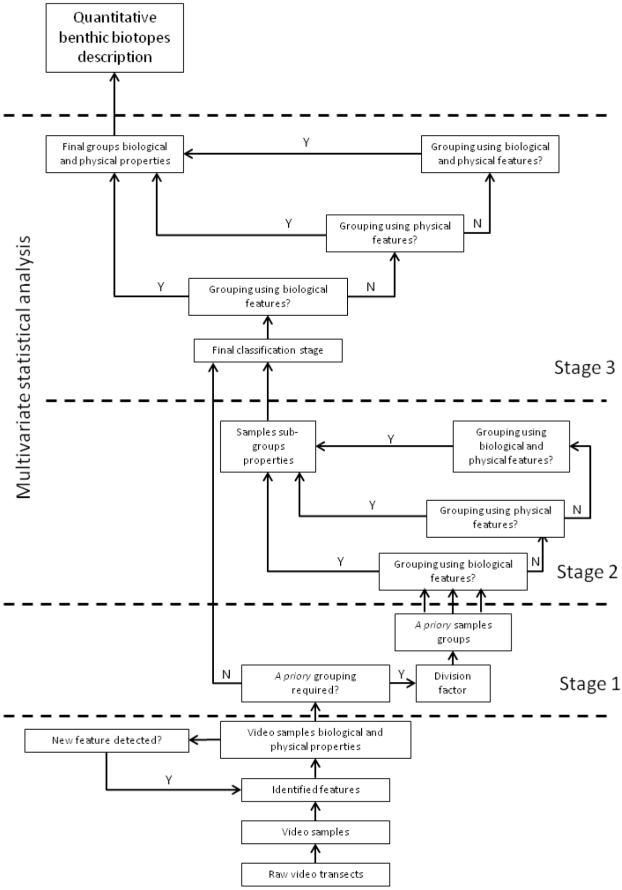

***Figure 13**. Procedure for quantitative benthic biotopes identification from underwater imagery used in this study. "Y" stays for "Yes", "N" stays for "No". Explanations in text.*

Since the initial number of samples was too big for handling in a single multivariate analysis (413 in the coastal area, 250 in the offshore area), they were *a priori* divided into smaller, manageable groups following the methodology proposed by Connor et al. (2004). In the coastal biotope study (*see Section 4.2.1*) all samples were divided into three *a priori* groups by the expanse of sand cover: 0-40%; 40-90% or 90-100% (126, 32 and 255 samples, accordingly). In the offshore area study, the video samples were divided also into three *a priori* groups by the geographical position of the sampling area: Southern, Northern or Western zones (74, 95 and 81 samples, accordingly), (Fig. 2).

At the second stage, the multivariate statistics analysis was applied separately to each *a priori* group. We derived groups of video samples based on visual biological (in the coastal area) or geological features (offshore area). Generally, the use of biological properties quantified in the same dimensions (e.g. cover percentage, or categories, or counts) is more preferable for grouping the samples, as biological features are sensitive to even slight differences in bottom environment, which often are not reflected in the geological setting (e.g. Arzamaztcev & Preobrazhenskij, 1990; Olenin & Ducrotoy, 2006). This was the case in the coastal area where the biological visual features were abundant and diverse enough to aid multivariate statistical analysis. However, in the offshore area 3 of 4 visual biological features were categorical (presence/absence) and therefore more abundant visual geological features (all quantified as percentage of cover) were selected as being more appropriate. Properties of the derived sub-groups were described quantitatively as the average of features values of all samples joined in a sub-group. This allowed transferring categorical values into quantitative ones and use biological properties for further analysis of the offshore video.

Because *a priori* division was artificial (in principle, any convenient criteria could be used on this stage), one more stage of the analysis was needed to derive natural distribution of the video samples, which can be used for the quantitative description of the benthic biotopes of biotopes.

At the third stage, all sub-groups of samples derived (separately for the coastal and offshore areas) were treated in the multivariate statistical analysis ignoring the *a priori* division. In our case, at that stage only biological properties were used for discrimination. Finally, the average features values within the final groups were calculated for the quantitative biotope description (Fig. 13).

The multivariate statistical methods used were the hierarchical cluster analysis and Multi-Dimensional Scaling (MDS). In all cases, Bray-Curtis similarity coefficient was used to create similarity matrices. In cases when samples features parameters significantly varied (numerical, categorical, semi-quantitative, etc.), data transformation techniques ($\sqrt{x}$, *log(x+1)*) were used to reduce these differences (Clarke & Warwick, 1994).

To derive dominant (primary) and co-dominant (secondary) substrate types, simple proportion to the maximum possible numeric value (cover 100%) was used. Dividing threshold was chosen empirically: 0.5-1.0 for dominant substrate types and 0.2-0.5 for co-dominant substrate.

3.4.2 Statistical modelling

There are two main applications of the statistical models in modern ecology: explanatory and predictive models (Guisan et al., 2002). The same mathematical methods can be applied for both uses, the only difference is the aim: explanatory models seek to provide insights into the ecological processes that produce patterns (Austin et al. 1990; Guisan et al., 2002), while predictive models are predicting the probability of species occurrence or estimating numbers of an organism at new, previously unsampled locations (Guisan et al., 2002). Different mathematical methods have their own strengths and weaknesses, and choice of the model depend on many factors: study objectives, available data (samples data and environmental data), and background information, available for the study area. In this study we used two types of models, Generalized Additive Model and Maximum Entropy model.

Generalized Additive Model

To find relations between response variables and predictors Generalized Additive Models are commonly used (Guisan et al., 2002; Boeck & Wilson, 2004). Generalized Additive Model is flexible when relations between responce and predictors are not linear, and able to deal with various data distributions (e.g., Gaussian, Poisson or Binominal). Model parameters were based on penalized regression splines with the maximum of 4 degrees of freedom for continuous predictor variables to maintain ecologically interpretable models (Wood & Augustin, 2002).

The combination of multibeam bathymetry, underwater imagery and statistical modeling have been already used in ecological studies (Iampietro et al., 2008; Young et al., 2010; Krigsman et al., 2012). However, that methodology was not used to find the significance of the seabed geomorphology for distribution of key benthic species in the rocky Norwegian Sea environment. Our response variables were individual counts of invertebrates or kelp plants in the fixed length video segments, therefore they fitted a Poisson probability, which is a discrete probability distribution that expresses the probability of a given number of events occurring in a fixed interval of time and/or space if these events occur with a known average rate and independently of the time since the last event. Small kelp (< 30 cm) counts were transformed as sqrt (counts), due to the very high variation (from 0 to 350 individuals) in the raw data. We used GAM model implemented in the R statistical package (R Development Core Team, 2008, R version 2.13.1) in the library "mgcv". Each response variable was modelled separately, but common model formula was used in all cases:

Response ~ s(Aspect, bs = "ts", k = 5) + s(Slope, bs = "ts", k = 5) + s(BPI_Broad, bs = "ts", k = 5) + s(BPI_Fine, bs = "ts", k = 5) + s(BTM_VRM, bs = "ts", k = 5), gamma=1.4, family=poisson

The models were built to identify which characteristics of the topography were important to the different taxonomic groups thus allowing the formulation of hypotheses about a wind farm construction's impact on mobile invertebrate and small kelp, knowing that the Havsul area is already impacted by the constant and heavy stress of wave exposure. The impact hypotheses were formulated based on the qualitative scatterplot graphs analysis of the significant predictors.

Maxent

For Baltic herring spawning grounds study, due to the difficulties collecting the data (cold water, low visibility) and probably the nature of Baltic herring spawning grounds in the Lithuanian coastal waters, detected eggs absences were not trustworthy, therefore any kind of models based on presence/absence data were not well suited for this case. From presence only methods, those that are based on Bayesian probability are reported as performing well. In Bayesian probability, the principle of maximum entropy is a postulate which states that the probability distribution which best represents the current state of knowledge is the one with largest entropy. The program MaxEnt, version 3.3.3k, was used to create probability maps of potential herring spawning habitats (Phillips et al. 2006; Philips & Dudik, 2008).

3.5 Methods and materials summary

This work compiles several study cases with different objectives, from benthic biotopes identification to deriving biota-environment interactions and predictive mapping. According to the study objectives, different data sets and analysis methods were used (Tab. 6).

Table 6. Summary of the methods and data used in different study cases.

Study area	Acoustical methods, area covered		Underwater imagery methods, number of transects			Benthic samples
	SSS	*Multibeam bathymetry*	*ROV*	*Drop-down video*	*Divers video*	
Norwegian Sea		**63.3 Km^2**	**18**			
Baltic Sea, coastal area				**202**		**131***

Baltic Sea, offshore area			**30**			
Baltic Sea, herring spawning grounds	**21.6 Km^2**	**10.7 Km^2**			**93**	**98******

* Benthic macrofauna samples

** Herring row samples

4. Results

4.1 Assessment of the accuracy, reliability and cost effectiveness of used video analysis methods

4.1.1 Comparison of absolute counts and cover estimations from raw video and video mosaics

Absolute counts

The results of the absolute counts of benthic organisms by the test groups from raw video and video mosaics (*see section 3.1.2.5*) are summarized in Fig. 14. There was no significant differences between sea urchins estimations from the raw video and mosaics in the Sample 1 (p-value of the t-test is 0.28) and Sample 2 (p-value of the t-test is 0.16) and for the kelp estimations in the Sample 1 (p-value of the t-test is 0.43). However, seastars counting results from mosaics and raw video were significantly different (p-values of the t-tests for both samples are less than 0.0001), with counting from mosaics much closer to the real values. However, even for mosaics the mean counts values (9.6 for the Sample 1 and 7.4 for the Sample 2) were almost twice lower than the complete number of seastars estimated by the expert (21 for the Sample 1 and 12 for the Sample 2). Kelp *Laminaria* sp. presence estimation for the second sample was significantly different (p-value of the t-test 0.01) and was more accurate from the mosaic, where majority of the observers had detected small and poorly visible frond, wich was missed by many while analysing raw video.

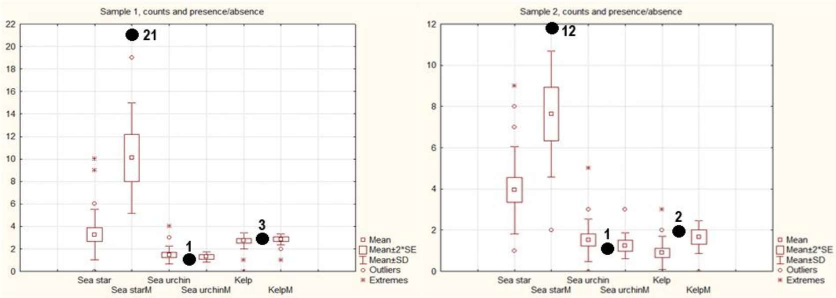

Figure 14. *Counts and presence/absence estimations from raw video and mosaics (marked with M) made by the test group. Black dots and numbers indicate counts and presence/absence estimations made by the expert.*

Cover estimations

The results of the benthic covers estimations by the test groups from raw video and video mosaics are shown in Fig. 15. There were no significant differences in the red algae cover estimations from raw video and mosaics (p-value for t-tests were 0.17 and 0.08 for Sample 1 and Sample 2 accordingly). Estimations of the *Lithothamnion* sp. cover were significantly different (p-values of the t-tests were 0.0001 and 0.04 for the Sample 1 and Sample 2 accordingly). Sand cover estimation was different for the Sample 1 (p-value of the t-test 0.0001) and not significantly different for the Sample 2 (p-value of the t-test 0.37). Unexpectedly, almost in all cases average cover estimation values from the raw video were closer to the semi-automatic estimations, comparing with estimations from video mosaics (Fig. 15).

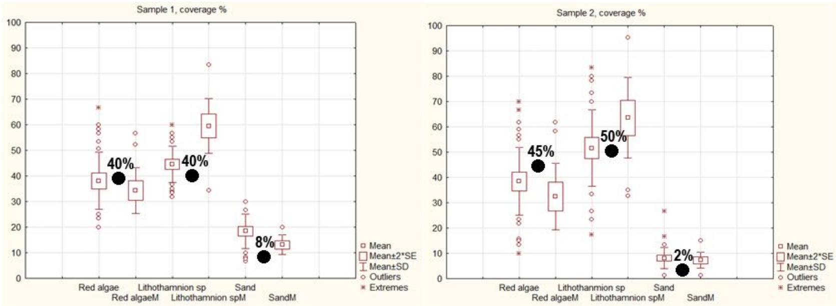

Figure 15. *Visual coverage estimations from raw video and mosaics (marked with M). Black dots and numbers are semi-automatic approach estimates.*

Influence of operator training on reliability of visual census benthic cover estimation

Results of the benthic cover estimations changes with growing operator experience (for more details *see section 3.1.2.7*) are shown in the Fig. 16. While in the beginning the difference between original and QC coverage estimations reached up to 30%, after approximately 11-12 quality control samples (less than 15 minutes of video analyzed) differences between original and QC sample analyses became marginal, not exceeding 10%, indicating that operator had achieved consistency in the analysis and no more training was necessary.

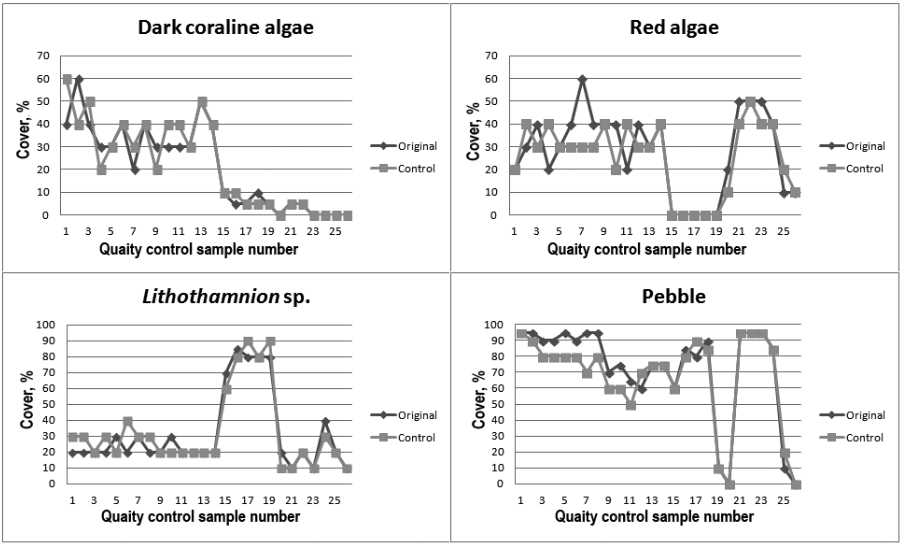

Figure 16. *Comparison of benthic cover estimations in the original and QC video samples.*

Testing results for categorical and qualitative features are shown in Tab. 7. Consistent analysis results were achieved from the beginning: there were only three cases of different estimations.

Table 7. Differences between original and QC video samples analyses. Zero indicates no difference. Cases where differences were detected highlighted with grey colour.

QC sample Nr.	Bryosoans, 1/0	*Didellium* sp., 1/0	Kelp, 0-4	Encrusting sponges, 0-2	Branching sponges, 1/0	Unidentified red algae, 1/0	Sea urchins, 1/0	Seastars, 1/0
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	1	0	0	0	0	0
4	0	0	1	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0

11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	-1	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0

Influence of different manually chosen benthic covers colour palettes on semi-automatic benthic cover estimations

Comparison results of the four video mosaics analyzed using different colour palettes (*see Section 3.1.2.7*) are shown in Fig. 17.

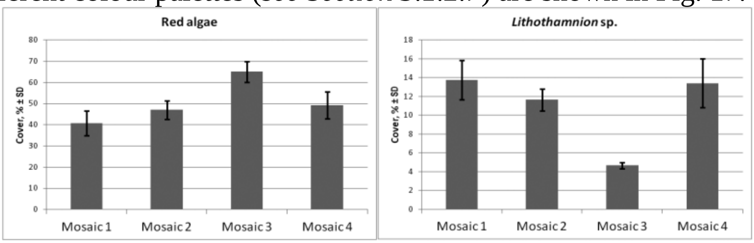

Figure 17*. Average benthic cover estimations with standard deviations, using different colour palettes.*

For the *Lithothamnion* sp. cover estimations, from the test mosaics average was 10.8% with average standard deviation of 1.5%, while for the red algae average cover was 50.5% with average standard deviation of 5.3%. Altrough general tendency is that standard deviation is greater for benthic covers having highier absolute values, variation still remains at an acceptable level. Most of the errors that were added to the variations, appeared on the borders between different features, where even manual classification (where to drow the line?) would be difficult and operator dependend.

Comparison of manual and computer-assisted cover estimations

The results of the benthic cover estimations using manual point-based and semi-automatic methods are shown in the Fig. 18, Tab.8 & 9. The results were broadly congruent. The most noticeable trend captured by both methods is an increase in red algae and corresponding decrease in *Lithothamnion* sp. cover for transects 8D and 9D in the 2011 season compared with the same transects in 2010 season. The biggest differences in the absolute features values derived using different methods were between less abundant features (sand in both seasons and *Lithothamnion* sp. cover in 2011 season), which were more affected by errors due to the limited amounts of random sampling points used in the manual analysis. For more abundant (in our case, with absolute values bigger than approximately 30 %) features, mean values for both methods were very close (Tab. 8), although manual point-based analysis results had much higher variation.

The most noticeable difference of the methods, is that statistical significance of the differences between 2010 and 2011 seasons in the ERBL cover estimations: semi-automatic method did not reported that there is a significant difference in EBRL cover for the transect 6E, while manual method reported significant difference in cover for the transect 9D (Tab. 9).

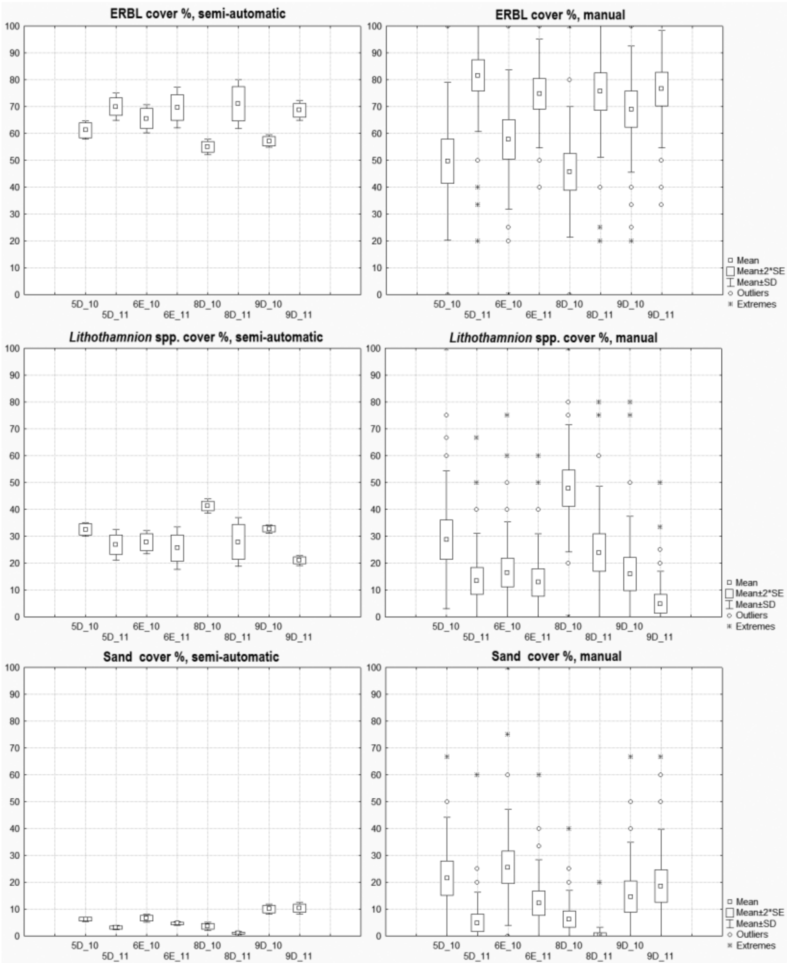

***Figure 18**. Semi-automatic cover estimations (on the left) compared to manual point-based cover estimations (on the right). Labels on the X axis represent transect code (5D; 6E, etc) and season (10 for 2010 and 11 for 2011).*

Table 8. Average values and standard deviations of the benthic features covers estimated using manual point based and semi-automatic methods for 2010 and 2011 seasons.

	2010 season		2011 season	
	Manual	**Semi-automatic**	**Manual**	**Semi-automatic**
ERBL	55.6 ± 25.8	59.4 ± 3.9	77.2 ± 21.9	69.8 ± 6.0
***Lithothamnion* sp.**	27.3 ± 22.5	33.9 ± 3.0	13.8 ± 18.2	25.3 ± 5.8
Sand	17.0 ± 18.8	6.8 ± 1.5	9.0 ± 12.9	4.8 ± 1.0

Table 9. Results of comparing benthic covers within transects between 2010 and 2011 seasons. The p-values of the t-test are shown. Values less than 0.05 indicates statistically significant difference at 95% confidence interval. With light gray color highlighted cases where no statistically significant difference in benthic covers was detected between 2010 and 2011 seasons.

	5D		6E		8D		9D	
	Semi-auto	*Manual*	*Semi-auto*	*Manual*	*Semi-auto*	*Manual*	*Semi-auto*	*Manual*
ERBL	<0.01	<0.01	0.20	<0.01	<0.01	<0.01	<0.01	0.10
***Lithothamnion* sp.**	0.04	<0.01	0.49	0.33	<0.01	<0.01	<0.01	<0.01
Sand	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.80	0.35

4.1.2. Cost-effectiveness analysis of underwater imagery processing approaches

Semi-automatic computer-assisted colour-based covers estimation

The computing time to create a mosaic from a 30 seconds video sample using the technique of Rzhanov et al. (2004) is approximately 15 minutes. Therefore, for the four video transects and 80 mosaics used in this study, the total computing time was 20 hours. However, the process could be easily paralleled using a modern computer with several processor cores and several copies of the software simultaneously running, without any performance loss. Such a computer would reduce the required computing time to 8 to10 hours.

In addition, the creation of a mosaic using this technique does not require a solid scientific background, thereby reducing personnel costs. Results using this technique are operator independent so that using multiple operators will result in faster production of the mosaics.

Manual points-based video analysis

The initial preparation for the manual point-based analysis requires only features selection and naming, and in our case was accomplished in about 4 hours by an experienced researcher. After the features set and the number of frames to be analyzed are determined, a single frame analysis can be completed in approximately 5 minutes. The analysis of the test study data (4 transects, 200 frames) took about 16 hours. The entire analysis process should be performed by an experienced researcher and the process cannot be paralleled. Although it is possible to divide the data between several people, the inter-calibration between each person and quality-control procedures are needed to ensure analysis uniformity.

Summary of the man-hours required to process our study data using semi-automatic and manual analyses is shown in the Tab. 10.

Table 10. Comparison of time, parallelization capabilities and operators qualifications for different steps of semi-automatic and manual imagery analyses.

Computer-assisted colour-based semi-automatic analysis				
	Work hours	Parallelization	Technician	Researcher
Mosaics creation	20	On same computer	Yes	Not required
Benthic cover colour palettes	8	No	Not recommended	Recommended
Mosaics analysis	3	Different technicians	Yes	Not required
Total:	31			
Manual points-based analysis				
Features selection	4	No	Not recommended	Recommended
Frame analysis	16	Different researchers	Not recommended	Recommended
Total:	20			

Although semi-automatic analysis needed 11 more hours to be completed compared to a manual points-based analysis, the majority of this time (20 hours) was the computing time required to prepare mosaics. This process can be easily paralleled either on single computer or between computers and technicians. Furthermore, the majority of the tasks can be performed by moderately trained technicians, and researcher input is required only for 8 hours. As result, semi-automatic analysis can be performed faster and cheaper than manual analysis, which require researcher on all stages of the process.

4.2 Quantitative identification of benthic biotopes based on underwater video

4.2.1 Biotopes identified in the coastal area of the Baltic Sea

Visual features

In the coastal area 16 benthic features were identified to be suitable for the analysis according to the criteria defined (*see Section 3.1.2.4*), from them 10 biological and 6 geological ones (Tab. 11).

Table 11. Biological and geological features identified from the Baltic Sea coastal area video data.

Biological features		**Geological features**	
Feature	**Dimension**	**Feature**	**Dimension**
Domiciles of bay barnacle *Balanus improvisus*	Cover, %	**Sand**	Cover, %
Colonies of the blue mussel *Mytulis trossulus*	Cover, %	**Pebble**	Cover, %
Sandy tubes of the spinonid bristle worms *Pygospio elegans*	Points, 0 to 3	**Gravel**	Cover, %
Bush-like colonies of hydrozoans (*probably *Cordylophora caspia)	Points, 0 to 3	**Mud**	Cover, %
Brown filamentous algae	Points, 0 to 3	**Clay**	Cover, %
Perennial red algae *Furcellaria lumbricalis*	Cover, %	**Boulders**	Cover, %
Green filamentous algae	Cover, %		
***Polysiphonia* sp.**	Cover, %		
***Ceramium* sp.**	Cover, %		
Carpet of brown algae	Cover, %		

Grouping of video samples

On the second analysis stage (Fig. 13) the *a priori* samples groups (*see Section 3.4.1*) were divided into 13 sub-groups at 50 similarity level: the “sand cover 0-40%” *a priori* group split into 5 sub-groups, the “sand cover 40-90%” into 4 sub-groups, and the “sand cover 90-100%” into 3 groups (Fig. 19).

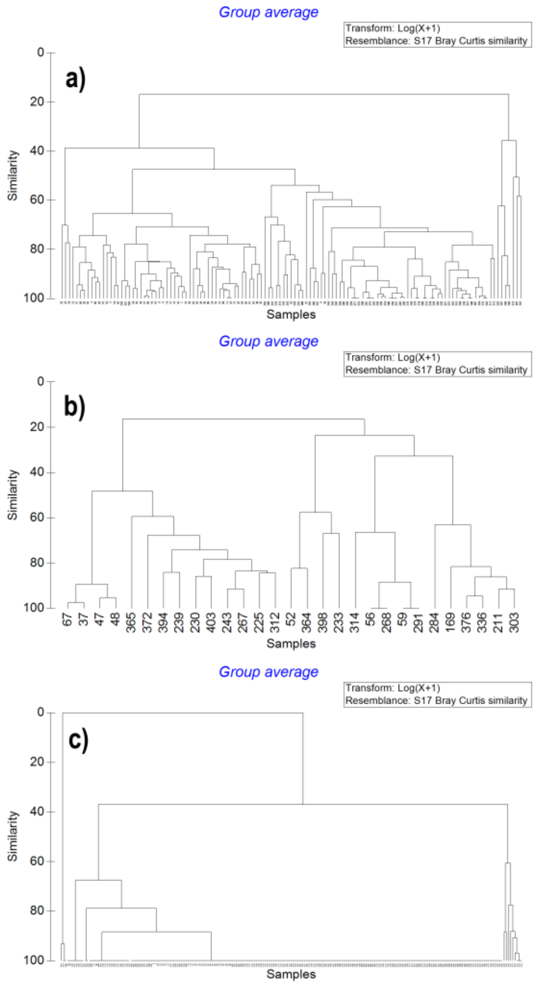

Figure 19. *Dendrograms, showing the sub-groups of video samples derived from the coastal area a priori groups: a) "sand cover 0-40%" a priori group, b) "sand cover 40-90%" a priori group, and c) "sand cover 90-100%" a priori group.*

The derived sub-groups were checked for inter-similarity, resulting in 6 final groups, 5 from hard and mixed bottom and 1 from soft bottom (Fig. 20).

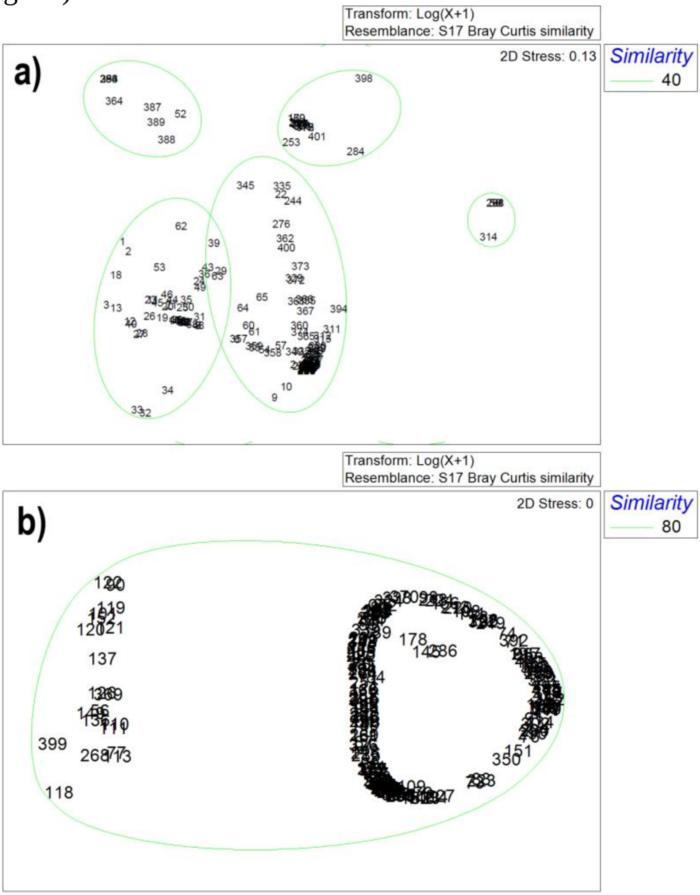

Figure 20. *MDS distribution for the video samples in the coastal area in the Baltic Sea: a) for soft and mixed bottoms; b) for soft bottoms.*

Further, the final groups (Fig. 13) were described quantitatively using visual features averaged values (Table 12) and were considered as representing six different biotope types.

Table 12. Average values with standard deviations of the biological and geological features of the six benthic biotope types derived after video data analysis in the Baltic Sea, coastal area. Bold font and dark grey colour marks primary substrates, bold italic font and light grey colour marks secondary.

	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
***Balanus improvisus*, %**	7.5±10.6	8.9±10,2	4.4±6.0	0	29.3±23.2	0.8±2.3
***Mytilus trossulus*, %**	0.3±1.0	25.6±18.4	25.2±15.8	0	5.1±9.2	44.5±24.1
***Pygospio elegans*, 1-3**	0.5±1	0±0	0.02±0.1	2.8±0.5	1.5±1.4	0.4±0.8
***Hydrozoa*, 1-3**	0±0	0±0	0,07±0,3	0	0.04±0.2	0.4±0.9
Brown filamentous algae, %	0.3±0,9	0±0	0±0	0.1±0.1	0.08±0.4	0.9±1.3
***F. lumbricalis*, %**	1.7±4.1	4.4±3.8	41.0±23.2	0±0	0±0	2.4±7.7
Green filamentous algae, %	36.9±30.1	2.2±1.9	0.3±2.0	0±0	0±0	1.4±6.7
***Polysiphonia* sp., %**	0±0	42.2±13.9	0.7±1.8	0±0	0±0	0.3±1.5
***Ceramium* sp., %**	0±0	6.7±8.8	8.5±17.2	0±0	0±0	0±0
Carpet brown algae, %	0±0	15.6±7.7	0	0±0	0±0	0±0
Sand, %	**50.3±40.1**	0±0	10.2±15.7	**99.8±0.9**	**56.6±38.4**	***19.1±26.9***
Pebble, %	0.6±1.9	0±0	2.0±4.7	0±0	0	0.8±2.0
Gravel, %	0±0	0±0	6.1±15.6	0±0	1.3±3.1	1.8±4.9
Mud, %	0±0	0±0	0±0	0.2±0.8	0±0	0±0
Clay, %	0±0	0±0	0.7±2.1	0±0	0.3±1.4	0.9±3.6
Boulder, %	***49.2±39.4***	**100±0**	**80.9±20.7**	0.2±0.9	***41.6±37.4***	**79.2±24.4**

As result of the video samples classification, the following six benthic biotopes were described.

- **Mixed bottom in shallow areas** (Type 1 in Tab. 12). The depth range from 2 to 4 meters. Primary substrate is sand (cover 50-80%, in some places up to 100%) secondary are individual boulders (cover up to 50 %). Boulders are densely accreted by green filamentous algae (cover 30-50%) and *B. improvisus* (cover 10-20%). There are no visible traces of bottom fauna on the sand (Fig. 21).

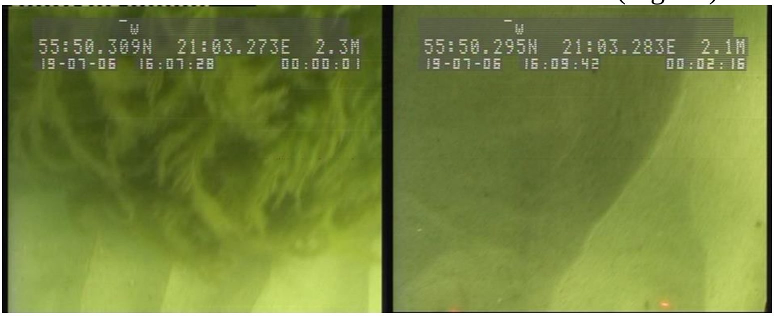

Figure 21. *Typical appearance in the underwater video of the biotope "Mixed bottom in shallow areas". Depth range 2-4 meters.*

- **Hard bottom with *Polysiphonia* sp.** (Type 2 in Tab. 12). The depth range is from 4 to 6 meters. Primary substrate is stony bottom (cover 100%). Stones are covered with red algae *Polysiphonia* sp. (cover 30-50%), and carpet brown algae (cover 10-20%); and by animals *M. trossulus* and *B. improvisus* (Fig. 22).

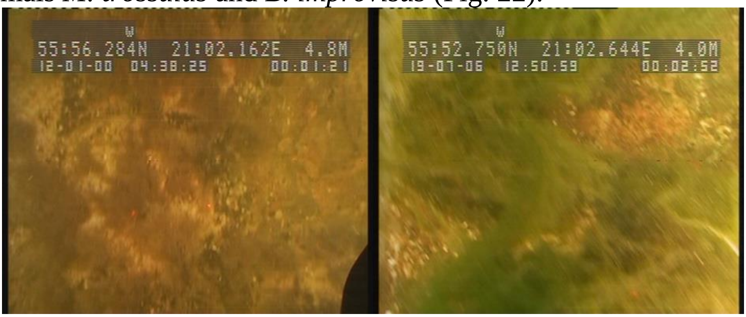

Figure 22. *Typical appearance in the underwater video of the biotope "Hard bottom with Polysiphonia". Depth range 4-6 meters.*

- **Hard bottom with *F. lumbricalis*** (Type 3 in Tab. 12). The depth range is from 6 to 8 meters. Primary substrate is stones (cover 70-90%) in small quantities sand, clay or pebble might be present. Stones are covered by *F. lumbricalis* (cover 30-60%) and *Ceramium sp*. (cover 10-30%); and by animals *M. trossulus* (cover 20-30%) and *B. improvisus* (10-20%). In small quantities red algae *Polysiphonia* sp., bristleworm *P. elegans* and *Hydrozoa* are present (Fig. 23).

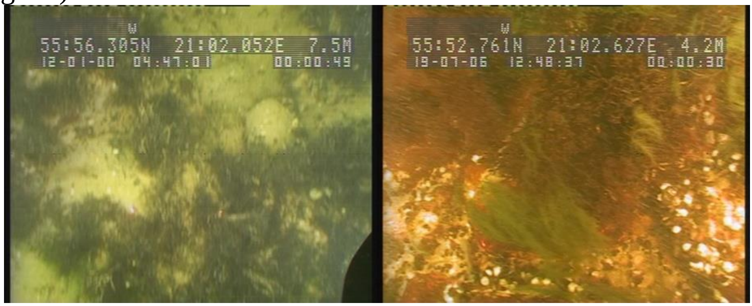

***Figure 23**. Typical appearance in the underwater video of the biotope "Hard bottom with F. lumbricalis". Depth range 6-8 meters.*

- **Soft bottom in deeper areas** (Type 4 in Tab. 12). The depth range is from 6 to 20 meters. Primary substrate is sand (cover 90-100%), with very little boulders (cover up to 10%). The only traces of living organisms that is firmly identifiable from video are "sand houses" of bristleworm *P. elegans*. On occasional boulders scarce *B. improvises* individuals might be present (Fig. 24).

***Figure 24**. Typical appearance in the underwater video of the biotope "Soft bottom in deeper areas". Depth range 6-20 meters.*

- **Mixed bottom with no dominant algae** (Type 5 in Tab. 12). The depth range is from 8 to 20 meters. Primary substrate is sand (cover 50-60%), secondary are groups of boulders (cover up to 50%). On the sand traces of *P. elegans* activity are identifiable. Boulders are covered by *B. improvises* (cover 20-40%). In small quantities *M. trossulus*, *Hydrozoa* and brown filamentous algae are present (Fig. 25).

Figure 25. *Typical appearance in the underwater video of the biotope "Mixed bottom with no dominant algae". Depth ranhe 8-20 meters.*

- **Hard bottom with no dominant algae** (Type 6 in Tab. 12). The depth range is from 8 to 20 meters. Primary substrate is boulders (cover 70-80%), secondary substrate sand (cover up to 30%), in small quantities clay and pebble are present. Boulders are covered by *M. trossulus* (40-60%) and *B. improvisus* colonies. In small quantities *P. elegans* and *Hydrozoa* are present (Fig. 26).

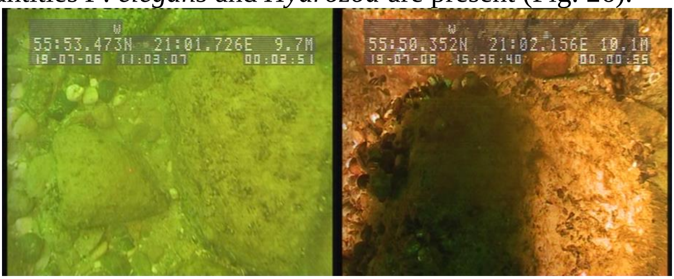

Figure 26. *Typical appearance in the underwater video of the biotope "Hard bottom with no dominant algae". Depth range 8-20 meters.*

Benthic biotopes verification with benthic macrofauna samples

To verify benthic biotopes derived from the video using proposed formalized approach, benthic macrofauna samples were used. After grouping those using multivariate statistical methods three sample groups were distinguished for benthic samples data from hard bottoms (Fig. 27 & 28)

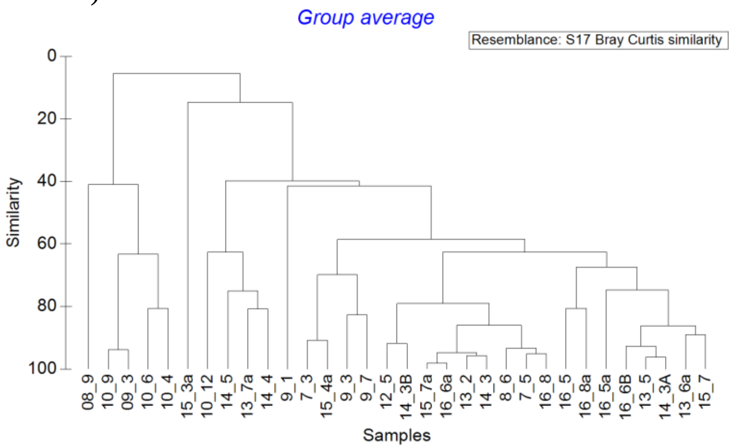

***Figure 27**. Grouping of the hard bottom benthic macrofauna samples from the coastal area of the Baltic Sea. At 35% similarity level three samples groups are distinguished.*

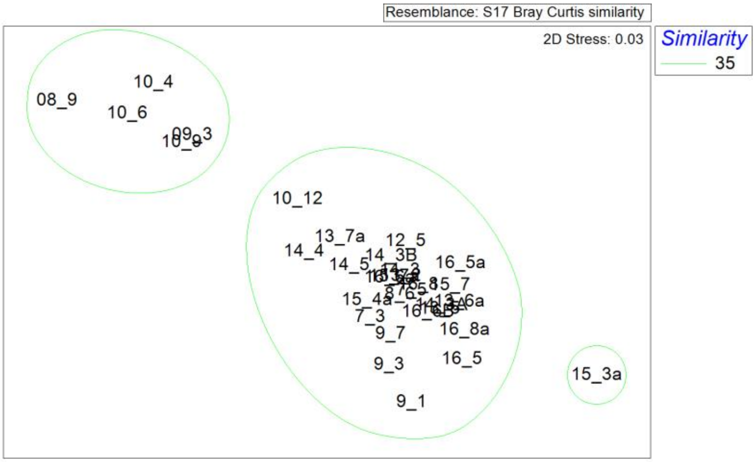

Figure 28. *Grouping of the hard bottom benthic macrofatuna samples according to MDS from the Baltic Sea coastal area.*

Comparing of the samples groups derived from macrofauna samples with groups derived from video analysis, the similar grouping was found: stations that according to video analysis belonged to the specific biotope type were in the similarly specific groups after benthic macrofauna samples analysis. One group derived from macrofauna samples was the appropriate for the hard bottom with *F. lumbricalis* (Type 3 in Tab. 12) biotope, second group was the appropriate to the mixed bottom in shallow area biotope (Type 1 in Tab. 12) and the third group was the appropriate to the hard bottom with no dominant algae biotope (Type 6 in Tab. 12). There was only one exception (location 10_12). According to video analysis, this sample should be from hard bottom with *F. lumbricalis* biotope (Type 3 in Tab. 12), but from the benthic samples analysis it was referred to the hard bottom with no dominant algae biotope (Type 6 in Tab.12).

For the benthic macrofauna samples from the soft bottom, after statistical analysis at 40% similarity level 9 groups could be distinguished (Fig. 29).

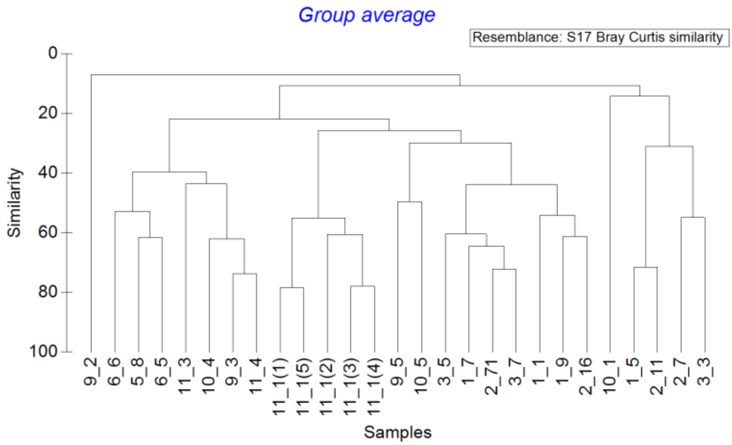

Figure 29. *Grouping of the soft bottom benthic macrofauna samples from the coastal area of the Baltic Sea.*

Only two biotope types were identified from the video data for the areas dominated by sand. However, no Van-Veen grab sample was taken in shallowest areas (on depths less than 4 meters), where one of two soft bottom biotopes (Mixed bottom in shallow areas, Type 1 in Tab. 12) was identified from video. In deeper areas the only biological characteristic was firmly identifiable from video – presence/absence of “sand houses” created by a bristleworm *P. elegans*, not allowing more detailed soft bottom biotopes classification.

4.2.2 Biotopes identified in the offshore area of the Baltic Sea

Visual features

In the offshore area 9 benthic features were identified to be suitable for the analysis according to the criteria defined (*see Section 3.1.3.4*), of them 4 biological and 5 geological ones (Tab. 13).

Table 13. Biological and physical features estimated from the Baltic Sea offshore underwater video.

Biological		Geological	
Feature	**Dimensions**	**Feature**	**Dimensions**
Mytilus trossulus	Cover, %	**Clay**	Cover, %
Saduria entomon	Points, 0 to 1	**Sand**	Cover, %
Pygospio elegans	Points, 0 to 1	**Gravel**	Cover, %
Hydrozoa	Points, 0 to 1	**Pebble**	Cover, %
		Boulders	Cover, %

Grouping of video samples

After *a priori* division (following Connor et al., 2004, *also see section 3.4.1*) of the samples into three groups according to the study area (South, North and West, see Fig. 2), on the second analysis stage (Fig. 13) samples were grouped using their geological features. Three samples groups were derived for Southern area, six groups for Northern area and five for Western area. Second stage classification results are presented in Fig. 30

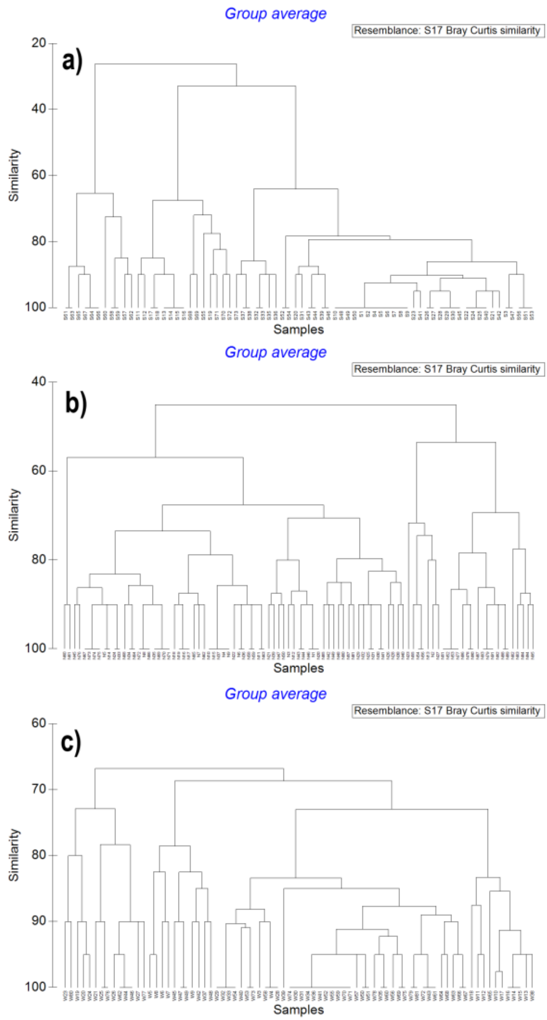

Figure 30. *Samples groups derived on the second stage of the analysis of the Baltic Sea offshore area video samples. a) Southern area; b) Northern area; and c) Western area.*

As result of the second stage of the analysis 14 samples sub-groups (3 for South area, 6 for North area and 5 for West area) were derived. At the final stage of the analysis (Fig. 13) biological properties of these groups were used for final grouping (Fig. 31).

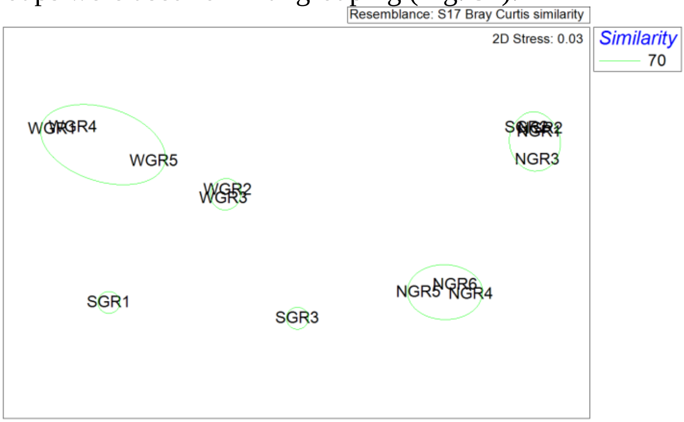

Figure 31. *Sample groups (GR) from South (S), North (N) and West (W) areas grouped by MDS on the final classification stage (Fig. 20) using biological features. Baltic Sea, offshore area.*

After final analysis stage six groups were derived (Fig. 31). Their geological and biological properties are shown in the Tab. 14.

Table 14. Average values with standard deviations of the biological and geological characteristics of the final video samples groups from the offshore area. Primary substrates are shown in dark grey and bold font, secondary in light grey and bold italic font.

	Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 5**	**Type 6**
***M. trossulus*,%**	19.7 ± 2.4	0.5 ±1.5	6.1 ± 1.0	3 ± 3.6	0.3 ± 0.5	1.9 ± 0.1
***S. entomon*, 1/0**	0.025 ± 0.05	0.4 ± 0.5	0 ± 0	0.3 ± 0.5	1.0 ± 0.05	1.0 ± 0.1
***P. elegans*, 1/0**	0 ± 0	0.4 ±0.5	0.1 ± 0.1	0.2 ± 0.4	0.2 ± 0.4	0.7 ± 0.1
***Hydrozoa*, 1/0**	0.2 ± 0.3	0 ± 0	0.03 ± 0.05	0.3 ± 0.5	0.07 ± 0.1	0.6 ± 0.3
Sand, %	***22.0 ± 11.2***	**76.4 ± 16.9**	***33.3 ± 23.***	5.3 ±11.8	**54.1 ± 35.2**	***28.6 ±24.0***
Clay, %	0 ± 0	0 ± 0	0 ± 0	0 ± 0	13.2 ± 8.6	11.4 ± 7.2
Pebble, %	***20.8 ± 11.9***	4.5 ± 6.9	10.1 ± 10.7	7.5 ± 9.6	4.5 ± 4.5	***22.3 ± 17.4***
Gravel, %	14.7 ± 5.5	19.1 ±20.7	***43.2 ± 22.7***	**81.5 ± 13.4**	***27.3 ± 50.0***	***30.5 ± 40.2***
Boulders, %	***42.6 ± 9.2***	0 ± 0	13.6 ± 4.1	5.7 ± 8	1.4 ± 1.9	7.3 ± 11.1

The derived groups represent six benthic biotopes, which were defined as follows:

- **Biotope of the blue mussels reef** (Type 1 in Table 14). The depth range is from 30 to 40 meters. Primary substrate are big boulders (cover 40-100%), which are densely overgrown with *M. trossulus* (cover 20-30%). Occurs mostly in the Northern study area and, partly in the Southern study area (Fig. 32).

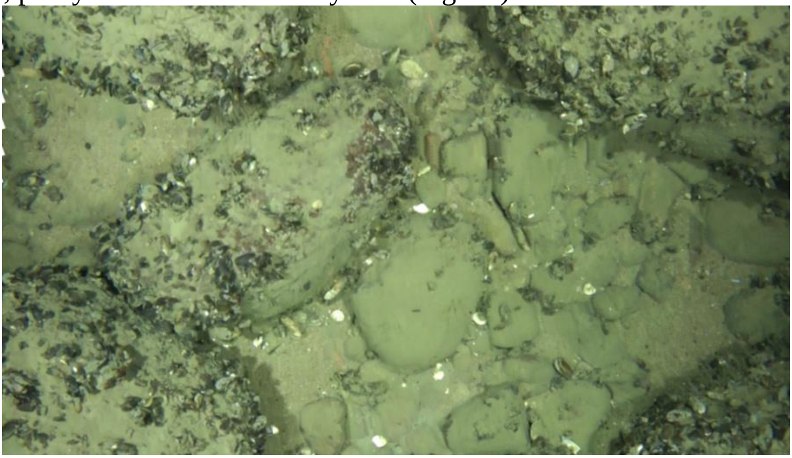

Figure 32. *Typical appearance in the underwater video of the "Biotope of the blue mussels reef". Depth range 30-40 meters.*

- S**oft bottom Biotope with *Pygospio elegans* and *Saduria entomon*** (Type 2 in Tab. 14). The depth range is from 30 to 40 meters. Primary substrate is fine sand (cover 60-100%). The main visual biological feature is the presence of the isopod *S. entomon* and polychahete *P. elegans* (found in 40% of the video samples) with occasional boulders overgrown by rare blue mussels. It occurs in the Southern study area (Fig. 33).

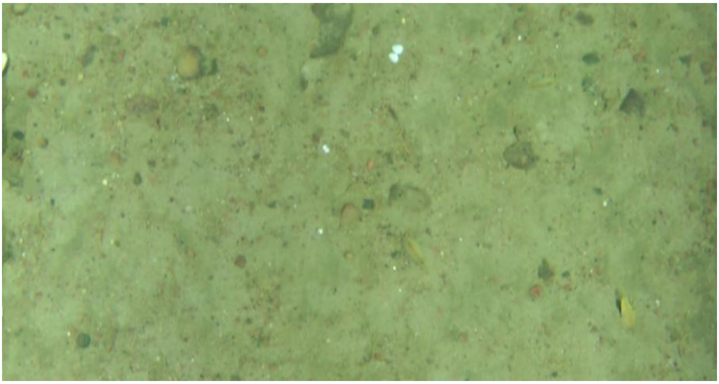

***Figure 33**. Typical appearance in the underwater video of the "Soft bottom Biotope with Pygospio elegans and Saduria entomon". Depth range 30-40 meters*

- **Coarse sand biotope** (Type 3 in Tab. 14). The depth range is 30-40 meters. Mix bottom with no primary substrate. Secondary are sand (cover 20-60%) and gravel (cover 20-60 %), some boulders (cover 10-20%) are present. The biotope is scarcely inhabited by rare blue mussels and hydroids on the boulders and *P. elegans* on the sand. Typical for the Northern study area (Fig. 34).

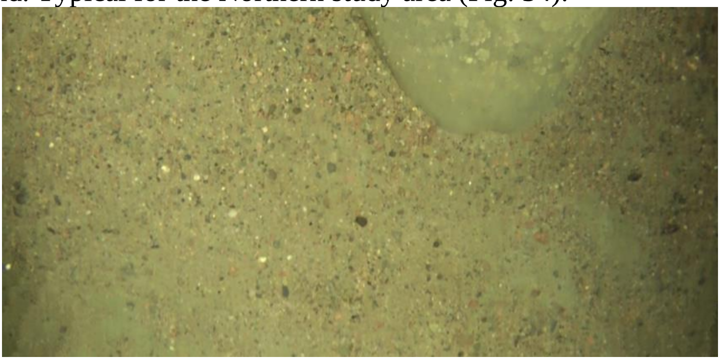

***Figure 34**. Typical appearance in the underwater video of the biotope "Coarse sand biotope". Depth range 30-40 meters.*

- **Gravel biotope** (Type 4 in Tab. 14). The depth range is 30-40 meters. Primary substrate is gravel (cover 70-90%). Similarly to the previous biotope this one is scarcely inhabited by rare blue mussels and hydroids on the boulders, but is characterized by more frequent presence of *S. entomon* (found in 30% of video samples) and *P. elegans* (present in 30% of video samples). Typical for Southern study area (Fig. 35).

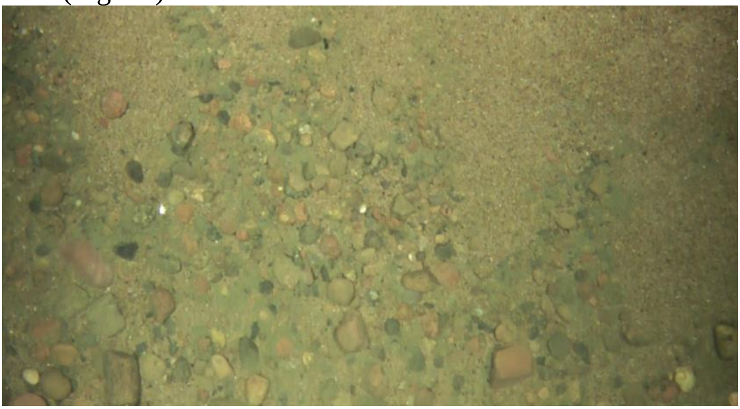

Figure 35. *Typical appearance in the underwater video of the biotope "Gravel biotope". Depth range 30-40 meters.*

- **Deep mixed bottom biotope** (Type 5 in Tab. 14). Depth range is 40-60 meters. Primary substrate is sand (cover 40-60%), secondary is gravel (cover 20-40%) with very rare boulders (cover 0-10%). Biologically this biotope is characterized by high presence of *S. entomon* and *P. elegans* (both are present in almost all video samples). Typical for Western study area (Fig. 36).

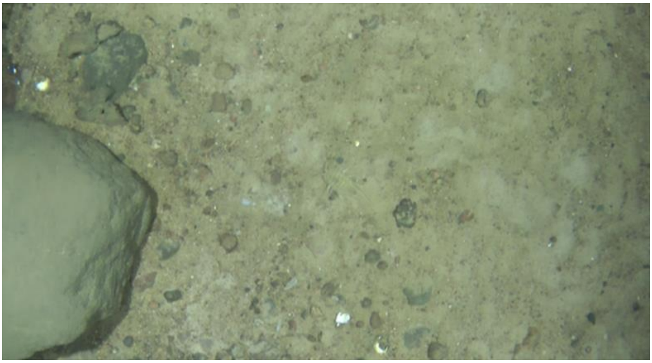

Figure 36. *Typical appearance in the underwater video of the biotope "Deep mixed bottom biotope". Depth range 40-60 meters.*

- **Deep mixed bottom biotope with *Hydrozoa*** (Type 6 in Tab. 14). The depth range 40-60 meters. There is no primary substrate, secondary are gravel (cover 30-40%) sand (cover 20-40%) and pebble (cover 20-40%). Additionally, some boulders (cover 10-20%) are present. Biologically this biotope is characterized by high presences of *S. entomon, P. elegans* (both are present in 100% of video samples) and *Hydrozoa* (present in 60% of video samples). Typical for Western study area (Fig. 37).

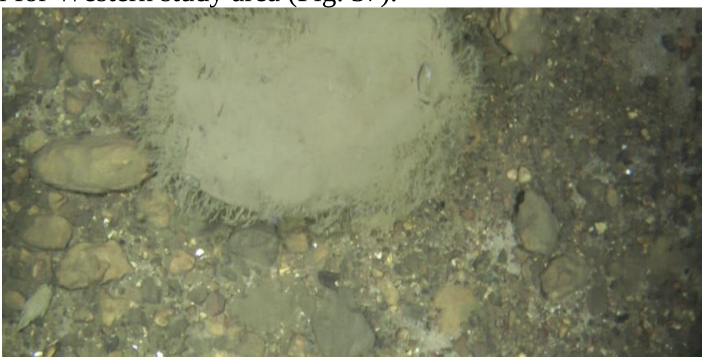

Figure 37. *Typical appearance in the underwater video of the biotope "Deep mixed bottom biotope with Hydrozoa". Depth range 40-60 meters.*

4.3 Explanatory models for wind farm impact assessment on the rocky Norwegian Sea coast

The Generalized Additive Models (*see Section 3.4.2*) were built for kelp, seastars and sea urchins explained between 63 % and 74 % of the deviance (Table 15). The model showed the significance of the chosen predictors for the majority of groups at the 95% confidence interval (p-values < 0.05), except for slope for seastars and sea urchins and BPI fine for sea urchins.

Table 15. GAM outputs values for kelp, sea urchins and seastars.

Kelp	*edf*	*Ref. df*	*Chi.sq*	*p-value*	*Significance*
s(Aspect)	3.1668	3.6050	15.639	0.002	**
s(Slope)	2.2080	2.7060	26.666	4.65e-06	***
s(Rugosity)	0.6405	0.8447	3.572	0.4618	*
s(BPI broad)	3.6596	3.8853	98.702	<2e-16	***
s(BPI fine)	3.7668	3.9577	30.793	3.21e-06	***

Deviance explained = 73.6 %

Sea urchins	*edf*	*Ref. df*	*Chi.sq*	*p-value*	*Significance*
s(Aspect)	3.8322	3.9755	20.059	0.000474	***
s(Slope)	0.5489	0.7895	1.418	0.179014	
s(Rugosity)	1.1040	1.2552	37.633	1.55e-09	***
s(BPI broad)	2.5603	3.1034	10.145	0.019014	*
s(BPI fine)	0.7078	0.9301	2.220	0.124269	

Deviance explained = 68.9 %

Seastars	*edf*	*Ref. df*	*Chi.sq*	*p-value*	*Significance*
s(Aspect)	3.540e+00	3.875e+00	32.713	1.17e-06	***
s(Slope)	3.863e-05	7.577e-05	0.000	NA	
s(Rugosity)	3.494e+00	3.822e+00	60.284	1.93e-12	***
s(BPI broad)	1.430e+00	1.770e+00	41.135	7.60e-10	***
s(BPI fine)	8.334e-01	1.030e+00	7.355	0.00704	**

Deviance explained = 62.7 %

Significance codes: > 0.0001= ***; 0.001= **; 0.01= *; 0.1= empty. Smaller p-values indicate features significance on higher confidence level. For example, P-value 0.05 indicates feature significance on 95% confidence interval.

Edf – effective degrees of freedom; Ref.df: estimated residual degrees of freedom; Chi.sq: an array of test statistics for assessing the significance of model smooth terms.

The distribution of geomorphic descriptor variables, which were identified as significant to selected taxonomical groups by the models, is shown in Fig. 38. Exploring the distribution of small kelp according to BPI fine index (which represents local effects) did not reveal clear pattern as kelp was present in both local depressions (negative values) and local elevations (positive values), although slight preferences for locally elevated areas could be noticed (Fig 38 a). On a broad scale, (which is calculated from 250 meters radius and represent broader effects), effect is more visible, abundance of small kelp was increasing with higher index values, indicating that small kelp generally prefer more elevated areas (Fig. 38 b). Although some relations could be seen between small kelp abundance and higher rugosity values (which indicates higher relief complexity), a substantial amount of small kelp were also present in areas with lowest rugosity (Fig. 38 c). The slope in Fig. 38 d indicated that small kelp seem to prefer gentle slopes, with the number of detected individuals decreasing on steeper slopes. Aspect appeared to play an important role for small kelp distribution (Fig. 38 e) as the abundance was increasing from 0 degrees (northerly direction) and reaching highest values around 180 degrees (southerly direction); while from 200 to 360 degrees (in a northerly direction) small kelp abundance began to decrease again.

For sea urchins, BPI broad values did not showed clear patterns (Fig. 38 f & g) even though BPI was significant (Tab. 15). The number of sea urchins tended to be higher on more complicated relief (higher rugosity values) (Fig. 38 h). Fig. 38 i indicates that the number of sea urchins individuals was higher on steeper slopes (higher slope values), but this tendency was not as strong as with rugosity (Fig. 38 h). According to Fig. 38 j, higher abundances of sea urchins were in a northerly direction (aspect close to 0° and 360°). Seastars, for which the highest count in 20-meter video segments was 14, did not show a very clear distribution pattern connected with BPI values either (Fig. 38 k & l) although it is significant (Tab. 15). However, it seems that like sea urchins, seastars preferred more complicated relief indicated by higher rugosity values and northern aspect (Fig. 38 m & o).

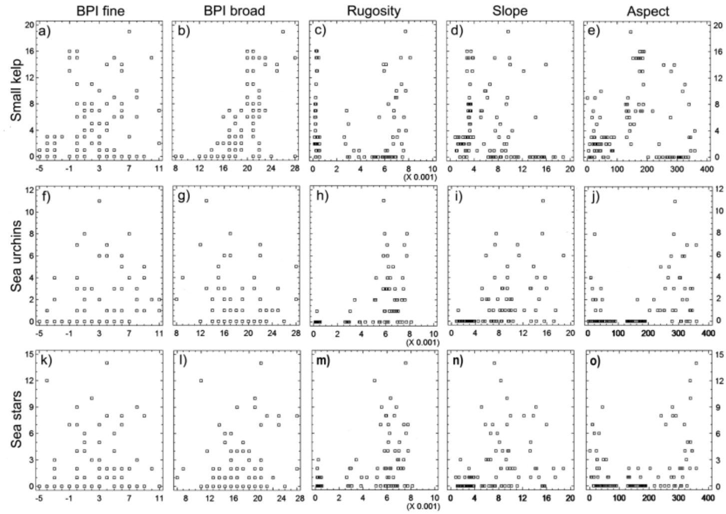

Figure 38. *Model predictors: relationships between organisms' abundance (per group) and bottom geomorphic descriptor variables indicated as significant by the model. Vertical axes represent counts in the video transects. Horizontal axes are the values for appropriate geomorphic descriptor variables.*

4.4 Determination of factors shaping the Baltic herring spawning grounds distribution

During this study Baltic herring eggs were found on three different substrates: perennial red algae (*F. lumbricalis* and *Polysiphonia fucoides*), and boulders without vegetation, overgrown by blue mussels *Mytilus trossulus*. Majority of eggs occurred on *F. lumbricalis* (21 locations from 25), 3 cases on *P. fucoides,* and single case on *M. trossulus*. From the total 98 sampling points 64 had *F. lumbricalis* cover corresponding to cover in spawning locations (higher than 10%), therefore eggs were present only in 32.8% (21 from 64) of potentially suitable *F. lumbricalis* locations.

Eggs development

Prolonged sampling period in 2009 allowed us to collect eggs at all development stages, from very early (*a-e*) to very last (*p-q*) (Tab. 16)

Table 16. Baltic herring eggs development stages, spawning substrate and depth during 2009 field season.

Date	Spawning substrate	Depth, m	Eggs stage*
April 7	*F. lumbricalis*	8	*a-e*
	M. trossulus	8.5	*a-e*
	F.lumbricalis	10.5	*a-e*
April 15	*F. lumbricalis*	6.5	*h-i*
	P. fucoides.	4	*f-g*
April 16	*F. lumbricalis*	7	*m-n*
April 21	*F. lumbricalis*	9	*m-n*
April 23	*F.lumbricalis*	8.5	*m-n*
	F. lumbricalis	4.8	*h-i*
	F. lumbricalis	6	*n-o*
April 24	*F. lumbricalis*	9	*o-p*
April 29	*F. lumbricalis*	8	*p-q*

* according to (Veersalu & Saat, 2003)

In this study three spawning locations were visited twice. Two of them (one with *F. lumbricalis* and one with *M. trossulus*) were visited on 2009.04.07, when the eggs were found at the very early development stages (*a-e*). Three weeks later on *F. lumbricalis* were found eggs at the very last development stages (*p-q*) and already empty eggs shells, whereas no eggs or empty eggs shells were present on *M. trossulus.*

4.4.1 Bottom profiles

Average 100 m profiles slope values to the eastern and western directions from sampling points, average profiles depth gradients as well as average maximum western and eastern slopes values for the 10 m segments with corresponding standard deviations are shown in Table 17. Graphical representations of bottom profiles are shown on the Fig. 39.

Table 17. Geomorphological characteristics of bottom profiles at the spawning locations. Positive values indicate eastern slopes and negative western slopes.

Direction from spawning point	Average slope (100 m)	Max West slope (10 m)	Max East slope (10 m)	Depth gradient (within 100 m)
To East	0.6±0.9	-2.1±1.7	4.1±2.4	1.9±1.0
To West	-0.7±0.9	-4.8±1.8	3.4±2.3	2.4±1.1

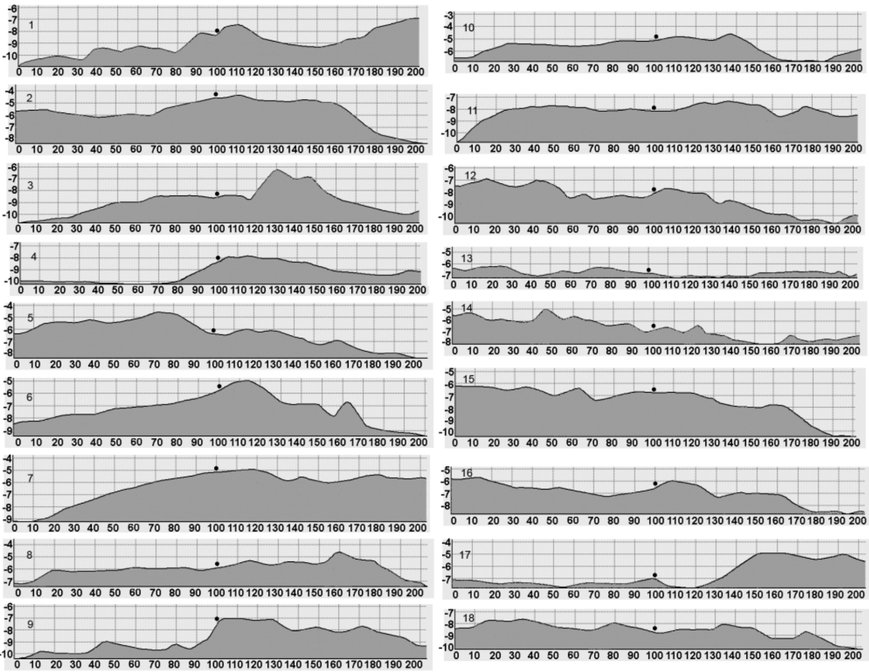

Figure 39. *Seabed profiles (200 m East-West direction) on the spawning locations. Coastal side is on the left, detected spawning locations are indicated in the center as black dots.*

The general bottom slope pattern, continuous increase in depth seawards, was determined only in 5 profiles (12, 13, 14, 15 and 16), while for the majority of the profiles the relief was more complex.

Average slope values for 100 m profiles (Tab. 17) indicate that in general towards the shore the eastern slopes prevailed over the western, contradicting with natural tendency of depth decline closing to shore. In the seaward direction (West) within 100 m distance majority of detected spawning locations share significant depth gradient (mean value 2.4±1.1 m) and occurrence of at least one 10 m segment with relatively steep western slope (mean value -4.8±1.8).

4.4.2 Herring spawning beds spatial modelling

Presence-only Maxent model was used to build Baltic herring spawning grounds predictive model. Environmental layers initially used as model predictors were:

1. Detailed multibeam bathymetry
2. Rugosity
3. Slope
4. Aspect
5. FineBPI
6. BroadBPI
7. Bottom sediments derived from SSS data

After tuning the model, four variables were used:

1. Detailed multibeam bathymetry
2. Bottom sediments derived from SSS data
3. BroadBPI
4. BroadBPI

Model receiver operating characteristic (ROC) curve averaged over the ten replicate runs is shown in the Fig. 40. The average test AUC for the replicate runs is 0.775, and the standard deviation is 0.158.

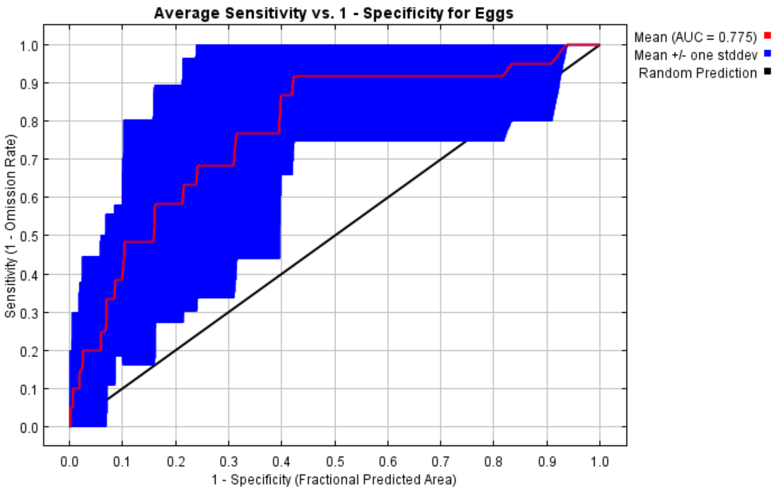

Figure 40. *Receiver operating characteristic (ROC) of Maxent model curve averaged over the ten replicate runs.*

Relative contributions of the environmental variables to the Maxent model are shown in Tab. 18

Table 18. Relative contributions of the environmental variables to the Maxent model averaged over ten replications.

Variable	Percent contribution	Permutation importance
Bathymetry	64.2	78.8
Sediments	20.1	0.9
BroadSPI	9.1	9.9
Slope	6.6	10.5

Environmental variables response curves for Maxent model are shown in the Fig. 41.

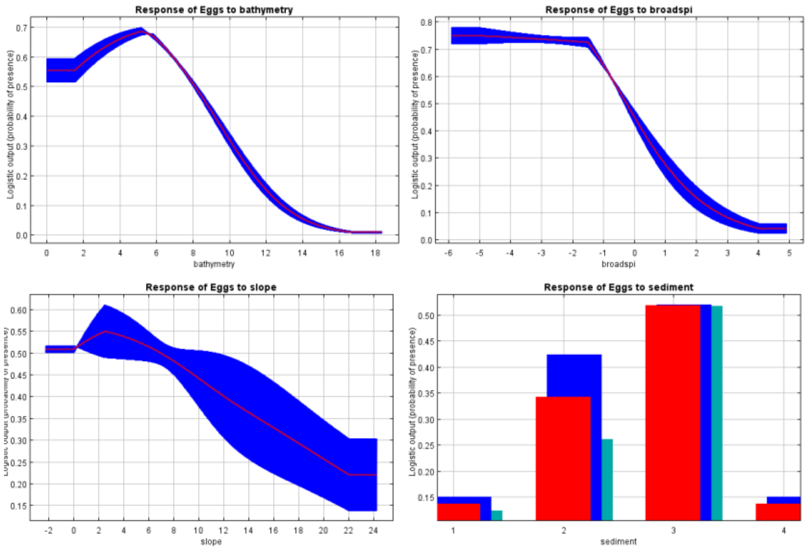

Figure 41. *Environmental variables response curves for Maxent model averaged over ten replications.*

The plots of average (after 10 replications) model and it standard deviations are shown in Fig. 42, and detected spawning locations on the multibeam bathymetry in Fig. 43.

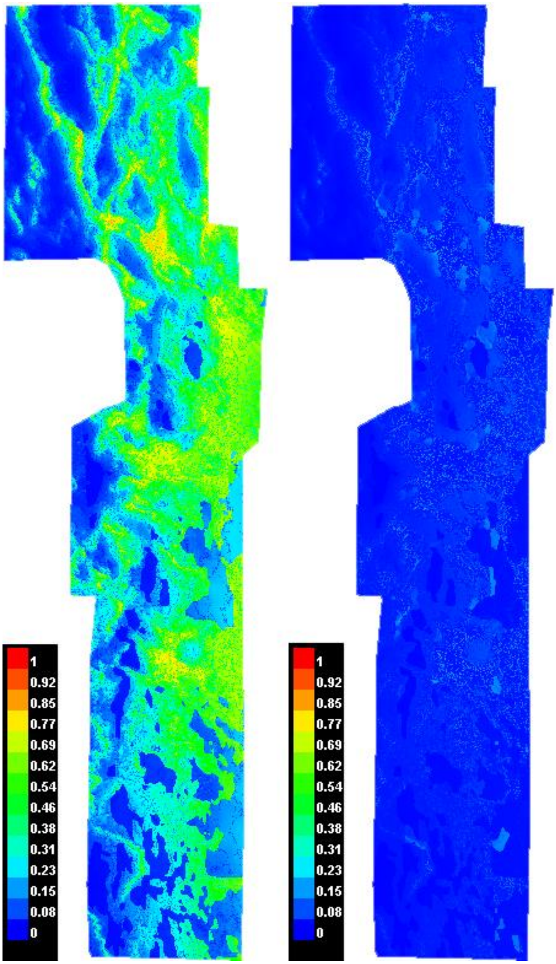

Figure 42. *Average Maxent model after ten replications (on the left) and Maxent model standard deviations (on the right).*

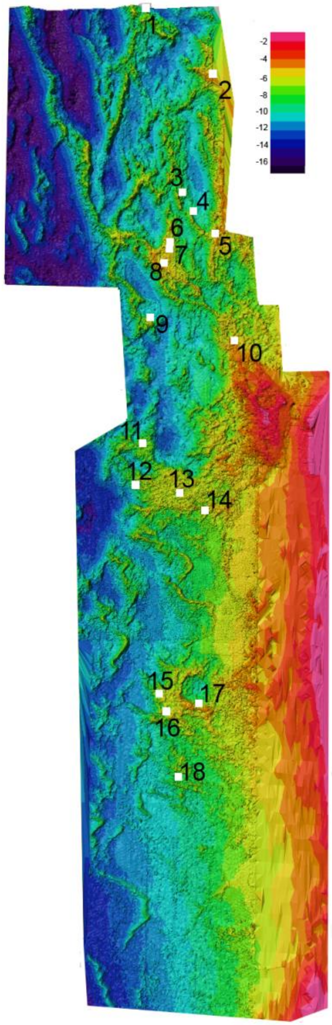

Figure 43. *Location of detected spawning beds on the multibeam bathymetry map (only presences are shown)*

5. Discussion

5.1. Manual and semi-automatic methods of underwater imagery analysis: advantages and limitations

5.1.1 Using underwater imagery for quantitative assessments: what is the influence of a human error?

Different approaches could be used to manually derive similar types of quantitative and qualitative data from the underwater imagery. Qualitative features estimation (like presence/absence of certain alga or animal species) can be done reliably visually even with inexperienced personnel (Fig. 16; Tab. 7). The same, in certain extend, can be told about absolute counts of benthic organisms: sea urchins (probably *Strongylocentrotus* sp) had been counted reliably and accurately from the Norwegian Sea raw video and video mosaics, even with inexperienced observers (Fig. 16). Counting of seastars was more challenging, resulting in significant underestimation in the counts, even when using video mosaics. Most probably, this was because seastars are more dificult to detect, comparing with sea urchins (Fig. 5 & 6). Probably, there is no real solution to this problem, except investing more time into operator training and analysis. On another hand, if need to be done quickly, features scale could be less detailed: there was no problem evaluating presence/absence of seastars from the similar imagery (Tab. 7) using 15 seconds video segments as video samples. Those segments could be used as sub-samples resulting in semi-quantitative estimations of the seastars abundance (for example, if use 90 seconds segment as one sample, it would contain six 15 second sub samples, allowing to have a scale from 0 to 6).

For benthic cover estimations manual point-based method and simple visual census are widely used (Deithier et al., 1993). A point-based method is more objective, but still is a subject to significant errors in estimations within individual frames, as it was shown in our study (Fig. 18), due to the limited amount of points that is practical to use (Miller & Müller, 1999). In our case each point was representing 20% benthic cover, even for features that visually were clearly not abundant enough: for example, sand cover estimations for individual frames was reaching more than 60% what was an obvious overestimation for the data used. This lead to conclusion, that manual point-based approach should be used with caution: although it can detect changes in the benthic environment (for example, increasing of ERBL cover and decreasing of *Lithothamnion* sp. cover between 2010 and 2011, changes detected by semi-automatic method as well), average cover values could significantly deviate from real values.

Importance of the methods differences calculating statistical significance of the benthic covers variations between seasons, inconclusive for ERBL (Tab. 9), is difficult to estimate. However, in general results shows that increase in ERBL cover is followed by decrease of *Lithothamnion* sp. cover, and in this aspect semi-automatic methods seems to be more accurate: when it detected no significant difference in EBRL cover for the transect 6E, it reported that there was no significant difference in *Lithothamnion* sp. cover as well. Manual analysis results do not show this tendency: for the transect 6E according to the manual method there was significant difference in the *Lithothamnion* sp. cover not followed by according changes in ERBL cover and in transect 9D situation was opposite, significant difference in the ERBL cover was not followed by according changes in *Lithothamnion* sp. cover.

Simple visual census approach for benthic covers estimations is not suffering from the limited amount of data used in the analysis (operator inspecting whole frames) comparing with point-based method, but it accuracy is operator dependent and difficult to predict and estimate (Fig. 15). Maybe this problem could be overcome by using larger number of operators: in our case despite individual errors in the test groups of inexperienced operators, average values were quite reasonable and close to semi-automatic method estimations. Nonetheless, with growing operator experience and training, simple visual census benthic coverage estimations fairly quickly became consistent, as it was shown in our test (Fig. 16). Therefore, using the same or several trained operators, simple visual census allows maintaining analysis uniformity and already known to providing with results at least as accurate, as point-based method (Deithier et al., 1993).

High variability in the data and difficulties estimating errors, typical for manual benthic cover estimation approaches, highlights the needs for development of more objective approaches, which are able to efficiently utilize modern computers capabilities.

5.1.2 Semi-automatic method performance: better, but some drawbacks remain

The semi-automatic approach to video mosaics analysis for benthic covers estimations have the ability to overcome some of the manual approaches difficulties, because the technique is objective, operator independent, and uses a much larger portion of the imagery (theoretically 100% of the imagery could be used in the analysis). In projects were large amounts of imagery are needed to be analyzed, a semi-automatic approach is faster and more efficient than any other analytical method, because, unlike manual methods, the most time consuming stage, the mosaics preparation, is mainly computing time and could be easily parallelized (Tab. 10).

The biggest challenge with semi-automatic benthic cover estimations are inconsistencies in the real world underwater imagery. The imagery changes because of the inherent non-linearity of underwater imagery caused by the different absorption rates of different energy photons (Duntley, 1963). This makes the proper compensation for such non-linearity a non-trivial task. The optical properties of seawater are dependent on many factors related to seasonal, geographical and hydrological differences. Different particles (biological and abiotic) also heavily affect the optical properties of the seawater and it properties can rapidly change, especially in coastal areas. These factors make any modelling of water optical properties imprecise and probably inadequate for practical use.

Therefore, to properly compensate for water clarity, it optical properties need to be quantitatively measured during the filming. Although such measurements are fairly simple to do (Fonseca & Raimundo, 2007; Fu et al., 2014; Vecchi et al., 2014), this kind of equipment is rarely used during imagery collection and has yet to become a common tool in the benthologist inventory. As of today, information about the optical properties of the seawater during filming is rarely available. Such uncertainties make the application of computer-vision algorithms for underwater video problematic, because the difficulties with colours and lightning add to the errors caused by the imperfections of the images-segmentation methods themselves.

Dividing video mosaics into different colour classes (Fig. 13) can overcome some of the problems created by inconsistencies within the imagery. Subdividing the mosaics compromises analysis uniformity to some degree because separate benthic-cover colour palettes are required for different mosaic colour classes. However, our results (Fig. 18) suggest that this compromise does not significantly affect the accuracy of the analyses. This conclusion is also supported by a comparison with a manual analysis, which is much less affected by imagery inconsistency due to greater flexibility of the human eye (Fig. 15 & 16, Tab. 8). Nonetheless, semi-automatic analysis results remained broadly congruent with manual point-based, even when the majority of the imagery from 2010 and 2011 belonged to different colour classes and hence different colour palettes that had to be used for semi-automatic features extraction (only one transect from 2011 was of the same colour class as 2010 transects).

There are ways to improve the results of automatic or semi-automatic underwater imagery analysis: use of more complicated and robust segmentation and/or imagery-preprocessing algorithms and improvements in the data collection procedures. While imagery processing methods development requires additional studies, implementation of stricter data-collection protocols is fairly simple. During this study, having more experience with data analysis after the 2010 season, we were able to reorganize data collection in 2011, which resulted into significant reduction in number of mosaics rejected during the semi-automatic data analysis; nine were rejected from the 2010 dataset whereas only three were rejected from the 2011 data (Tab. 3).

The technique used demonstrated good performance. Because large amount of the imagery is used in single mosaic, number of mosaics for the video transect could be much lover. As result, average for the video transect are tightly grouped around mean value, with relatively low variability (Fig. 18) what makes deriving of statistically significant differences between video transects and/or seasons more likely, comparing with manual estimations.

However the technique still has significant limitations. Not all benthic features available for manual point-based analysis were possible to derive using colours, and we had to significantly reduce the number of features used in the semi-automatic analysis.

One of additional advantages of semi-automatic approach, is that already produced mosaics can be used for other types of imagery analysis, such as count of visually distinguishable benthic organisms (e. g. seastars or sea urchins), which can significantly benefit from it (Fig. 14). Comparing with the raw video, where only one of several overlapping frames can be seen at the time, and where zooming and scrolling becomes more difficult, video mosaic can be easily scrolled in any direction and zoomed in and out, using many of the available image viewing software, making imagery inspection from mosaics simpler and more flexible, thus less tiresome an probably more accurate.

The method can be adapted to imagery collected in different environments, containing different benthic features: all is needed is to select appropriate benthic features and create colour palettes for them. For monitoring purposes, when data is repeatedly collected in the same environment, filming equipment and collection protocols are standardized, there is no need to change the imagery analysis procedures between the surveys and the same colour palettes can be used over and over again, saving time and funds.

5.2 How suitable is underwater video for the benthic biotope identification?

5.2.1 Particularities of benthic biotope identification from underwater video

Many benthic biotopes classification systems use easily visible features as determinative properties of identified biotopes (Dauvin et al., 1996; Olenin et al., 1996; Connor et. al., 2004; Olenin & Daunys, 2004; EUNIS, 2010). Therefore, even with taxonomically incomplete datasets, typical for the underwater imagery, biotope determinative features could be identifiable with acceptable accuracy.

During this study, using proposed benthic biotopes identification scheme (Fig. 13), number of benthic biotopes was derived in the phoptic and aphotic zones of the Lithuanian part of the Baltic Sea. Although on the final analysis stages (Fig. 13) only biological features were used, identified benthic biotopes demonstrated good concordance between physical and biological factors, as it was expected based on previous studies (Olenin et al., 1996; Olenin, 1997; Olenin & Daunys, 2004). Additionally, previously undescribed in the Lithuanian part of the Baltic Sea "Hard bottom with *Polysiphonia* sp." benthic biotope had been identified in the coastal area, demonstrating an advantage of the formal approach. In the offshore area, relevance of the biological features for benthic biotopes identification also was demonstrated: identified biotopes reflected even marginal differences in the bottom substrate compositions. Bottom substrate was most important feature only for "Rocky mussel reef" biotope, which was characterized by boulders coverage more than 30%. In the areas with soft and mix bottom substrates more important were biological features, such as *S. entomon*, presence, especially abundant in the depth range 40-60 meters, and bristleworm *P. elegans* and *Hydrozoa* presences, which were limited by suitable substrate availability. Two benthic biotopes, characterized by relative absence of the any type of benthic organisms (rough sand and gravel biotopes) still were distinguished as separate groups during statistical analysis of biological properties, indicating sensitivity of the formal approach used in this study.

The biological differences between derived offshore biotopes in some cases were not too great (Tab. 14), and partly could be explained by patchiness of the study areas, especially typical for the Western part, where were no long continuous patches of uniform bottom, but rather mix of small patches of different sediments types. Using longer video segments as video samples, most probably some of the benthic biotopes would be combined together into bigger classes: for example, “Rocky mussel reef”, “Soft bottom”, “Mixed bottom” (containing “Coarse sand” and “Gravel” biotopes) and “Deep mixed bottom” (combining “Deep mixed bottom” and “Deep mixed bottom with *Hydrozoa*” biotopes. However, an important theoretical question, how big or small elementary biotope unit should be, goes beyond the scope of this work.

5.2.2 Comparison of the biotopes identified from video with existing classification systems

First marine benthic biotopes classification system for Lithuanian part of the Baltic Sea was proposed in 1996 (Olenin et al., 1996). The scope of this work was mainly in the coastal (photic) areas and it included 10 different biotopes types: five for soft bottoms, two for mixed and three for hard bottoms. This classification had been revised in 2004 (Olenin & Daunys, 2004), while only five biotopes types were identified, two for sort bottoms, two for hard bottoms and one for mixed bottoms. Currently, most developed benthic biotopes classification system for the Baltic Sea is HELCOM List of Baltic Sea underwater biotopes, habitats and biotope complexes (HELCOM, 2013), which include all Baltic Sea geographic regions and based on the division to the photic and aphotic zones. During this study, for Lithuanian part of the Baltic Sea 12 benthic biotopes were identified: six for coastal area (photic zone) and six for offshore area (aphotic zone). Summary of benthic biotopes identified during different studies is shown in the Tab. 19.

Table 19. Benthic biotopes identified at the Baltic Sea Lithuanian cost in previous works and in this study

Photic zone

Olenin et al., 1996	**Olenin & Daunys, 2004**	**HELCOM, 2013**	**This study**
Shallow coastal area without visible macroflora and macrofauna	Mobile sand biotope	**AA.J4U** Baltic photic sand characterized by no macrocommunity	Mixed bottom in shallow areas
Shallow descending in sandy bottom with unattached algae	Not present	Not present	Not present
Large boulders with green filamentous algae in shallow areas	Mobile sand biotope	**AA.A1S** Baltic photic rock and boulders characterized by annual algae	Mixed bottom in shallow areas
Mobile sand with gammarus and mysids	Mobile sand biotope	Not present	Mixed bottom in shallow areas
Gravel and boulders with *B. improvisus* and gammarus in shallow areas	Mixed bottom	**AA.A1I1** Baltic photic rock and boulders dominated by barnacles (*Balanidae*)	Mixed bottom with no dominate algae
Stony bottom with *F. lumbricalis*	Stony bottom in photic zone	**AA.A1C5** Baltic photic rock and boulders dominated by perennial filamentous algae	Stony bottom with *Polysiphonia*
		AA.A1C3 Baltic photic rock and boulders dominated by perennial foliose red algae	Stony bottom with *F. lumbricalis*
Stony bottom with *M. edulis*	Stony bottom in afotic zone	**AA.A1E1** Baltic photic rock and boulders dominated by *Mytilidae*	Hard bottom with no dominant algae
Sand and gravel with rare in- and epifauna	Mixed bottom	**AA.A1I1** Baltic photic rock and boulders dominated by barnacles (*Balanidae*)	Mixed bottom with no dominant algae
Muddy bottom with polyhaetas *Hediste (Nereis) diversicolor* and *Marenzelleria viridis*	Not present	**AA.H3M3** Baltic photic muddy sediment dominated by *Marenzelleria* spp.	Not present
Sandy bottom with bivalia *Macoma baltica* and	Soft bottom biotope	**AA.J3L9** Baltic photic sand dominated by multiple infaunal	Soft bottom in deeper areas

bristleworm *P. elegans*		bivalve species: *Cerastoderma* spp., *Mya arenaria*, *Arctica islandica*, *Macoma balthica*	

Aphotic zone	
HELCOM, 2013	**This study**
AB.A1E1 Baltic aphotic rock and boulder dominated by *Mytilidae*	Biotope of the blue mussel reef
AB.J3N1 Baltic aphotic sand dominated by *Monoporeia affinis* and *Saduria entomon*	Soft bottom Biotope with *Pygospio elegans* and *Saduria entomon*
AB.J4U Baltic aphotic sand characterized by no macrocommunity	Coarse sand biotope
AB.M2T Baltic aphotic mixed substrate characterized by sparse epibenthic macrocommunity	Gravel biotope
AB.M1V Baltic aphotic mixed substrate characterized by mixed epibenthic macrocommunity	Deep mixed bottom biotope
AB.M1G1 Baltic aphotic mixed substrate dominated by hydroids (*Hydrozoa*)	Deep mixed bottom biotope with *Hydrozoa*

Comparison of distinguished biotopes with previously identified ones shows good concordance with other bottom biotopes classifications created for our area: every biotope identified from video have it analogy in the Olenin et al., 1996 and HELCOM 2013 classifications.

The same benthic biotopes deriving scheme (Fig. 13) had been successfully used for benthic biotopes identification in different seas and conditions: Black Sea and White Sea, allowing deriving non-evident interactions between biotic and abiotic environment. In the White Sea, for example, particularities of the seastars and soft corals distributions according to depth were derived based on their density (Šaškov & Olenin, 2012). Those results once again demonstrate method (Fig. 13) robustness, sensitivity and applicability in different environments.

5.3. When underwater imagery is not enough: adding acoustical data

5.3.1 Explanatory models

A large variety of spatial statistical modelling approaches exist today, and are widely used to answer various ecological questions such as predicting habitat distribution and deriving interactions between species and the environment (Franklin, 1995; Elith, 2000; Guisan & Zimmerman, 2000; Ferrier et al., 2002). However, good environmental layers are essential for building high resolution models. Such data can be provided by acoustical methods, which are able to derive full coverage high resolution data. Combination of the underwater imagery for biological information and multibeam bathymetry for environmental information were used in the planned offshore wind park impact study.

While the impact of offshore wind farms on soft-bottomed communities are becoming increasingly better understood, the impact of offshore wind farms on hard-bottomed communities is still a matter of speculation (Shields et al., 2009; Dahlgren et al., 2014; but see Schläppy et al., 2014). The introduction of hard substratum through turbine foundations and scour protection will not have the same significance on rocky reefs as it has on soft-bottomed area where it introduces a new potential habitat. The monitoring techniques traditionally used for assessing impacts on the fauna and flora on soft-bottomed communities, such as grabs, dredges and trawls are of little relevance for monitoring on rocky reefs as they might be impossible to use. Grabs cannot close on bedrock and give poor results on gravel or stony bottoms due to lack of standardization. Trawls may work on flat bedrock but not in areas where the bathymetry is highly variable. In short, other methods are necessary to monitor rocky reefs intended for offshore energy production.

Combining video observations and multibeam bathymetry in a generalized additive model allowed for a better understanding of the factors influencing the species' distribution and their interactions with their environment at Havsul. The variables: aspect, slope, rugosity, and benthic position indexes, were confirmed to be of significant importance for the groups of organisms found at Havsul. More specifically, it allowed us to estimate the organisms' habitat preference before impact and to hypothesize over the potential impacts during the construction and operational phase.

Kelp occurred in areas of high rugosity and gentle slopes where holdfast attachment is probably facilitated. Kelp presence was more likely at elevated areas with a southerly orientation which is probably due to their need for sunlight. Since aspect significantly explained the presence of kelp on the sheltered side of geological features (rock, bedrock), more specifically at S-SE directions between 90 and 180 degrees, kelp might be expected to grow better on the sheltered side of foundations. Since the diversity of the flora was highest at locations with low numbers of sea urchins, it would follow that the migration of urchins to different locations may result in increased flora diversity in areas where urchins are absent. Although sea urchins have been reported to remove young kelp plants and thus keep the population numbers low (see Hagen, 1983, 1995), no evidence of this is apparent in the results.

Unlike sea urchins, seastars showed a marked preference for bedrock which cannot be explained by their ability to camouflage well on the bedrock surface (often partially covered with pink encrusting algae) since both seastars and sea urchins in this study have similar pinkish colours. The difference in bedrock usage by those two groups may be related to urchins preferring steeper slopes whereas slope characteristics did not significantly affect seastars distribution (and bedrock in Havsul has large areas that are flat). Since both seastars and sea urchins show a preference for a complex local relief (rugosity) and changes in elevation (BPI fine and broad), their distribution pattern might change during and after foundation construction and cable route preparation which is likely to remove rugosity, at least locally. However, until the final design of the foundations and scour protection is chosen, little can be said about how the wind farm will impact the rugosity in the area.

In short, the generalized additive model based on multibeam bathymetry and videos allowed us to formulate hypotheses of possible impact as recommended by (Gill, 2005). The deviance explained by the model was in the order of 60-70 %, emphasizing that although geomorphic descriptor variables are important for species distribution, other factors such as biological interactions (shading and competition) probably also plays a role in shaping species distributions. The hypotheses formulated here may thus be less speculative than those that could have been formulated with just a general knowledge of the area, which in the case of Havsul is, in any case, rather scant.

In the future, it would be worthwhile to explore non-topographic variables (wave exposure, currents and turbidity) on the presence of local taxa. Turbidity would probably increase manifold during the construction phase and shading and scouring may be expected on the local fauna and flora. Ideally, investigations of the impact from storms and large oceanic wave action on subtidal rocky habitats would be carried out at Havsul, as assemblage composition in space and time has been shown to be shaped by strong mixing and rip currents (Wernberg & Connell, 2008; Scheibling & Lauzon-Guay, 2010; Burrows, 2012). The construction of turbine foundations is expected to add to this disturbance.

Since the environmental impact of wind farms on rocky reefs is difficult to predict (Shields et al., 2009) and rocky reefs are often subjected to high levels of physical stressors such as currents, waves, low salinity and exposure to air during low tide (Christie, 1983; Gaylord, 1999; Denny & Gaylord, 2010), detecting any impact on rocky reefs is a challenge although it is important to try (Gill, 2005). The combination of video, multibeam bathymetry and generalized additive models can be considered a useful tool for assessing potential impact at rocky reef locations.

5.3.2 Predictive model

Although our Baltic herring spawning grounds study was relatively short term (only two spawning seasons), it results show that Baltic herring spawning beds remain constant from year to year even at the small spatial scale (Fig. 43), and their distribution does not depend on the seasonal hydrological conditions. The spawning beds are very patchy and only one third of potentially suitable area (vegetated hard bottom in depth interval of 4-8 m) is actually used for spawning in our area.

Baltic herring is not substrate specific during spawning, but substrate is important for eggs development: eggs spawned on *M. trossulus* were not found during repeated survey and most probably failed to develop and hatch. Collected data confirm findings of other authors that in the Lithuanian coastal waters the seabed dominated by *F. lumbricalis* is the most important biotope for herring reproduction (BaltNIIRH, 1989; Olenin & Labanauskas, 1995; Maksimov et al., 1996; Fedotova, 2010). Additionally, red algae *P. fucoides* also serves as a suitable spawning substrate.

Lithuanian coast do not have sheltered areas, preferred by other populations of the Baltic herring during spawning (e.g. Aneer et al., 1983; Kääriä et. al., 1997; Krasovskaya, 2002; Rajasilta et. al., 2006), which probably explains why in our area Baltic herring spawns deeper (4-8 m) comparing with 0,5-4 m, typical in shelter areas (Aneer et. al., 1983). With increased spawning depth, Baltic herring have limited access to algal beds, because here only two red algae species (*F. lumbricalis* and *P. fucoides*) form sufficiently dense covers (Bučas et al., 2009), suitable for the successful eggs development.

According to Rajasilta et. al. (1989, 1993, 2006) red alga (including *F. lumbricalis*) have a negative effect on the Baltic herring eggs, causing higher eggs mortality. However, in our study embryos, in eggs collected from *F. lumbricalis* thalli, developed normally to the very last development stages resulting in the successful mass hatching (Tab. 16). One of the *F. lumbricalis* advantages as a spawning substrate could be extended 3D structure of the firm *F. lumbricalis* thalli, which can accommodate larger amount of eggs while ensuring their proper aeration comparing with other spawning surfaces, where eggs could be laid in multilayers. It is known, that embryo oxygen uptake is increasing with the later development stages (Silva &

Tytlerb, 1973), and in multilayer mats only eggs in the upper layers successfully develop to the last stages, while eggs in deeper layers aborts (abortion stage is layer depended, the deeper the egg, the earlier abortion stage) and/or show severe embryos abnormalities (Messich & Rosenthal, 1989), most likely due to a lack of oxygen, which is less likely to develop when *F. lumbricalis* is used as a spawning substrate.

Slope proved to be a good geomorphic descriptor for Baltic herring spawning beds. Majority of detected spawning locations were characterized by relatively steep seaward slopes, significant changes in depth and are on the local seabed elevation (Tab. 17; Fig. 43). Significance of relatively small geomorphological features suggests that any kind of spatial spawning grounds estimations or modeling using rough bathymetric data are going to significantly overestimate actual spawning areas and availability of high resolution bathymetry is essential. Due to high patchiness of the spawning beds it is easy falsely detect their absence, therefore presence-only approaches (e.g. Maximum entropy modelling) are preferable over presence-absence methods (e.g. Logistic regression).

Plotted model (Fig. 42) in general follows local geomorphology and higher Baltic herring eggs occurrence probabilities were calculated on local elevations (Fig. 42 & 43). According to the model response curves, most important factor was a bathymetry (Tab. 18). Bottom sediments have relatively high percent contribution, but low permutation importance. Percent contribution values are only heuristically defined: they depend on the particular path that the Maxent code uses to get to the optimal solution. Permutation importance measure, on another hand, depends only on the final Maxent model, not the path used to obtain it, and could be better indicator in this case. Therefore, differences between percent contribution and permutation importance for the bottom sediments, could indicate that Baltic herring indeed not substrate specific during the spawning. However, response graph for sediments (Fig. 41) indicates that herring eggs are associated with hard and mix bottoms (substrate types 3 and 2), and not with soft and gravel bottoms (substrate types 1 and 4). This could explain relatively high percent contribution score: substrate was used by model to exclude areas with soft and gravel sediments from areas with higher eggs presence probabilities. BroadBPI response curve plot (Fig. 41) indicates higher Baltic herring eggs presence probability in the areas with negative to neutral index values. It seemly contradicts with theory that Baltic herring chooses spawning grounds on local elevations (which are indicated by positive BPI index values), but bottom profiles images (Fig. 39) shows that bottom relief in the spawning locations is quite complex and minor elevations and depressions are present, what could be picked up by the model. Slope response curve shows relatively high deviation between slope values and Baltic herring eggs presence probability, but overall tendency is that presence probability is higher with lower slope values.

Overall model performance is not bad, scoring average AUC 0.775. Standard deviation was quite high (Fig. 10), but model was built over only 18 eggs presences in the multibeam area (Fig. 9 & 43), therefore such results to be expected and could be improved with larger dataset.

The spawning locations remained constant for both seasons, and based on our results we believe that most probably explanations for such consistency are local geomorphological features: combination of slopes and depth gradients, because the latter are relatively stable over time compared to the hydrological conditions. Other authors had reported that spawning locations are often close to deeper areas (Kääriä et. al. 1988; Rajasilta et. al., 1993; Kääriä et. al., 1997), which is in a good agreement with our findings. It suggests that observed phenomena is not specific for the Lithuanian cost, but rather indicates more general pattern, typical for other Baltic herring populations as well.

5.4. Gaps and future perspectives

Biological data that could be extracted from underwater imagery can vary: qualitative, categorical, and quantitative. Depending on the task in hands, different methods could be used, from simple visual estimations, sufficient for tasks such as benthic biotopes identification to complicated manual and/or semi-automatic analyses.

Underwater video analysis can be quite noisy and variability of the samples could be quite high due to the nature of the video data: it covers significant areas of highly heterogeneous benthic environment, therefore individual samples properties could significantly vary. However, larger number of the samples that could be included in the analysis allows overcoming this problem: as our tests shows, even high variability within groups allow to derive meaningful mean values (Fig. 18). Similar conclusions were made in previous studies: for example, even in the very diverse coral reef environment, only 5 points per frame was found to be appropriate for manual point-based analysis, while applying more points (which can reduce variability between frames properties estimations) was found unpractical (Miller & Müller, 1999). One of the approaches to reduce variability of the data is to include more imagery in the analysis and to use more precise methods (such as semi-automatic, *see section 3.1.2.6*). Semi-automatic benthic cover estimation method proposed in this study demonstrated the following advantages:

- **Accuracy**. In all our tests cover values derived using semi-automatic method were close to the average values derived from multiple repetitions using manual methods: either when analysis was performed by group of different people (Fig. 15) or large number of frames was analyzed (Fig. 18). Despite it is impossible to measure accuracy of the different methods directly (true cover values are unknown), lower variability of the semi-automatic approach allows to detect statistically significant differences in the environment more accurately.
- **Reliability**. Proposed semi-automatic method is fully formalized: unlike manual underwater imagery analysis methods, with chosen colour palettes it will provide exactly the same analysis results every time, regardless of the operator. Manually chosen colour palettes, according to our test (Fig. 17) do not add too many variations, which could sufficiently affect method reliability.

- **Cost-effectiveness**. Most complicated part of the semi-automatic benthic cover estimation method is picking colour palettes, what can be done by researcher in approximately 8 hours. The rest of the tasks are mostly computing time and technical operations that are not operator dependent and can be done by moderately trained technician. Additionally, majority of those tasks could be easily paralleled without suffering to the results. The bigger data set, the more efficient semi-automatic approach could be (Tab. 10).

Unlike widely used manual point based method (Aronson et al., 1994; Carleton & Done, 1995; Vogt et al., 1997; Sweatman et al., 2001; McDonald et al., 2006; Lejac & Ordmon, 2007; Dumas et al., 2009), semi-automatic method have an ability to use all imagery in the analysis, not just several points from the selected frames. Because it is a formal method, do not depending on the operator, results could be used in long-term programs, when data collecting and analyzing personnel are likely to be changed over time. On another hand, semi-automatic method has its own limitations (for example, limited amount of features that are suitable for it (*see Section 3.1.2.6*)), and it is unlikely that manual video data treatment will go away any time soon.

Simple visual census methods are capable of providing quite accurate results, comparable with semi-automatic method (Fig. 15), especially with trained operator (Fig. 16). However, with manual analysis approaches, video mosaics did not demonstrated additional benefits for visual benthic covers estimation, although they proved it usefulness counting not easily visible benthic fauna individuals (Fig. 14).

Benthic biotopes concept today is used for coastal management purposes implementing ecosystem based management principles (Olenin & Ducrotoy, 2006; Halpern et al., 2008; Foley et al., 2010; Katsanevakis et al., 2011), therefore a system for scientifically solid and accurate identification and description of benthic biotopes properties have a significant practical value (Fig. 13). During this study, benthic biotopes were successfully identified and described from underwater imagery in different zones (coastal and offshore areas). Comparison of benthic biotopes identified from underwater video in the coastal area of Baltic Sea with benthic biotopes derived from benthic samples (Fig. 27 & 28) and existed national and international classifications (Tab. 12) proved that underwater video based identification (Fig. 13) is accurate and correspond with results derived by different methods.

Modern acoustical methods can provide full coverage high resolution data on various aspects of benthic environment. There are two main types of data that could be collected with such methods: bathymetry and backscatter. Detailed high resolutions bathymetry had been proven to be able derive not only depth, but various geomorphic descriptors, that are important for benthic organisms (Pickrill & Todd, 2003; Wilson et al., 2007). Backscatter data give sediments types, although it interpretation sometimes could be challenging. Usually, even with most advanced equipment acoustical methods resolution do not exceed tens of centimeters; therefore with few exceptions, they cannot map biologic features directly. Underwater imagery have much greater resolution (centimeters, in some cases even millimeters) and widely used for biological features detection (e. g. Solan et al., 2003). Unfortunately, it is impossible to cover large areas using underwater imagery methods, and direct biological mapping is also impossible. However, combination of acoustic and imagery can be successfully used solving various tasks in benthic ecology (e. g. Brown et al., 2011). Empirical modelling using biological data from underwater imagery as model response and environmental layers derived from acoustical methods can be used to create probability maps of biological features and hence used for applied tasks: stock assessments, protected areas designation, even for environmental monitoring programs. Probability map built for the Baltic herring spawning grounds distribution during this study is a good example of such application.

Evaluation of the environmental impact on benthic communities in the hydrologically active areas could be a very challenging task, because those areas are already experiencing a very heavy stress. It is especially difficult, when planned activity is localized, such as when building offshore wind farms. Interactions between living organisms and environment could be very complicated and hard to detect. Explanatory models are one of the ways to derive such dependences, allowing formulating grounded impact hypotheses. In order to do that, detailed information on the environmental variables is needed, what could be achieved using high resolution multibeam bathymetry (Wilson et al., 2007).

There are still a number of theoretical questions related with spatial distribution and mapping of the benthic organisms and biotopes that remain unanswered. Picking appropriate scale for spatial mapping (Brown et al., 2011), defining and mapping biotopes borders (Smith & Smith, 1975; Naumov, 1991; Martin et al., 2011), best practices for bottom mapping in different environments (based on the biotoc or abiotoc features, using supervised and unsupervised classifications, what validation methods should be, etc.) (Brown et al., 2011), those aspects are beyond the scope of this work and require additional studies. However, with new developments and constantly growing number of successful applications of the underwater remote sensing data solving various tasks in the benthic ecology, our understanding in those fields is expanding.

Conclusion

1. Accuracy of the manual video analysis is dependent on the methods and visual features chosen. While counting benthic organisms, counts of easily distinguished organisms and/or qualitative estimations (presence/absence) were accurately derived from a raw video. More cryptic feature, camouflaged seastars, was significantly underestimated while counting from raw video, and counting from the video mosaics was more accurate. Visual benthic covers estimations were not benefiting from usage of the video mosaics, but improving with operator training.

2. The proposed semi-automatic computer-assisted benthic cover estimation method based on video mosaics was compared with manual point-based cover estimation method. The new semi-automatic method proved to be more accurate (less variability in the results), more consistent (being fully formalized, operator independent and not affected by human bias) and reliable (i. e. based on disproportionally larger amount of the imagery involved in analysis).

3. Developed formalized procedure can be successfully used for quantitative identification of the benthic biotopes from underwater video. Using this method, 12 benthic biotopes (including a biotope not described previously for the coastal zone of the Lithuanian part of the Baltic Sea: hard bottom with *Polysiphonia* sp. (depth range 4-6 m)) were identified and validated in the Baltic Sea coastal and offshore areas.

4. Multibeam bathymetry and underwater imagery integrated into explanatory models allowed to identify geomorphic descriptor variables important for essential biological features in the benthic biotopes: seastars, sea urchins (probably *Strongylocentrotus sp.*) and kelp *Laminaria* sp. According to the model, the kelp prefers sheltered areas and might be expected to grow better on the sheltered side of wind farm pillar foundations. Seastars and sea urchins show a preference for a complex local relief (high rugosity areas) and Benthic Position Indexes (BroadBPI and FineBPI) indicating changes in elevation. It is assumed that their distribution pattern might change during and after foundation construction and cable route preparation which is likely to remove rugosity, at least locally.

5. The Baltic herring spawning locations were detected on the local elevations, in the areas with average depth gradient 2.4±1.1 m and western slope -4.8±1.8 within 100 m distance. The high resolution (20x20 m) probability map of the spawning grounds based on acoustical data and SCUBA divers survey shows that in the investigated area (10.7 km^2) the probability of herring eggs presence in general is following local relief, and higher than 0.6 for the area of 1.1 km^2 and higher than 0.7 for the area of 0.2 km^2. In the model, the most important predictor was the bathymetry (contribution 64 %),

followed by sediments (20 %), BroadBPI (9%) and slope (7 %). Model had been built on 18 presence locations and it overall performance was satisfactory: the average test AUC for the ten replicate runs was 0.775, and the standard deviation is 0.158

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Technical annex

Video equipment

C-Technics drop-down system

Drop-down remote underwater system used in this study was produced by C-Technics and consists of underwater unit and control box (Fig. 1).

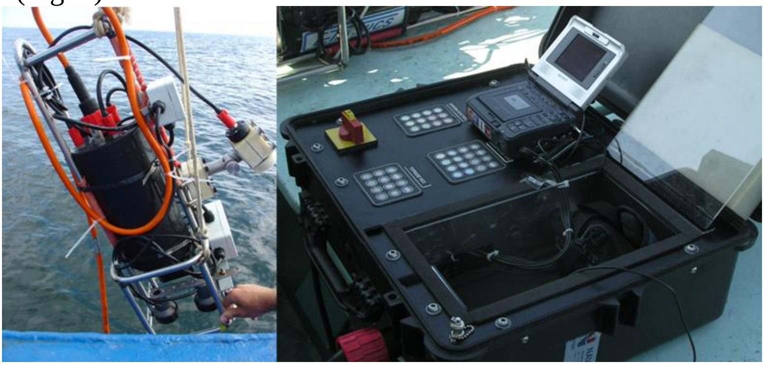

Figure 1. *Drop-down C-Technic remote underwater video system, underwater unit (on the left) and control box (on the right)*

The underwater unit is equipped with depth sensor, laser pointers, 4*50 watt xenon light bulbs and two cameras, colour (resolution 540 TVL) and black-white. Video from the underwater unit in real-time is transmitted into the control unit. Control unit is equipped with GPS antenna and overlay block, which allow GPS coordinates, depth sensor readings, data and time being superimposing into the video stream. Video is recorded in DV format on the miniDV cassette.

Mariscope ROV

Survey class Mariscope remotely operated vehicle (ROV) is a relatively small (weight approx 60 kg) system equipped with two colour cameras: one mounted in tilted unit with practical resolution 320 TVL and used mainly for navigation purpose, and scientific camera: 3CCD, fullHD (1920x1080) resolution, high quality Leica Dicomar lenses, 10X optical zoom. Scientific camera can be mounted in various fixed positions, but usually it is mounted vertically, looking directly down at the seafloor. Light system consists of 18 super bright LED's joined into 6 stations: 4x4 for the scientific camera and 2x1 for the navigation camera. Additionally ROV equipped with digital compass, depth sensor, acoustical altimeter and acoustical ultra-short baseline (USBL) navigation system (Fig.2).

Figure 2. *The Mariscope ROV in use underwater.*

Argus ROV

Argus ROV is a medium system (weight approx. 450 kg), equipped with several cameras for achieving ROV control, and one for the video data collection. The ROV have a main body containing the electric motors, controls, and a stainless steel frame on which the equipment is mounted (Fig. 3). This included a depth sensor, USBL underwater navigation system, area sonar, compass, two laser line-pointers (for scaling) and attitude sensor (measuring roll, pitch and heave of the vessel). The camera used for underwater imagery had a Hama digital objective Hr 0.5x, colour HD, resolution 1920 x 1020, with autofocus, and four external light sources (xenon light bulbs, total power 600 Watts). A video converter was used to record the video on a HDD drive. The ROV was attached to the boat by an umbilical cable through which data communication and vehicle control was achieved. The ROV was maneuvered through a control console located on the ship and equipped with joysticks controlling altitude and direction (Fig. 4), several video monitors and computer screens providing with information about ROV position and status of various ROV systems (Fig. 5).

Figure 3. *Argus medium class ROV*

Figure 4. *Control panel of the Argus ROV*

Figure 5. *Video and computer monitors used for the Argus ROV control*

Acoustical equipment

Multibeam systems

Kongsberg EM3002D

This is a single head beam forming multibeam sonar with working frequency 300 kHz, designed for a shallow water (in certain conditions, down to 300 m) operations. It can transmit up to 254 beams up to 40 times per second. Maximum angular coverage of the system is 130°, pulse length 150 μs. It is a high resolution system with depth resolution up to 1 cm and range resolution up to 5 cm. System was mounted on the R/V "Hakon Mosby" (Fig. 6).

***Figure 6**. R/V "Hakon Mosby" equipped with Kongsberg EM3002D multibeam sonar used for bathymetric survey in the Norwegian Sea (courtesy of www.marinetraffic.com).*

In the Baltic Sea multibeam bathymetry had been collected using L3 Communications SeaBeam 1185 multibeam sonar (180 kHz, up to 126 beams) which was mounted on the LMSA R/V "Varūna" (Fig. 7).

Figure 7. *R/V "Varūna" equipped with SeaBeam 1185 multibeam sonar, used for bathymetric survey in the Baltic Sea (courtesy of www.ve.lt).*

Side Scan Sonar system

The Side Scan sonar system used was EdgeTech 270-TD Side scan sonar was used. It is a high resolution system capable of one from two operational modes: 105 kHz and 390 kHz, with horizontal beam width 1.2° at 105 kHz and 0.5° at 390 kHz. Vertical beam width is 50° in both modes. This is a towed body (so called "sonar fish") system, therefore it position underwater and altitude above the sea floor was controlled only by speed of the vessel and amount of descended cable.

Acoustical data collection

Acoustical data quality is directly depending on the acquisition hardware and system set-up (Le Bas & Huvenne, 2009). Multibeam sonar is a complex system consisting from sonar transducer head (could be of different configuration, with differently located and shaped transducers and receivers, operating on different frequencies), motion reference unit (could be based on different physical principles (solid state and fiber optic gyros)) and sound velocity measuring equipment (Sound Velocity Profiles (SVP) or Conductivity, Temperature, Depth (CTD) probes). All parts of the system should be carefully installed, configured and calibrated in order to get satisfactory results. System performance also depend on the mounting type (hull mounted or towed body), depth range in the study area (greater depths reduces data resolution), hydrological conditions (if they changing rapidly, sound velocity profiles will be less accurate, hence distort final results). (Lurton, 2002; Kenny et al., 2003; ICES, 2007; Le Bas & Huvenne, 2009; Pandian et al., 2009; Brown et al., 2011).

Side Scan Sonar datagrams consist of acoustical backscatter data (Lurton, 2002), which are depending on the number of factors. First of all, backscatter strengths are directly depends on the geoacoustical properties of bottom surface: it porosity, density, etc. They are determining how original acoustic signal is absorbed or scattered by the surface, what allows us to judge about surface physical properties and to map bottom features (Blondel, 2009). There are a number of additional factors that are affecting backscatter data and biasing the results. Backscatter strength is distance depended – the longer sound wave had to travel, the stronger it attenuation due to the signal absorption by the water (Lurton, 2002). This results in the different backscatter strengths when going further from nadir. Returned signal strength is also affected by changes in the sonar fish altitude, pitch, and roll. Changes in the sonar fish yaw may result neighboring pings to overlapping from one side and leaving gaps from another, what cannot be properly compensated during the processing. Sudden changes in the sonar fish speed (for example, due to wave actions toward the towing vessel and/or the cable) also could result in the data artifacts and inconsistency in the along the track resolution (Blondel, 2009). Other sources of inconsistencies and distortions in the acoustical backscatter data are:

- Variations in water column. Changes of water density (due to variations in the salinity and temperature) result in different speed of sound in different water layers. Due to that objects in the sonar image could be displaced or distorted.
- Acoustical noise. Noise made by passing ships is known to have negative effect on backscatter data, adding various artifacts.

- Sub-surface reflections. Depending on the acoustical signal strength and frequency, it can penetrate the surface and some sub-surface echoes might occur, adding even more anomalies in the data.
- Geometric artifacts. Backscatter strength is affected by the slope angle of the surface – if surface is angled toward the transmitter it will give stronger echo. Geometrically complicated surfaces could produce multiple echoes adding various ghost images.

Another important component of the good acoustical survey is accuracy of navigation source. For high resolution bathymetry surveys assisted GPS (Differential or RTK modes) capable of sub-meter accuracy is essential. In areas where obtaining good tide information is difficult, even greater accuracy (less than 10 cm) is needed, what could be achieved by using Fixed RTK navigation mode. For towed systems, most common way to derive sonar fish position is using combination of GPS coordinates from fixed antenna on the ship, depth sensor readings from the sonar fish and cable length in the water. Such systems have lot of potential sources of errors (towed body weight (with possible depressor), lift and drag, cable diameter, cable length and weight (Kamman & Huston, 1999), therefore usage of Ultra Short Base Line (USBL) underwater navigation systems is desired for towed bodies applications. Modern USBL systems could give accuracy within 5 m even on full ocean depths (Vickery, 1998; Parkinson, 2001) and significantly less in shallow areas.

Geomorphic descriptor derived from multibeam bathymetry

In general, geomorphic descriptor variables can be divided into two groups: not full-cover and full-cover.

Not full-cover variables describe conditions only for certain positions, not having full area coverage. Not full-cover geomorphic descriptor used in this work were a bottom profiles, which were created using IVS Fledermaus 7 profiling tool. Quantitative characteristic derived from the bottom profiles was slope, which is a ratio between vertical (elevation) difference and horizontal range. Slope can be calculated for any point of the profile, or as average for the profile segment, or of the whole profile. Positive slope values are corresponding with the surface inclinations and negative with the surface declination, therefore knowing bottom profile direction, slope describes not only degree of inclinations, or steepness, but also shelter information: for example, Western slopes are sheltered from the East while Eastern slopes are sheltered from the West.

Full-cover geomorphic descriptor variables were calculated for each cell where bathymetry is available, providing with continuous coverage for the area. Some of them were calculated from one cell at the time, others needed neighbouring cells for calculation. This factor needs to be taken into account when specific resolution of the final product is needed. For geomorphic descriptors which are calculated from one cell only, raw bathymetry could be downscaled to needed resolution first, and descriptors are calculated from downscaled bathymetry, saving computing time. For descriptors that are require several cells to be calculated, usage of higher resolution raw bathymetry first, and downscaling of produced geomorphic descriptor layer later, could be a better solution. Although this approach requires more computing time, results will be more accurate.

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