ESMIC

Estimation, monitoring and reduction of plastic pollutants in Latvian-Lithuanian Coastal area via innovative tools and awareness raising

Report on assessment testing results

(D.T.1.2.1)

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Content

1 Abstract

ESMIC project aims to develop a sustainable, cost-effective framework for plastic litter detection, monitoring and management in marine and coastal environments. Plastic litter is linked with negative economic, social and ecological consequences and common challenges related to plastic litter are complex: increasing amounts of microplastic, direct harm to marine biodiversity and negative impacts on recreational activities. Plastic that accumulates in algal wracks on a shore or in algal scum might be a target area for plastic pollution estimation and mitigation measures. The project aims to develop the methodological guidelines for operational and cost-effective monitoring of algal wracks or scums by linking remotely sensed (using satellite imagery and drones) algal features with marine plastic litter. This asset of monitoring will allow the development of efficient beach wrack and litter management, which municipalities or national authorities can use in Lithuania and Latvia.

2 Introduction and scope

This document is dedicated to summarising the collected data and achieved results of the methodology for monitoring marine plastic litter in association with accumulated and/or floating material in the coastal areas testing. The uncertainties of the used methods (sample analysis, remote sensing data processing, automatic detection of scum, or wracks) are investigated according to the methodology described in D.T1.1.2. The final method for cost-effective estimation, monitoring, and reduction measures of plastic litter is defined and described.

3 Plastic litter monitoring in association with beach wrack

3.1 Satellite-based remote sensing of beach wrack detection, monitoring and evaluation

Optical satellite images were used to detect the location of beach wrack accumulation considering the entire coastline of Lithuania and Latvia. The Multispectral Imager's (MSI) on-board Sentinel-2A and Sentinel-2B data with a spatial resolution of 10 m are considered as the best data source for beach wrack detection and mapping, however only for the evaluation of relatively larger (i.e., larger than 100 m^2) areas covered by wrack, but they are not suitable for the detailed monitoring and mapping of relatively smaller beach wrack accumulations. The small-scale wrack detection should be done using drone-based remote sensing solutions that provide much detailed information in terms of spatial resolution as described in subsection 3.1.1.2. The primary detection and identification of beach wrack accumulation zones were done by using the open source portal EO Browser: https://apps.sentinel-hub.com/eo-browser. False colour red-green-blue (RGB) composition was used to distinguish beach wrack from sand, rocks or water. The automated data download was performed via the Copernicus Open Access Hub https://scihub.copernicus.eu/ using aria2 - a lightweight multi-protocol & multi-source command-line download utility. Normalized Difference Vegetation Index (NDVI) which quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs) is suggested to be used for beach wrack mapping. Pixels with NDVI ranging from 0.2 to 1.0 are considered as beach wrack.

A schematic description of the processing of the satellite images and a prototype of an alerting system about the beach wrack presence is provided in Figure 1. The download of the image is possible after ~3 hours of the satellite platform overpass. However, upon the agreement with the European Space Agency, the Near Real Time acquisition is possible, leading to the gathering of the data within ~15 minutes after the satellite overpass. After the ingestion of the image into the operational processing system the pre-processing of the image is performed, which includes subsetting, projection, cloud detection and masking, land detection and masking, quality check. After the pre-processing the NDVI is calculated and values are classified in order to detect the beach wrack presence. The post-processing includes the determination of the exact location of the beach wrack as latitude and longitude as well as identification of the region, calculation of the area covered by beach wrack and preliminary volume assuming that the height of the beach wrack is around 0.3 m. Note, the volume calculation is preliminary, as it is impossible to retrieve this information from the satellite images. If needed, a more accurate evaluation can be performed using drone imagery. The relevant information to users after the post-processing is displayed on the screen.

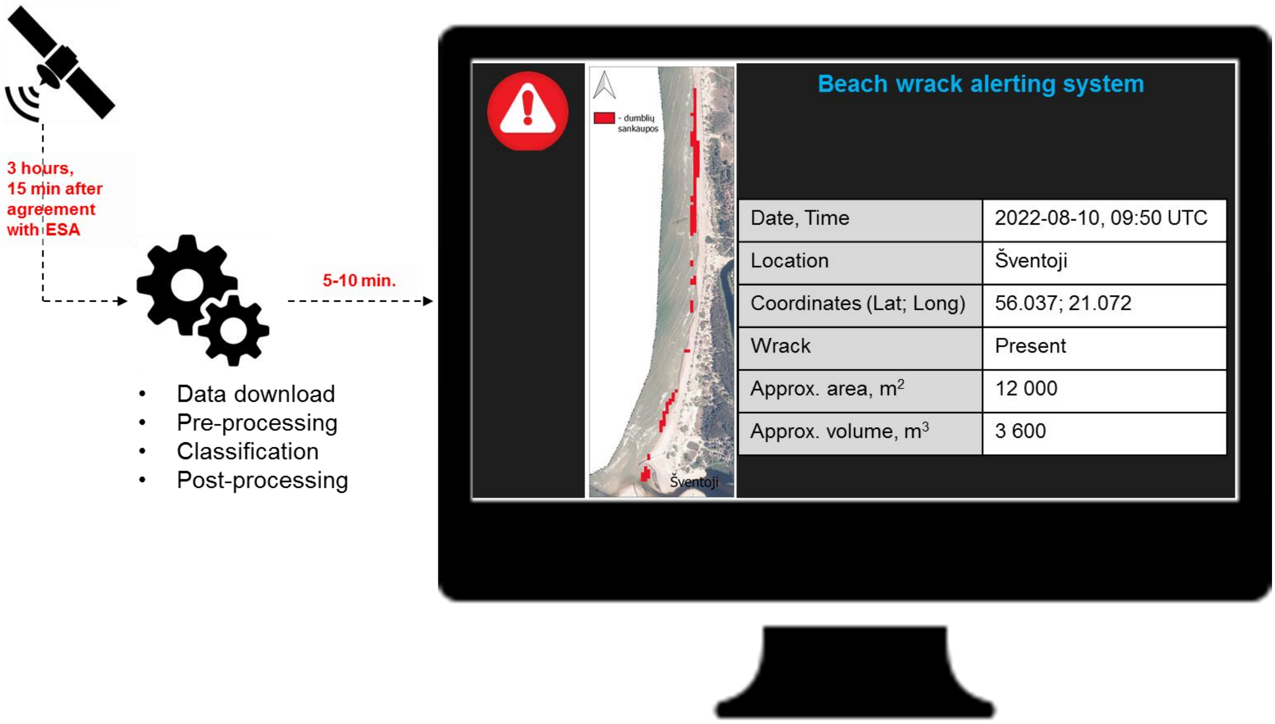

Figure 1. Data processing chain and prototype of the Beach wrack alerting system.

By using the processing of satellite images as described above, a detailed analysis of beach wrack presence was evaluated in four Lithuanian sites (Melnragė, Karklė, Palanga, Šventoji) and six Latvian sites (Pape, Liepaja, Pavilosta, Kolka, Kaltene, Lapmežciems) covering the period from 2020.01.01 to 2022.10.14.

The monitoring of beach wrack presence indicated that mostly the beach wrack is present during a warm period of the year, i.e., June-September (Figure 2). In Lithuania, beach wrack was more often present in Šventoji, while in Palanga it occurred less frequently, probably due to the permanent beach cleaning. In Latvia, the beach wrack was often present in Pavilosta, where it was also present during the cold period (i.e., from March until October).

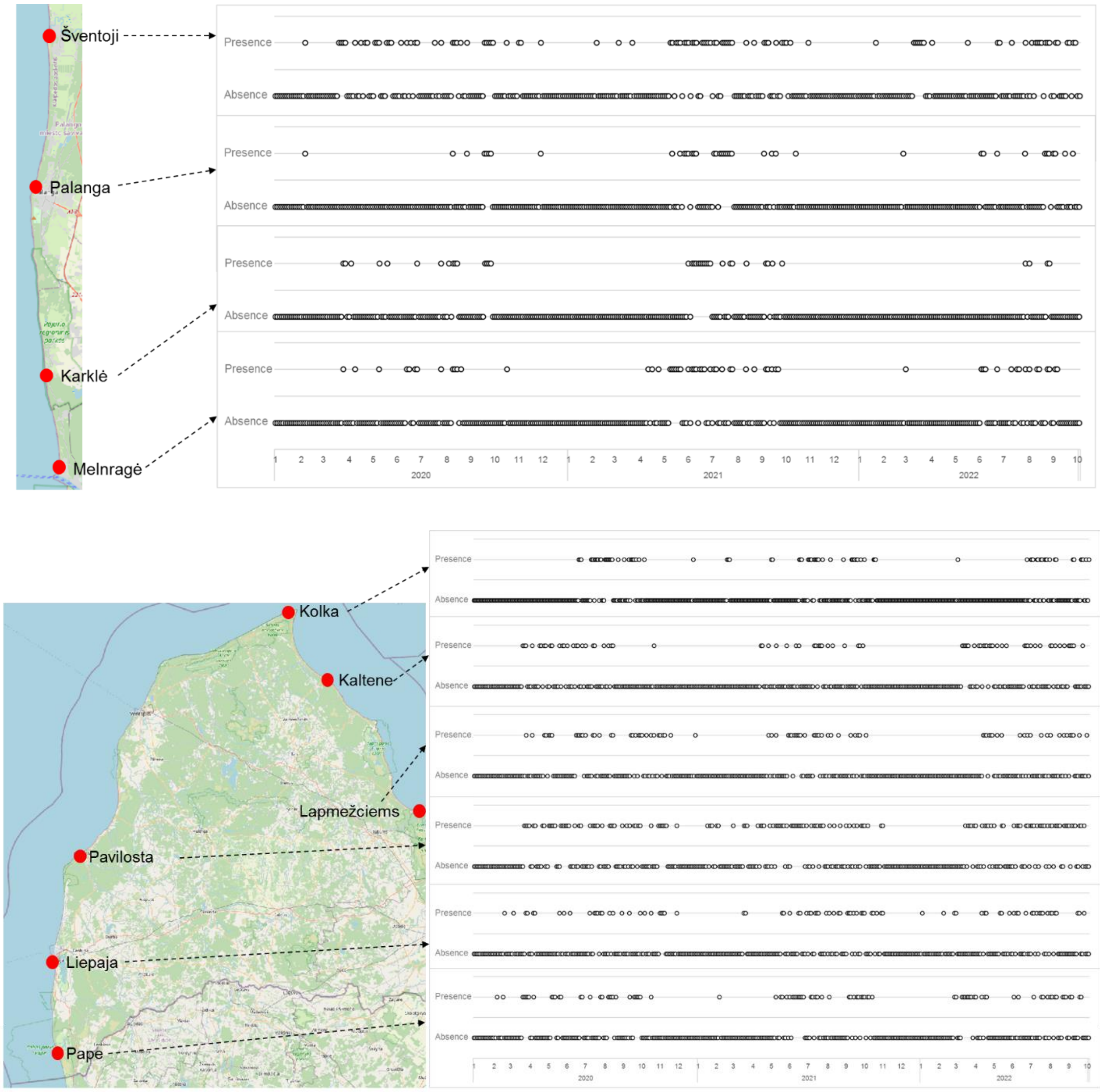

Figure 2. Beach wrack presence in Lithuanian and Latvian coastal regions during 2020.01.01-2022.10.14.

For example, the beach wrack was investigated on 14th July 2021 along the Klaipėda – Liepoja coast. The total area covered was 232 600 m^2, an approximate amount – 69 780 m^3 (Figure 3).

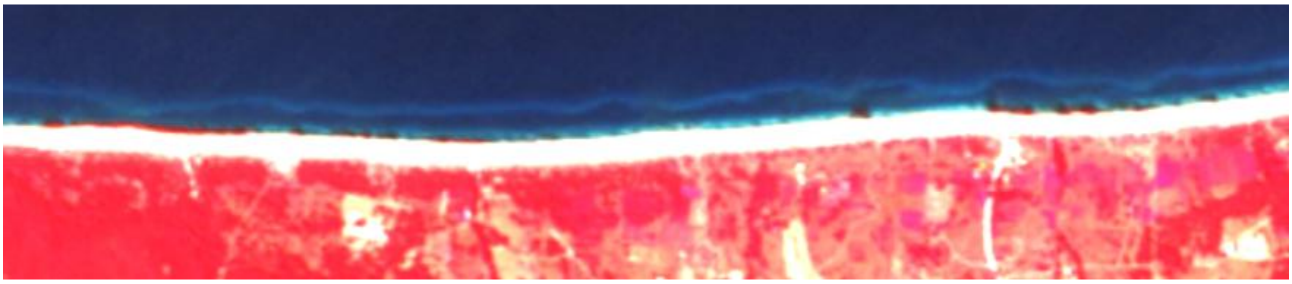

Figure 3. Beach wrack detection in the Latvian coastal region near Nica during 14th July 2021.

3.2 Drone-based remote sensing of beach wrack

Drone flights were carried out approximately every 10 days following the methodology described in D.T1.1.2. Beach wrack accumulations were mostly found on Melnragė beach (88% of all observation cases) and Šventoji beach (76% of all observation cases). This is probably related to the nearby algae growth areas (in Melnragė - port structures and jetties, and in Šventoji - the stony bottom near Palanga and the structures of the former port of Šventoji). However, it is likely that hydrodynamic processes, prevailing wind patterns, and the slope and geometry of the coast and coastline also influence the spatial distribution of algae accumulations.

Beach wrack accumulations were found less frequently in Karkle and Palanga (44-45% of all cases). Although there are algae growth areas (rocky bottom) at Karkle, probably due to the relatively steep shore, the accumulated algae remain in the water more often than they are brought to the shore. Palanga beach is an area of intensive recreation, therefore, it is likely that beach wrack accumulations were observed less often in this place due to beach management. In Palanga, wrack accumulations were more often found in the winter-spring period, when the recreational season has not yet started, and in late summer-autumn, probably due to the 2021 prevailing worse weather and the end of the recreational season (Figure 4).

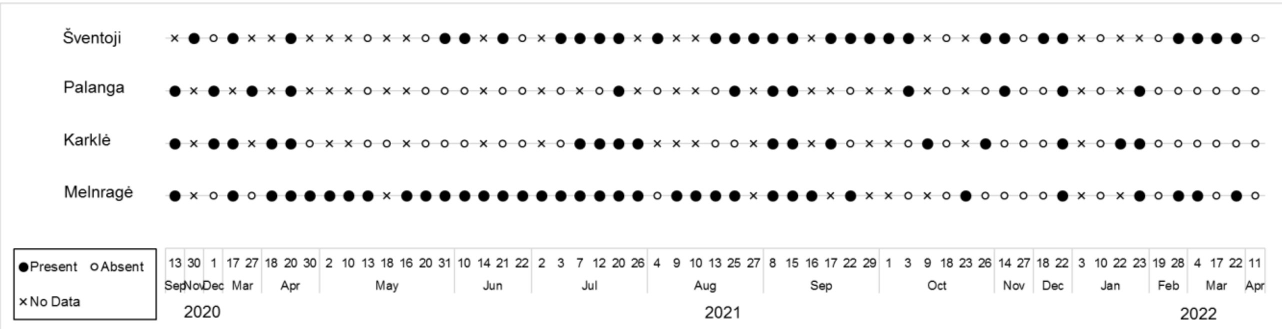

Figure 4. Beach wrack presence in four testing sites in Lithuania during September 2020 – April 2022.

The estimation of the amount of beach wrack through the use of machine learning (convolutional neural networks) and remote sensing data was performed using the collected drone images with a multispectral camera installed, as the most accurate estimates were determined in comparison with the RGB camera. In Šventoji on 1st October 2021, the Jaccard index for beach wrack was 0.65, for potential wrack 0.39, for water 0.82, for sand 0.82, and for unidentified it was 0.95. The total area of the classification was 3394.04 m^2 and the total volume was 2905.15 m^3 (Figure 5). These results indicate that the model was able to accurately classify the different classes within the study area, with relatively high Jaccard indices for most classes. The volume and area estimates can be used to inform management and conservation efforts, as they provide a quantitative assessment of the size and distribution of the different classes within the study area.

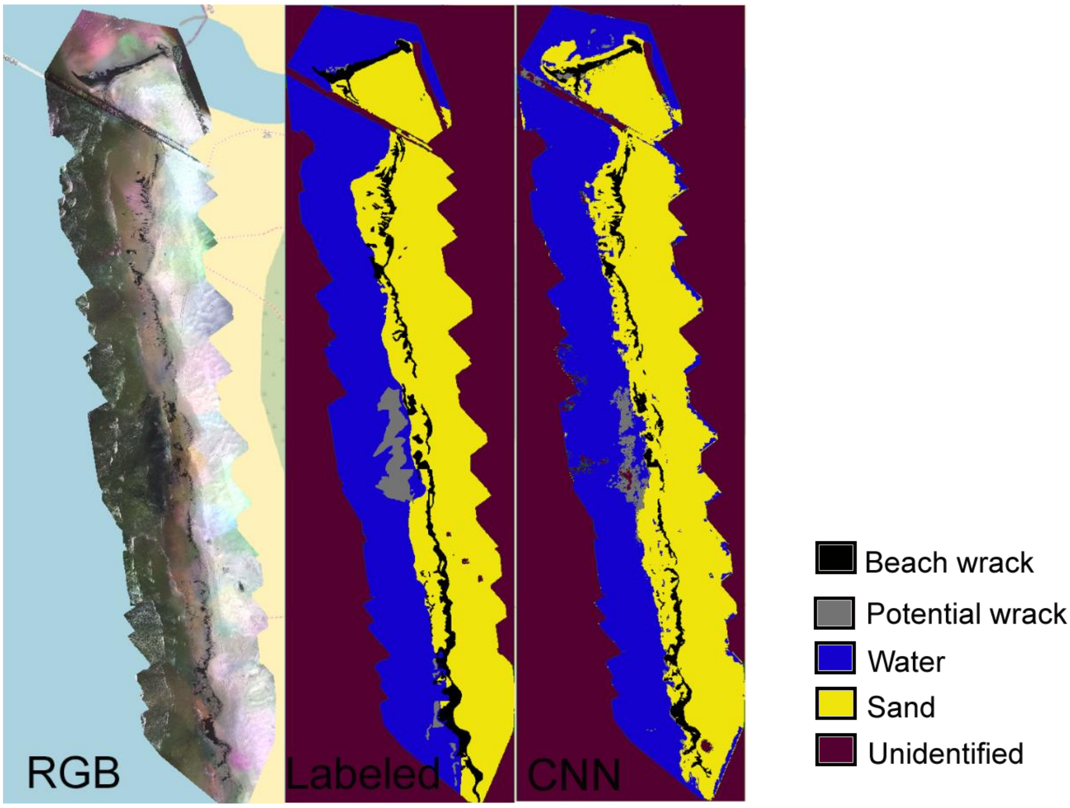

Figure 5. Beach wrack distribution in Šventoji, 1st October 2021.

In Melnrage on 2021-09-15, the Jaccard index for beach wrack was 0.56, for potential wrack 0.17, for water 0.45, for sand 0.55, and for unidentified 0.63. The total area of the classification was 924.95 m^2 and the total volume was 537.45 m^3. It suggests that the model had some difficulty accurately classifying certain classes, such as potential wrack and water, within the study area (Figure 6).

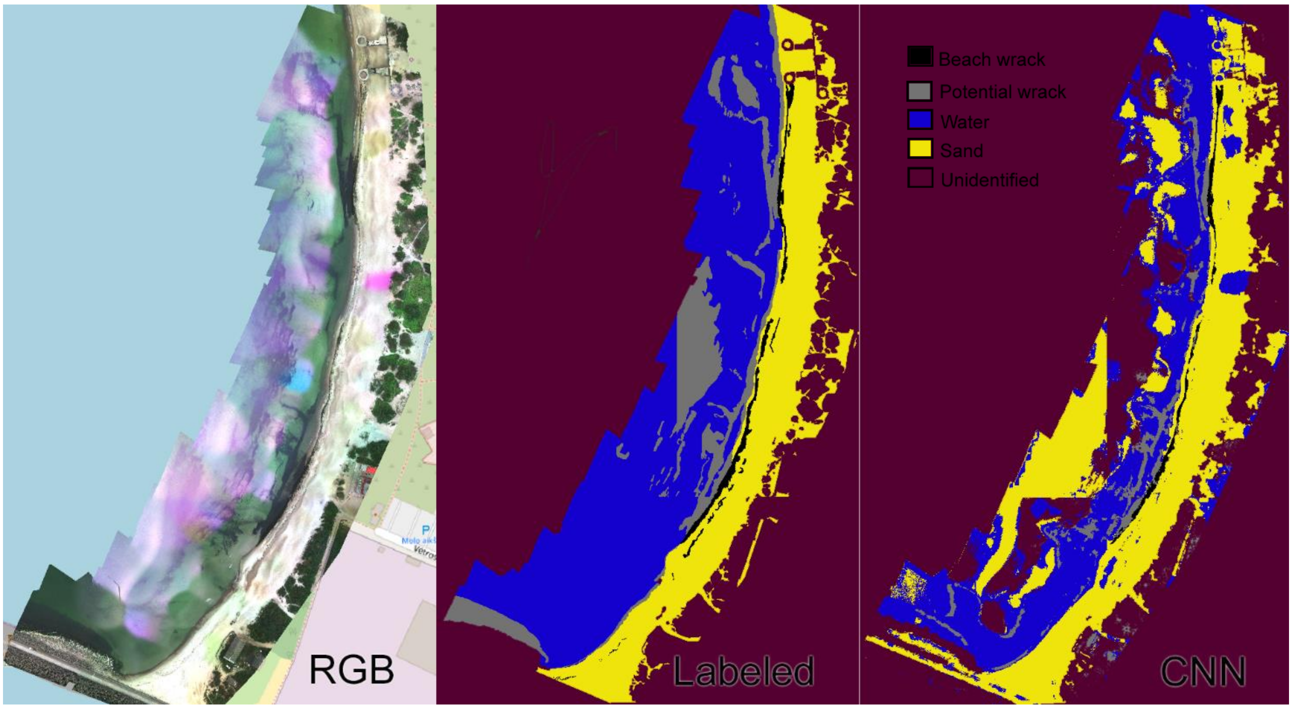

Figure 6. Beach wrack distribution in Melnragė, 15th September 2021.

In Karkle on 2021-09-17, the Jaccard index for beach wrack was 0.65, for potential wrack 0.37, for water 0.58, for sand 0.76, and for unidentified 0.96. The total area of the classification was 856.31 m^2 and the total volume was 191.31 m^3. These results show that the model could accurately classify most classes within the study area, with relatively high Jaccard indices for most classes (Figure 7).

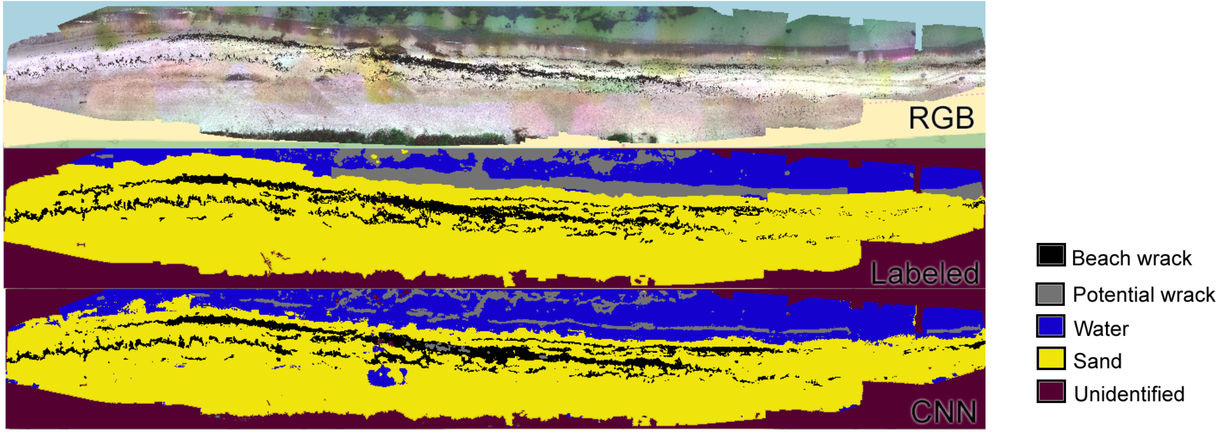

Figure 7. Beach wrack distribution in Karklė, 17th September 2021.

In Palanga on 2021-09-08, the Jaccard index for beach wrack was 0.62, for potential wrack 0.00, for water 0.54, for sand 0.72, and unidentified 0.94. The total area of the classification was 444.86 m^2 and the total volume was 2.22 m^3. It is worth noting that the Jaccard index for potential wrack was 0.00, which suggests that this class was not present or was not accurately detected in the study area (Figure 8).

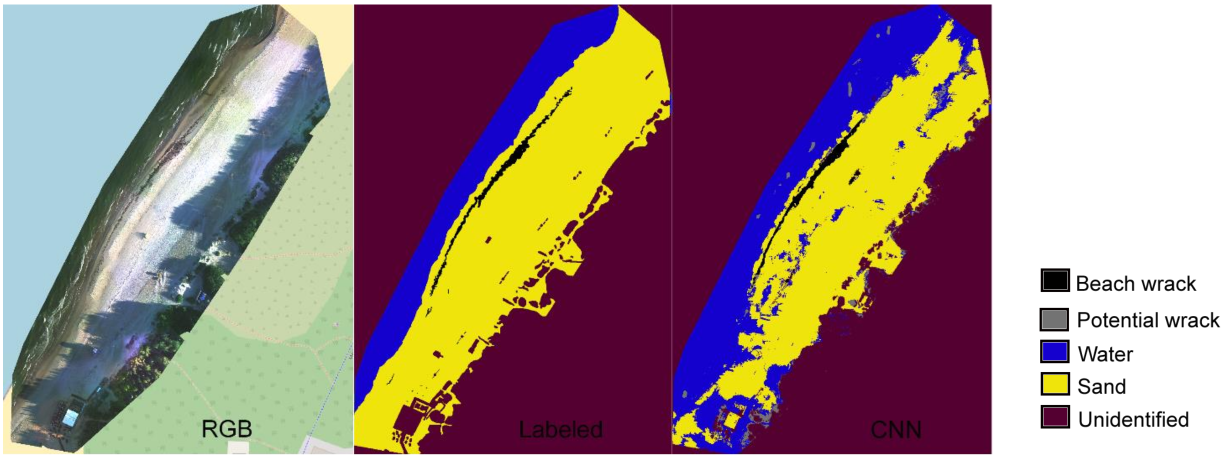

Figure 8. Beach wrack distribution in Palanga, 8th September 2021.

The area covered by beach wrack was different among the testing sites. In Melnrage, relatively smaller areas of beach wrack were determined, ranging from 36 to 1475 m^2. Similar areas of beach wrack were mapped in Karklė and Palanga, however they occurred much less frequently. The largest areas covered by beach wrack were determined in Šventoji, where areas ranged from 260 to 11 000 m^2. The largest areas covered by beach wrack were determined from 25th August to 18th December 2021 (Figure 9). However, relatively large amount of beach wrack in Šventoji was present also during February-March 2022.

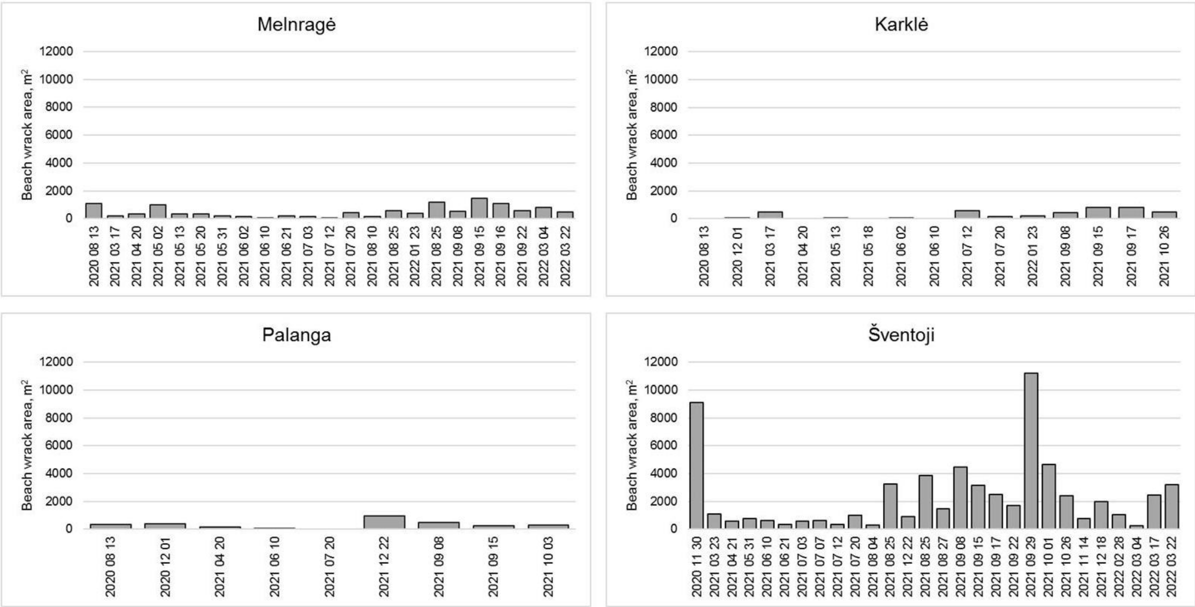

Figure 9. Areas covered by beach wrack mapped using the drone with multispectral camera at four testing sites in Lithuania.

3.3 Field surveys and collected data

3.3.1 Summary of the data collection

In total, 12 field surveys were performed to collect in situ data and map beach wracks with the drone during April-October 2021. Due to the uneven presence of beach wracks, the most visited site was Melnragė, where 5 field surveys were performed. The beach wrack was monitored only once in Palanga (Table 1, Figure 10).

Table 1. Summary of field surveys performed in Lithuania.

Location	1 sampling	2 sampling	3 sampling	4 sampling	5 sampling	Total
Melnragė	20/04/2021	02/06/2021	18/06/2021	10/08/2021	16/09/2021	5
Karklė	27/07/2021	17/09/2021				2
Palanga	29/07/2021					1
Šventoji	07/07/2021	27/08/2021	17/09/2021	01/10/2021		4

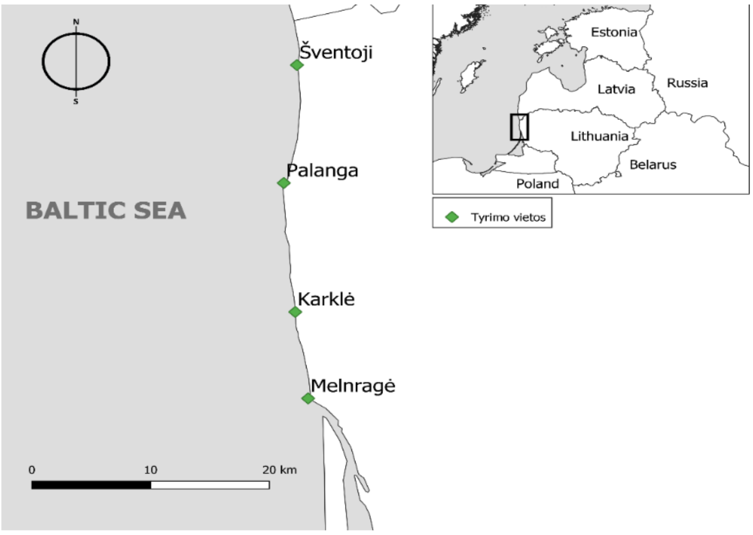

Figure 10. Monitoring sites in Lithuania.

3.3.2 Beach wrack

At Melnragė, Karklė, Palanga and Šventoji sites (see Figure 9), after the beach wrack accumulation event, macroalgae and aquatic angiosperms were sampled from the coast and the water according to the methodology described in D.T1.1.2.

The amount of beach wrack in the water ranged from 0.63 ± 0.19 g l^{-1} to 8.12 ± 1.04 g l^{-1}. The lowest amount was determined in Šventoji on 17th September 2021 (Figure 11). The highest amounts were determined in the Melnragė site on 18th June 2021, in the Palanga site on 29th July 2021, and in Šventoji on 1st October 2021.

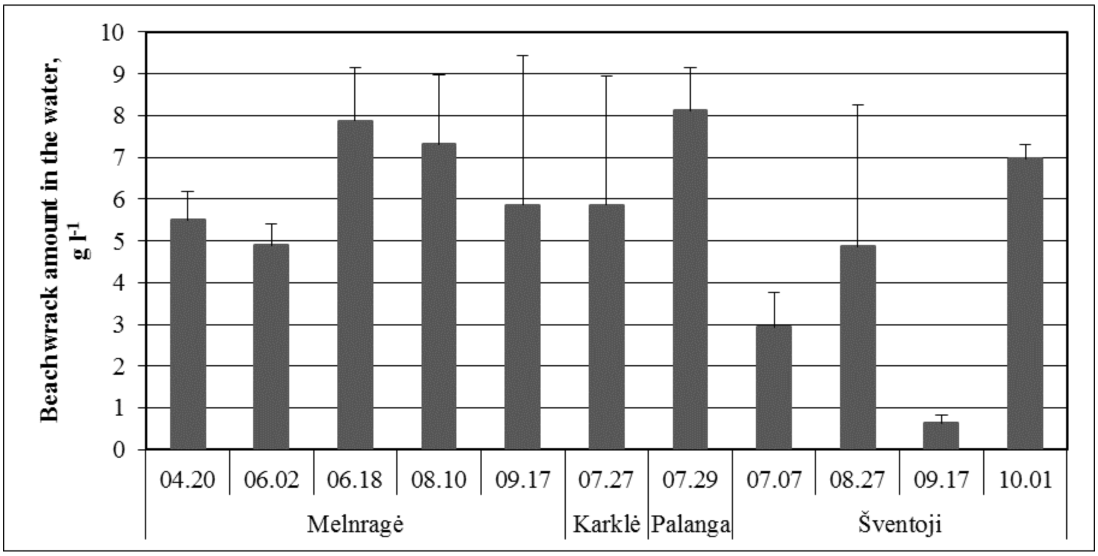

Figure 11. Beach wrack amount (dry weight) in the water at the monitoring sites in Lithuania in 2021.

The relative amount of macrophytes in the beach wrack usually increased seawards or was the highest in the middle part of a wrack (Figure 12). Red algae dominated (> 70 %) in beach wracks, followed by green algae (< 20 %), while brown algae and freshwater macrophytes comprised < 1 %. The amount of red algae increased northwards, most likely due to their main habitats located near Palanga. The southwards increase in the amount of green algae and freshwater macrophytes was due to exposure to waters of the Curonian Lagoon, which often float these macrophytes from the lagoon.

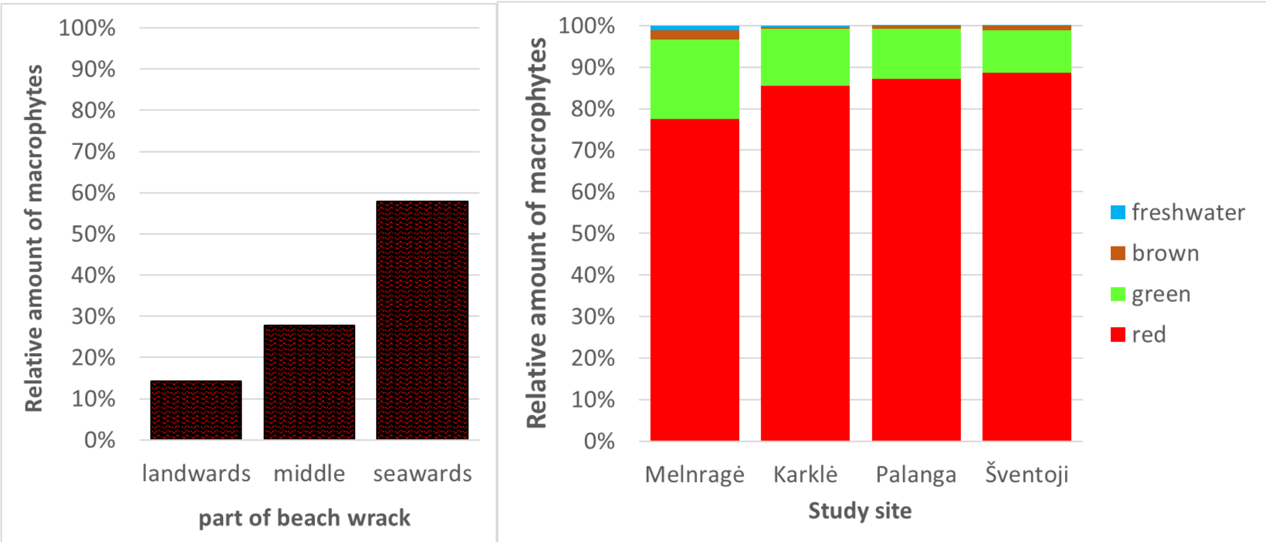

Figure 12. Relative amount of macrophytes in different parts of beach wrack (left) and the composition of beach wrack in the study sites.

The species composition in beach wracks consisted of 9 macroalgae taxa and several freshwater macrophyte taxa (Figure 13). The red algae dominated (80 %) in the wrack, where *Furcellaria lumbricalis* comprised ca. 60 %, while *Vertebrata fucoides* < 20 %. Two filamentous green algae (*Cladophora rupestris* and *C. glomerata*) almost reached 20 %. The composition of wrack changed during the season, where *F. lumbricalis* mainly dominated during the cold season (Autumn and Winter), while filamentous algae were abundant during the warm season (Spring and Summer). Freshwater macrophyte species were abundant mainly in spring, most likely due to enhanced discharge from the Curonian Lagoon. The highest amount of annual filamentous algae, such as *Ceramium spp.*, *C. glomerata* and *Ulva spp*. was recorded during Summer.

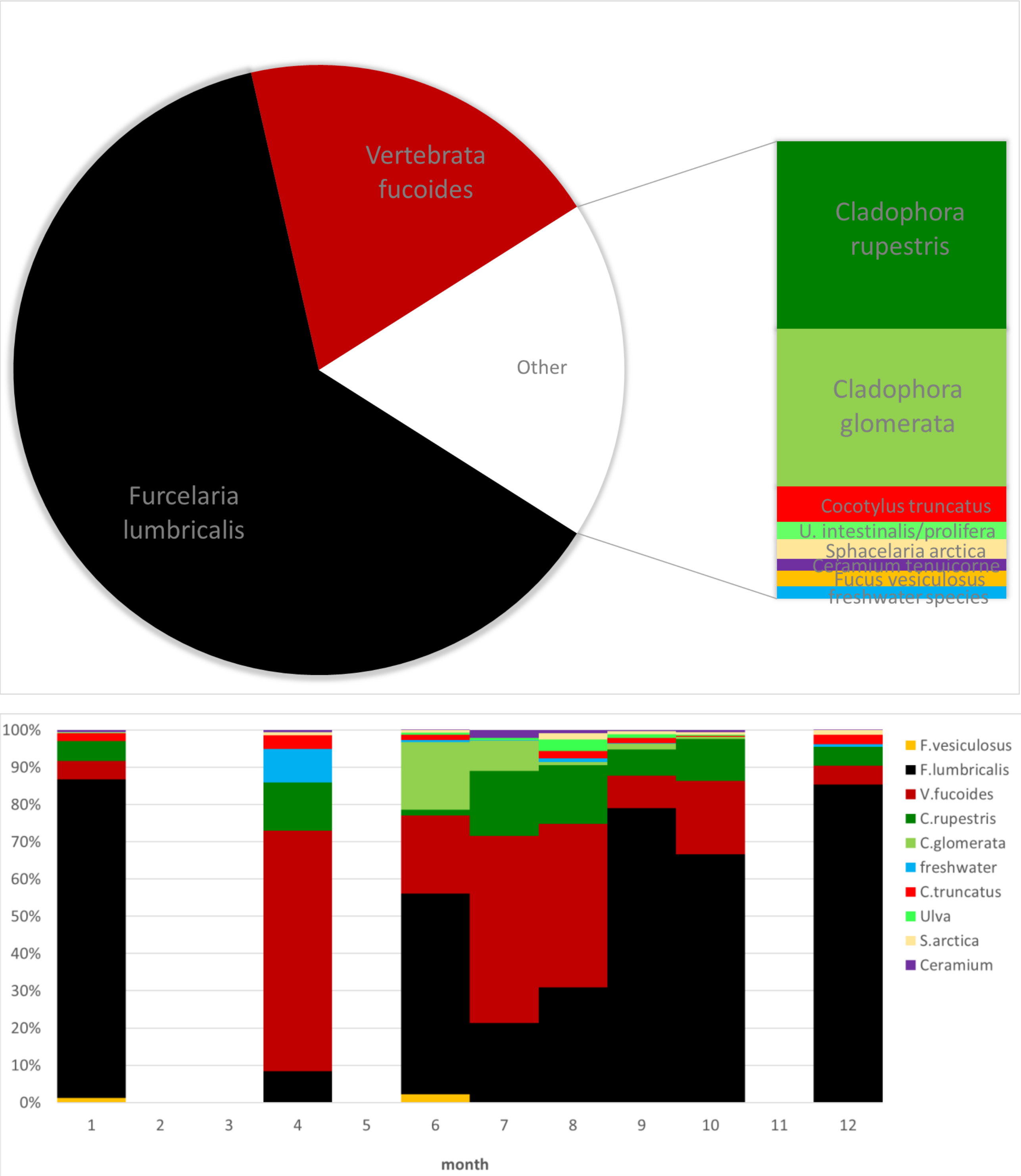

Figure 13. Species composition (above) of beach wrack and their seasonal succession (below).

3.3.3 Plastic litter in wrack

3.3.3.1 Microplastic litter in wrack

Under the activities of this project four compartments of the beach have been monitored: wrack zone, water with floating algae (further called al.water) as a reference also have been taken sand and water samples. Plastic litter is being found on the entire beach, not excluding any monitored compartment. The distribution of litter concentrations within the mentioned beach compartments are being discussed further in this chapter.

Totally 16 expeditions were implemented within the period of this project for the beach investigation in different Lithuanian coastal locations (Melnrage, Karkle, Palanga, Sventoji). Note that microplastic particles are the most common items in the beach wrack samples, the lowest amounts of plastic items found in the water (reference) (Figure 13). Such results prove that the accumulation of beach wrack contains significantly more plastic litter than any other monitored beach compartments. That indicates the problematic situation regarding various pollution levels: the biological (accumulation of seagrass) and an extensive physical (by artificial polymer items).

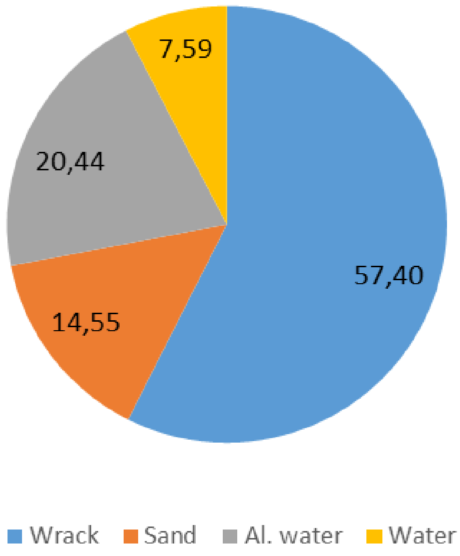

Figure 13. Percentage of findings in different compartments.

The mean values in each of the compartments of monitored beaches varied (Figure 14): for instance, mean value of beach wrack sample contains 0.43 items per cm3, and this is 4.3 times more than mean abundance of findings in the sand sample, 14.3 times more than in water with algae and 43 times more than in water samples.

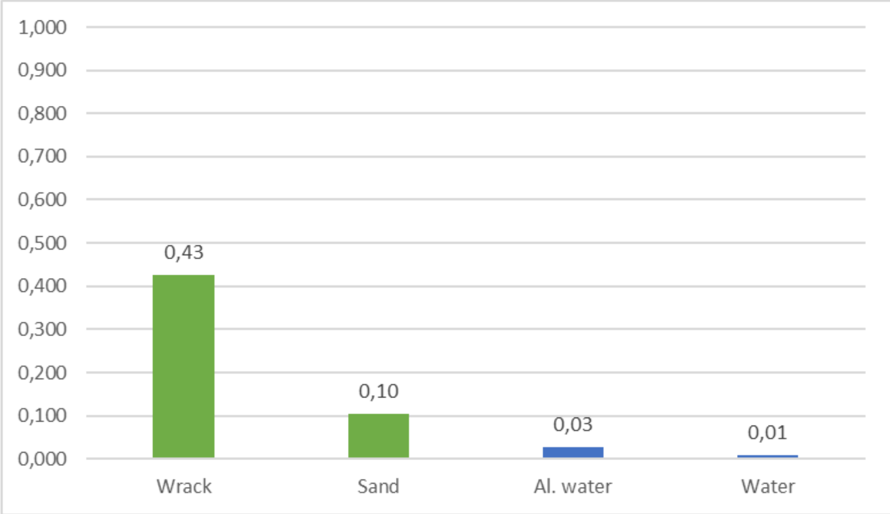

Figure 14. Average of items per cm3 found in different compartments.

Dividing compartments into two main divisions: based on land (Figure 14., marked green: wrack and sand) and based on water (Figure 14., marked blue: al. water and water) it is clearly shown that samples with algae in it have relatively more plastic items than the ones without. Among the land-based samples (wrack and sand) the difference is 4.3 times, comparing water-based samples (water and algae water) they differ 3 times. In comparison between wrack and algae water, the first one 14.3 times higher. Possibly because micro particles are wider spread in the water, not captured in between the algae as it is in the wracks ashore. As for the reference zone, which is represented by sand and water samples, more items are detected in the sand which is 10 times more than in the water. Plastic litter in association with beach wrack.

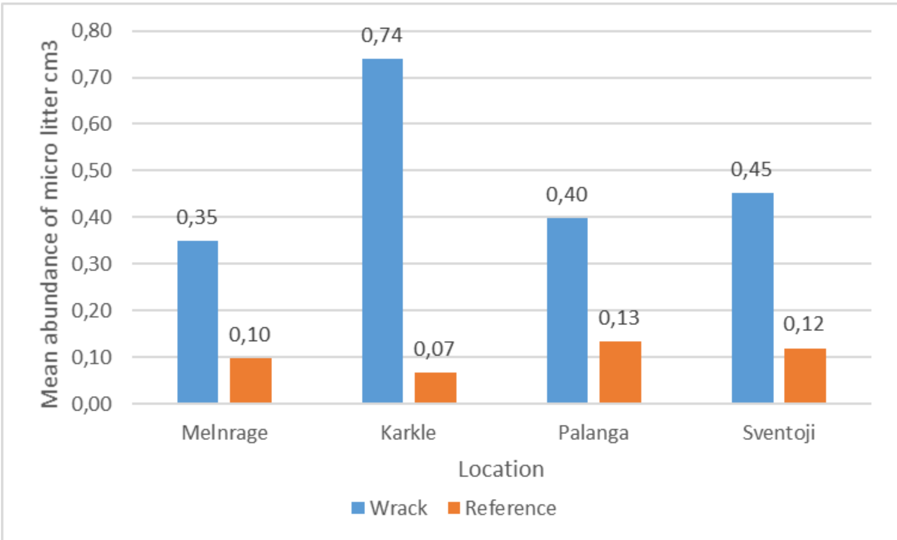

Figure 15. Mean of plastic litter found in beach wracks and reference samples of different locations (cm3)

When comparing different beaches it was evident that Karkle showed the highest number of microplastics per cubic centimetre, which resulted in 38% of total items found. Meanwhile other analysed locations: Sventoji (23%), Palanga (21%) and Melnrage (18%), where less contaminated by microplastics. The ratio between the microplastic amounts in beach wrack and in reference research area (beach sand) shows that beach wrack contains significantly more microplastic particles. It was determined that in Melnrage there is

3.5 times more microplastics in beach wrack when compared to the nearby sand, accordingly in Karkle 10.5 times, in Palanga 3 times and in Sventoji 3.7 times.

It is important to note that beach wrack events have been observed mostly in Melnrage (7 expeditions) and Sventoji (5 expeditions), while expeditions to Karkle and Palanga implemented twice in each.

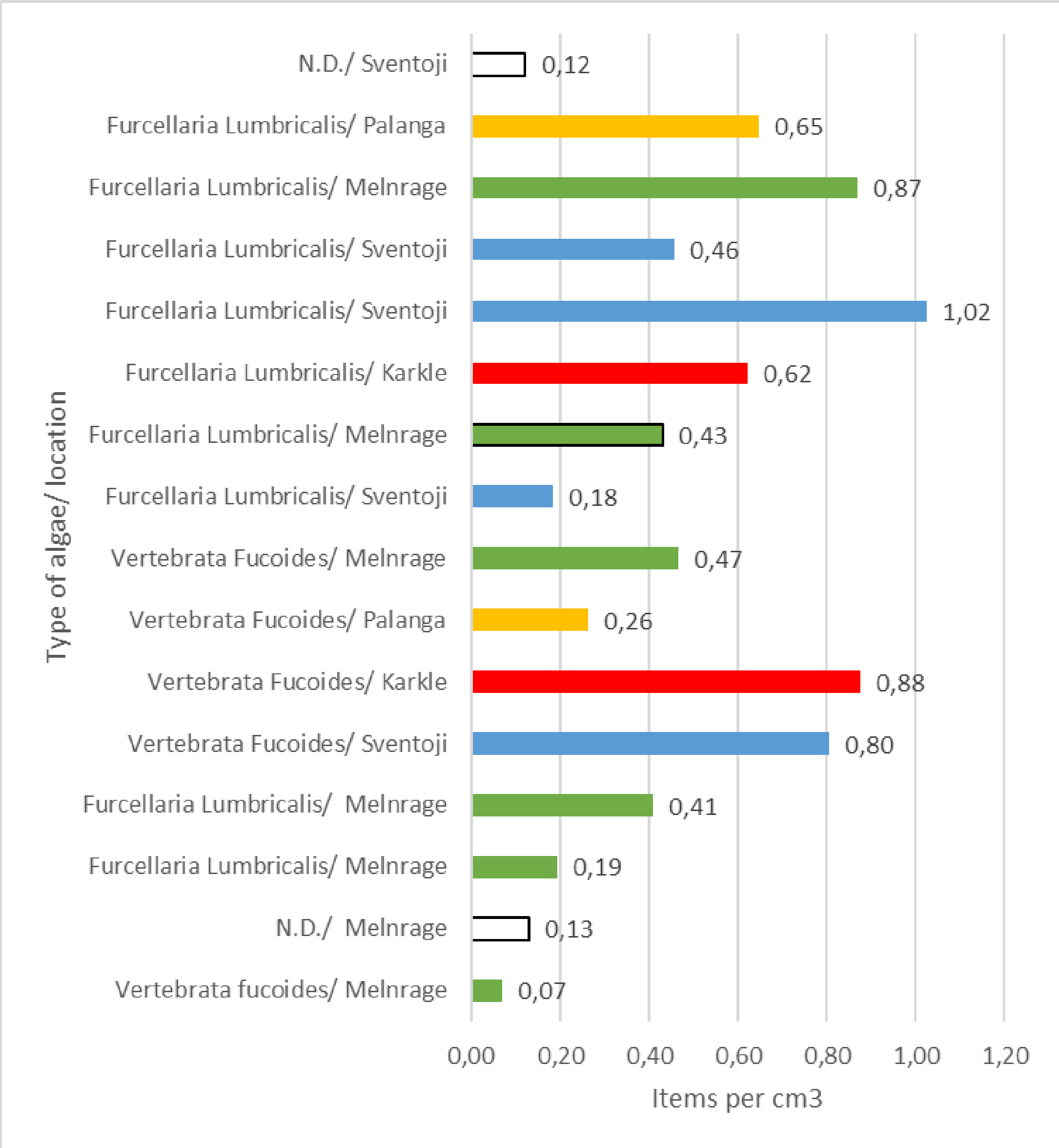

Figure 16. Mean of items found per cm3 in different algae types and locations

Within the period of investigations two dominant types of seagrass - *Furcellaria lumbricalis* and *Vertebrata fucoides* have been registered. The highest concentrations of items were detected in Sventoji - 1.02 cm3 (*Furcellaria lumbricalis*), in Karkle 0.88 (*Vertebrata fucoides).*

Comparing the abundance of the items found in both algae types separately, it appeared that samples contained almost the same amounts of microplastic per volume of cm3.

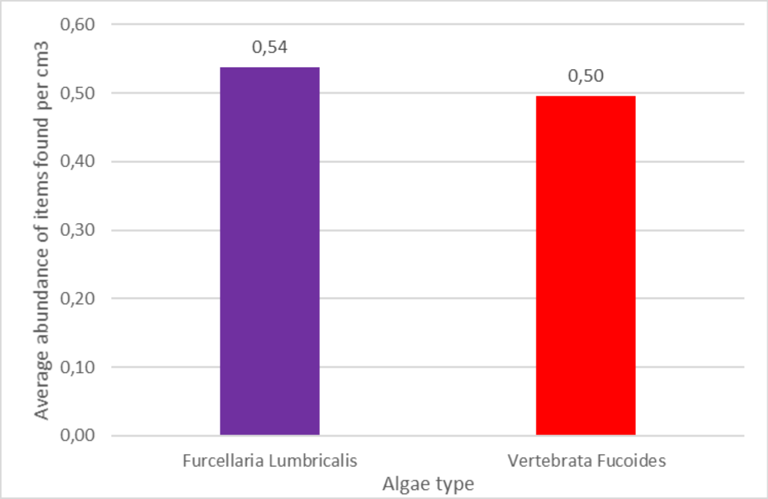

Figure 17. Dominant algae types and mean of microplastic concentrations (cm3)

3.3.3.2 Macroplastic and mesoplastic litter in wrack

Macro and meso fraction litter were also collected and counted in the study sites. Larger fraction (>5 mm) items were collected to the sample containers. Differently to micro size litter samples, larger fraction samples collected only from the surface and no additional material (as sand, water or wrack) was taken. The highest amounts of >5 mm fraction litter were found in Sventoji (1.4 item/sq. m) and Melnrage (0.95 item/sq. m) (Figure 18). In comparison to reference sites, wrack sites contains extremely high numbers of litter items: in Palanga beach 8.5% items were wound in reference samples and 91.5% in wrack samples of total findings, similarly in Karkle – 5.75% in reference and 94.25% in wrack, Sventoji 2.37% in reference and 97.63 % in wrack, in Melnrage 2.55% in reference and 97.45% in wrack. The actual concentration values provided in the graph below (fig. 18).

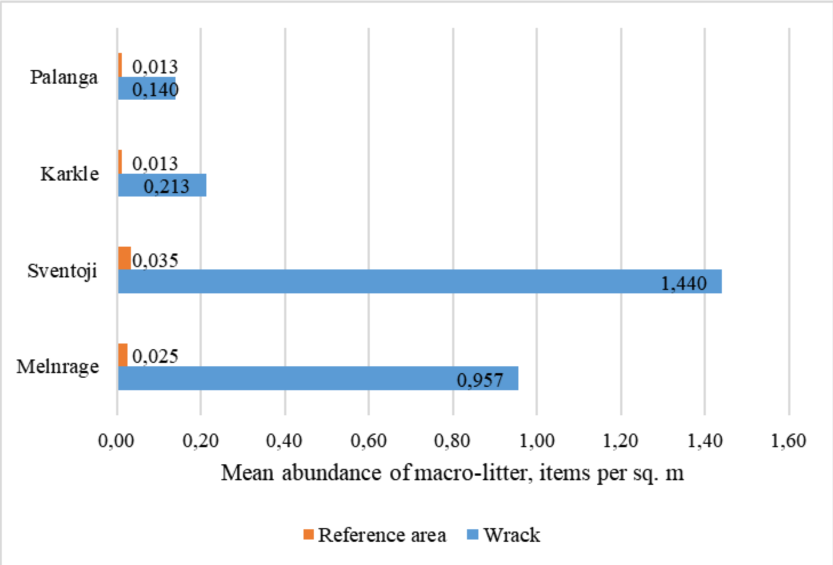

Figure 18. Concentrations of the larger size of marine litter in different beaches

Despite the fraction size of litter the beach wrack always contains higher concentration of marine litter. As shown in the graph below (figure 19.), concluding all samples taken the clear tendency to mean abundance of macro litter item concentration is 36.5 times higher than the reference samples.

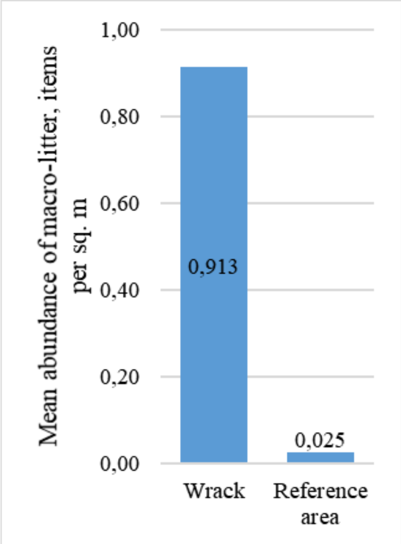

Figure 19. Mean abundance of macro litter per sq. m.

During the action "My sea campaign", collected data is valuable for comparison of pollution by marine litter. The graph below (Figure 20) shows the abundance of macro litter concentration applying two different methods: 40 m2 (for beach wrack investigations) and official beached marine litter monitoring (for 100 m length of the same beach).

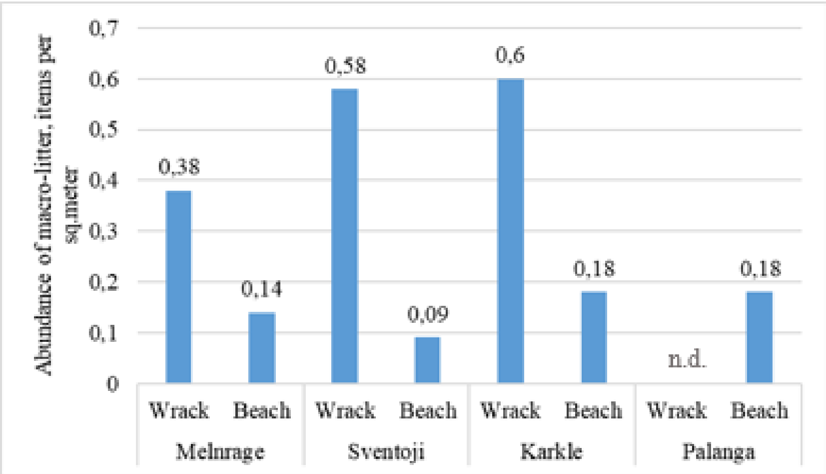

Figure 20. Abundance of macro litter collected using 40m2 and OSPAR methods

Two methods applied, the investigations proved that samples containing wrack show significantly numerous amounts of beach litter found. The differences vary from 2.7 times (Melnrage), 3.3 times (Karkle) to 6.4 times (Sventoji). It was impossible to measure the abundance of macro-liter in Plnaga, since during the "My Sea Campaign" activities there was no beach wrack present.

Table 2. Total findings in beach wrack and among floating algae amount and concentration in Lithuanian sites.

Location	Date	Total amount of litter items (<5 mm)	Microplastic litter item/cm3	Total amount of litter items (>5 mm)	Total amount of floating litter items
Melnragė	2021.04.20	17	0.07	67	
	2021.05.16	18	0.13	31	
	2021.06.02	30	0.19	18	
	2021.06.18	72	0.41	12	19
	2021.08.10	63	0.47	18	
	2021.09.16	55	0.43	96	
	2022.01.24	146	0.87	26	n.d.
Karklė	2021.07.27	99	0.88	2	
	2021.09.17	80	0.62	15	
Šventoji	2021.07.07	86	0.80	168	6
	2021.08.27	23	0.18	17	0
	2021.09.17	88	1.02	46	n.d.
	2021.10.01	75	0.46	28	6
	2022.08.11	20	0.12	29	n.d.
Palanga	2021.07.27	46	0.26	3	0
	2022.01.24	62	0.65	8	n.d.

The amount of microplastic, i.e., <5 mm, considering the total beach wrack volume present on the coast, was ranging from 3.69 mln items to more that 770 mln items (Table 3). The amount of plastic litter > 5 mm, considering the total beach wrack area present on the coast, was ranging from 57 items to more that 3000 items. The total estimated beach wrack volume during 9 field campaigns was 3016.15 m^3, and total amount of microplastic associated with the beach wrack was 1820.4 mln items. The total estimated beach wrack area during 9 field campaigns was 11761.30 m^2, and total amount of plastic litter associated with the beach wrack was 13 034 items (Table 3). Considering that the amounts of microplastic and plastic litter associated with beach wrack was significantly higher than at the reference zone, i.e., areas not covered by beach wrack, it was proved that beach wrack plays a key role in aggregation of marine litter in the coastal regions.

Table 3. Total beach wrack area and volume, microplastic and plastic litter amount in Lithuanian sites.

Location	Date	Total wrack area, m^2	Total wrack volume, m^3	Microplastic, items/cm^3	Microplastic items/Total wrack volume in m^3	Total amount of plastic litter items (>5 mm)	Plastic litter items (>5 mm)/Total wrack area in m^2
Melnragė	2021.04.20	327.5	55.7	0.07	3.90 mln	67	549
	2021.06.02	148.9	19.4	0.19	3.69 mln	18	67
	2021.08.10	126.1	20.2	0.47	9.49 mln	18	57
	2021.09.16	1079.5	226.7	0.43	97.48 mln	96	2591
Karklė	2021.09.17	814.4	407.2	0.62	252.46 mln	15	305
Šventoji	2021.07.07	642.5	321.25	0.80	257 mln	168	2699
	2021.08.27	1459.9	467.2	0.18	84.10 mln	17	620
	2021.09.17	2517.8	755.3	1.02	770.41 mln	46	2895
	2021.10.01	4644.7	743.2	0.46	341.87 mln	28	3251
Mean		**1306.81**	**335.13**	**0.47**	**202.3 mln**	**53**	**1448**
Standard deviation		**1460.34**	**286.05**	**0.31**	**247.2 mln**	**51**	**1363**
Sum		**11761.30**	**3016.15**	**4.24**	**1820.4 mln**	**473**	**13034**

In addition to the plastic amount assessment, the plastic litter was tested for potentially pathogenic bacteria such as *V. vulnificus* and *V. cholera.* The presence of pathogens was assessed using the methodology provided in deliverable T1.1.3. The pathogens were assessed on the plastic items found in the beach wrack sites (water, sand, wrack) and on the plastic found in the beach sites without wrack. Half of the plastic items harboured *V. vulnificus* genes, less often *V. cholera* genes and more than half of positive samples had both genes at once. The highest proportion of *V. vulnificus* positive plastic items were found in water affected by wrack, less in the wrack on the beach, and least on the clean beach. In the areas affected by the wrack, if *Vibrio* were found on plastic, they were also found in the environment. Detailed methodology, results and recommendations on pathogens on the plastic are provided in Deliverable *D. T1 .2. 2.*

4 Plastic litter monitoring in association with cyanobacteria blooms/scums

The first attempt was to perform the data collection during intensive cyanobacteria bloom in the open Baltic Sea and coastal waters. However, during 2021 and 2022 cyanobacteria bloom was not observed. Instead, data collected during field surveys of national monitoring in collaboration with the Environmental Protection Agency were used. Data were collected in 2020-2021 over the coastal waters of Lithuanian Baltic Sea and the Curonian Lagoon (Figure 22). The dataset combines both, measured chlorophyll-a concentration – a proxy of phytoplankton biomass, and microplastic amount. The analysis was performed according to the methodology described in D.T1.1.2.

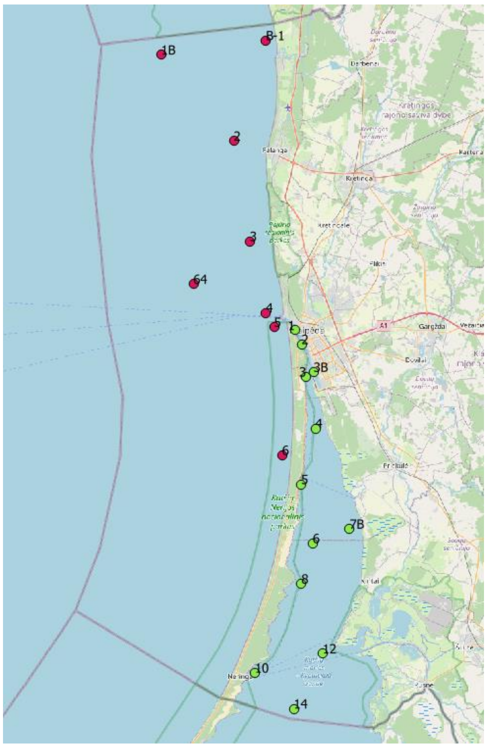

Figure 22. Chlorophyll-a concentration and microplastic collection in the coastal waters of the Lithuanian Baltic Sea (red circles) and in the Curonian Lagoon (green circles).

Chlorophyll-a concentration was ranging from 3.37 to 151.40 mg m^{-3}. There was no correlation determined between chlorophyll-a concentration and microplastics in the coastal waters of the Lithuanian Baltic Sea (R^2 = 0.0006, N = 10) or in the Curonian Lagoon (R^2 = 0.001, N = 59) (Figure 23).

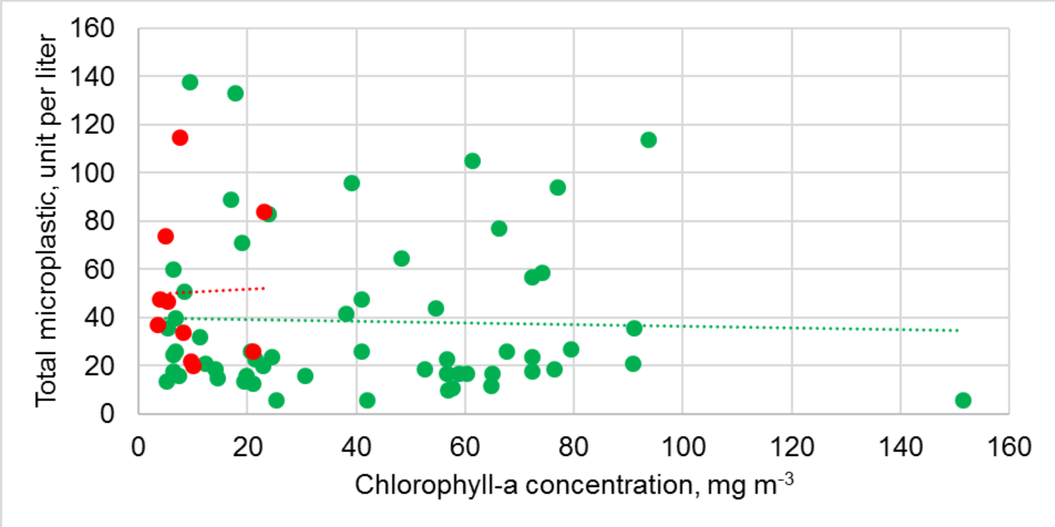

Figure 23. Relationship between chlorophyll-a concentration and microplastic in the coastal waters of the Lithuanian Baltic Sea (red circles) and in the Curonian Lagoon (green circles).

Relatively similar amounts of the microplastics were determined considering different chlorophyll-a concentration classes. Microplastics ranged from 20±11 items per liter at chlorophyll-a concentration equal to 50-60 mg m^{-3}, and approximately 40 items per liter at remaining investigated chlorophyll-a concentration classes (Figure 24).

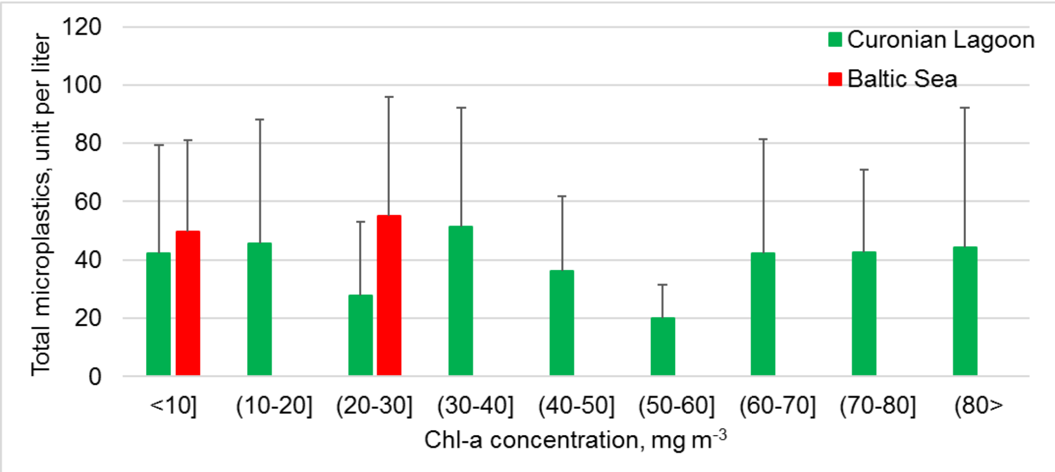

Figure 24. Variations of microplastic according to chlorophyll-a concentration classes in the coastal waters of the Lithuanian Baltic Sea and in the Curonian Lagoon.

5 The final method for cost-effective estimation, monitoring, and reduction measures of plastic litter

The consortium has found that most management authorities are cleaning the beaches permanently during the recreational season despite the beach wrack is present or not, as the cleaning is also focused on the removal of litter, or upon the notification that the beach wrack is present and causes negative effect for the citizens, however without prior evaluation of the total amount of beach wrack present.

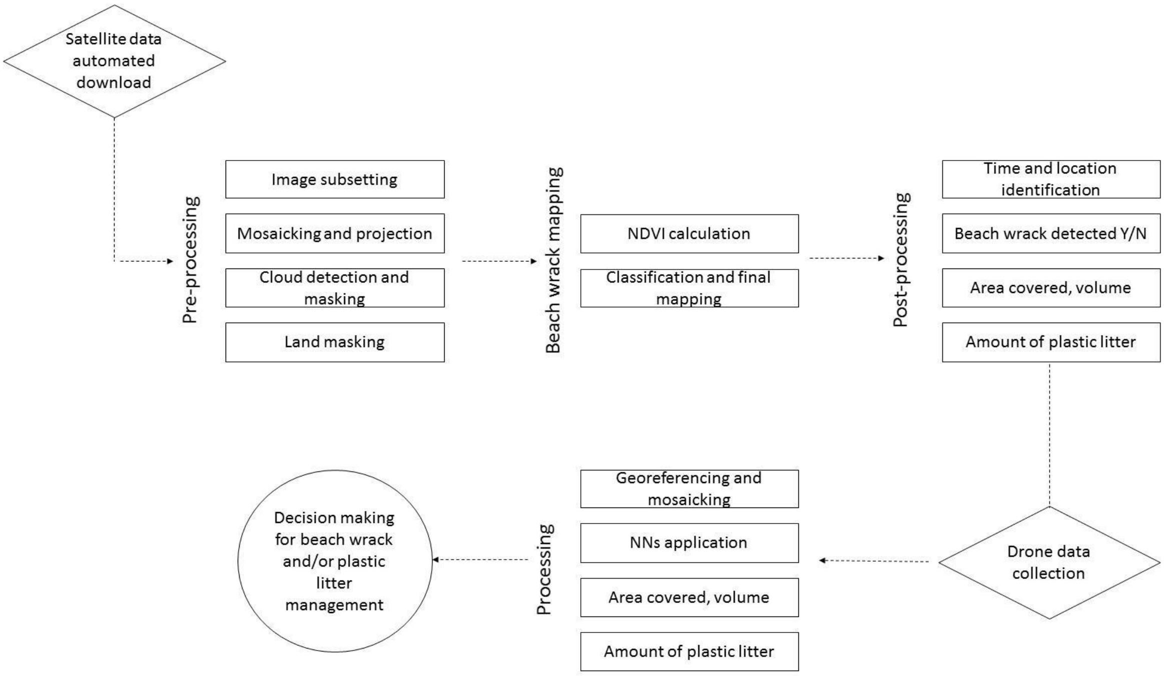

Figure 25. The workflow of the method for estimation and monitoring of beach wrack and plastic litter.

This strategy has three large drawbacks:

- The direct costs and person-hours associated with sending out the personnel to clean the beach.
- The direct costs of the technique and equipment rent to clean the beach.
- The direct costs of the collected beach wrack utilisation.

The management without prior knowledge of where the beach wrack is located requires extrapolation over large areas, yielding the increase in person-hours, technique, and equipment rental (if any) costs. The unknown amount of beach wrack prior to the management activities may also influence the rental of inappropriate and overpriced techniques (too large or too small). The unique value of the alerting system is that it uses spatial and high-frequent measurements to precisely identify beach wrack location, diagnose the total area covered and amount of the beach wrack in a cost-effective, comprehensive and highly precise manner, and informed management decisions to ensure sustainability. However, prior to the final set-up of the alerting system at the user's premises, the primary investments should be considered, which include: an integrated workstation to run the operational processing of the satellite and drone imagery, the drone-type unmanned aerial vehicle with an integrated multispectral camera. After the set-up of the system, only the person-hours associated with the system utility are required. In addition, time-to-time upgrade of the alerting system is required related to software updating, processing chain maintenance, available as an external service, or the employee training might also be foreseen. The final scheme of beach wrack and plastic litter estimation, monitoring, and reduction measures is provided in Figure 25.

6 Final conclusions and remarks

- Beach wrack more often occur on the beach during the warm season, starting from April and until October. The pronounced seasonal variation of beach wrack composition was determined with a pre-dominance of perennial macroalgae and significant increase of annual filamentous macroalgae during warm season. This period should be considered for the optimal beach wrack removal and management;
- Satellite data support the detection of beach wrack on the seashore, identification of the exact location, and approximate area covered. Once the alerting system is setted-up, the information can be provided within 3h 10min, or within 25 min after the agreement with ESA to access NRT data. However, satellite imagery does not resolve smaller beach wrack patches than 10 m^2, therefore the integration of UAV-based imagery is of great advantage;
- Multispectral camera in comparison with RGB camera mounted on the drone platform, shows much better accuracy for beach wrack classification, as it has a near-infrared spectrum that distinguishes vegetation (and beach wrack) very well. Machine learning methods allow to estimate beach wrack quicker, however, volume estimations still need further experimentation for improvement;
- Remote sensing data-based alerting system can support and optimize expensive manual monitoring, and serve as a valuable tool for decision making in beach management activities. The volume and area estimates can be used to inform management and conservation efforts, as they provide a quantitative assessment of the size and distribution of the different classes within the monitored area.
- The algal/cyanobacteria amount up to 150 mg m^{-3} does not act as a natural trap for the in-water microplastics, therefore at these conditions the removal of algal/cyanobacteria biomass will not serve as a sustainable measure for microplastics reduction. Further investigations at a significantly higher amount of algae/cyanobacteria should be conducted.
- Considering the beach wrack amount determined by remote sensing methods in combination with the field observations of plastic litter during 2021, with 1000 m^3 of beach wrack in total 603 mln microplastic items could be removed, and with 1000 m^2 of beach wrack in total 1100 items of meso- and macro-litter items could be eliminated. By these findings we confirm that the removal of beach wrack could serve as a sufficient measure to reduce marine litter from the coastal environment.