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Aerial Photography For Assessing The Sensitivity Of The Coast To Oil Spills (On The Example Of The Kola Bay)

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Abstract. The article describes the use of unmanned aerial vehicles (UAVs) to collect the initial data required for the environmental sensitivity index (ESI) mapping. On the example of several areas of Kola Bay, practical methods of ESI mapping are shown as well as algorithms for processing and systematization of received information (orthomosaic) and its integration into GIS. The results of this work are important for the preparation of ESI maps, which are necessary for oil spill response plan (OSR) and directly for oil spill response operations, as well as for cleaning contaminated coastal areas from oil and oil products.

Keywords: ESI, sensitivity, oil spills, aerial photography, GIS

1. Introduction

In Russia, as it is in other countries, there is an acute problem of environmental protection during the development of offshore oil fields and transportation of hydrocarbons by sea. The most important environmental protection activity during oil spill response in the coastal sea zone is the development of oil spill prevention plans (OSR). One of the components of such plans is multi-scale maps of coast sensitivity and maps of the coastal-marine zones vulnerability to oil (IPIECA, 2000; Etkin, Welch, 2005; IMO et al., 2012;Shavykin, 2018 and others). Such maps are a key element in spill response planning (IPIECA, 2000). The maps indicate areas of priority protection – the most vulnerable areas that need to be protected first, and also show the least vulnerable areas that can be sacrificed to minimize damage from both oil spills and response operations. Such maps facilitate the process of choosing the combating tactics during OSR operations. All of this allows to assess and significantly reduce negative economic and environmental consequences of oil spills and operations of its elimination (Etkin, Welch, 2005). Vulnerability and sensitivity maps are also important for environmental engineering surveys and environmental impact assessments of offshore projects. In Russia, there is no unified methodology for mapping both vulnerability and sensitivity, although in many countries they are actively used (see a detailed review of such methods in (Kola Bay, 2018, Ch. 11)). Further, we will consider only the maps of the sensitivity of the coastline to oil.

Sensitivity maps are based on the classification of coastline types originally proposed in (Gundlach, Hayes, 1978). Today there are many different guidelines for making such maps (NOAA, 2002, 2008; Petersen et al., 2019;and others). Sensitivity maps have been prepared for all US coast (available on (NOAA's OR&Rwebsite)) and other countries (IPIECAetal., 2012; Gotoet al., 2006). Some projects cover the coastlines of entire seas (Risk of oil …, 2013). In Russia, such maps are also being prepared for various projects (Kara Sea, 2016; WWF, 2010;and others). As a rule, when oil spills at sea, coastal areas will be the most susceptible to oil pollution. At the same time, the type of coast and its geomorphological characteristics are often fundamental in determining the sensitivity to oil pollution (Petersen et al., 2019).

In this work, we consider sensitivity maps (ESI) based on recommendations of the NOAA (Petersen et al., 2019) and IPIECA (IPIECA et al., 2012). This approach, takes into account the qualitative and quantitative characteristics of the coast, reflecting on the order scale the relationship between the geomorphological structure of the coast and the physical processes that occur when oil reaches the coast. In the end, the contact of oil with the shore determines the sensitivity of the coastline, as well as the impact of oil, which leads to various negative consequences for the coastal zone. The original 10-index classification scale (Gundlach, Hayes, 1978) has been modified to include a variety of subtypes (IPIECA et al., 2012). Currently, it includes over 40 types and subtypes (Petersen et al., 2019). Various sources can serve as a basis for determining the shoreline type (Boak, Turner, 2005):

- various archival sources (historical photos, nautical plans and maps)
- photos and video, made with the use of aircraft and from the board sea vessels
- field observations carried out directly from the coastline and with logging (including coordinates) observed geomorphological structures;
- wide technical varieties of remote sensing methods (multispectral/hyperspectral images, microwave sensors, etc.).

The original NOAA recommendations (Petersen et al., 2019) for the preparation of sensitivity maps do not prescribe specific survey methods - to obtain information about the geomorphological characteristics of the coast, which may be susceptible to oil pollution. There are mentions of such methods as using of the vessel, airborne survey, or pedestrian inspection for coast type estimation. Overall, the definition of ESI can be divided into three groups: based on photos or video made directly from the shore, from a ship, or an aircraft. However, each of these shoreline survey methods has advantages and disadvantages.

Determining the type of coastline directly from the shore is usually the most informative, as it allows you to determine all the necessary characteristics on the spot. But at the same time, this approach is the most labor-intensive and can be used mainly in some of the most important areas (points) to clarify the type of coast or its characteristics.

The photos taken from the vessel can also be applied to define shoreline type. Earlier (Vashchenko, 2018), we identified 8 main types of shores for the Kola Bay (Table 1). Presented classification based on the initial recommendations of international organizations (IPIECAetal., 2012). We modified it by excluding those types of shores which cannot be found in the Kola Bay. To perform shooting from the vessel, a camera with a built-in GPS receiver was used, this made it possible to link each specific image to the coordinates of the shooting point. The shooting was carried out when the vessel was moving as close as possible to the coast. Each photo was performed in case of visual detection of a coastline type change (the end-to-end survey was not applied). For more details on the survey technique and the results obtained, see (Vashchenko, 2018). In the early works (Vashchenko, Kalinka, 2013; Kola Bay ..., 2018), we used to perform shooting from the vessel and a pedestrian survey of the coast.

Table 1. ESI Shoreline Classification for the Kola Bay (the Barents Sea) shoreline. ESI code in order of increasing sensitivity to oil spills (Vashchenko, 2018)

ESI code	Shoreline type
1	Exposed, solid man-made structures
2	Rocky shoals and bedrock ledges
3	Fine grained sand beaches
4	Coarse grained sand beaches
5	Mixed sand-pebble beaches
6	Gravel and rubble beaches; Riprap
7	Exposed tidal flats
8	Flat gravel and sandy beaches with large banks of algae or grasses

Making photos from the vessel has several disadvantages. First of all, the processing of such a survey requires a significant investment of time in the interpretation of the results. The binding of the information reflected in the image (characteristics of the coast) to a specific point on the map can be carried out only manually by the operator. The reason is that the image captures only the position of the shooting point and not the position of the objects within the shot. In addition, in the case of the vessel applied, the information content of the images is often reduced since sometimes it is difficult to approach for a short distance to the shore. Moreover, the shooting itself is often performed at a slight angle to the shore surface (in case if it is a shallow area).

Aerial photo and video filmed from aircraft give significantly better results, but it is also not able to fully meet the requirements of completeness and detail of the initial data. One of its disadvantages is an approximate estimate of the granulometric composition of the coastline sediments (Kara Sea, 2016) since the survey height is quite large (several hundred meters). In this regard, the use of UAVs that can fly at low altitudes is promising. This allows not only a very detailed survey, but also a more correct assessment of the grain-size composition of the coastal zone and its slope. Recent developments and availability of UAVs have great potential to facilitate the process of receiving primary data on the characteristics of the coastline. Work with images received from UAV requests less labor input and it is more accurate for the task of spatial reference, especially with taking into account the availability of special software for these tasks. However, most of the available publications related to results of ESI assessment and use of aerial photography, as a rule, are not describing methodological issues (IPIECA, 2015; NOAA, 2015).

The work aims to approbate the methods of aerial photography from UAVs to collect the initial data necessary to build coastline sensitivity maps based on the ESI system. The more accurate initial data obtained by such a survey will subsequently make it possible to assess the sensitivity not only on the scale of order but also on the scale of ratios. It was necessary to assess the possibility of identifying shores with different types of ESI sensitivity, to analyze the effectiveness of surveying at different heights, and to determine the slope of the coast and presence of the algae.

2. Materials and methods

To build a sensitivity map, based on the survey results, it is necessary to identify where shoreline-specific features are located. For this, it is necessary to identify such features as particle grain size, surface inclination angle, presence of biota (algae), ... and others. The main object of oil impact on the shore is the littoral area (the territory flooded at high tide) and the supralittoral - the splash zone, that is, the zone where oil gets with the surf).

We used DJI Phantom 4 Pro to perform photos. The characteristics of the aircraft and its camera are shown in Table 2. To fly in "mission fly" position mode was applied. All following characteristics of Phantom 4 Pro are related to position mode(see (DJI website)for more).

Table 2. Characteristics of the UAV – DJI Phantom 4 Pro (manufacturer's data)

Aircraft	
Weight (Battery&PropellersIncluded)	1388 g

Max Ascent Speed	5 m/s
Max Descent Speed	3 m/s
Max Speed	P-mode: 31 mph (50 kph)
Max Wind Speed Resistance	10 m/s
Max Flight Time	Approx. 30 minutes
Operating Temperature Range	0...+40 °C
Satellite Positioning Systems	GPS/GLONASS
Hover Accuracy Range	Vertical: +/- 0.1 m (with Vision Positioning); +/-0.5 m (with GPS Positioning) Horizontal: +/- 0.3 m (with Vision Positioning); +/-1.5 m (with GPS Positioning)
Camera	
Sensor	1'' CMOS Effective pixels: 20M
Lens	FOV 84° 8.8 mm/24 mm (35 mm format equivalent) f/2.8 - f/11 auto focus at 1 m - ∞
ISO Range	100 - 3200 (Auto); 100- 12800 (Manual)
Mechanical Shutter Speed	8 - 1/2000 s
Electronic Shutter Speed	8 - 1/8000 s
Image Size	16:9 Aspect Ratio: 5472 × 3078
Gimbal	
Stabilization	3-axis (pitch, roll, yaw)
Controllable Range	Pitch: -90° to +30°
Max Controllable Angular Speed	Pitch: 90°/s
Angular Vibration Range	±0.02°
Remote Controller	
Operating Frequency	2.400 - 2.483 GHz
Max Transmission Distance	2.400 - 2.483 GHz (Unobstructed, free of interference); CE: 2.2 mi (3.5 km)
Operating Temperature Range	32° to 104°F (0° to 40°C)
Battery	6000 mAhLiPo 2S

The survey was carried out in an automated mode based on the "mission flight". Mission flight was compiled using special software – DJI Pilot. The parameters were following (default values): camera tilt angle 90°; overlap ratio 60% in both directions; UAV movement speed 5 m/s. To find the optimal shooting mode, several flights were performed at different altitudes: 1, 5, 30, 50, 100, 200 m in certain areas of the Kola Bay coast.

It is important to note that the flight altitude is only one of the parameters that define the detailing of the resulting images. In general, it is more correct to operate with Ground sample distance – GSD. GSD depends on flight altitude (H) and camera characteristics (sensor width, focal length, image width – for parameters of the used equipment see table 2). Even when flying at a constant height, the images may not have the same GSD. This is due to terrain elevation differences and changes in the angle of the camera while shooting (See (Pix4D website) for more). In our case, when describing the results, we mention only flight altitude above the littoral surface (altitude above take-off point which is shown by Phantom 4) since only one and same UAV was used. If another camera is used, all conclusions related to fly altitude should be reconsidered.

To clarify differences in detailing between the images taken at different heights, the scale bar (printed on an A4 sheet) was placed on the ground before shooting (see Fig. 1).

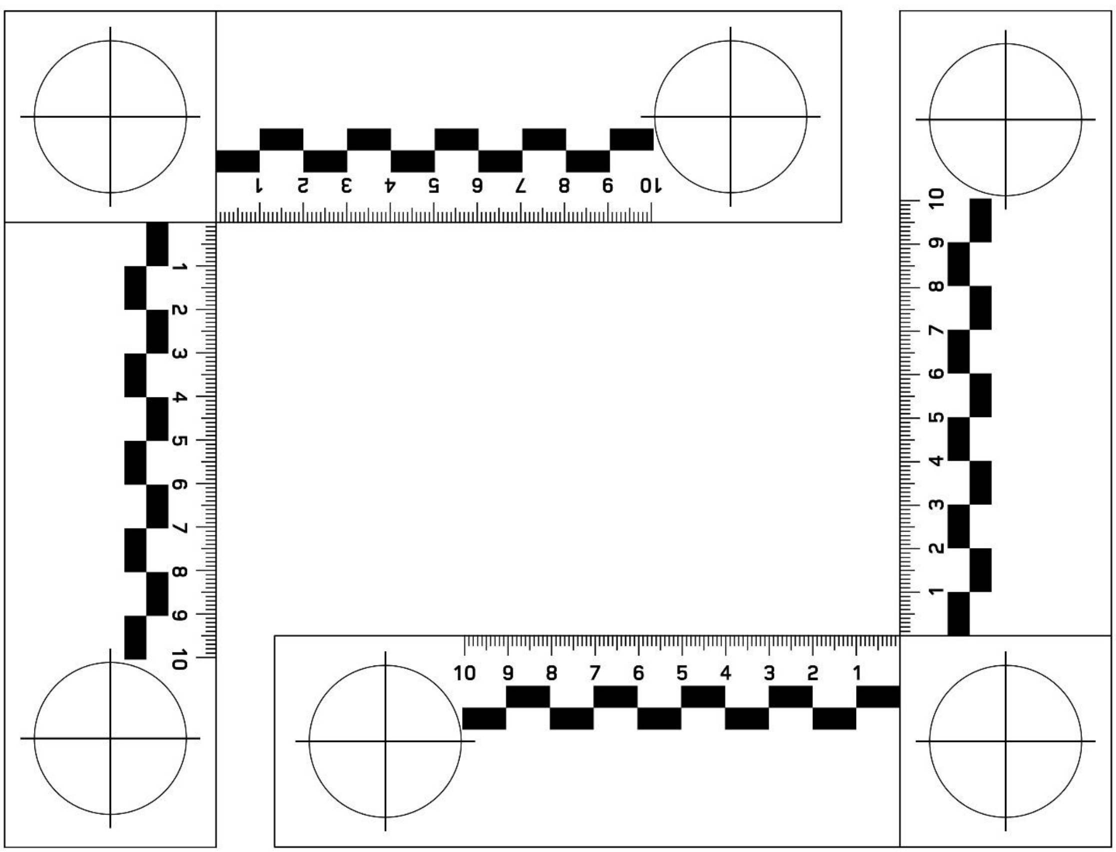

Figure 1. Original scale bar sample (sample should be printed as full size on A4 paper)

The resulting set of aerial photographs was processed in AgisoftMetashape to build the orthomosaic. In general, it is a mosaic of individual images, assembled in such a way as to avoid distortion of the shapes and areas.

To assess the sensitivity index, the following characteristics, reflected on orthomosaic, were analyzed: 1) granulometric composition of the substrate of the shore (belonging to such classes as pebbles, gravel, coarse - fine sand) as well as the presence/absence of boulders and man-made structures, 2) the height difference from the water's edge to the splash line and the presence of the litoral puddles; 3) the presence of algae (projective cover in case of presence).

The characteristics of the grain size composition of the "substrate" and the presence of large boulders and man-made structures were assessed visually by orthomosaic.

The original ESI system (Petersen et al., 2019) contains recommendations for taking into account the coastal slope as a criterion for assessing the sensitivity index. For most shore types, the guidelines indicate the slope in degrees for assignment to one or another ESI type. In this work, we did not carry out direct estimates of the slope; an estimate of the elevation difference was carried out, which can be converted into a slope if necessary. To estimate the heights of each point of the orthomosaic, we used AgisoftMetashape – Build DEM (digital elevation model - DEM). The resolution (m) displayed by the program, during construction of the models for all considered areas were in the range from 0.15 to 0.30 m.

Additionally, to be able to assess the results of received DEM in the surveyed areas a control section was laid in an arbitrary place before aerial photography. We used a level to mark a meter difference from a randomly selected point (a point which one meter higher than the selected one) (see Fig. 2). The cut formed in this way was marked on the ground with a signal tape. (seeFig. 5 below).

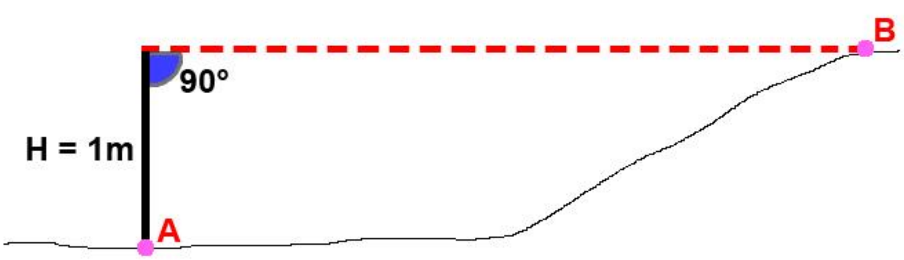

Figure 2. Scheme of heights estimation.

The latest revision of NOAA recommendations (Petersen et al., 2019) contains instructions on the presence of algae for assigning certain ESI index to the coastline. For example, ESI 5 (see Petersen et al., 2019; p. 21) must have at least 20 percent of the area covered with algae. In our work, the presence/absence of algae was assessed visually from the images. If algae were found, the boundaries of their location were delineated on the orthomosaic (Draw polygon were used) for the subsequent determination of the area of the coastal area occupied by them.

In total during 2021, surveys on 12 sections of the Kola Bay coastal zone were made.

3. Results and discussion

Identification and differentiation between solid man-made structures (ESI 1), rocky shoals (ESI 2), and exposed tidal flats (ESI 7) are possible at all performed altitudes (up to 200 m). Identification of pebble (ESI 5) and gravel (ESI 6) as a rule, are possible at an altitude less when 100 m. Identification and differentiation between fine grained sand (ESI 3) and coarse grained sand (ESI 4) are the most difficult issue. Images received from altitudes more than 5 m (see Fig. 3) does not allow to make a difference between ESI 3 and ESI 4.

Figure 3. Samples of photos taken at 1, 5, 30, 50, 100, 200 m. The coverage of the image from each of the altitudes is shown (the original and displayed scale doesn't match). The location of the sheet with the scale bar (SB) is shown by an arrow.

In common, the possibility to makes a difference between these types can be described by following: shoots performed from 1 m altitudes allows identifying of millimeter lines on the scale bar; shoots performed from 5m altitudes allows identifying of centimeter lines; at heights of 30 m and above, the divisions on the scale bar are not visible (see Fig. 4).

Figure 4. Scale bar visibility (enlarged orthomosaic fragment) at 1 (left) and 5 m (right) high.

The visual determination of the substrate from the images is very subjective and depends on the experience of the operator. To solve this problem, multispectral photos have great potential (to apply Normalized Difference Vegetation Index - NDVI) and raster image analysis systems (such as – Trimble eCognition). Together, these tools should allow finding areas within the image with the same (specified) characteristics, as well as to estimate the size of the objects (for example, the size of the pebbles on the beach). This is an issue for further study.

Shooting at a different altitude also determines the time needed to cover an area of interest. For example, to cover an area of 100 m^2 (the Phantom 4 Pro with the following parameters were used: camera tilt angle 90°; overlap ratio 60% in both directions; UAV movement speed 5 m/s), from altitude 10 m, it takes ~ 30 minutes; from 30 m - 7 minutes 50 sec.; from 50 m - 2 minutes 20 sec., from 100 m - 2 minutes; from 200 m - 1 min 40 sec. For approximate estimates, the time spent per unit of coastline length can be described as follows - the length of the coastline is 710 m (the width of the littoral and supralittoral is ~ 15 m), at a speed of 5 m/s and a flight altitude of 30 m, are covered in ~ 15 min. According to our results, for estimation of time needed for shooting it is more effective to think about a shoreline as an area rather than a line (although on the map, in most cases, it will be represented as a line). For more correct time estimations for any specific areas, it is optimal to use specialized software (such as DJI Pilot) which is designed to build a flight mission and take into account the characteristics of your UAV.

The results of height difference measured within orthomosaic (all measurements were made in AgisoftMetashape) are presented in Fig. 5. According to the results, deviations between the laid and measured values are less than 10 cm per 1 m (1 ± 0.08 m) (point 1 is located at a height of 3.86, and point 2 at a height of 4.77 m). In this particular case, we recalculated DEM values to start from the location of the water surface at the moment of shooting. It is important to note that this uncertainty value characterizes this particular pair of points represented in Fig. 5. The mean uncertainty value for all covered areas of DEM was 18 cm.

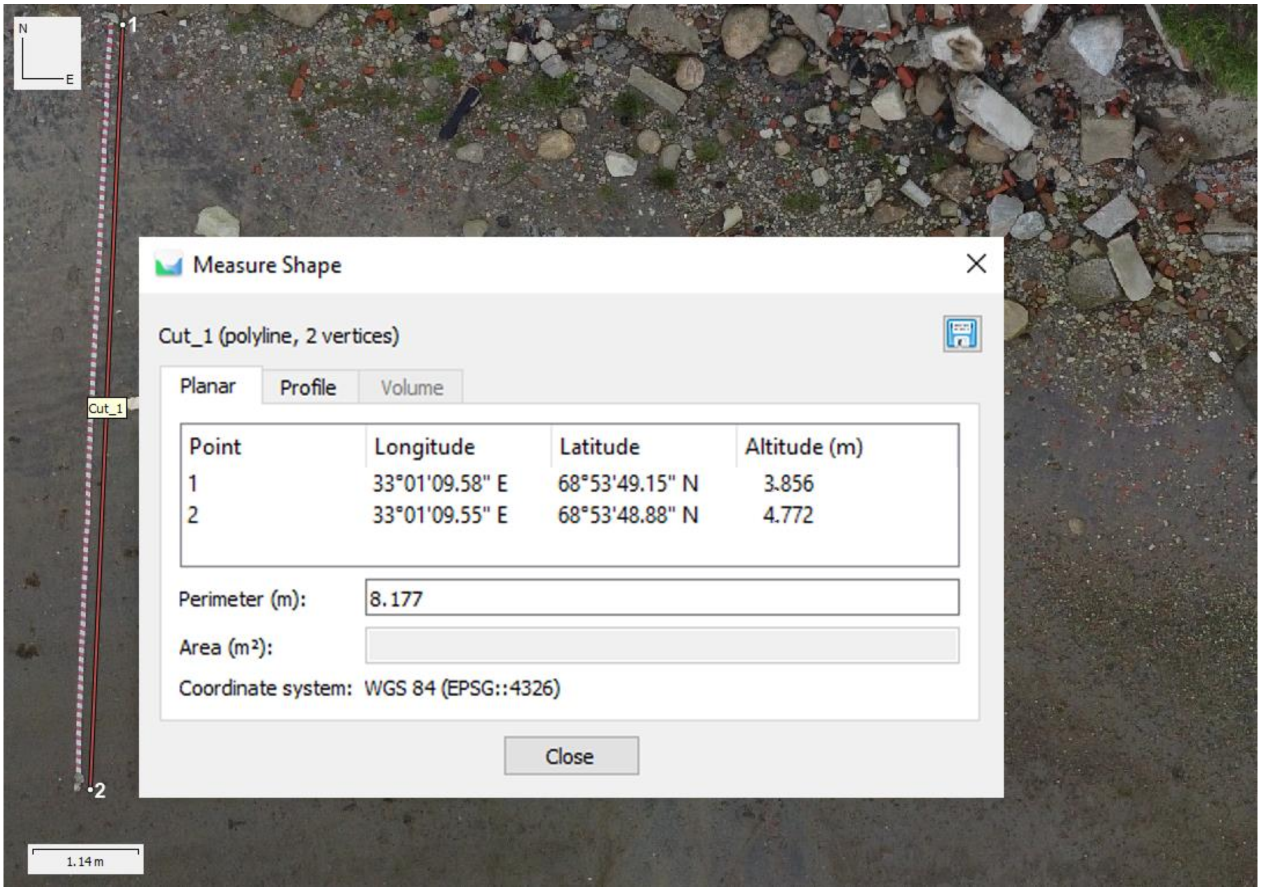

Figure 5. Orthomosaic fragment at the upper part of the littoral.

The elevation difference in Cut_1 is presented. The red-white dashed line represents the signal tape (placed on the ground before shooting), the red line is the control cut in AgisoftMetashape (1 and 2 - points by which the elevation difference was estimated); scale bar is located in the lower-left corner of the image. In the center of the image, there is an information window with the measurement results.

It is shown that identification of the presence/absence of algae are possible at all altitude (up to 200 m) (see Fig. 6). At the same time, the accuracy of estimates of the projective cover objectively decreases with altitude. In general, this is not an obstacle for identification of ESI 8 (flat gravel and sandy beaches with large banks of algae or grasses), since this type of sensitivity includes only large accumulations of algae. It is also should be mentioned that shooting from a height of 1 m and 5 m allows detecting other biological objects on the orthomosaic. For example, from an altitude of 5 m, it is possible to identify small benthic organisms (such as Balanomorpha) on the boulders. From an altitude of 1 m, it is possible to count each individual species (Fig. 7).

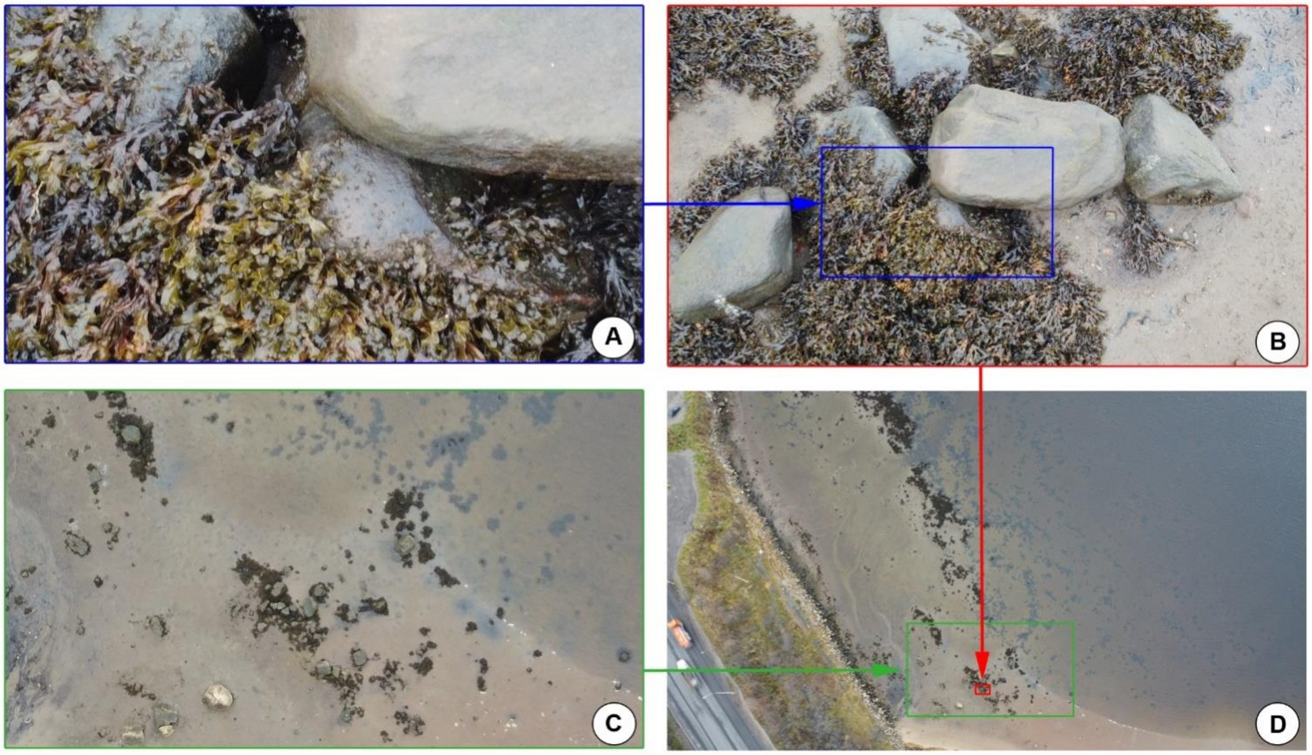

Figure 6. Algaes on the shore. Samples of photos taken at 1 m (a, b) and 200 m (c, d). b, c – coverage of single photo; a, c – a fragment of the photo at a 1:1 ratio

Figure 7. Benthic organisms on the stones. Samples of photos taken at 1 m. A – a fragment of the photo at a 1:1 ratio; B – coverage of single photo

4. Conclusion

Images received from altitudes less than 200 m, allow to identify of solid man-made structures (ESI 1), rocky shoals (ESI 2), and exposed tidal flats (ESI 7), as well as flat gravel and sandy beaches with large banks of algae or grasses (ESI 8). Identification of pebble (ESI 5) and gravel (ESI 6) as a rule, are possible at an altitude less when 100 m. Identification and differentiation between fine grained sand (ESI 3) and coarse grained sand (ESI 4) are the most difficult issue. The altitude no more than 30 m can be recommended as optimal for the identification of ESI 3 and 4.

An optimal altitude to perform surveys is 30 m. It takes into consideration the possibility to identify all coastal features to asses of ESI types. Shooting at a different altitude also determines the time needed to cover an area of interest. To cover an area of 100 m^2 from altitude 30 m it will take 7 minutes 50 sec.; narrow, elongated areas with a length of about 500 m are covered by a survey in about 10 minutes. For more correct time estimations for any specific areas, it is optimal to use specialized software (such as DJI Pilot).

The resulting digital elevation model made it possible to identify elevation differences of 1 m with a mean uncertainty value from 0.15 to 0.30 m. Such measurements are sufficient to determine the shore slope for ESI

Identification of the presence/absence of algae is possible for images shooted from an altitude of 200 m. GIS tools allow estimating the area of the coast occupied by algae.

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